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Effects of Color on Sustained Attention and Recall

Harry Steinharter

Connecticut College, steinharterharry@gmail.com

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Harry Steinharter

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Abstract

Sustained attention, the process by which people focus on something for a long period of time, is a well documented phenomenon. It has enormous implications for life, from tasks as complex as surgery to as mundane as driving a car. However the effect that color has on sustained attention is rarely studied. The current study examined the effect of the presence of canonical color in images versus inverted colors, or black and white images. This effect was measured via a go/no-go paradigm gradual onset continuous performance task (gradCPT). A memory task was presented after the gradCPT in order to determine if color information affects implicit recall ability. Among the data from the sustained attention task, no difference was found in performance on the task between color and BW, or between canonical color (CAN) and inverted color (INV). However reaction time (RT) was significantly faster for the CAN compared to Inv. RT was approaching significance for color compared to BW. The memory task did show some interesting results. In experiment 1 and 2, recall ability was better for the stream images (no-go trials) than the city images (go trials). Recall was also better for color images compared to BW, and for CAN images compared to INV images. Although no difference was found for sustained attention performance, the data suggest that the presence of more color information, as long as that information is accurate, improves reaction time and recall ability. The data also show that recall is better for images that are more important, even if they are seen much less.

Contents

The human mind and human behavior have fascinated scholars for centuries because of the implications that understanding why people act, allows you to predict, or possibly control their behavior. This power to predict and control, has inspired philosophers and scientists alike to study how people pay attention, and what they pay attention to. The current study sought to follow this trend. The goal was to examine how the presence of color information can affect the ability to focus on a task for an extended period of time. Not only that, but examining how color information during periods of focus affects what you remember later was a goal of the current study as well. Throughout this paper, the historical contexts and epistemology of attention research will be summarized, and the impacts of previous researchers and philosophers will be described within the context of the current study. The evolution of research and the methods used for data collection will be discussed as well, allowing for a full understanding of the background that previous studies provide to the current research.

Background

Historical Views of Perception

Aristotelian

Aristotle spoke of attention and inattention, although he did so indirectly. Aristotle knew and acknowledged the competition for your attention between two stimuli. He likens cognitive stimuli to that of flavors: honey and wine are stronger when tasted alone, than when paired with others. The same is true of colors, music, and other stimuli. Aristotle's understanding of perception includes understanding of senses and sense organs. To paraphrase his writings: For senses, objects interact with our sense organs, and leave a perception. Feelings form from these perceptions and exist even after the perceptions have ceased (Gallop, 1996). For Aristotle, perception was relative to physiology. All perceptions from sense organs had to be transferred to and from the heart, and competitions between these movements explained the competition between stimuli (Fiecconi, 2021). At the time of Aristotle, not much was known about the brain, so it was thought that the heart was the center of thought and emotion.

Early Modern and Enlightenment Philosophers

Centuries after Aristotle, after anatomy and physiology had become more understood, the study of the mind still gripped many scholars. Philosophers such as John Locke speculated on the role of "attention". In his 1689 book, *Essays On Human Understanding*, Locke likened human thoughts to a train, coming naturally one after another. This train was labeled "attention". Locke differentiated this train of thoughts from thoughts that were focused on, and could not as easily be disregarded. Locke labeled these thoughts as "intention" or "study". René Descartes spoke briefly on the role of attention in his book, *Meditations*, originally published in the 1640's. Descartes wrote that everything can be doubted, which contradicted another writing of his which said that clear ideas were beyond doubt. To rationalize this contradiction, Descartes said that "as long as we attend to a truth that we perceive very clearly, we can not doubt it". Descartes and Locke, while they had differing views of attention, they both acknowledged that *focus* on a thought or a subject allowed a person to hold it in their mind for longer periods of time. However, psychology as a science, would still not exist for much longer. The common critique of psychology, which Immanual Kant published in a 1786 book, was that psychology was attempting to study something that could never be empirically measured. At this time there was no method of measuring the phenomena of the mind.

Early Psychology

Herman Fechner, in an attempt to counter the criticism that psychology could not be an empirical science, published *Elements of Psychophysics* in 1860. This book sought to bridge the gap between empirical science, and psychology. Fechner founded three methods of empirically measuring human behavior. His three methods – the method of limits, the method of adjustments, and the method of constant stimuli – paved the way for behavioral research and much of modern behavioral science. Fechner studied the limits of human perception using his three methods. They allowed him to test his participants' ability to detect change in whatever sense he was studying at the time, be it hearing, touch, taste, or any other sense. Thirty years later, William James published his book *Principles of Psychology* (1890). James, along with psychologist Carl Lange, developed a theory of emotion that revolved around an individual's perception of the physiological response to the emotional stimuli. The theory, aptly named the James-Lange Theory, posits that a stimulus causes a response (e.g. crying) and your perception of the response determines the emotional valence of the event.

Attention and perception research continues into the 1950’s where it begins to flourish. Norman Mackworth’s famous study on vigilance (1950) was inspired by concerns of radar operators’ efficacy during WWII. Mackworth studied the sustained attention of radar operators by displaying a ring of white circles, against a black background. One of the circles appeared red, and would rotate around the ring, moving from circle to circle, like the hand of a clock, around the ring. At irregular intervals, the red dot would skip a circle, and jump two positions, instead of one. The radar operators were tasked with detecting and reporting when this occurred. The findings of his vigilance study laid the groundwork of research for generations. He found that radar operators' performance declined over time. This meant that at the beginning of the task, they may report when the dot skipped a location accurately 80% of the time, but by the end of the task, they may only be reporting with 30% accuracy due to fatigue. Mackworth also found that surprising events could briefly pull participants out of their fatigued state which caused participants to return to a normal operating level, in this case back to 80% accuracy. Mackworth's vigilance study is also one of the oldest studies of sustained attention, which is notably different from "regular" attention, in that sustained attention requires an individual to maintain focus over a long period of time. Mackworth's study examined *visual* sustained attention specifically. People are able to attend to things in many different sensory and/or cognitive capacities, for instance visually vs auditorily. People can attend to things cognitively, without external stimuli, for example doing mental math, and attention can either be held, like sustained attention, or it can be captured by an external stimulus, which will be discussed more later on. Mackworth's original research relied entirely on behavioral data, meaning he was looking at what a participant was actually doing, their behavior. He did not have the technology at the time to look at an individual's brain waves or neuronal connections during the task. Cognitive and behavioral research has progressed greatly in the past half century, to the point where we can examine and analyze data such as that.

Modern Methods of Data Collection

Behavioral Data

Historically, behavioral data have been the only data that were feasible to gather during studies of attention. Behavioral data focuses on reaction times, movement times, and correct vs. incorrect responses. For example, during the Stroop task: in this task participants see a list of color words, and the color words are written in colored font. Sometimes participants are asked to say the word aloud, other times participants say the font color while ignoring what is written (Stroop, 1935). Behavioral data from this are gathered on how long people paused before speaking, and if they said the correct thing.

Pupillometry

Pupillometry is the measure of pupil size and reactivity. In psychological research, it is often used to measure participant focus on the task. It has been shown that pupil size increases with the effort exerted by a person in response to the demands of a task (Kahneman & Beatty, 1966). Pupil size can then be used as a physiological marker of how much mental effort was exerted by an individual. Prior to this, mental strain could only be assessed using surveys, which are less accurate and rely on participant self-report.

EEG

Electroencephalography, first discovered in 1929, but still widely used today, works by placing a series of electrodes along an individual's scalp. Highly sensitive electrodes placed along the scalp are capable of picking up electrical signals from pyramidal neurons located in the cortex of the brain. Due to the high sensitivity, the electrodes are capable of picking up electrical signals from lights or electronic devices nearby. This can interfere with the signal and introduce noise into the data. They can also be affected by muscular activity in a person, especially their face. EEG’s goal is to gain a temporally useful view of what is happening in the brain. The electrodes respond to pyramidal cells on the outer layer of the brain. These cells align and produce a small electrical signal when that region of the brain is stimulated. The EEG data can then be read as an ERP, event related potential, which shows at what time a person’s brain was responding to a stimulus. ERP’s are calculated by averaging many trials together, because a response to a single trial is not visible in EEG data. EEG’s high sensitivity also allows for precise timing of neuronal activity, without precise spatial information, however. EEG is still one of the most temporally precise methods of data collection, so it is still widely used, despite being originally discovered nearly a century ago.

PET

Positron emission tomography (PET) is a functional imaging technique that uses radioactive substances (radiotracers) in order to target certain metabolic processes (Bailey et al., 2005). Radiotracers were designed to target blood oxygen or glucose, in which case it could show how these molecules are being used by the body. In the brain, increased glucose or blood oxygen is an indicator of higher activation of those areas. PET was first developed in the 1950’s. However, PET scanning of the brain was not common until the 1970’s when an appropriate radiotracer for cerebral use was developed (Portnow et al., 2013). PET scans and fMRI are both functional measures of brain activity, meaning they can measure changes over time. However, PET is unaffected by small movements, whereas with fMRI, if the participant moves at all during a scan, the data for the entire scan may be invalidated.

MRI and fMRI

MRI, magnetic resonance imaging, shows an anatomical view of an individual's brain. While the concepts behind MRI were first discovered in the 1950’s, a practical way of doing full body MRI scans was not developed until the 1970’s. It works by using a strong magnetic field to misalign protons, then radio waves are used to interrupt and realign the protons. The key to MRI is that the hydrogen atoms that respond to the magnetic field respond differently depending on their surroundings. This allows the scan to differentiate between different regions of the brain. While MRI is predominantly used clinically to identify different tissues and structures in the body (e.g. tumors vs healthy tissue, or different regions of the brain), fMRI can be used in other forms of research to examine changes in the body over time. fMRI was first developed in 1990, and it shows a scan over time of blood oxygenation in the brain. Hemoglobin, a portion of blood, has different magnetic properties when oxygenated vs when deoxygenated. The fMRI scan shows regions of the brain that have heightened levels of oxygenated blood vs deoxygenated blood. This is correlated to regions of the brain that have more activity (Mather et al., 2013). This has been influential in attentional research by allowing researchers to see in real time, which regions of the brain are being activated in response to a given stimulus. While fMRI is capable of showing changes over time, it is not highly temporally sensitive, unlike EEG, which can show precise timing of neuronal firing in the cortex.

Filtering

There are many hypotheses that exist regarding how information is processed and attended to, however, there are two major hypotheses that others are based on: The late filter, and the early filter. The filter hypotheses are relevant to the discussion of sustained attention because it aids with the understanding of how distractions occur, and how attention is pulled away from a task at hand.

The late filter hypothesis posits that you attend a little bit to everything going on around you, and information is not considered irrelevant and thus filtered out until a late stage of processing. Once irrelevant information is automatically filtered out, purposeful attention can be devoted to a task at hand. This can be seen with the “Cocktail Party Phenomenon,” discovered by Edward Cherry (1953). When attending to a conversation in a party, you're able to “tune out” conversations around you because they are irrelevant to the conversation you are paying attention to. However, if someone in a far off conversation says your name, even if the rest of the conversation is filtered out and not processed, you will still notice your name being said. All the auditory information from the party was processed a small amount, which explains how hearing your name could grab your attention. If external conversations were not processed at all, your name would not pull attention.

The early filter hypothesis (Broadbent, 1954) posits that all information can be filtered out early on, using a feature (sound, color, shape, direction, etc.) as filtering criteria. This is most easily recognized in day to day life in searching tasks. If you are looking for your friend in a bright green jacket, you may automatically filter out people wearing less obvious colors, for instance brown, gray, or beige. However, this filtering out can be impeded by the presence of distractors.

Another proposed model of attention is the memory selection model, which is a variant of the late filter model. Duetsch and Duetsch (1963) suggested that items are not being immediately filtered out. Instead, information that does not have any personal relevance is immediately forgotten. In the cocktail party scenario, your own name, as well as the conversation being attended to, have significance to you, however all the other conversations do not. Hollingworth & Hwang (2013) examined the memory selection model with regard to visual working memory. Visual working memory is the ability to hold an image or a concept (like a specific shade of green) in mind for a task.

Sustained Attention

Attention is broad and can be defined and studied in numerous different ways. People can attend to stimuli in all manner of senses as well: auditory and visual, as well as gustatory and olfactory. One fMRI study on attention of smell and taste information found distinct brain regions active for either smell or taste attention, and one region that was activated for both (Veldhuizen & Small, 2011). Veldhuizen & Small asked participants to focus on a selected stimulus among other stimuli. They were doing this task while in an fMRI machine enabling the researchers to identify the activated regions of the brain. This study focused on *selective attention*: the ability for people to focus on a single input in the presence of others. However other attentional modalities exist. *Attentional capture* is when an individual attends somewhere else when presented with an unfamiliar or startling stimuli. *Sustained attention*, the topic of the present study, is the ability to maintain focus and continue to respond to a given stimulus or task over a period of time. The exact length of this time period is not concrete. Some studies of sustained attention only last a few minutes, while others last much longer.

The importance of sustained attention cannot be understated. From the classroom to the car to the operating room: people are focusing on tasks for long periods of time, and sometimes there can be severe consequences for a loss of attention. This is why it is so important to study sustained attention. For example, surgeons in the operating room must focus on their task at hand for several hours at a time, all while there are possible distractions happening, or the surgeon could simply lose focus. These could lead to mistakes by the surgeon, with possibly fatal results (Jung et al., 2020).

Sustained attention abilities are affected by external sources, and they can also vary minute by minute. Variance time course analyses (VTC) have been used to examine participants' attention during a task. Esterman et al. (2013) found that participants had distinct periods of increased performance, and distinct periods of decreased performance during the task they were presented with. The task participants saw in the Esterman et al. study (2013) was a series of images displayed one after another. The study was a “go/no-go” paradigm, meaning the majority of the time participants were tasked with responding, but had to withhold their response on rare critical trials. This paradigm is what will be used in the current study. In Esterman et al. (2013) participants were doing a keypress study on their own personal computer. When an image of a city appeared, participants pressed “M”, and when an image of a mountain appeared participants had to do nothing. Mountains were the critical “no-go” trials. In this analysis, the performance was being compared to their own average performance. These “in the zone” and “out of the zone” periods cycled between one another, with more time spent out of the zone towards the end of the experiment. This is in line with previous studies that found decreased performance over time. Critically, Esterman (2013) found that performance on a sustained attention task cycled up and down. For a period of time participants performed above their own average performance (i.e. made less mistakes). This period of heightened performance was then followed by a period of decreased performance (i.e. made more mistakes). Performance on the task oscillated back and forth during the task, with more time “out of the zone” and making more mistakes later in the task.

Mackworth’s vigilance study (Mackworth, 1950) showed just how unreliable human sustained attention can be. One of Mackworth’s findings showed that participants’ attention decreased over time. This was able to be counteracted by a surprising event. However attention can be reinforced by numerous different stimuli. Esterman and colleagues (2016) found during a vigilance experiment that anticipation of payment attenuated the effect of decreased attention over time. Esterman (2016) had two conditions. Participants did the same Cities/Mountains sustained attention task as Esterman (2013). In one condition, participants lost a small amount of their $18 reward for each mistake they made. In the other condition, participants lost the full $18 if they responded incorrectly to a single important trial towards the end of the task. In the condition of full monetary loss, participants had significantly better performance later in the task. This shows that the anticipation of reward (or avoidance of losing the reward) mediated the increased rate of making mistakes later in the task.

Fatigue and Boredom

Mental fatigue is one of the predominant causes of decreased performance over time. The concept is very similar to that of physical fatigue. In this vein, mental and physical fatigue have been studied together before. Slimani et al. (2018) had participants do the Stroop task (as described in “Modern Methods of Data Collection”) with 5 sheets of paper, each with 45 words (225 words total). Participants did this for 30 minutes continuously. The control condition had participants read from regular magazines at their own pace. The Stroop task was done to fatigue participants. To assess attention, participants did the D-2 task of attention. In this task, the letters D and P are presented many times in a row. Each letter has one or two marks above and/or below the letter. The participants must cross out each D that has a total of two marks around the letter, while ignoring all P’s and D’s with other numbers of markings. The study did successfully show that participants in the mentally fatiguing condition did worse on the D-2 task. The study also found that mental fatigue affects physical endurance, with mentally fatigued individuals having less endurance as measured by the pacer test (running back and forth between two lines in a continually shortening amount of time).

Alternatively, Pattyn et al. (2008) examined two hypotheses underlying decreased abilities over time. The “underload” hypothesis, in which abilities decrease due to low arousal (i.e. boredom), and the “overload” hypothesis, in which abilities fail due to sustained mental effort (i.e. fatigue). To monitor arousal levels during the task, Pattyn and colleagues used measures of nervous system activation via electrocardiogram (ECG) and respiration data. Participants saw a screen of 9 boxes arranged in a 3x3 grid. They had to respond based on color, shape and location of target stimuli appearing in the boxes. Pattyn et al. found that the underload hypothesis was supported in their study. Participants did not show very heighted nervous system arousal, but did still show decrement in their accuracy and reaction time after 30 minutes of testing.

Distractors

Distractors can have a negative effect on a person's ability to attend to a task at hand. Distractors, by capturing attention, briefly "pull" a target's attention away from the task at hand. The attenuation model of attention describes the effect of distractors well (Triesman, 1969). In the attenuation model, all unnecessary information is filtered out, but in filtering out information, some information will leak through the filter if it passes a certain threshold. For instance, if you're looking for your friend in a green jacket in a sea of beige jackets, but one person is wearing red, you will also attend to the red jacket, while filtering out the beige. This effect is seen in countless studies of salient distractors. Lamy et al. (2003), had participants look briefly at an image (45 ms) of shapes arranged in a ring. In half of the trials, the target shape was there, while in the other half the target was absent. A distractor was present appearing in a bright color (either green or red). Lamy et al. found that the salient distractor did affect participants' ability to identify the target. As with the attenuation model, Lamy's findings show that salient distractors can pull attention away from a target. The brightly colored distractors from Lamy's stimulus were salient enough to "force" a participant to briefly attend to it.

However, distractors come in countless forms, and brightly colored shapes or objects are just one example. Another kind of distractor can come in the form of emotion. The emotional blink occurs when individuals require time to process a highly emotional image, this causes a lapse in recall ability of things coming immediately after the emotional image. This effect can be seen in the 2010 study by Schwabe & Wolf. This study, as opposed to using images, presented participants with words. Words were either from a neutral list (e.g. line, wood) or an emotional list (e.g. bitch, ass). Each word was presented for a short period of time, then the next word would appear. During the study, participants would see an emotional target word, and a neutral target word, as well as many distractor words (targets indicated by red font, distractors in white).

Schwabe & Wolf (2010) found that participants struggled to identify the second target word, when it appeared within 500ms of the first, emotionally salient, target word. This study, however, also looked at the emotional state of the participants. This was measured via salivary cortisol. Schwabe & Wolf (2010) found that compared to individuals who did not have high-stress (as measured by cortisol), those with high stress had a reduced effect of the attentional blink.

The emotional attentional blink, however, may not be a consequence of emotions alone. The effect could also be due to the pop-out effect, which is another type of salient distractor. Santacroce & Tamber-Rosenau (2022) determined that the emotional blink is caused by two factors. The first factor was the immediate salience of the object, regardless of its emotional valence. This is similar to the effect caused by one red object appearing amongst green objects. However, in this example, the items are appearing sequentially. The second factor Santacroce found was due to emotional salience of the image, and this led to a delayed attentional blink effect. Their experiment manipulated the brightness of the images. This was done in order to single out the specific attribute of the image that was capturing attention. By manipulating the brightness of the image. Santacroce and Tamber-Rosenau were able to adjust the salience of the image independently of the emotional value of the image.

Signal Transduction of Light

Colored distractors are a common paradigm in sustained attention research. However, visual color information is not processed exactly the same as black and white information. The visible spectrum of light is 380-700 nm. The transduction of light requires light to come from a light source (e.g. the Sun) and reflect off an object. Objects absorb certain wavelengths of light, and the color that is perceived by the viewer is the light that is not absorbed. For instance, healthy grass does not absorb the middle of the spectrum of visible light, thus, grass appears green. The light reflects from the object and enters the eye via the cornea. Transduction of light into an electrical signal begins when the light hits the back of the eye, the retina. The retina is home to two main types of cells: rods and cones. Rods are responsible for vision in low light. They do not receive color information, instead they can only convey black and white information. Cones are responsible for color.

The process by which the photons of light are transduced into an electrical signal in the brain is highly complex, and depends on different photoreceptor molecules in the eye (Mannu, 2014). The four types of photoreceptors are rods, short wavelength cones, medium wavelength cones, and long wavelength cones. Each photoreceptor is home to a different pigment molecule that reacts when exposed to a certain wavelength of light. Rods contain the pigment rhodopsin, and the cone cells contain 3 different pigments, called iodopsin. These are erythrolabe, chlorolabe, and cyanolabe. Erythrolabe undergoes a conformational change when exposed to 565 nm wavelengths of light. This wavelength is perceived as red light. Chlorolabe is sensitive to 535 nm wavelength, which is green light, and cyanolabe is sensitive to 440 nm wavelengths, blue light (Terakita, 2005).

The reaction of photons hitting photoreceptor cells in the retina causes the corresponding pigment molecule to change conformation (from cis to trans) and allows for the chemical reaction that opens ion channels to create the electrical signal. When light causes the change from cis to trans in a photoreceptor, that molecule continues a cascading process in which the end result is increased outward flow of K^+ ions from the cell, thus hyperpolarizing the cell. It is through a lack of depolarization that photon signals get converted into electrical signals (Kizhatil et al., 2009).

The optical network is just a small facet of neural mechanisms that underlie visual attention. There are several specific regions of the brain that display either significant increase or decrease during periods of focus. Another important network for attention is the default mode network. This network of connected brain regions is active during low arousal “normal” state, but then is inhibited during high arousal attentive states.

Default Mode Network

In 1997, Gordon Shulman and colleagues discovered that while people were doing a novel or challenging task, there was a marked decrease in activity in a series of neural areas. This was the initial discovery of the default mode network (DMN), a series of linked neural areas in the frontal and parietal lobes of the brain that is active during resting state activities, but is less active during difficult activities, novel tasks, or learning. Shulman analyzed data from 9 previous PET studies of visual information processing. Participants' PET data during the 9 tasks was compared to their PET readings while passively looking at the same stimulus. What they found was a significant decrease in the following areas while performing any task: posterior cingulate cortex, left and right inferior parietal cortices (IPC), left dorsolateral and left inferior frontal cortices (DLPFC, IPFC), left inferior temporal gyrus, and the right amygdala. This showed a clear relationship between visual attention, mental effort, and these regions. These regions showed simultaneous inactivation during episodes of visual focus. This paved the way for future research into what would become known as the default mode network.

Greicius et al. (2002) examined the functional connectivity of two regions in the cingulate cortex. Functional connectivity measures how regions of the brain interact with selected target regions. The connectivity is measured with fMRI using the blood oxygen level dependent (BOLD) response. The BOLD response measures neural activity via correlation with higher amounts of oxygenated blood (as opposed to deoxygenated blood) in selected regions. The posterior cingulate cortex (PCC) and the ventral anterior cingulate cortex (vACC) are both regions that have been associated with the DMN, and were the subject of Greicius and colleagues' study. They presented participants with a working memory task in which they had to indicate if a presented stimulus was in the same location on screen as it was two trials prior.

Greicius et al. (2002) found that resting state (not doing the working memory task) activity of the PCC was associated with activity in a number of regions, including many that are associated with the DMN: vACC, left and right IPC, IPFC, and DLPFC. The vACC at resting state was found to be strongly associated with the following regions: PCC, precuneus, nucleus accumbens, and hypothalamus. During the task, the connectivity between the regions was virtually the same. What this shows is that these regions experience activation and deactivation simultaneously dependent on the individual's current level of stimulation. The regions were less active while the participants were doing the task, and more active during the resting state scans. Griecius's data was in line with Shulman's 1997 data, showing connectivity with nearly all the regions identified by Shulman.

With the discovery of the DMN and its deactivation with focus on a task, this led to the question of what is aroused during a task? Fox et al. (2005) used fMRI to compare blood oxygen levels in the brain during three different conditions: visual fixation on a crosshair, eyes closed, and eyes open in low light without a crosshair. Fox et al. then compared the BOLD response data between the attentive condition and the resting condition. In the resting condition, they found consistent DMN activation, and during the attentive condition, they found DMN deactivation, and activation in a task-positive network. This network consists of: IPS, dorso-lateral and ventral prefrontal regions, SMA, and insula. They discovered a secondary network that cooperates with the DMN, and showed that the brain has distinct regions that it can oscillate between during periods of either relaxation, or mental focus.

Sustained Attention: Color and Categorization

Color can be studied in numerous ways, via recognition, identification, memory, etc. Wilschut and Mathôt (2022) examined the categorical bias of colors. Understanding how the brain processes and attends to different colors is integral to understanding the effect color has on sustained attention. Wilschut and Mathôt had participants view three colors, one second later they were cued on which of the three colors to hold in their memory. At the end, participants were asked to locate that color on a color wheel. 50% of the time there was an interference probe between the cuing and the replication. The probe was another differently colored circle. They found that pupil size constricted the most when the probe was a color that was not related to the cued color at all, this is compared to a color in the same category, and a color nearby on the color wheel but of a different category. Magnitude of pupil dilation in this study indicated the amount of mental effort was being exerted by participants. However, pupil dilation lasted longer for probes from matching categories as the cued color. This suggests that matching colors hold attention longer and more strongly than non-matching colors, whereas a highly salient color only briefly captures attention and the effect is quickly diminished by the color being held in memory.

Color is an integral part of perception and categorization, and color perception's usefulness extends to all aspects of life. However, how sensitive to color are people? Cohen and colleagues (2020) used head mounted virtual reality displays to immerse participants in artificial real-world environments. The presented environments began in full color, and after a few moments, the scene would desaturate except for a radius around where the participant was looking. Their findings showed that a large portion of people (~25%) did not notice when the outer 70% of the radius of their visual field was in black and white. This suggests that even though color information can be perceived, it does not always need to be.

The current study seeks to investigate the relationship between color information in images and ability on a sustained attention and recognition task. Relevant to this, Snodgrass & Vanderwart (1970) created an image database of images and their associated words. In this study Snodgrass and Vanderwart presented participants with 260 unique images sequentially. Participants wrote down the name of what was pictured (e.g. “Lion”, “Knife”), ranked their familiarity with the image, ranked the complexity of the image, and participants described the image agreement (how closely the image matched their mental image of what was pictured). While this foundational study has many important findings, their findings on visual complexity are most relevant to the current study. This is because, in the current study, the differences between colored images and black and white or color inverted images could be most easily described as a difference in visual complexity.

Snodgrass & Vanderwart found a significant negative correlation between visual complexity and image agreement. This meant that as images were rated more complex, people rated the image as less similar to their mental image of what was depicted. This negative relationship most likely stems from the characteristics intrinsic to what is being depicted. As an object becomes more complex, more ways of depicting the object arise. Image complexity was also negatively correlated with familiarity. Snodgrass & Vanderwart hypothesized that this relationship stemmed from the object's grammar of representation: how it is represented in thought and in words, similar to a heuristic of the object. Familiar objects by definition must be thought about frequently, thus people will have developed quick and efficient mental shortcuts to representations of these objects. Because of this, familiar objects most likely have simple representations, which would explain the positive correlation between familiarity and image agreement, as well as the negative correlation between familiarity and complexity.

A 2004 study by Rossion & Pourtois expands upon the visual complexity findings of Snodgrass & Vanderwart. The drawings from the original Snodgrass & Vanderwart study were all simple line drawings, and complexity was entirely dependent on what detail was put into the drawing. For instance, how many brush strokes, or how much shading was used in the drawing. Complexity was largely subjective, which for the purposes of the Snodgrass & Vanderwart study, was acceptable. Rossion & Portois, however, sought to empirically classify levels of detail in images. They created three levels of complexity: simple line drawings, textured line drawings, and colored drawings. The simple line drawings were the same original Snodgrass & Vanderwart images. The textured images had more black and white detail added. And the colored images were colorized versions of the black and white images. By studying these three intrinsically different levels of detail, Rossion & Portois avoid the differences in inter-categorical differences. Participants saw one of the three conditions, and performed the naming, familiarity, and visual complexity rating tasks from Snodgrass & Vanderwart. Rossion & Portois also collected color diagnosticity data from 11 independent subjects who did none of the three conditions. This task asked participants to rate how highly the color of an image was intrinsic to the image itself, for instance, a red apple would receive a high score because red is so often associated with apples.

Rossion & Portois found a highly significant correlation between reaction time and the amount of surface level detail in the image. Colorized images had much faster reaction times than the simple line drawings. The black and white images varied depending on the category of image: man-made with diagnostic color, man-made without diagnostic color, fruits/vegetables, or animals. To test whether this effect was concrete they examined the effect against images that had fast RT's as line drawings and those that had low RT's as line drawings. They found that the speeding up effect of adding color was significant for images that are both quickly or slowly recognized as line drawings. For the black and white drawings, however, RT's were only improved for the images that were named slowly as line drawings. For the quickly recognized line drawings, the addition of black and white texture detail did not speed up recognition at all, but it did not slow it down either. Visual complexity was rated the same across the three image sets. Rossion & Portois also found that the image agreement scores (how closely the drawing matches their mental image) was significantly lower for non-diagnostic color man-made images when presented in color or black and white versus when presented as a line drawing. This is the inverse relationship to all the other image categories, including diagnostic color man-made images. These data show that color can clearly affect recognition and processing speed, and there's a suggested interaction between color and mental representations of an object. If an object is more clearly represented as a mental image, then the addition of color information that agrees with your mental image will aid in recognition. Whereas less specific mental images (no diagnostic color) have recognition inhibited by the addition of unnecessary surface level detail.

Wichmann et al. (2002) also examined the effects of color on recognition and memory. Wichmann and colleagues presented participants with a series of images, both in color and in black and white through a series of experiments. Wichmann tested participants' memory by presenting them with an image along with a prompt asking if they had seen it before. They found that memory was 5-10% better for colored images than for black and white images. However, this effect was negated when the tested images appeared differently than the exposure images. This means that if an image is originally presented in color, but then later presented in black and white, recognition will not be as strong as if the image was presented in color a second time. Wichmann also found that non-canonical color images did not have better recognition than the black and white images. This suggests that the simple presence of color is not what drives the improved recognition, but instead there must be top-down effects of what colors are expected in an image, vs what colors are presented in an image.

Webster et al. (2018) examined the effects of canonical characteristics of images on participant inattentional blindness. Canonical characteristics refers to characteristics that are the default state of that image. Webster and colleagues found that canonical brightness, orientation, and color had a strong effect on attention. While attentional demands were high, only the canonically represented images were able to fully capture attention. The canonical scenes aided participants in interpretation of the gist of the scene, which allowed them to discriminate more rapidly. The non-canonical colors were not as easily discriminated because it was more difficult to quickly extract the gist of the scene.

The Current Study

In the current study, instead of looking at how people perceive color, the goal was to examine how color affects speed and accuracy of what is perceived. The experimental procedure was similar to that used by Fortenbaugh et al. (2014). Participants performed a go/no-go paradigm in which they responded to images of cities and streams in both color and black and white, or canonical and inverted color, depending on the experiment. The go/no-go paradigm is a frequently used procedure in which participants respond (go trials) more often than they withhold responses (no-go trials). Response accuracy and speed on critical no-go trials can indicate a participant's level of attention. Performances of reaction time and accuracy were analyzed between conditions to examine the effect color has.

The task performed in the Fortenbaugh et al. (2014) paper is an example of a gradual-onset continuous performance task (GradCPT). A CPT is a type of task in which participants have to pay attention, for instance in a go/no-go paradigm task for a prolonged period of time in which stimuli are presented sequentially. A GradCPT is very similar, however the stimuli fade between one another. While one stimulus is fading out (decreasing opacity), the next stimulus is overlaid with the previous one and fading in (increasing opacity). This can be seen in Figure 1, taken from Fortenbaugh et al. (2014), to illustrate how the images overlap with one another.

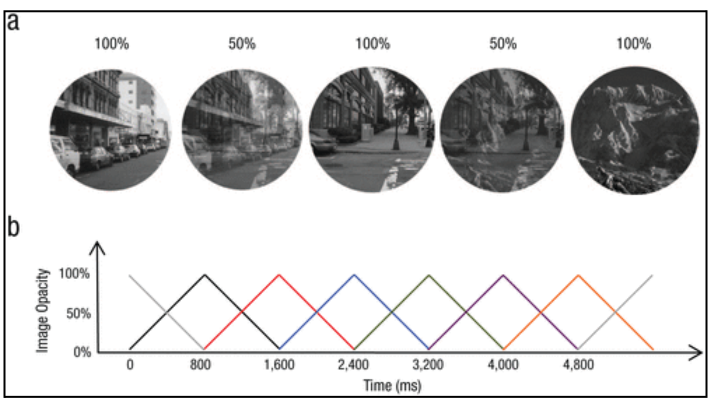


Figure 1: Taken from Fortenbaugh et al. (2014). (a) Shows the process of one trial increasing in opacity and then decreasing, while the next trial after it increases in opacity. (b) Shows the opacity of different images over time.

It was hypothesized that performance on the color condition would be better than performance on the black and white condition during the gradCPT due to previous research that color information aids image recognition (Wichmann et al., 2002). Because of this, it was also hypothesized that canonical color images would be recalled more accurately in the implicit recall task. In the canonical color vs inverted colors experiment, it is hypothesized that performance will be better with canonical color compared to the inverted colors (Webster et al., 2018). To test these hypotheses, the current study included two online experiments. The current study manipulated the images participants saw. Across the two experiments, there were three total conditions. Experiment 1 compared color images to black and white images. Experiment 2 compared color images to inverted color images. The current study took place during the 2022/2023 academic year at Connecticut College.

Methods

Participants

There were 107 total participants in the current study; 53 for Experiment 2, and 54 for Experiment 1. Participants were primarily gathered from the internet using the crowdsourcing platform, Prolific (prolific.co). Participants were also students from Connecticut College. The Connecticut College participants were psychology students participating in studies during the semesters for credit or extra credit for classes. Some participants were recruited outside of the psychology department in order to recruit as many participants as possible. Connecticut College students from outside the Psychology department were recruited via flyers put up around campus, as well as by word of mouth. Participants not eligible for class credit instead received payment in the form of $5. Some ($n=3$) early participants from Connecticut College were paid $10, before the compensation amount was reduced to match the amount of time the study takes. The study was conducted virtually. Participants were not able to receive both course credit, and monetary credit. If course credit was available for a participant, they could only receive the course credit. Participants recruited from Prolific were compensated with $5.

To be included in the study participants must have had normal or corrected to normal vision, and normal color vision. First language was asked in the demographics, but participants were not excluded based on their response (Thierry et al., 2009). Participants also had to be at least 18 years old.

Experiment 1. Color vs. BW images. 4 participants were collected from Connecticut College. Total number of participants was 53. The participant pool was 63% male *(n = 34)* and 37% female *(n = 20)*. The participants were 76% white *(n = 41)*, and 13%, 7%, and 4%, asian, black, and other/did not specify, respectively *(n = 7, n = 4, n = 2)*. 93% of the sample listed English as their first language *(n = 50)*, 6% listed Spanish, and 2% did not specify *(n = 3, n = 1)*. The ages of the participants varied from 18, to 66 years old *(M = 36.74, SD = 11.68)*.

Experiment 2. Canonical color vs. inverted color image. The total number of participants was 54. The participants were 70% female *(n = 37)* and 30% male *(n = 16)*. The sample was 70% white *(n = 37)*, and 13%, 11%, 4%, and 2% black, asian, other/did not specify, and mixed race, respectively *(n = 7, n = 6, n = 2, n = 1)*. 87% of the sample listed English as their first language *(n = 46)*, Spanish was listed twice, and Vietnamese and Russian were each listed once *(4%, 2%,* and *2%*, respectively). 3 people *(6%)* did not specify a language. 83% of the sample was not hispanic *(n = 44)*, 11% was hispanic *(n = 6)* and 3 did not specify *(n = 3)*. Participant age ranged from 19 to 69 years old *(M = 37.58, SD = 11.48)*. In Experiment 2, no participants were recruited from Connecticut College. This was done in order to streamline the experimental process, since recruitment from Connecticut College was largely unsuccessful in Experiment 1.

Procedure

The experiments performed had near identical methods. The experiments differed in the images shown to participants, but the overall order and procedure was the same. The two image sets compare: 1) Color images vs. black and white images; 2) Canonical color images vs. inverted color images. The images were of city streets, and of streams (see Appendix A). First participants saw an informed consent document (see Appendix B). Participants then did two GradCPTs. The images shown during the GradCPT were dependent on the current experiment (image sets described above). The order of which was counterbalanced. The GradCPT was a go/no-go paradigm in which participants were instructed to press the “M” key on their keyboard when presented with an image of a city, and withhold a response when presented with an image of a steam. After each GradCPT, participants were given a short break to combat fatigue. The experiment paused on a screen instructing them to take a break, and continue whenever they feel ready. During the GradCPT, participants were instructed to respond as quickly as possible. Responses were not required on any image, the images would continue cycling every 500ms regardless of participant engagement. Data from participants were checked prior to compensation being rewarded, to ensure that participants were engaged with the task, and not simply opening the study and letting it run.

After the break, participants began the recall task. The recall task presented each image from the task (cities and streams) as well as city and stream images that were not present. There were 80 images total in the recall task: the 10 cities in the study, the 10 streams in the study, and 10 novel images of each, streams and cities. Each scene appeared in two images, once per each condition (e.g. once in black and white, and once in color). Each image was presented on its own, and participants were asked: Did this image appear during the previous attention task? Participants were instructed to press the “Z” key if the image was new to them, or the “M” key if they recognized the image. After completion of the study, participants saw a demographics questionnaire (see Appendix C). Finally, participants saw a debriefing statement (see Appendix

D). The images that participants saw during the GradCPT were randomized by participant, and each participant will see the same images in the color and black and white conditions. A sample series of trials of the sustained attention task can be seen in Figure 2.

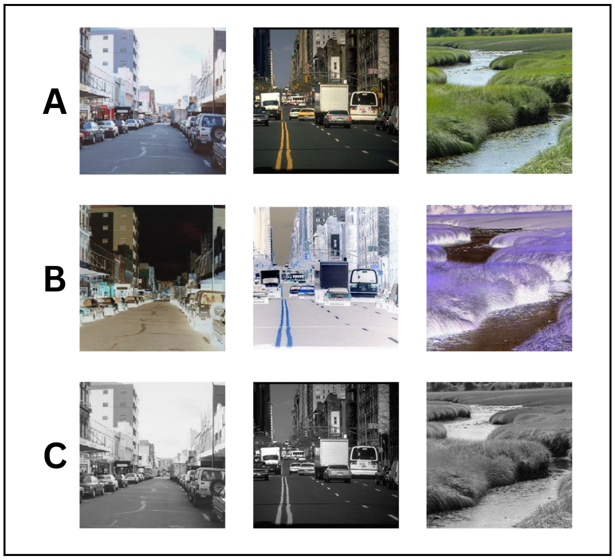


Figure 2: Shows a series of 3 canonical color images (a) and a series of the same 3 images with inverted colors (b) and in black and white (c). The canonical color images were used in both Experiments 1 and 2, the inverted images were only used in Experiment 2, the BW images were used only in Experiment 1.

Results

Data were analyzed using SPSS. Behavioral data – reaction time and response accuracy – were recorded for the gradCPT as well as the implicit recall task. False alarms, a behavioral measure, are defined as an error when the participant responds on a no-go trial. In the current study, this would occur when a participant pressed the "M" key when a stream image appeared. The gradCPT consisted of 400 trials. For data analysis, the 400 trials are broken up into 4 blocks of 100 trials. This was done in order to assess change over time. There was no indicator to participants that this was occurring. All error bars are the standard error of the means.

Experiment 1

A repeated measures ANOVA of recall accuracy on the memory task showed a significant effect of image type, stream or street, $F(49) = 8.897$, $p = .004$. A significant effect of color, color or black and white, was also found, *F(49) = 6.561, p = .014*. However, no significant interaction was found between the two (Figure 3).

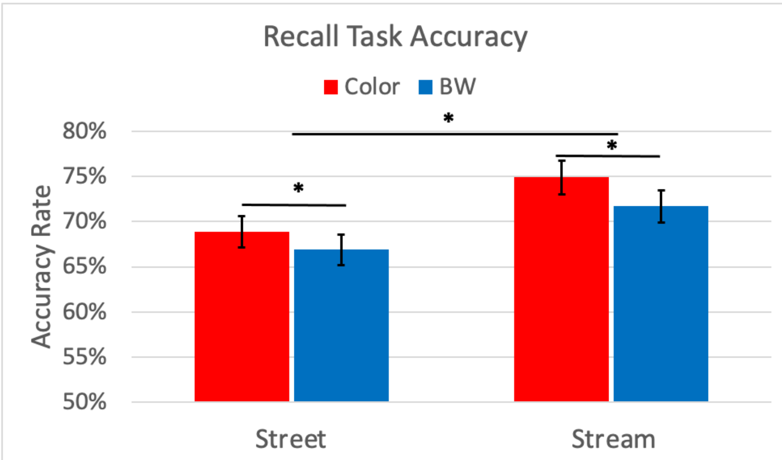


Figure 3: Performance on the recall task. Significant effects of image type (Street/Stream) *(p = .004)* and color presence (Color/BW) *(p =.014)* were found.

* p < .05.

A repeated measures ANOVA examining false alarm rate over time found no significant effect of color, or a significant interaction, although a significant effect of time point was found *F(49) = 3.654, p = 0.14* (Figure 4). When analyzed separately, no significant increase in false alarm rate was found for the color images *F(49) = 0.674, p = .569*, but a significant increase was found for the BW condition *F(49) = 0.674, p = .004*. Post-hoc analyses of contrasts found no significant difference between any two time points separately.

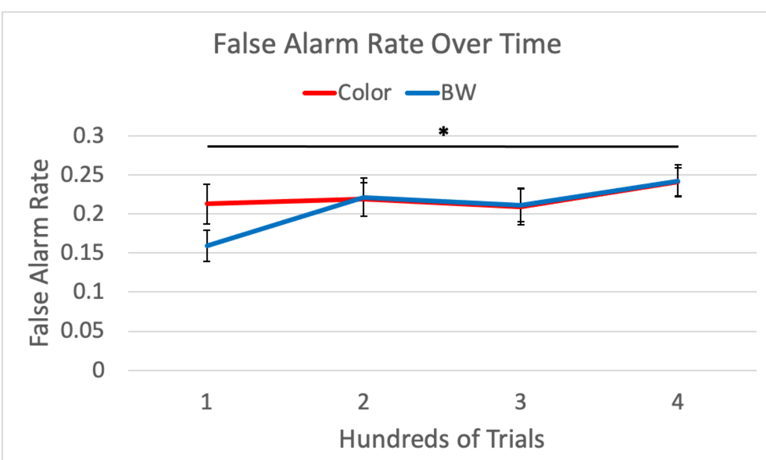


Figure 4: A significant overall increase in false alarms over time was found *(p = .04)*. A significant effect of time point on BW images was found *(p =.004)*, but not for the color condition *(p = .569)*.

* p < .05.

When the first block difference in false alarm rate between color images and BW images (Figure 4) was analyzed via a paired samples T-test, no statistically significant difference was found, but it shows a slight trend toward significance $t(49) = 1.735, p = .089$.

A paired samples T-test of false alarm rate overall, regardless of time point was conducted. No significant difference between false alarm rates across the two conditions was found. Reaction time was approaching significance, $t(49) = -1.982, p = .053$. Reaction times for the color images had an average of 669.59 ms $(SD = 52.76)$ whereas the BW condition had an average RT of 680.41 ms $(SD = 55.45)$. Reaction time analysis was collapsed over time, and was not delimited every 100 trials as was the case with the false alarm analyses.

Experiment 2

A repeated measures ANOVA of participant performance on the memory task showed a significant effect of image type, stream or street, $F(50) = 16.405, p < .001$. A significant effect of color type, canonical or inverted, was also found, $F(50) = 10.542, p = .002$. However, no significant interaction was found between the two (Figure 5).

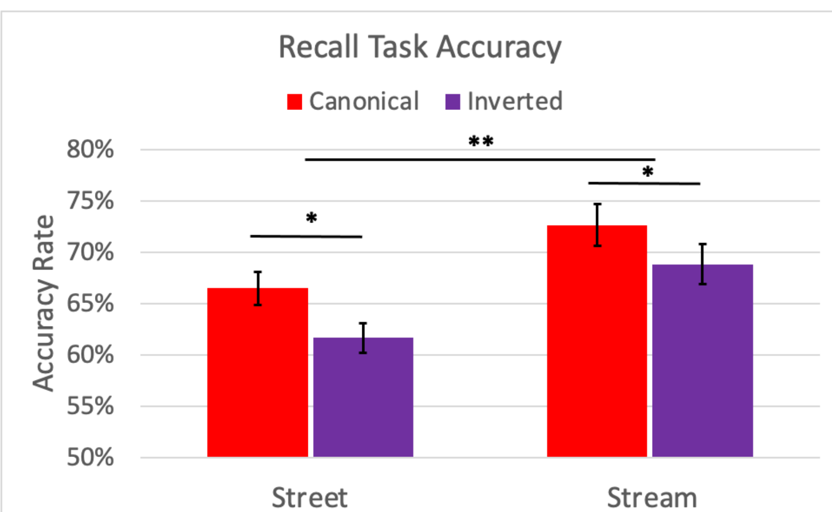


Figure 5: Performance on the recall task. Significant effects of image type (Street/Stream) $(p < .001)$ and color type (Canon/Inv) $(p =.002)$ were found.

* p < .05, ** p < .001.

A repeated measures ANOVA of false alarm rate over time found no significant effect of color type, or a significant interaction, although a significant effect of time point was found *F(50) = 8.988, p < .001* (Figure 6). False alarm rate did increase over time, although no difference was found between conditions, similar to the results from Experiment 1. The time points are defined as the first, second, third, and fourth set of 100 trials, as in Experiment 1. When analyzed separately, a significant increase in false alarm rate was found over time for the canonical color images, *F(50) = 5.178, p = .004*. A significant effect of the time point was also found for the inverted color images, *F(50) = 6.061, p < .001*. Separate analyses were conducted to examine if the increase in false alarm rate was being driven by just one condition, as it was in Experiment 1. However, in Experiment 2, this was not the case, because both conditions had a significant increase in false alarms over time. Post-hoc contrasts showed a significant difference between the first and second blocks of 100 trials, *F(1) = 17.777, p< .001*.

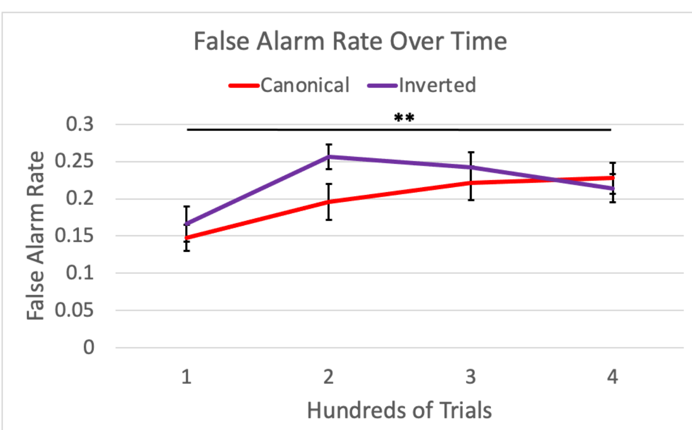


Figure 6: A significant overall increase in false alarms over time was found *(p < .001)*. Significant effects were also found for just the canonical color images (*p = .004)* and for the inverted color images *(p < .001)*.

** p < .001

A paired samples T-test found a significant difference between reaction times in the canonical and inverted color conditions *t(50) = -4.684, , p < .001.* Reaction time averages were collapsed across all trials. Reaction time over time was not analyzed. Reaction times for the canonical color images had an average of 683.94 ms *(SD = 70.29)* whereas the inverted colors condition had an average RT of 704.35 ms *(SD = 75.10)* (Figure 7).

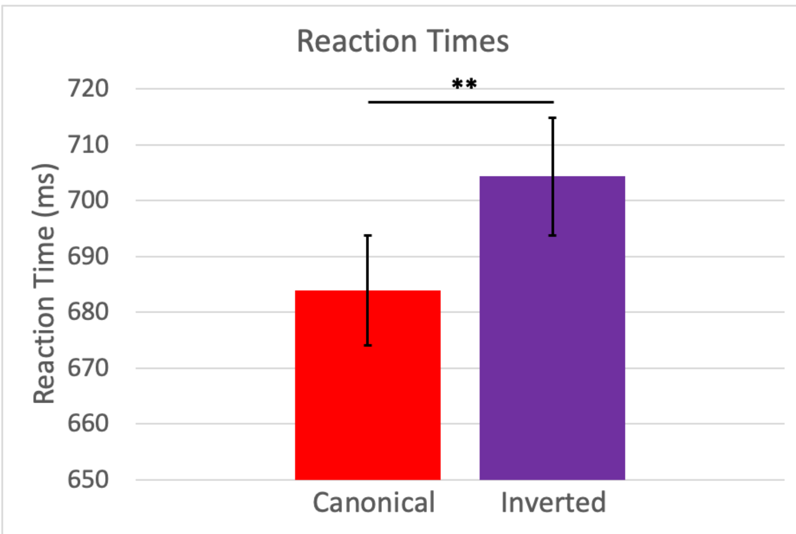


Figure 7: Paired samples T-test found a significant difference between the reaction times of the canonical and inverted color images *(p < .001).*

** p < .001.

Discussion

The goal of the current study was to examine the effect of color on sustained attention and recall. Sustained attention was measured using a go/no-go gradCPT paradigm in which participants had to respond to cities (90%) and withhold responses for streams (10%). Recall was assessed after the gradCPT's. This was done by presenting an image to the participant and asking if the image was familiar or unfamiliar. Images in Experiment 1 were in canonical color (CAN) and black and white (BW). In Experiment 2 the images were either CAN or inverted color (INV). No significant differences were found between any conditions during the gradCPT. CAN recall accuracy was significantly higher than INV or BW recall accuracy. Streams were remembered more accurately than cities as well.

There was an increased false alarm (FA) rate over time. Operationally, this means participants were responding to more stream images later in the task than they were in the beginning of the task. When analyzed separately, it was found that canonical color only showed an increase over time in Experiment 2 and not in Experiment 1. The increase in FA rate over time in Experiment 1 was driven by the increase for the BW condition. This was likely due to noisy data. Many studies on sustained attention have previously demonstrated a consistent finding that false alarm rate does increase over time, as participants get fatigued and bored with the task at hand (Esterman et al., 2012; Fortenbaugh et al., 2015). In the current study, across both experiments this can be seen as well, dependent on which condition a participant saw first. For example, participants who saw the BW condition first in experiment 1, did better on the BW condition than participants who saw the BW condition second.

Although the data do not show an effect of color on sustained attention, there were interesting findings. In line with Rossion & Pourtois (2004), the colorized images did produce significantly faster reaction time than the inverted color images. This means that participants were responding sooner when presented with a CAN image than an INV image. Previous work on sustained attention has found that faster response time leads to higher FA rate. Although the current data do not show any difference in FA rate between conditions, even with a significant RT difference.

While a significant difference in RT was not found between BW and color images, the difference was approaching significance. It is likely that with more data, that difference would become significant. While the mechanism that is underlying this phenomenon is unknown, the data suggest that the accurate color information can speed up recognition time, as is shown by the RT differences. It's possible that when presented with an image that does not match expectations, RT is slowed down. The inverted images would fit this criterion because the color information is intrinsically opposite to what is seen in normal life. This could also explain why there was no difference between BW and CAN, because seeing something presented in black and white is much less unexpected than something presented with inverted colors.

The reaction time data being significant could also be due to the low level processing of color information. Color information is processed very early on in the occipital cortex. The current data show that accurate color information allows for more rapid processing, but accuracy during the gradCPT was unaffected. One possible explanation for this is that the accurate color information can be processed more quickly by the early occipital cortex. Inverted images present inaccurate color information, this information may require more advanced areas of the occipital cortex to interpret and process. This interpretation may help explain why the current data do not show a significant difference between CAN and BW. The effect may be smaller between those two because they can both be easily processed by early visual processing regions.

This interpretation would also explain the lack of difference found in the gradCPT data. The gradCPT data reflects participants' conscious decisions to press or not press the "M" key in response to the presented image. In order to make the conscious decision to press the key, the stimulus (in this case images) must be fully processed by the visual cortex. While the color information is processed early on in the cortex, the "what" information – whether or not the image is a stream or a street – is not processed until later in the visual cortex. This could explain why there is no difference in gradCPT performance between CAN and BW, or between CAN and INV. The "what" information of the image is being processed the same between conditions, but the color information is being processed differently, and the color information processing difference presents itself in RT data.

There were also interesting findings among the data from the recall task. In both experiments, recall of the stream images was significantly better than recall of the city images, despite the stream images only being displayed 10% of the time. The other 90% of the images during the main task were city images. This suggests that the number of times an image is presented may not be as critical for recall and memory encoding as the importance of the image. The stream images would have greater importance than the city images because they are the critical "no-go" trials when participants must withhold their response. Even though the streams were displayed much less frequently, participants consistently were able to recognize and recall them more accurately than the more common, but less important city images.

Performance on the recall task was also significantly better for the CAN condition when compared to either BW or INV.. This suggests that accurate color information can aid recognition of images. Similar to the reaction time finding, it seems that the presence of color information is not what aids recognition. If this were the case, then there would be no difference in recall ability between the canonical and the inverted color images. While they have the same amount of color information, the accuracy of the color information is drastically different between the two images. The accuracy of the color information is determined only by an individual's expectations. It's likely that the inverted images are less well recalled because the expectation is for color information to appear as it does in the real world. Through life experience, expectations for how things should look are fabricated from the information around us. The data suggest that images that subvert these expectations take extra time to process, and are less well recognized.

Although no significant differences were found in false alarm rate depending on the available color information, the pattern of false alarm rate changes was very different for the inverted images, versus the canonical images. It's possible the pattern of false alarm rate for the inverted images was caused by a learning period. In the four blocks measured, it's possible the first one has the lowest false alarm rate because the participants are the least fatigued. Then, the FA rate increases sharply as they become bored with the task. However, the next two blocks where the FA rate decreases could be caused by participant learning, and getting more used to responding to the inverted images. This possibility is built upon the idea that the participants would get fatigued from the inverted images more quickly. No other condition had such a large increase in the FA rate from the first to the second block. It is also entirely possible this pattern of false alarm rate changes is only caused by noisy data.

Whether or not the top-down processing of color or the bottom-up processing of color is more important for image recognition is still unclear. Differences in top-down or bottom-up processing were not the original goal of the study, however the data do suggest a narrative around the two theories of perception. The current data show that accurate color information aided in recall ability and reaction time. Recall ability was improved significantly with accurate color information compared to BW or INV color information. However, RT differences were only significant when comparing CAN to INV. From a top-down theoretical perspective this could be due to the fact that we are more familiar with black and white images than we are with inverted images. The BW images are closer in appearance to what we would expect. Which may explain why there was no significant difference between BW and CAN for reaction time. From a bottom-up theoretical perspective, however, this could be due to the fact that it may be easier to process black and white information than complex, inverted color information.

The recall ability data seems to suggest that top-down processing may dominate when identifying images based on color information. The images that matched what we were familiar with (those with canonical colors) were recalled significantly more accurately than images that had an unfamiliar appearance (BW or INV).

The top-down or bottom-up argument is certainly without its answer. It's likely that booth top-down processing and bottom-up processing are critical in image recognition. However, when remembering or quickly categorizing images, the data suggest that top-down processing may be more important than bottom-up.

Limitations

A major limitation of the current study was the between subjects design. Having each participant do both conditions allowed the current study to not require as many participants to achieve equal statistical power. However, the between subjects design did introduce a significant amount of noise into the data. Since participants' false alarm rate increased over time, whichever condition was completed second had much higher false alarm rate than whichever condition was completed first. This led to unexpected results that did not align with a significant amount of previous sustained attention research. It is likely that the noise introduced via the between subjects design is the cause of such noise.

Secondly, there are limitations that occur when relying on crowdsourcing platforms for participants, as was done in the current study which used *Prolific.co*. While crowdsourcing platforms allow for data collection from a broader sample than would otherwise be available at Connecticut College, it also introduces unknown variables. For instance, since the study was made to be able to be completed on anyone's computer in the browser, differences in screen size, brightness, color settings, etc. may vary between participants in an unknown way.

Another limitation regarding the online nature of the study is the break time. After each GradCPT participant took a short break. However, the length of this break was entirely up to participant choice. Some participants took longer breaks than others, although the average length of the study was ~20 minutes for both Experiment 1 and Experiment 2. However, break length likely had an impact on performance during the second GradCPT, as well as performance on the memory task. The magnitude of this impact is unknown, as break time was not measured, thus it is an unknown, and uncontrolled variable that may have impacted the current data.

Future Research

A future study would be a between subjects design in order to avoid the noisy data. A future study would also look at the mechanisms behind the reaction time and recall properties of images based on color information. An EEG study could look at the temporal activation caused by different amounts of color information, and how this translates into differences in reaction time. An fMRI study could also examine the spatial differences and blood flow to different neural regions during the task. This could elucidate different neural pathways and patterns of activation that may occur when a person is viewing images that either do, or do not, meet their expectations.

Alternatively, in order to examine task difficulty directly, without contamination of the data from reaction time and false alarm data, a future study could utilize self-report or pupillometry. Self-report data would gauge participants' perceived level of difficulty for each condition, however, it would not be able to measure physiological changes that occur subconsciously. Pupillometry, the measurement of participants' pupil size and movements during the task, can show these physiological changes that happen without conscious control. A more dilated pupil would show that a task required more mental effort, or, a more dilated pupil would show that the condition at the time was more difficult.

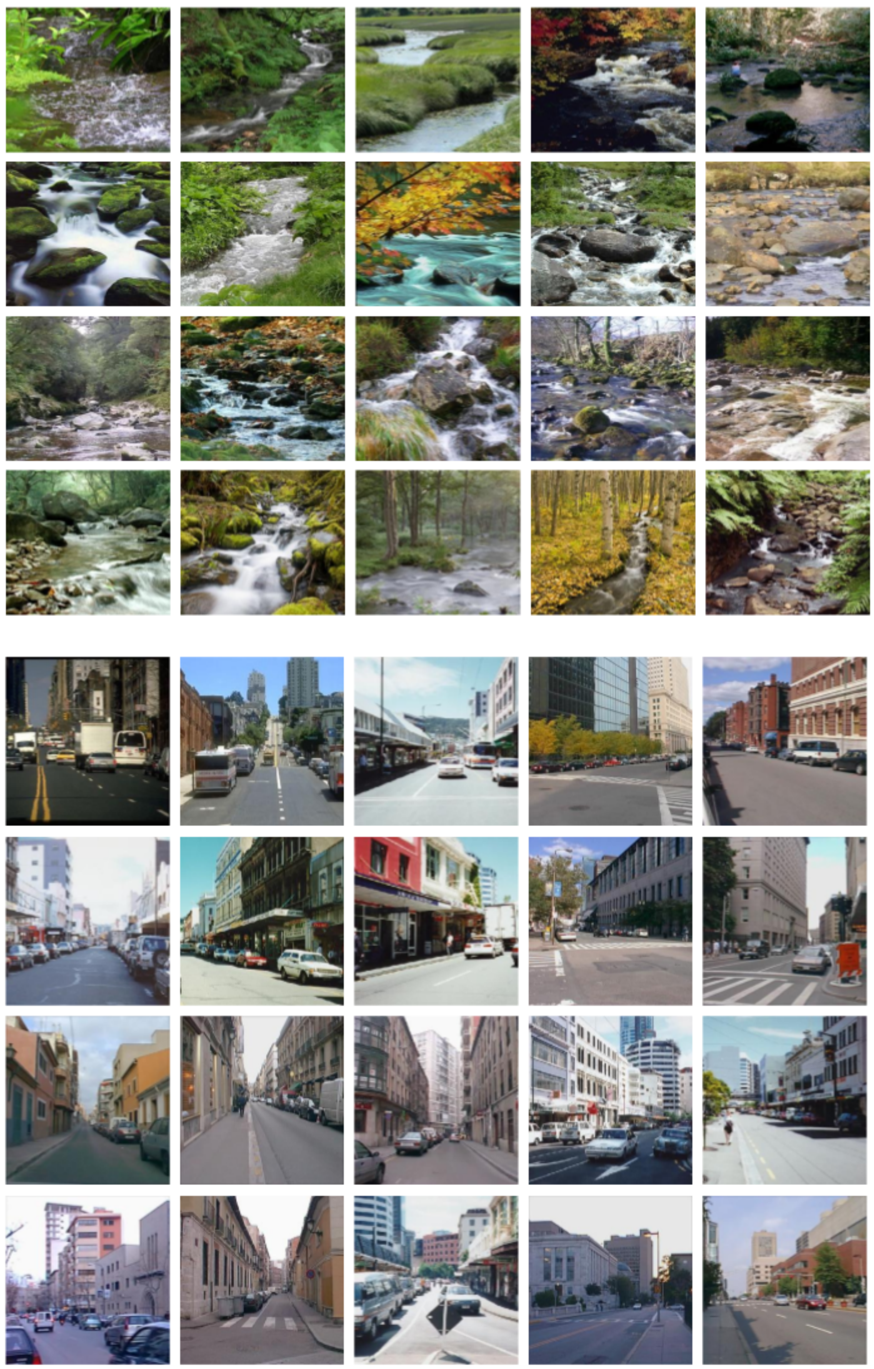
Conclusion

Although the data did not suggest any effect of color information on sustained attention ability, there was a clear effect of color information on reaction time, and recall ability. Not only that, but there was a strong effect of image type on recall ability. Although the stream images were presented much less, they were recalled more accurately because they were much more important images. Future research would look at the underlying neural mechanisms behind these phenomena via EEG and fMRI to examine the timing and the patterns of neural activation.

Appendix A

Examples of Possible Images

From Konkle et al. (2010)



Appendix B

Informed Consent Document (Course Credit)

You are invited to participate in a research study. Taking part in this research project is voluntary. The purpose of the study is to gain insight into the effect that color, and other surface level changes, can have on sustained attention during a continuous performance task using images of scenes. The goal is to see if changes to an image's color or rotation can affect your ability to focus, and make accurate decisions during an attention task spanning several minutes. You must be at least 18 years of age to participate.

Things you should know:

- The purpose of the study is to determine if surface level changes to an image affect performance on a sustained attention task. If you choose to participate, you will be asked to respond with a keypress to images for several minutes. The total time for the study will take roughly 15 minutes (2, ~7 minute blocks of trials).
- Risks or discomforts from this research include possible mental and physical fatigue, as well as possible eye strain. All resulting from paying close attention to the screen in front of you, and responding by pressing a button on your keyboard for several minutes.
- There are no direct benefits to the participant for taking part in this study.
- Taking part in this research project is voluntary. You don’t have to participate and you can stop at any time.

Please take time to read this entire form and ask questions before deciding whether to take part in this research project.

If you choose to participate, you will be asked to remain at your computer for several minutes in order for the study to be carried out. You will see one of three possible experiments. Each experiment will consist of 2, ~7 minute blocks of trials, and each experiment will have the same overall format. The format will consist of this informed consent document, then one block of trials, a short break, and then a second block of trials. After this, there will be a brief demographics questionnaire. All collected data, including if it is published, will be marked only with an individual ID number. There will be no markers that will allow any person to link any data to a participant. No names or any other identifying information will be shared.

The three possible experiments you could see will now be explained. One possibility consists of one block of trials where images are in color, and one block of trials where the images are in black and white. A second experiment would have a block of trials of colorized images, and a block of trials in which the images are colorized, but the colors are inverted. The third experiment has a block of colorized images, and a block of colorized images, but the images are rotated 180º. In all three experiments, the images will be the same, but they will be manipulated as described.

One possible minimal risk you may encounter is eye strain and mental or physical fatigue associated with computer usage and repetitive motion. In order to combat any potential harm, it is important to remind you that you have the option to drop out of the study, or have your data exempt from analysis at any time. If you choose to do any of these, you will not be punished in any way. Participation is voluntary at every step of the process.

It is important to note that by agreeing to participate in the study, you are also consenting to having your data published. Your data will not be linked back to you. To protect your privacy, data will not include any information that could directly identify you. We will protect the confidentiality of your study results by eliminating any indicators of personal information. Your name and any other information that can directly identify you, will not be linked to the data collected as part of this study. Additionally, your research data will not be shared with other investigators.

It is possible that other people may need to see the information we collect about you. These people work for Connecticut College and government offices that are responsible for making sure the research is done safely and properly. We will keep your research data to use for future related research. Your name and other information that can directly identify you will be deleted from the research data collected from this survey.

You will be receiving compensation for your participation in the form of course credit. You will receive 30 minutes of research participation credit. Opting to drop out of the study, having your data exempt from analyses, or skipping questions will not jeopardize your entitlement to the credit.

Choosing to participate in this study is completely voluntary; even if you decide to be part of this study now, you may change your mind and stop at any time. You do not have to answer any questions you do not want to answer. If you decide to withdraw before this study is completed, all data provided by you will be deleted.

If you have questions about this research, you may contact Harry Steinharter at hsteinhar@conncoll.edu. If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researchers, please contact either Professor Jeff Moher at jmoher@conncoll.edu or Professor Joseph Schroeder at jasch@conncoll.edu. You can also contact Professor Jason Nier, chair of the IRB, at janie@conncoll.edu.

By signing this document, you are agreeing to be in this study, and you are confirming that you are at least 18 years old. Make sure you understand what the study is about before you sign. Once completed, you will receive a copy of this document for your records. The researchers will also keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

I understand what this study is about and the types of questions I will be asked. Any questions/concerns I have are answered.

Informed Consent Document (Financial Compensation)

You are invited to participate in a research study.Taking part in this research project is voluntary. The purpose of the study is to gain insight into the effect that color, and other surface level changes, can have on sustained attention during a continuous performance task using images of scenes. The goal is to see if changes to an image's color or rotation can affect your ability to focus, and make accurate decisions during an attention task spanning several minutes. You must be at least 18 years of age to participate.

Things you should know:

- The purpose of the study is to determine if surface level changes to an image affect performance on a sustained attention task. If you choose to participate, you will be asked to respond with a keypress to images for several minutes. The total time for the study will take roughly 15 minutes (2, ~7 minute blocks of trials).
- Risks or discomforts from this research include possible mental and physical fatigue, as well as possible eye strain. All resulting from paying close attention to the screen in front of you, and responding by pressing a button on your keyboard for several minutes.
- There are no direct benefits to the participant for taking part in this study.
- Taking part in this research project is voluntary. You don’t have to participate and you can stop at any time.

Please take time to read this entire form and ask questions before deciding whether to take part in this research project.

If you choose to participate, you will be asked to remain at your computer for several minutes in order for the study to be carried out. You will see one of three possible experiments. Each experiment will consist of 2, ~7 minute blocks of trials, and each experiment will have the same overall format. The format will consist of this informed consent document, then one block of trials, a short break, and then a second block of trials. After this, there will be a brief demographics questionnaire. All collected data, including if it is published, will be marked only with an individual ID number. There will be no markers that will allow any person to link any data to a participant. No names or any other identifying information will be shared.

The three possible experiments you could see will now be explained. One possibility consists of one block of trials where images are in color, and one block of trials where the images are in black and white. A second experiment would have a block of trials of colorized images, and a block of trials in which the images are colorized, but the colors are inverted. The third experiment has a block of colorized images, and a block of colorized images, but the images are rotated 180º. In all three experiments, the images will be the same, but they will be manipulated as described.

One possible minimal risk you may encounter is eye strain and mental or physical fatigue associated with computer usage and repetitive motion. In order to combat any potential harm, it is important to remind you that you have the option to drop out of the study, or have your data exempt from analysis at any time. If you choose to do any of these, you will not be punished in any way. Participation is voluntary at every step of the process.

It is important to note that by agreeing to participate in the study, you are also consenting to having your data published. Your data will not be linked back to you. To protect your privacy, data will not include any information that could directly identify you. We will protect the confidentiality of your study results by eliminating any indicators of personal information. Your name and any other information that can directly identify you, will not be linked to the data collected as part of this study**.** Additionally, your research data will not be shared with other investigators.

It is possible that other people may need to see the information we collect about you. These people work for Connecticut College and government offices that are responsible for making sure the research is done safely and properly. We will keep your research data to use for future related research. Your name and other information that can directly identify you will be deleted from the research data collected from this survey.

You will be receiving financial compensation for your participation. The amount you receive will be $10. Opting to drop out of the study, having your data exempt from analyses, or skipping questions will not jeopardize your entitlement to the credit.

Choosing to participate in this study is completely voluntary; even if you decide to be part of this study now, you may change your mind and stop at any time. You do not have to answer any questions you do not want to answer. If you decide to withdraw before this study is completed, all data provided by you will be deleted.

If you have questions about this research, you may contact Harry Steinharter at hsteinhar@conncoll.edu. If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researchers, please contact either Professor Jeff Moher at jmoher@conncoll.edu or

Professor Joseph Schroeder at jasch@conncoll.edu. You can also contact Professor Jason Nier, chair of the IRB, at janie@conncoll.edu.

By signing this document, you are agreeing to be in this study, and you are confirming that you are at least 18 years old. Make sure you understand what the study is about before you sign. Once completed, you will receive a copy of this document for your records. The researchers will also keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

I understand what this study is about and the types of questions I will be asked. Any questions/concerns I have are answered.

Appendix C

Demographics Questionnaire

Questions appear as written. Possible answers appear as written. "" indicates a free response.*

- Please enter your age *
- Please enter your gender *
- What is your first language? *
- Race (select all that apply)
    - "American Indian or Alaska Native", "Asian", "Black or African American", "Native Hawaiian or Other Pacific Islander", "White"
    - Other*
- Vision:
    - "Normal", "Corrected-to-normal"
- Color Vision:
    - "Normal", "Blue-Yellow blindness", "Red-Green Blindness", "Red-Green complete blindness", "Complete color blindness"
- What is your handedness?
    - "Left-handed", "Right-handed, "Ambidextrous"

Appendix D

Debriefing Statement

Thank you for participating in the study. If you are eligible for receiving credit or financial compensation, you will receive it, regardless of any section of the experiment you skipped or if you are choosing to exempt your data. You may not receive both financial compensation, and class credit.

The primary purpose of this study was to see if there was an effect on memory and task performance between images presented in black and white, and images presented in color. A secondary element to the study was to examine the memorability of critical images (images you do not respond to) and the rest of the images in which you do respond to them. The goal was to determine if the colorized images would be more accurately recalled, and if performance on the task would be better for the colorized condition. The hypothesis was that performance would be better for the colorized condition, based on previous data suggesting that color aids with image recognition.

Now that you have completed the study, if you wish to withdraw your data from the study, you may do so. You will not be penalized in any way for withdrawing your data. Please feel free to ask any questions you may have. Any questions, comments, or concerns you wish to express to the researcher can be directed to Harry Steinharter at hsteinhar@conncoll.edu. Please do not share information about this study. If you wish to get in contact with the chair of the Institutional Review Board (IRB), Professor Jason Nier, you may contact him at janie@conncoll.edu. Thank you for your participation in this research. If you are interested in other related research, see below:

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