VISUAL PERCEPTION

A comprehensive overview of the visual processing system.

Kelly Meredith

February 18, 2019
HF700, Spring 2019

Introduction

In design, what one sees is not only about first impressions but is arguably one of the most important aspects of design. Oftentimes, products are designed without consideration for how humans process visual information. Just because something is pretty, or sleek, does not mean it is correct. In an attempt to mitigate common design flaws, this paper will give an overall review of visual perception, the evolution of visual perception and its workings, and an example of how these mechanisms apply to real world stimulus. I will begin by reviewing the notion of color vision, the anatomy of the human eye and potential theories of evolutionary advantages of color. I will then move into a discussion regarding sensory perception of visual stimulus. This discussion will include the signal detection theory, visual acuity, spatial frequency, and color visual characteristics such as hue, saturation and luminance. To conclude this paper, I will give an in-depth product review showcasing how these factors can affect human interaction and experience with a product. The product under review is a postal scale, most typically used in an office setting.

Human Anatomy and Evolution

The human eye is a complex organ through which an individual is able to see and process visual information. In visual processing, one of the most important parts of the eye is the retina, which is the "sensory membrane that lines the inner surface of the back of the eyeball" and houses two types of specialized cells, called photoreceptors (Heiting, 2017, p. 1). The two types of cells are referred to as rods and cones, shown in Figure 1 (Heiting, 2017). Rods do not perceive color, are highly sensitive in detecting motion and operate in low-light conditions, while cones pertain to color vision and operate in well-lit conditions (Nathans, 1999). Human eyes contain four visual pigments of which are used to detect color. These pigments consist of the blue, short-wave pigment, the green, middle-wave pigment, and the red, long-wave pigment. These three pigments are found in the cone receptors, while the fourth, rhodopsin, is found in the rod photoreceptors (Nathans, 1999). As mentioned above, the cone photoreceptors are used for well-lit conditions while the rod photoreceptors are utilized in darker conditions.

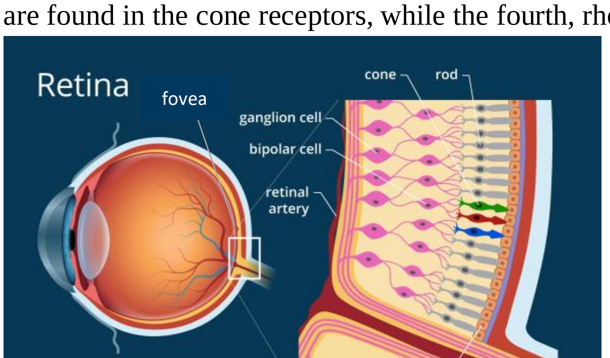

Figure 1: Anatomy of retina, including rods, cones and fovea (Heiting, 2017).

Within the retina, at the center of this membrane, is the fovea, a small area containing only cones (Jenkins & White, 1976). Visual analysis occurs in the fovea, where vision is sharpest (Ware, 2013). The fovea is where "one focuses the image of objects one wishes to see in minute detail" (Jenkins & White, 1976, p. 190). The further from the central, or foveal vision, the more the regularity and density of the photoreceptors decreases, and this is referred to as peripheral vision (Ludwig, Davies & Eckstein, 2014). It is thought that the visual selection of the peripheral vision can vary based on the level of foveal processing load, meaning the more the central vision has to focus on, as when reading, the less the peripheral process will engage (Ludwig et al., 2014). In other words, depending on the visual load, the useful field of view, or the area surrounding a fixation point, will vary in width (Mackworth, 1965). This information is consistent with the idea that foveal analysis and peripheral selection occur parallel and independently (Ludwig et al., 2014).

Many theories have been proposed for the evolutionary benefits of color vision. Some animals, like chickens, have evolved to possess greater depths of color vision than humans, while other animals have evolved with less (Nathans, 1999). In each case, there is likely an evolutionary advantage to this development. One theory for trichromatic vision evolution in humans is the importance of fruit identification and apparent ripeness for food selection. Nathans (1999) mentions that, because of the pollination benefit of humans eating fruits, the colors of fruit support this hypothesis due to their bright colors at peak ripeness; colors that would be easily seen amongst a background of greenery.

Visual Processing Pathway

From the rods and cones, the visual pathway continues to the parvocellular and magnocellular layers of the geniculate body, a six layered structure after the retina that is involved with visual perception (Livingston & Hubel, 1988). These layers of cells, referred to as parvo and magno, are necessary to receive information from the photoreceptors and use this information to recognize spatial discontinuities in patterns of light (Livingston & Hubel, 1988). The magno and parvo cells differ in their functions of color, acuity, speed and contrast sensitivity, suggesting the two have different functions within the visual system. Like rods, the magno cells do not detect color, while the majority of the parvo cells detect the long, middle and short-wavelengths of color. The parvo cells often have the ability to see one of the wavelengths while being inhibited by another (Livingston & Hubel, 1988). Livingston and Hubel (1988, p. 741) note that "a cell may be excited by long-wavelengths (red), inhibited by short-wavelengths (blues and greens), and be unresponsive to some intermediate wavelength (yellow)". Visual, or spatial acuity, is a measurement of one's ability to recognize detail or differentiate between points based on distance (Ware, 2013). Just like in foveal and peripheral vision, visual acuity is different between magno and parvo cells, where parvo cells have a much smaller receptive field center than magno cells (Livingston & Hubel, 1988). Because magno cells have a quicker response than parvo cells, it is likely that the magno system is involved in motion detection, according to Livingston and Hubel (1988). The contrast sensitivity function is "the ability of the visual system to detect luminance contrast at different spatial frequencies" (Mullen, 1985, p. 381). Magno cells have a higher sensitivity to contrast than parvo cells (Livingston & Hubrel, 1988). Williams, Sekiguchi, and Brainard (1993) note that the density of photoreceptors, inhibited by light absorption, causes a downward shift in the contrast sensitivity function for all spatial frequencies.

Numerous studies suggest that the visual system processes color and luminance through separate pathways and that "the relative sensitivities of the visual system to colour and luminance contrast change with spatial frequency" (Mullen, 1985, p. 397). Luminance is the measurement of the amount of light coming from an object or region of space and luminance contrast is thought to be the basis for pattern, motion and depth perception (Ware, 2013). Livingston and Hubrel (1988, p. 746) note that "the perception of three-dimensional shape from shading indeed depends solely on luminance contrast", giving the example that to produce the illusion of depth, a shadow can be a different hue providing that is darker than the unshaded portion of that surface. Mullen (1985) states that color contrast sensitivity peaks at a lower spatial frequency than luminance contrast sensitivity. Legge, Parish, Luebker, and Wurm (1990) tested color and luminance contrast on reading rates and found that, for both, lower contrast caused a sharp decline in reading rate. Using a threshold contrast that produced a reading rate of 35 words/minute, Legge et al. (1990) found that maximum reading rates require contrast to be six times that of the threshold contrast. While color contrast and luminance contrast act similarly due to spatial frequency, the two act independently from one another in terms of their effects on reading efficiency (Legge et al., 1990).

Signal Detection Theory

Signal detection theory is used to predict how a user is able to detect and discriminate between stimuli and noise (Wickens, 2008). It can be used to analyze, and sometimes predict, the number of hits, misses, false alarms, and correct rejections. Hits and correct rejections are accurate responses to the stimulus while misses and false alarms are errors on the subject's part (Wickens, 2008). In testing signal detection, the study design is often that of discrimination or detection. If the detection is of a stimulus that is one of two options, it is referred to as discrimination, while if there is an insignificant stimulus option, the test is called detection (MacMillan, 2002). Based on the extremities of the consequences, the ratio of hits to misses can be affected. For example, a high stress situation where missing a stimulus can cause great harm, a user may have a higher number of hits while also having a higher number of false alarms. Should the situation have a lesser consequence for missing a stimulus, the user may have lower hits, but more correct rejections (MacMillan, 2002).

Attention and Color Perception

Attention can be defined in many different ways, dependent on the type. In this section I will focus on exogeneous attention and how it is affected by color perception. Two main aspects of color include hue and saturation. Hue is referred to the wavelength of a color while saturation is the purity of that color (Fuller & Carrasco, 2006). Saturation and hue differ in that saturation, like contrast and spatial frequency, has a more obvious directionality from one end of the spectrum to the other. Hue, on the other hand, is perceived in more subjective ways, often using descriptions such as blue-green, or yellow-green (Fuller et al., 2006). Exogeneous attention is when one's attention is suddenly brought to a specific stimulus, as in "attention was 'captured' by a sudden flash, abrupt movement, or change in the periphery" (Fuller et al., 2006, p. 4032). Fuller et al. (2006) recognized that exogenous attention alters the perception of saturation in color, though has no effect in the change of perceived hue, even when there are changes in saturation. This incurs that saturation and color are perceived differently and independently. In conclusion of their study, Fuller et al. (2006, p. 4043) note that "increased contrast and saturation facilitate the discrimination of the feature of the signal and make it easier to discriminate the signal from the background" while there is no indication of the necessity for attention to affect the perceived hue in either direction.

Applying the Principles

In this paper I have given a brief introduction into visual perception, including concepts such as the signal detection theory, color perception, attention, and a summary of the anatomy of the eye. In the following section I will apply these principles in a comprehensive review of a common office product – a postal scale.

Figure 2: Office postal scale

The product in Figure 2, while unnecessary to be bold and flashy, underperforms in terms of ease of visual perception. As visible in the picture to the left, the product is two shades of dark gray. The buttons on this machine are a more saturated color than the background, however due to both grays being of higher saturation, with little color contrast it may be difficult for one to detect immediately. Fuller et al. (2006, p. 4043) explains that “two hues at the discrimination threshold do not become more discriminable if their physical saturations are increased proportionately while their hues are held fixed”.

A second misstep with visual perception on this machine is the screen above the buttons. Not only is the screen a dark hue, but the digits on the screen are as well, as shown by the yellow border. As noted above, low color and luminance contrasts cause a decline in the rate of reading. In order to be most beneficial to the user, either the colors or the luminance levels should be more contrasting. The issue of the screen contrast not only slows down the user’s speed in reading the information, but due to the low luminance in general, the user’s exogenous attention may not be activated. The change of the screen will not cause enough of a stimulus to alert the user. Livingstone and Hubel (1988) note that “people can follow brightness alternations at much faster rates than pure color alternations”, suggesting it would be more beneficial to have a higher luminance contrast on the screen than a color contrast. Furthermore, due to the high spatial frequency of this screen, the sensitivity will be greatest when the stimulus has strictly luminance contrast (Mullen, 1985).

While the two issues above can cause major usability problems, the machine’s use of white lettering on the dark grey buttons, is an example of higher color contrast, making it easier for the user to not only detect, but read the information on, or near, the buttons. Both the white and gray are of higher saturation, and the hues are very different, a combination that allows for greater contrast in color.

Conclusion

This paper has discussed key topics in the visual processing system and utilized them in an analysis of a current product. It is important, in product development, to use best practices in color contrast and luminance contrast in consideration of such factors as spatial frequency, attention and visual acuity. The human visual processing system is complex, though well understood, and should not be overlooked in the design of products, web pages, experiences and space. It is imperative to create goods utilizing the highlighted visual processing factors for best user experience practices. These practices will not only help users navigate the product but will create an easier unconscious experience. For example, knowing what we know about motion detection, should the postal scale require an action of the user based on a change in options on the screen, perhaps, still utilizing a greater luminance contrast, the screen options should flash to allow the users peripheral vision to pick up on the change. Designers should learn to create products based on the needs of people. People should not need to learn to use products based on the wants of designers.

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