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Decomposing the effect of color on memory: How red and blue affect memory differently

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Abstract

Color has been shown to have a beneficial effect on memory in the general population and in some clinical populations, such as those with dementia and autism. Many factors within the effect of color on memory have been tested, however the differences among colors has been largely ignored. This study aimed to close this gap by comparing the effects of red, blue, and black on recognition memory. In addition, this study was designed in a way that could help test one of the main theories on how color enhances memory, the attention and arousal theory. This theory posits that the effect of color is due to increased attention and arousal, and would predict a larger beneficial effect when using red due to higher amounts of attention and arousal. The experiment included 48 male and female participants, who viewed object pictures in luminance-matched red, blue, and black. The participants were later tested on their memory for the objects in a recognition memory test. Results indicated that participants had significantly higher accuracy for red objects than for blue objects, and also had a more conservative response bias for red objects than for blue or black objects. These results indicate that there is a difference in the effect on memory depending on the color. The results also supported the theory of attention and arousal, providing further understanding on how this process works. This knowledge can help researchers and clinicians by enabling them to take better advantage of the effect of color on memory.

Introduction

Memory performance is an important aspect of life, and problems with it can cause various degrees of impaired functioning and distress. Furthermore, these problems are common throughout ages, sexes, and races, so ways to improve memory is a huge field of research. One way that memory may be improved is by using color. Many studies have shown a positive effect of color on memory using stimuli such as natural scenes, nonsense stimuli, and color overlays (Cernin, Keller, & Stoner, 2003; Cui, Gao, Zhou, & Guo, 2016; Wichmann, Sharpe, & Gegenfurtner, 2002). Many factors within the color effect have been studied such as context of color (Kunieki, Pilarczyk & Wichary, 2015), color inconstancy (Hurlbert & Ling, 2005), long-term effects (Spence, Wong, Rusan, & Rastegar, 2006; Wichmann et al., 2002), and the effect on recognition vs recall (Smilek, Dixon, Dudahy, & Merikle, 2002). Additional studies that have investigated the effects of color have performed EEG as an attempt to find the mechanisms behind the effect (Cui et al., 2016; Fortier-Gauthier, Dell'Acqua, & Jolicœr, 2013). Finally, studies using clinical populations such as people with autism spectrum disorders (Ludlow, Taylor-Whiffin, & Wilkins, 2012) and different types of dementias (Cernin et al., 2003) have shown that the use of color materials can be beneficial for those with cognitive disabilities. This indicates that clinical practitioners can take advantage of this effect in patients with memory problems, and illustrates the importance of fully understanding the effect of color on memory.

Despite all of these studies, differences between specific colors have not been extensively studied, perhaps because there are so many other factors to consider. Even in studies that have used more than one color, the colors were usually not differentiated. Instead, these studies often compared "color" groups, such as multi-colored stimuli or stimuli of multiple different colors grouped together, to black and white (Cui et al., 2016; Spence et al., 2006; Wichmann et al., 2002). An improved understanding of the differences between colors could help researchers and clinical practitioners take better advantage of the color effect.

In addition, an understanding of the differences between colors could lend support to one of the main theories of why color has a positive impact on memory. One theory credits the beneficial effect of color to increased attention and arousal to stimuli (Dzulkifli & Mustafar, 2013). Several studies have shown that warm colors such as red, and cool colors such as blue, may affect attention and arousal to different degrees (Yoto, Katsuura, Iwanaga, & Shimomura, 2007). Warm colors in particular have been found to increase attention, specifically red, even when saturation and brightness are held constant between warm and cool colors (Aziz & Mertsching, 2008; Osberger & Maeder, 1998; Pal, Mukherjee, & Mitra, 2012). If red has higher attention saliency**,** then if red stimuli enable better memory performance than blue stimuli, this could support the attention and arousal theory because higher attention saliency would have had a more beneficial effect. However, if both colors lead to similar memory performance, the effect may be due to processes attributed by alternative theories such as the color-in-context theory of Elliot and Maier (2012). This theory accredits the effect of color to an interaction between color and the context the color is in, such as an emotional one. The current experiment was designed to have a neutral context, so the results would be inconsistent with the color-in-context theory if there are significant differences between colors. Similar to knowing what colors are more beneficial, understanding the actual mechanisms behind the beneficial effect of color on memory can help maximize the use of this effect in both research and practice.

Background

As stated above, many studies have been conducted to form the consensus that there is strong evidence of a positive color effect on memory. These studies have included various stimuli from objects, to overlay on words, to natural scenes in order to illustrate the overarching effect of color on memory. In a study conducted by Wichmann, Sharpe, and Gegenfurtner (2002), participants viewed natural scenes in either color or luminance-matched grayscale. The results showed that color significantly enhanced recognition memory in comparison to grayscale. A similar study with natural stimuli also observed significant effects, showing that these results are replicable (Spence, Wong, Rusan, & Rastegar, 2006). A more recent study investigated the color effect for participants viewing nonsense stimuli, in this case overlapping loops in different colors (Cui et al. 2016). The study found that color significantly improved overall recognition. This study also had an average interval of five days between the study and test phase, indicating that color can have long term effects on memory. In addition, an improvement in recall as well as recognition due to color is illustrated in a study in which undergraduate students performed significantly better on a recall test when study stimuli were colored (Smilek, Dixon, Dudahy, & Merikle, 2002).

The color effect can be utilized to improve memory performance in diverse populations. Colored overlays and colored backgrounds on mobile devices increased memory performance on text excerpts for people with autism spectrum disorders as well as control subjects (Ludlow, Taylor-Whiffin, & Wilkins, 2012). Similarly, recognition memory for colored and non-colored objects were tested for participants who had cognitive disabilities, such as Alzheimer’s and other dementia-related disabilities, and cognitively intact individuals (Cernin, Keller, & Stoner, 2003). The use of color significantly improved memory performance, further demonstrating the effect of color on different types of stimuli, in addition to indicating that this effect may be present across different types of populations. An increased understanding of the effect of color on memory could help clinical practitioners better utilize this effect in patients with memory problems.

There are a few different ways color is thought to increase memory performance. It is generally assumed to heighten the encoding process, and a common theory is that this is due to heightened attention to the stimuli (Dzulkifli & Mustafar, 2013). This theory holds that color has a direct effect on cognitive processes, specifically attention. In addition, arousal increasing attention may also be a factor in encoding (Dzulkifli & Mustafar, 2013). To fully understand this theory, one must first understand the difference between attention and arousal. Attention is the broad concept of our brains selectively choosing information for processing because we cannot process all of the information we are exposed to (Banich, 2010). Arousal is a specific, lower-level feature of attention, that focuses on the ability to be receptive to new information (Banich, 2010). This is related to overall alertness or wakefulness, which enables one to focus on a task or on specific details. In summary, and in regard to memory, overall attention focuses on the brain concentrating on specific information to remember, and arousal enables us to be receptive to this information. By enhancing the encoding process of memory through attention and arousal, stimuli should be coded more efficiently and less likely to be forgotten in later experimental trials (Dzulkifli & Mustafar, 2013). This process in the context of color is discussed in a review by Dzulkifli and Mustafar. In this review, the authors summarize many studies that have shown how attention and arousal can increase memory performance, how color can increase attention and arousal, and how these studies can be interpreted to explain the process of why color is beneficial to memory.

Many studies have tested the effects of color on attention and arousal. One study paired EEG recordings with the experimental task to test the effect of color on attention and arousal as directly as possible (Kuniecki, Pilarczyk, and Wichary, 2015). Participants had significantly faster and more accurate responses when stimuli were red than when they were black. These faster reaction times indicate early attention engagement, and the neural components could help explain the higher accuracy. Participants exhibited increased visual cortex activation and higher magnitudes of the P1 ERP component when responding to red cues. Previous research has theorized that a higher magnitude of this P1 ERP component reflects more efficient sensory processing (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Pourtois, Schettino, & Vuilleumier, 2013; Feng et al., 2014), which could help explain enhanced memory. In addition, a study by Pan (2010) found that color was more efficient than other factors, such as shape, at guiding attention. Another study, conducted by Küller, Mikellides, and Janssens (2009), found that participants performing tasks in colored rooms had higher attention and arousal than participants in grey rooms, as measured with self-report, EEG, and EKG to measure heart rate. Overall, these studies indicate that color can increase attention and arousal, so it is plausible that this increase would be the reason for the beneficial effect of color on memory.

Though it is clear that color can improve memory, it is relatively unclear if specific colors can help more than others. Studies that have tested color on memory generally compare only one color or a multi-colored stimulus to black/white, so it is uncertain whether different colors would have had better or worse effects. For instance, the studies involving natural scenes included a variety of colors in each stimulus (Spence, Wong, Rusan, & Rastegar, 2006; Wichmann, Sharpe, & Gegenfurtner, 2002), and the experiment with stimuli in an emotional context included only red stimuli (Kuniecki, Pilarczyk and Wichary, 2015). Similarly, the experiment with nonsense stimuli, though it used three different colors, did not compare the colors in results (Cui et al., 2016). It only compared a “color” condition vs a “non-colored” condition, and it grouped the three colors together. If these studies had included more conditions and separated colors when analyzing results, more information about the color effect could be gathered. Differentiating between colors could help researchers and practitioners take full advantage of the color effect, in addition to gaining a better understanding of why it occurs.

Because different colors are believed to elicit different amounts of attention and arousal, it is likely that they will affect memory differently. Pal, Mukherjee, and Mitra reported that hues closer to red were more likely to increase attention (2012). Similarly, an experiment studying the N2pc ERP component, which is linked to selective attention, indicated that there was an early attentional preference for red over green (Fortier-Gauthier, Dell'Acqua, & Jolicœr, 2013). Yoto et al. (2007) found blue had the highest arousal between red, blue, and green, however in the same study, red caused more activity in central cortical regions associated with attention as measured by EEG. Although this study found higher arousal in blue than red, alternative studies have shown the opposite (Jacobs & Suess, 1975; Stone, 2003). These studies found that long-wave colors such as red often have higher arousal than shorter wave colors such as blue. If the attention and arousal theory is accurate, this would indicate that long-wave colors would have higher benefits on memory than lower-wave colors. For this reason, it is indicated that warm colors, specifically red, may have potential memory benefits over cool colors such as blue.

Independent of the actual color, some studies have found that a higher contrast between colors can help memory performance (Hall & Hanna, 2003). Furthermore, the same study also found contrast between warm colors such as red and orange helped performance more than similar contrast levels between cool colors such as brown and gray. In addition, color combined with stimuli with high emotional valence also had a higher attentional effect than color alone (Kunieki, Pilarczyk, & Wichary, 2015). To avoid these confounds in the present research, luminance was matched as closely as possible between stimuli, neutral objects were used, and the colors were rotated between objects to account for any color-object interactions. These enabled us to take the colors out of emotional and luminance context in order to ensure results were based off of the intrinsic factors of the colors.

Additional theories attribute the color effect to emotional or biological contexts instead of intrinsic values of color. These theories also rely on the concept of attention and arousal increasing memory performance, however they consider this increase to be due to factors other than just the color itself. One theory points toward emotional valence for the effect of color (Elliot & Maier, 2012; Lang, Bradley, & Cuthbert, 1998). This is based on the idea that certain colors may have emotional valence over gray-scale, creating arousal and attentional bias towards color stimuli. This theory mainly relies on cultural connotations of colors, for instance, red has both positive and negative valence as it correlates to artifacts such as fire/danger and sex. For example, in the U.S., red has many positive and negative emotional valences, however a color like brown is more neutral. According to this theory, red stimuli would be more easily remembered because of the emotional value associated with it, even in a simple task not directly involving emotion. This theory was not widely tested, as it was quickly incorporated into the color-in-context theory, which is discussed below.

Another theory states that colors may have an increasing effect on attention and arousal for evolutionary reasons, as explained in an article by King (2005). Many organisms, for instance wasps or poison dart frogs, use color as a way to warn potential predators that they are dangerous. Similarly, certain foods such as fruit change color when they are at proper ripeness to eat, and primates may have evolved to pay more attention to color for these reasons (King, 2005). While it is hard to find evidence for this theory experimentally, King describes how the eye and color vision may have evolved to take these environmental colors into account.

An additional theory by Elliot and Maier (2012) posits that the attentional and arousal effect has to do with both emotion and culture, and is context-dependent in its effect. This context would be a combination of the environment of the participant or stimuli interacting with a color. A study performed by Kuniecki, Pilarczk, and Wichary (2015) supported this theory. In this study, red captured attention better when in a positive or negative context than when in a neutral one. Another study found that participants walked faster when an assistant was wearing red in a romantic setting, where red is seen as positive, than when the assistant was in blue (Meier, D'Agostino, Elliot, Maier, & Wilkowski, 2012). In contrast, participants walked slower when an assistant was wearing red in an achievement/intelligence review setting, where red is correlated with negative emotions due to often being used to mark items as incorrect in a scholastic setting in the U.S. Although this study did not test memory, it is a good example of how red can modulate behavior depending on context. However, this theory would not explain the positive effects of color that have been found in neutral contexts, such as a simple neutral memory task. All of these theories support the idea that attention is a part of what increases memory, however what causes this increase in attention is not clear. While these theories are not necessarily mutually exclusive, the results of this experiment could lend support to one of them over the other. Because the experiment was designed to be context-independent, a significant difference between the colors and between black stimuli could indicate that the memory effect is at least partially due to an intrinsic value of the color.

In summary, this experiment could increase our knowledge of the beneficial impact that color has on memory. There is little question that color can improve memory performance, and there are many studies indicating that this is due to increased arousal and attention to the stimuli. However, some factors, for instance the specific color of the stimulus, are not well understood and need further research. In addition, there are alternative theories of why the color is beneficial to memory, one of which supports the idea that the effect only occurs in the presence an emotional context. This study could lend support in understanding differences between colors, in addition to the mechanisms behind the effect. This in turn would help researchers better utilize the effect as a whole. This could help people both in everyday situations and in education settings and could be especially impactful for people with memory and attentional problems.

Differences in color were tested using pictures of objects in luminance-matched red, blue, and black. These stimuli were first presented in a study phase, then tested in a second phase in order to assess recognition memory performance. Because the theory of attention and arousal is widely supported, and red seems to lead to higher attention and arousal, it was predicted that red would have the best recognition memory performance, followed by blue, followed by the control condition of black.

Method

Participants

The experiment included 48 male and female participants with normal or corrected-to-normal vision. Participants were either paid participants (*n=2)* or credit participants (*n=46)*. Paid participants were recruited from the Paid Psychology Research System website (http://ucboulderpaid.sona-systems.com) and from Tim Curran's lab website (http://psych.colorado.edu/~tclab), and were paid $5 for completing the experiment. Credit participants were recruited from the Psychology 1001 Subject Pool website (http://ucboulder.sona-systems.com) and were compensated with class credit for participating in the experiment.

Design and Procedure

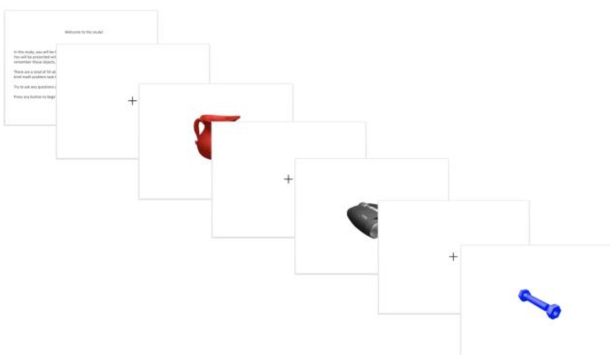
Figure 1

Examples of the objects used in black, red, and blue.

Materials for this study were 114 pictures of objects (Figure 1), which were randomly assigned to six different groups for counterbalancing across conditions. The pictures were obtained from The Object Databank on the CNBC Wiki which is under GNU Free Documentation License. There were six variations of the experiment, where the six groups of objects were rotated through the six experimental conditions: 3 object colors (red, blue, black) x 2 memory status (studied or not studied). Both color and memory status were manipulated within subjects. The luminance of the three different colors of each individual object was assessed with a LS-100 luminance meter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ). The luminance for each object was matched between colors using Adobe Photoshop CC 2018, then recorded (μ_{red}=10.692 cd/m^2, μ_{blue}=10.413 cd/m^2, and μ_{black}=10.597 cd/m$^{2)}$. Three additional objects were added to the beginning and three at the end of the study phase, which were not tested in order to avoid primacy and recency effects (i.e. better memory for objects at the beginning and end of the list).

The experiment consisted of a study phase, distraction task, and test phase. Informed consent was obtained from the participants, who were then given instructions about the three phases. Both the study and test phases of the experiment were run on Mac desktop computers in individual rooms. The math distraction task was completed on paper in the same room. Prior to starting, participants were told they would be later tested on their memory for the objects shown in the study phase.

Figure 2



Example of the study phase. A welcome page was displayed with instructions for the study phase, which was followed by images and fixation crosses for set amounts of time.

The study phase was made up from three groups of the objects, in addition to the primacy/recency objects. The images were displayed using PowerPoint, and the order was randomized for every participant using a slide randomizer macro in the visual basic editor. Stimuli were presented for 3000ms with a black fixation cross shown for 1000ms between each object (Figure 2). After the study phase, the participant completed a 3-minute math distraction task consisting of addition, subtraction, multiplication, and division to ensure that no objects were still in working memory. The test phase was then completed. This phase consisted of the same objects as the study phase in congruent colors with the additional three groups of non-studied objects in each color. Memory was tested using the online survey website Qualtrics. Each object was displayed, randomly and one at a time, with a multiple-choice question with two options, “studied” or “not studied.” “Studied” indicated that the participant remembered seeing the object in the study phase, and “not studied” indicated that the participant did not remember seeing the object in the study phase. Participants were told that they had unlimited time, but asked to answer the questions as quickly and accurately as possible with a mouse click. The experiment lasted approximately 20 minutes.

Analyzation and Statistical Programs

Microsoft Excel was used to calculate mean luminance values for red, blue, and black objects. Microsoft Excel was also used to calculate the mean and standard deviations for accuracy. Repeated-measure ANOVAs were used to test significance of accuracy between color conditions in RStudio. Finally, paired t-tests were calculated using RStudio in order to more directly compare significant differences between colors.

Results

The initial data regarding participant responses consisted of four main values in each color condition: correctly marking studied object as studied (hits), incorrectly marking non-studied objects as studied (false alarms), correctly marking non-studied items as not studied (correct rejections), and incorrectly marking studied items as not studied (misses). Accuracy was analyzed using two measures, sensitivity and threshold, which were calculated from this initial data. These two measures are based on the strength theory of recognition memory (Kahana, 2012). According to this theory, items in memory have a certain strength, and studying items increases their strength. A stronger strength would indicate a stronger feeling of familiarity in a person. When a participant is tested on their memory for an item, they use this strength to decide that an item was either studied or not studied.

An important factor in this memory retrieval process is the threshold value (C). The threshold value is the strength at which a participant will respond that they remembered an item (Kahana, 2012). As such, this value indicates the likelihood of a participants' response, in this case 'studied' or 'not studied,' because many participants will have a threshold value that is biased either positively or negatively. A negative C value indicates that a participant is more likely to respond 'studied' in the test phase, and a positive C value indicates the participant is more likely to respond 'not studied.' For example, if a participant had a strongly negative C, they would be biased towards choosing the 'studied' response and more likely to get the studied items correct, and the not studied items incorrect. A C value of zero would indicate that the participant had no tendencies to respond towards 'studied' or 'not studied' more often.

Sensitivity is another measure that is important in assessing memory according to the strength theory of recognition (Kahana, 2012). This experiment used the standard measure for sensitivity, d', which is calculated by subtracting the mean false alarm rate from the mean hit rate, expressed in standard deviation units. Sensitivity is a measure of a participants' discrimination between studied and not studied items. For instance, if a participant had no discrimination between the studied and not studied items, then d' would be equal to zero. In contrast, a participant who had high discrimination between studied and not studied items would have a high d' value. This measure is especially important to use because it is independent from C. This allows us to avoid participant biases while looking at accuracy.

Table 1: Descriptive Statistics

d'	Red	Blue	Black	*C*	Red	Blue	Black
Mean	2.33	1.89	2.10	Mean	0.22	-0.05	-0.06
SD	1.27	1.34	1.16	SD	0.43	0.22	0.20

Values for the means and standard deviations of d' and C for red, blue, and black.

Mean values for d' and C were computed from the raw data in Microsoft Excel and are recorded in Table 1. Three subjects were excluded from the data analysis. These participants had either d' or C values that were at least ±3 standard deviations away from the mean d' or C value, and thus were considered outliers. d

Repeated measure ANOVAs were run in RStudio to calculate any significant effects of color on d' and C. There was a significant effect of color on d', $F(2,88) = 3.46$, $p < .05$. We also found a significant effect of color on C, $F(2,88) = 9.35$, $p < .01$.

Paired t-tests were run in RStudio to find significant differences between individual colors for d' and C. The d' value was significantly higher for red than for blue, $t(44) = 2.42$, $p < .05$. The C value for red was also significantly higher than the C value for blue, $t(44) = 2.96$, $p < .05$, and for black, $t(44) = 3.40$, $p < .01$. There was not a significant difference between the d' values for red and black, $t(44)= 1.58$, $p = .12$, the d' values for blue and black $t(44) = 1.14$, $p = 0.258$, or the C values for blue and black $t(44) = 0.37$, $p = .72$.

Discussion

In this experiment, participants viewed a series of objects in red, blue, or black, and were later tested on their memory for these objects. As predicted, color had a significant effect on memory. Red had a significantly higher discrimination (d') value than blue objects, which was calculated to analyze accuracy of responses and used as a measure for memory performance. Similarly, the response threshold value (C) for red was significantly higher than for blue and black, however, no significant difference was found between blue and black images. In addition, the d’ values were not significantly different between red and black objects or between blue and black objects. As such, the hypothesis was only partially supported.

A higher accuracy of responses for red objects indicates that recognition memory was better for red objects than for blue objects. This provides evidence that the effect of color is different between colors, and that some colors are better for improving memory than others. This evidence can be utilized to take better advantage of the effect of color on memory in both research and in clinical practice on improving recognition. Because color has been shown to be beneficial both in the general population (Cui, Gao, Zhou, & Guo, 2016; Wichmann, Sharpe, & Gegenfurtner, 2002), and in populations with disorders such as dementia (Cernin, Keller, & Stoner, 2003) and autism (Ludlow, Taylor-Whiffin, & Wilkins, 2012), further improvement may be observed when using red over other colors while trying to enhance memory performance.

The increased memory performance of red objects in a neutral context supports the theory of attention and arousal. Many studies discussed earlier found that red increased attention (Fortier-Gauthier, Dell’Acqua, & Jolicœr, 2013; Pal, Mukherjee, & Mitra, 2012) and arousal (Jacobs & Suess, 1975; Stone, 2003) over other colors such as blue. These studies indicated that red would have a higher memory performance than blue if the attention and arousal theory was correct. In contrast, the color-in-context theory holds that the color effect is due to interactions between context and color creating emotional valence that can increase or decrease memory, so if it had been correct, then there should have been no significant differences between colors. The objects were chosen to be context-independent, and because red had higher accuracy than blue, this indicates that the increase of memory was due to intrinsic factors of the color. This supports the attention and arousal theory of memory because the results point towards an effect of the actual color, not an interaction with context.

These findings are also in accordance with an experiment performed by Xia, Song, Wang, Tan, and Mo (2016). Although this study did not explicitly test memory, it tested other cognitive tasks. One such task was a simple detail-oriented experiment where participants completed a proofreading exercise. This exercise in particular is focused on because the memory task in the current experiment could also be considered a simple detail-oriented task. This is in contrast to the other tasks in the Xia et al. study where color effects on creatively oriented tasks were examined. In addition, the proofreading task was also emotionally-neutral. In Xia et al.'s experiment, participants had significantly higher accuracy when proofreading with a red background than with a blue one. This is a similar enhancement as in the current experiment.

Although there was a significant difference between d' of red and blue, there were no significant differences between red and black, or blue and black. One possible reason for the lack of differences could be participant bias. Because the participants knew that the experiment was studying the effect of color on memory, they may have made a conscious effort to remember the black images just as well as the colored ones. In addition, although an effort was made to minimize color-object interactions, it is possible that there were still some interactions with color constancy and inconstancy. Hurlbert and Ling (2005) found that objects were more likely to be remembered if they were colored in a way that is constant to the natural world. Although objects were chosen that are often represented in many different colors, such as cups, cars, or tennis rackets, it is possible that some of these objects are more often black/white in daily life, and thus were easier to remember when black/white. This could have increased memory performance for black objects and, as a result, decreased the difference between black and the colored objects.

However, having each object shown in red, blue, and black limited color-object interactions having an effect on the results. Similarly, having each object in both the study and test phase in all three colors accounted for objects that may be easier or harder to remember. Finally, luminance-matching the stimuli was an important factor in ensuring that color effects were due to actual color, instead of luminance, which have been shown to have an impact on memory (Shieh, Chen, & Wang, 2005).

The significantly higher C value for red objects signifies a more conservative response bias, meaning participants were more likely to respond that red objects were not studied. This is in comparison to the C values for blue and black objects, which were closer to zero (unbiased) and not significantly different. One explanation for this difference is that the C value increased due to the higher memory strength of red objects. This idea is supported by the belief that when memory strength for a category increases, the participant will require a higher memory strength to mark items in that category as studied (Hirshman, 1995). As a result, the threshold value C increases and the participant has a more conservative response bias.

In order to further analyze the differences between colors and their effect on both attention and arousal and on memory, it would be beneficial to run a similar experiment with EEG. This would enable researchers to look at specific ERP components related to attention and arousal in a neutral context, while also testing memory. Most of the studies that examined color effects while using EEG have tested either attention and arousal or memory, but not both at once. A study using EEG could further support the attention and arousal theory by looking at ERP components and investigating if these correspond with both specific colors and an increase in memory. This could provide further evidence that colors can intrinsically increase memory, in the absence of emotional stimuli.

In addition, testing more colors would be beneficial to see why there is a difference between colors. More warm and cool colors could be tested to see if the difference lies between these two groups, or more definitive aspects of color could be tested such as the hue or saturation. Finally, a similar experiment with nonsense stimuli or an increased number of objects could help decrease the possibility of stimuli-color interactions. All of these potential studies could further increase our knowledge of the effect of color on memory, specifically how this effect occurs and how it differs between colors.

Thousands of people in the U.S. suffer with memory problems, whether this is due to trauma, developmental disorders, or other acquired issues. These problems can be a huge problem in daily living abilities, so ways to lessen them are of huge importance. Gaining information like the results of this study can help provide clinical researchers more evidence of the color effect in order to carry on more experiments using color as a memory tool in clinical populations. Showing that some colors are more beneficial than others can help narrow down possible clinical interventions, potentially having higher effects than they would have when using many colors or colors with a lesser effect.

The significant difference in accuracy of red and blue provided evidence that colors affect memory to different degrees. This experiment also indicated that the effect of color is due to increased arousal and attention to the stimuli, which enhances memory performance. This information can be used to better take advantage of the effect of color on memory, which could in turn help people both in everyday situations and educational settings, and could be especially impactful for people with memory problems. The results in this experiment show that the largely ignored factor of differences between colors in the color effect could be very important. In addition, further research could contribute even more important information to better understand the effects found in this experiment, such as why different colors affect memory differently, and more objective support to the attention and arousal theory of the color effect.

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