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The Power of Colors to Maximize Attention and Readability in Visual Communication: Insights from an Eye-Tracking Behavioural Study.

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Abstract - With the increase in digital visual content and the need to capture and maintain audience attention, understanding the impact of colors on attention and legibility is essential. This research explores the role of colors in visual communication and their influence on human attention and reading difficulty. The two primary goals of this study were to determine which colors are more visually appealing and which are more readable. We used eye-tracking technology (Gazepoint) to monitor 27 participants with an average age of 19.125 years (SD= 0.95) as they read slides with different background colors, aiming to discover which colors attract more attention and provide better legibility. When it comes to the colors that draw the most attention, yellow was the color that people see the most, appearing in 49 different instances. Blue has 19 occurrences, orange has 23 occurrences, and green has 31 occurrences. On the other hand, red and purple attracted less attention, with only 8 occurrences for red and 5 for purple. In relation to pupil dilation for different colours, it was observed that the average dilation values were similar, suggesting no significant difference in pupillary response regarding the attention and concentration required during the reading of the evaluated slides. However, when considering the maximum dilation values, it was observed that black, followed by purple and green, caused a more pronounced pupil dilation. On the other hand, red and yellow showed the lowest maximum dilations, suggesting reading that requires less focus. Similarly, when analysing the minimum dilation values, it was found that purple, followed by black and orange, resulted in lower minimum dilations, indicating less concentration required during reading. On the other hand, yellow, green, and black recorded the highest minimum dilations, suggesting a higher level of required concentration. This suggests that these colors can be deliberately employed to draw attention and guide the viewer's gaze. These are the intriguing results about the effects of color on attention and legibility. Additionally, this knowledge has consequences for advancing communication techniques and increasing accessibility. In conclusion, future research on the individual, contextual, and multidimensional subtleties of color perception present a wealth of opportunities for enhancing design techniques, visual communication, and marketing strategies.

***Keywords*:** Colors, Attention, Legibility, Visual Communication, Accessibility

1. Introduction

In the area of design, color is essential to visual communication since it can evoke strong feelings and send powerful signals. Because color is an information carrier, studies have shown that over 80% of visual information is linked [1]. In addition to other aspects of user interface design, color is vital for product or brand identification, product quality, and other features [2]–[5]. Eva Heller's book "The Color Psychology," which is based on an extensive study involving 2,000 participants in Germany ranging in age from 14 to 97, amply illustrates the subtle but potent impact that colors have on

human perception, evoking feelings and generating distinctive environments [6]. For designers hoping to communicate certain messages with visual works, it is imperative to comprehend these affective connections [2], [7]–[11]. It is clear from recent years that technological improvements have made our environment more intrusive and stimulating. This makes it extremely difficult for people to make wise decisions in a world where there are too many stimuli to deal with daily [12]. The amount of digital visual stuff that is continuously being exposed to society nowadays is increasing [13] and the average daily time spent on the internet is 6 hours and 37 minutes [6] [4]. Consumer impatience is reflected in their present behaviour, which puts more pressure on businesses to know how to produce visually appealing material. This fact is eloquently illustrated by the findings of the Rock Content Trends 2019 report, which shows that 66.3% of businesses that use content marketing struggle to create materials that genuinely interest the audience [14]. Using color effectively becomes one of the main ways to draw attention to something visually appealing in this situation, and comprehending the perception of color is a challenging endeavor due to its association with multiple ideas that pertain to biological elements, a potential universal scale of personal inclinations, and inherent attributes of stimuli. Furthermore, social and cultural contexts might affect how people react to colors, which nuanced their visual impact [15]–[19].

Additionally, to understand which colors work well in design considers accessibility and legibility, professionals may guarantee that their works are easily comprehended by the intended audience under all viewing conditions by utilizing colors with good contrast and making sure the text is readable [20]–[23]. In this sense, this study looks beyond how a design appears on the eye to investigate how colours affect human perception. We investigated which colours are more likely to draw attention and have better legibility using the eye tracking approach.

This method, which is based on eye tracking, has been used extensively in earlier research to look into how colours affect visual processing of human perception [24]. This method made it easier to track participants' eye movements precisely as they looked at coloured stimuli, providing insightful information about how colours affect visual attention and decision-making [24]. Another study examined the value of eye tracking and how it might be used in virtual reality (VR) environments to improve user performance and comprehension of cognitive processes. The researchers used high-precision eye tracking equipment to observe participants' eye movements as they engaged with a virtual environment. This allowed them to get important insights into users' visual search methods, attentional guidance, and visual perception [25]–[27].

These studies demonstrate the usefulness of eye tracking as an effective tool for improving the human-computer interaction in virtual environments and giving users a more efficient and engaging experience. Eye tracking has been shown to be a useful technique for studying how perception and behaviour are influenced by colour in previous studies. Expanding upon these developments, the goal of this study was to do a thorough analysis of the connection between colour, visual focus, and readability to further this field of study. It is anticipated that doing this will offer professionals in communication, design, marketing, and other disciplines useful insights that will make it easier to create visually striking and efficient products and content for conveying information. In this sense, the aim of our study is to analyse which colours are more likely to draw attention and offer superior legibility. It was feasible to assess the visual reactions and spot behavioural patterns associated with the various backdrop colours used in the presentations by observing the participants' eye movements. These results will further our knowledge of how colors affect text reading and visual perception.

2. Methodology

2.1 Participants

Twenty-seven participants (13 male and 14 female), with an age range of 18 – 24 years (M = 21.1, SD = 1.24) were recruited through announcements in classrooms. Exclusion criteria included visual impairments exceeding ± 0.5 dioptres and the use of any form of corrective visual assistance. Participants were instructed to carefully complete an online questionnaire meticulously designed to assess their compliance with the exclusion criteria. This comprehensive questionnaire had the specific purpose of identifying potential confounding variables that could have a substantial impact on the accuracy and reliability of eye-tracking data. These variables include ocular and physiological conditions such as neurodegenerative diseases, eye disease, physical use of glasses or lenses, respiratory diseases, or conditions such as

inflammation and nasal congestion, or the possibility that participants are under the influence of psychotropic or psychoactive medications or other specifics. All participants were checked tested for this kind of conditions.

2.2 Stimuli's and set up

Eye trackers were configured using Gazepoint Control software version 6.7.0 to operate at a sampling frequency of 150 Hz with default settings. The data acquisition of the experiment was recorded at a sampling frequency of 150 Hz using the Gazepoint GP3 remote infrared eye tracker. To eliminate daylight interference, the experimental setup ran with a consistent artificial lighting intensity of 500 lux in a room free from strong shadows and significant contrasts. The temperature was maintained at a constant 19 degrees Celsius. The testing protocol was executed individually for each eye tracker, with the sequence of tracker usage randomized. Prior to each session, the eye tracker underwent calibration employing a 9/9 nine-point calibration procedure, iterated until successful calibration was achieved for all nine targets for both eyes. Participants failing to attain this threshold were still tasked with completing the assigned activities; however, data from such instances were subsequently omitted from the results analysis.

Figure 1: Gaze Point GP3 150 Hz

2.3 Procedure

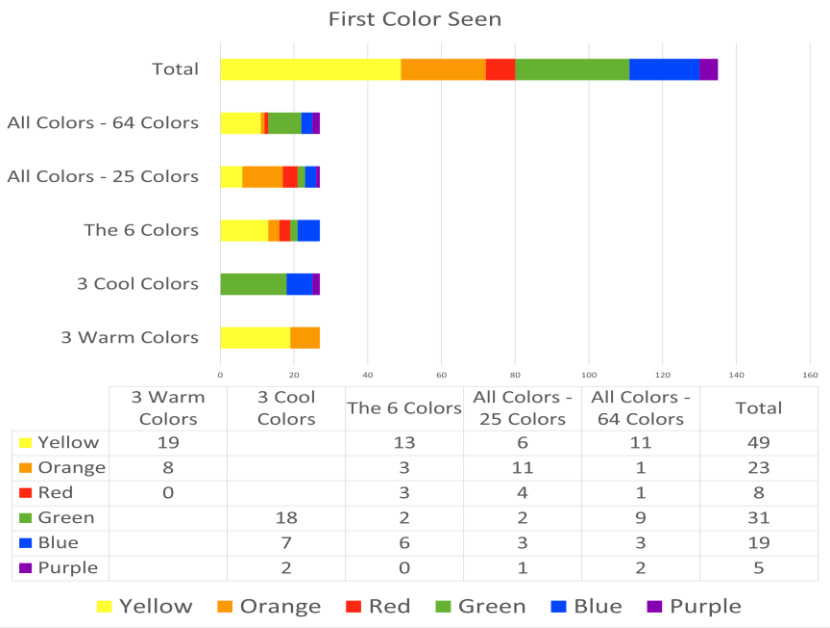
Each participant was given three different layout instructions: single-column, two-column, and three-column forms. They were to be read aloud. As previously mentioned, monitoring and evaluating participants' pupil dilations, frequency of blinks, and length of fixation were our main priorities. We also gathered audio recordings to qualitatively examine any instances of stuttering or misspelled words. These features might shed light on how difficult it is to interpret these layouts. Three background colors—yellow, orange, and red—were shown on the first slide. The text in each color had the identical content and was composed of 101 characters (not including spaces) that told a children's narrative meant to be read aloud for 15 seconds. Next, during the second slide's read-aloud, which lasted for fifteen seconds, the backdrop colors were altered to green, blue, and purple, but the content remained the same. The third slide was a single slide with the same 15-second text that featured all six of the previously discussed colors. The fourth slide had the same six colors, but this time, readers were presented with 25 single words to read for ten seconds as opposed to full sentences. The fifth slide kept the same format but added more words to read—64 words in all—during the same 10-second time frame (Figure 2).

Figure 2: Experimental Protocol

With the aid of an eye tracker to monitor eye movement, these preliminary slides were created to determine which color subjects concentrate on initially. This technique allows one to identify the color that attracts the most visual attention. The seven slides that followed included independent presentations of the six colors that were previously discussed as well as black. For a read-aloud of 13 seconds, each color had a paragraph of text with an average length of 102 characters (not including spaces). Pupil dilation analysis was done at this point to evaluate the text's legibility against various background colors. With the help of these investigations, it is possible to determine which color provides the best legibility and comprehend how pupil dilation reveals how easy or difficult it is to read in each color. The relationship between background colors and their effects on visual attention, text legibility, and eye behaviour during reading might be examined thanks to this research. The results will help design experts choose the right colors for their creations and advance knowledge of how colors can affect visual communication.

3. Results

The study shed light on how colors affect readability and attentiveness, which deepens our understanding of this important design principle. A set of twelve slides with white text on various colored backgrounds were shown to a diverse sample of twenty-seven individuals. It was observed that certain colours captured participants' attention more prominently in the first 5 slides, which contained a variety of colours. By utilizing the eye tracker to analyse participants' visual and behaviouralresponses, the colors that attracted the most attention from the beginning of the research were identified. These findings allowed for a better comprehension of the relationship between background colours and visual attraction, as well as their influence on text legibility. Among the tested colours, yellow stood out as the colour that garnered the most attention, being observed 49 times as the first colour to capture participants' attention. Following that, green was observed 31 times, orange 23 times, blue 19 times, red 8 times, and purple 5 times (Figure 3).



	3 Warm Colors	3 Cool Colors	The 6 Colors	All Colors - 25 Colors	All Colors - 64 Colors	Total
Yellow	19		13	6	11	49
Orange	8		3	11	1	23
Red	0		3	4	1	8
Green		18	2	2	9	31
Blue		7	6	3	3	19
Purple		2	0	1	2	5

Figure 1: First Color Seen

The time_first parameter is also analysed considering the experimental protocol (Figure 4). Considering individual screens associated with six colors, it is evident that various variables under analysis exhibit distinct values. The graph highlights a descending order of colors based on the time_first variable: purple > blue > green > red > orange > yellow. Thus, we observe that the color yellow is detected most rapidly, followed by orange, red, green and finally purple. In the case of screens displaying all six colors simultaneously, the behaviour of the time_first variable shows analogous characteristics regarding the yellow and orange colors. However, the red and green colors stand out with higher values of time_first.

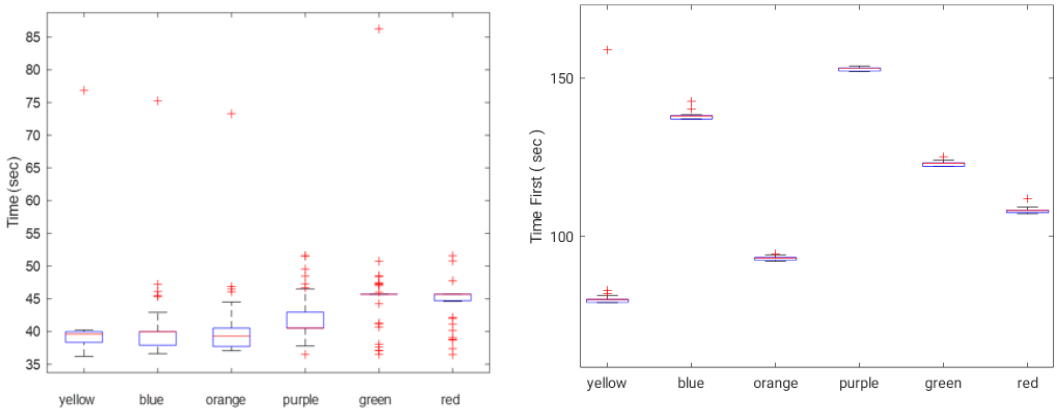


Figure 2 Time Fist Values, considering the singe colors (left) and the screen of 6 colors (right)

In the case of screens displaying all six colors simultaneously, the time_first variable exhibits analogous behaviour concerning the yellow and orange colors. However, the red and green colors stand out with higher values of time_first. To assess whether these observed values are statistically different, the Wilcoxon test was employed at a 95% confidence level. The analysis revealed statistically significant differences in the time_first variable among individual colors (1-6). When examining screens with all six colors simultaneously, several statistical differences were observed (Table 1). The diameter of left and right pupil dilation is also analysed (Figure 5). When analysing the box plot of pupil diameter in the left eye, it is evident that cool colours present a larger box compared to warm colours, indicating greater data dispersion. The difference in box size between cool and warm colours suggests that the pupil diameter values for cool colours are more dispersed, meaning they vary more widely in relation to warm colours. This may suggest a greater sensitivity of the left pupil to stimuli related to cool colours. Furthermore, the median for cool colours is higher than that for warm colours, indicating that the central value of data for cool colours is higher than that for warm colours. This indicates a general tendency of pupil dilation in response to cool colours. When examining the box plot of pupil diameter in the right eye, it can be observed that warm colours present a larger box compared to cool colours, indicating greater data dispersion. This means that the pupil diameter values for warm colours vary more in relation to cool colours, suggesting a potentially higher sensitivity of the right pupil to stimuli related to warm colours.

Table 1: Wilcoxon test considering the screen with 6 colors

	#yellow	#blue	#orange	#Purple	#green	#red
#yellow	1,00E+00	5,46E-01	3,86E-01	4,54E-11	1,06E-08	1,85E-09
#blue		1,00E+00	8,81E-01	3,62E-07	4,03E-07	1,65E-07
#orange			1,00E+00	6,64E-05	9,14E-07	5,81E-07
#purple				1,00E+00	2,24E-04	9,61E-04
#green					1,00E+00	2,21E-01

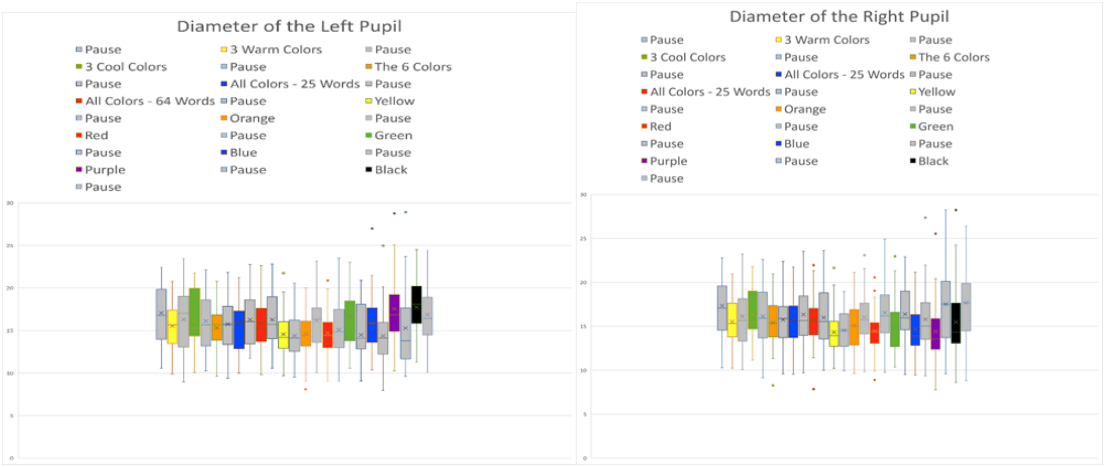


Figure 5: Diameter of the Left Pupil and Right Pupil

Additionally, when comparing the medians, it can be noted that both yellow and red have higher medians than blue and purple, while orange has a higher median than green. This indicates that, on average, the central values of data for warm colours are higher than those for cool colours. These differences in medians may suggest that warm colours have a greater impact on dilation of the right pupil compared to cool colours. These analyses indicate variations in pupillary response to different colours, highlighting differences in visual stimulation capacity.

4. Discussion and Conclusions

This study aimed to investigate the visual appeal and readability of different colors, shedding light on their impact on attention and cognitive effort during reading. In terms of attention capture, yellow emerged as the most prominent color, drawing attention in 49 instances, followed by green (31), orange (23), blue (19), red (8), and purple (5). These findings suggest intentional use of colors to guide attention and viewer gaze, a valuable insight for design and visual communication professionals.

Considering color legibility, pupil dilation was examined, a metric linked to attention and concentration demand during cognitive tasks [28]–[30]. Average pupil dilation values for various colors showed no significant differences, indicating similar effects on attention during slide evaluation. However, analyzing maximum dilation values revealed that black, purple, and green induced more pronounced pupil dilation, suggesting heightened attention and concentration requirements during reading. Conversely, red and yellow exhibited lower maximum dilations, hinting at less demanding reading tasks. Minimum dilation values further emphasized these distinctions, with purple, black, and orange resulting in lower dilations, indicating reduced concentration demand. In contrast, yellow, green, and black recorded higher minimum dilations, suggesting increased concentration requirements.

It is crucial to note that individual variations in pupil dilation values exist, making maximum and minimum values less indicative of overall legibility. These initial insights can be complemented by more extensive and individual studies to precisely understand visual responses to different background colors during reading.

The analysis of box plots of pupil diameter revealed a compelling trend, with cool colors demonstrating a more pronounced effect on left pupil dilation, while warm colors influenced right pupil dilation. This finding implies that different chromatic stimuli may distinctly affect pupillary activity in each eye.

Future studies can expand on these insights by broadening participant samples to include diverse age, ethnic, and cultural groups, providing a comprehensive understanding of individual color responses. Exploring variations in visual stimuli, such as color intensities, background textures, and geometric shapes, can further enrich our understanding of their influence on visual perception and pupillary response[7], [10], [23], [27], [31].

Additionally, studying the interaction between colors within the same visual stimulus can unveil information about synergies or contrasts, offering insights into how color combinations affect attention and legibility [32]. Contextual exploration, such as the practical applications of colors in work environments, digital interface design, and advertising, can provide valuable guidelines for professionals.

Beyond pupil dilation and blinking, future studies can consider additional physiological and behavioral measures, such as heart rate, skin conductance, and emotional responses, to deepen our understanding of color effects on human perception.

In summary, the findings of this study provide valuable insights into how color impacts legibility and attention. Yellow stands out as a powerful attention-grabbing color, while the analysis of legibility indicates that all colors considered are similarly legible as text backgrounds. The nuanced relationship between cool and warm colors and their influence on left and right pupil dilation adds a multidimensional aspect to color perception, providing a foundation for improving design practices, visual communication, and marketing strategies. These insights empower professionals to make informed decisions about color usage, enhancing their ability to attract attention and improve the legibility of visual content.

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