The Visual Perceptual System

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The Visual Sensory Perceptual System

The human body perceives the world through its sensory receptors in specialized organs such as the eyes, ears, nose, mouth, and skin, as well as internal organs (Marzvanyan & Alhawaj, 2013). The perception of the stimulus, i.e., the input signal to the senses, is processed in two stages: The initial *bottom-up (sensory) processing*, where perception is based solely on the external stimulus, followed by the *top-down (cognitive) processing*, which is contextualized by expectations and stored knowledge (Eysenck, 1998). Since sensory perception is independent of personal experience, its principles are equally applicable to all human beings; interaction designers can leverage these concepts to understand the strengths and limitations of human sensory systems and design accessible products and applications responsibly. This paper will focus on visual perception and a scientific design review of an electric wheelchair controller.

Visual Contrast

In most scenarios, the stimulus is degraded by some internal or external noise; the higher the noise, the higher the margin for error. To present coherent, reliable signals to the user, interaction designers must include some redundancy (repetition of the core signal) and decoration (aesthetic value) with the stimulus to overcome the effects of the noise (Meinhardt et al., 2006). The *Signal Detection Theory (SDT)* is a framework that can be used to discriminate between two stimuli and extract the signal from noise (Green & Swetts, 1966). The ability of the eye to discriminate between signals or a signal and noise is called *visual acuity* (Lim, 2021). One way of achieving this is through contrast manipulation.

Understanding Contrast

Contrast in the perceptual sense can be described as an assessment of the difference in the appearance of two or more parts of a field seen simultaneously or successively (Normalisatie B.V., 2011). Contrast is critical in determining the fundamental response of the visual system (Harley, Dillon & Loftus, 2004). However, the precise definition of visual contrast and its use in various applications remains a topic of ongoing research and discussion (Azeddine et al., 2020).

In interaction design, local contrast (or visual saliency) is a crucial factor influencing how users navigate interfaces. An item's distinctiveness within its surroundings, directs users' attention towards its specific spatial region, thereby improving search efficiency and impacting their interaction experience (Still & Masciocchi, 2012).

Determinants of Contrast

Luminance, the achromatic component of light is the strongest determinant of contrast. The visual clarity of a lighting environment is significantly affected by changing the general color of its illumination (Hashimoto & Nayatani, 1994), and can influence task performance, comfort and well-being. Other components of *color* such as *saturation* (to a larger extent) and *hue* (to a smaller extent) can be used to implement contrast. For example, high saturation, high contrast regions draw our attention. An object's color is also determined by the spectral characteristics of the *scene* in which it appears (Lotto & Purves, 2000), which includes its *background color*, *environmental distractions*, *lighting quality* or *surface texture*.

The contrast can be enhanced further by adding additional cues, such as relative *size* or spatial scale (second largest determinant of contrast), *motion*, *depth*/*distance*, or *disparity*, as per research compiled from various studies by Lotto and Purves (2000). An *abrupt onset*, that is the sudden appearance of a strong stimulus, can also be used to gather visual attention. It is, however, important to avoid creating a distracting *after-image* that may be created due to prolonged exposure to a very strong signal or frequent changes in surface illumination, which could cause *fatigue* (Smith, 1979), and consequently reduce engagement, increase errors, and potentially damage the eye.

Mechanics of Human Vision

The human visual system is complex and consists of several interacting anatomical structures.

The Human Eye

Cornea

The *cornea* is the transparent outer layer of the eye where light strikes. The curvature of the cornea causes rays of light to refract and brought to a focus inside the eye on a plane called the *retina*. (Swanston & Wade, 2013).

Pupil and Iris

After passing through the cornea, the light enters through a hole in the center of the eye called the *pupil*. A ring of muscles around the pupil called the *iris*, dilates (called mydriasis) and constricts the pupil to control the amount of light entering the eye; in low-light conditions, the pupil dilates to capture more light, and in bright conditions, it contracts to capture less light. (Lim, 2021)

Lens

The *lens* is a biological tissue that flattens when we are focusing on something far away and gets thicker when we focus up close. This process is called accommodation. (Lim, 2021)

Retina and Optic Nerve

Retina is at the back of the eyeball. In the center of the retina is a small pit called the *fovea*. Compared to the rest of the retina, the fovea has the highest *visual acuity*. Changes in specialized neurons in the retina result in *nerve action potentials*, which are relayed to the brain via the *optic nerve*. Visual processing by the brain results in ‘visual perception’, the construction of a sensory image that is consciously appreciated as vision (Armstong & Cubbidge, 2014).

Visual Neurophysiology

Neurons

Neurons are nerve cells that transmit signals along the nerve fibres in pulses of fixed amplitude, called nerve impulse or action potential. (Swanston & Wade, 2013)

Receptors

The process of vision is initiated by light falling on specialised *receptors* in the retina. Light passes through the neural layers before striking the receptors, which contain the photosensitive pigments. The retina is organized vertically with specialized cells called the *bipolar cells* and *retinal ganglion cell*s, and horizontally with *horizontal cells* and *amacrine cells*.

Rod Photoreceptor Cells. Visual information from our peripheral vision is generally detected by *rod cells*, which are most densely concentrated outside the fovea. They are most sensitive to light that has a wavelength of 500 nm (blue-ish green). Rods are maximally active in low-light conditions, which is why our surroundings appear to have a blue-ish tint at night; this is referred to as the *Purkinje Shift*.

They have a high-convergence network, which can add many small signals together to create a seemingly larger signal. However, a disadvantage of this type of organization is that it is difficult to identify exactly which photoreceptor is activated by the incoming light, which is why accuracy is poor when seeing stimuli in our peripheral vision (Kawamura & Tachibanaki, 2012).

Cone Photoreceptor Cells. *Cone cells* allow for high-acuity vision. They are most densely packed at the fovea, corresponding to the very center of the visual field. They make up the minority of photoreceptors.

Cone cells have very low synaptic convergence. In fact, at the point of highest visual acuity, a single cone photoreceptor communicates with a single pathway to the brain. The signaling from low-convergence networks is not additive, so they are less effective at low light conditions. However, because of this low convergence organization, cone cells are highly effective at precisely identifying the location of incoming light (Kawamura & Tachibanaki, 2012).

Cones are responsible for processing our sensation of color. The typical human has three different types of cones, with each of these three types tuned to specific wavelengths of light. The short wavelength cones (*S-cones*) respond most robustly to 420 nm violet light (*blue cones*). The middle wavelength cones (*M-cones*) exhibit peak responding at 530 nm green light (*green cones*), and the long wavelength cones (*L-*

cones) are most responsive in 560 nm red light (*red cones*). Every color on the visible spectrum is represented by some combination of activity of these three cone photoreceptors, which is the basis for Young-Helmholtz trichromatic theory. (Kalloniatis & Luu, 2007)

Vision Limitations

Designers should consider the vision issues and limitations to avoid alienating large user groups.

Color Vision Deficiencies. Commonly called color blindness, this is a very common condition resulting from a dysfunction in cone photoreceptor cells. If one of the three types of cone cells fails to respond to the correct wavelengths of light, the person will lose the ability to differentiate between certain colors on the visible light spectrum. (Lim, 2021) This is most common in red cones.

Aging. Our vision deteriorates with age and virtually every measure of visual function shows declining performance with increasing age including decreased visual acuity, decline in sensitivity of visual field, decreased contrast sensitivity, and increased dark adaptation threshold. Decreased visual function is a combination of mainly ageing changes in neuronal elements of visual system, changes in ocular media, and pupillary miosis (Salvi, Akthar & Curri, 2006).

Chromatic Aberration. Lights of different wavelengths are not focused equally. Due to the difference in focusing power for different wavelengths, shorter and longer wavelengths are focused in front of and behind the retina, respectively; only the middle (yellow) wavelengths are in good focus. (Swantson & Wade, 2013)

Design Review of Electric Wheelchair Controller

Independence in mobility is one of the most important determinants of quality of life for individuals with disabilities. Powered wheelchairs are suited for individuals with a combination of physical and cognitive or perceptual impairments, but using controllers require cognitive and physical skills that not all individuals possess (Simpson, LoPresti & Cooper, 2008). The product in consideration, the controller of the X-9 ComfyGO Electric Wheelchair features independent control of the backrest and left/right leg rests for a customized experience for the users, a 360 degree waterproof joystick with 8 buttons, a battery power gauge and a speedometer.

Figure 1. Controller of X-9 ComfyGO Electric Wheelchair from User Manual.

Figure 2. Powered on controller of X-9 ComfyGO Electric Wheelchair from Amazon.

Evaluation

Positives

Distinction Between Active and Passive Buttons. Based on their functionality, the buttons on the remote can be classified as: *active*, that is, buttons that are critical during navigation of the wheelchair (power, horn, acceleration/deceleration buttons); and *passive*, which are used when the wheelchair is still (back-rest and foot-rest adjustment buttons). The active buttons are highlighted making them visibly larger and lining them with a low-saturation blue border. The passive buttons are smaller, without borders.

Sizes and Colors of Acceleration/Deceleration Button Icons. These icons are in a low-saturation bright yellow which contrasts well with the black background. Their equal size buttons draw them equal amount of attention, indicating their similarity in function.

Negatives

The Speedometer and Battery Power Gauge. The speedometer displays 5 different speeds based on the number of yellow dots visible on the meter. The battery power gauge displays the remaining battery capacity in 5 levels from low to high as red to yellow to green; when the power gauge shows yellow, the wheelchair needs to be charged. Both of these are important indicators. However, during mornings, it would be difficult for the eye to discriminate the yellow light from that of the sunlight. There is the possibility that the user may get confused between the two indicators about their level of acceleration due to the similar-sized dials, and similar colors of light.

Colors of Power and Horn Buttons. The horn button is placed right below the power button. There is insufficient contrast between these buttons in multiple areas. There isn't enough contrast between hues if their icons - red and orange – are of similar frequencies. Due to mid-level saturations, neither color stands out against the black background. Both shapes, while not exactly the same, have little frequency of change, which makes it difficult to discriminate between them. Both buttons have a similar blue border. This makes their proximity to each other a serious hazard for users, especially those with tremors such as patients of Multiple Sclerosis, Cerebral Palsy, Multiple System Atrophy, Progressive Supranuclear Palsy, and Parkinsons' Disease (Simpson, LoPresti & Cooper, 2008); there could be dangerous consequences if, while trying to hit the horn while traveling, the user ends up turning off the whole wheelchair system.

Potential for Improvement

The power button could be placed placed below the rest of the buttons so that the proximity to the horn button would reduce, but the button would be visible regardless. Similarly, the battery capacity indicator could also be moved to the bottom near the power button so that its proximity to the speedometer could be reduced. A different pattern of arrangement could be chosen for the speedometer levels to differentiate them from the battery indicator. High-intensity light-adaptive LEDs could be chosen to display the speed -

blue lights during mornings, and yellow lights in the evenings. Using buttons with high level of change could make the horn button more dramatic.

Conclusion

Understanding the intricacies of the human visual system is integral to effective interaction design. By considering principles such as visual contrast and the mechanics of human vision, designers can create interfaces that enhance user experience and accessibility. The design review of the X-9 ComfyGO Electric Wheelchair controller underscores the importance of clear visual cues, highlighting areas for improvement to ensure user safety and ease of use. Incorporating these insights can lead to more intuitive and inclusive interface designs for individuals with diverse needs.

Armstrong, R. A., & Cubbidge, R. P. (2014). The eye and vision: an overview. *Handbook of Nutrition, Diet and the Eye*, 3-9.

Azeddine, B., Muhammad, A.Q., Seyed, A.A., Aladine, Ci. & Marius, P. (2020). A Critical Analysis on Perceptual Contrast and Its Use in Visual Information Analysis and Processing. *IEEE Access*, 8:156929-156953. doi: 10.1109/ACCESS.2020.3019350

Salvi, S. M., Akhtar, S., & Currie, Z. (2006). Ageing changes in the eye: This article is part of a series on ageing edited by Professor Chris Bulpitt. *Postgraduate medical journal*, *82*(971), 581-587.

Simpson, R. C., LoPresti, E. F., & Cooper, R. A. (2008). How many people would benefit from a smart wheelchair?. *Journal of rehabilitation research and development*, *45*(1), 53.

Fehr, L., Langbein, W. E., & Skaar, S. B. (2000). Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey. *Journal of rehabilitation research and development*, *37*(3), 353-360.

Gorea, A., & Sagi, D. (2001). Disentangling signal from noise in visual contrast discrimination. *Nature neuroscience*, *4*(11), 1146-1150.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics* (Vol. 1, pp. 1969-2012). New York: Wiley.

Harley, E. M., Dillon, A. M., & Loftus, G. R. (2004). Why is it difficult to see in the fog? How stimulus contrast affects visual perception and visual memory. *Psychonomic Bulletin & Review*, *11*, 197-231.

Hashimoto, K., & Nayatani, Y. (1994). Visual clarity and feeling of contrast. *Color Research & Application*, *19*(3), 171–185. https://doi.org/10.1002/col.5080190305

Kalloniatis, M., & Luu, C. (2007). The perception of color. *Webvision: the organization of the retina and visual system [internet]*.

Kawamura, S., & Tachibanaki, S. (2012). Explaining the functional differences of rods versus cones. *Wiley Interdisciplinary Reviews: Membrane Transport and Signaling*, *1*(5), 675-683.

Koontz, A. M., Ding, D., Jan, Y. K., de Groot, S., & Hansen, A. (2015). Wheeled mobility. *BioMed research international*, *2015*, 138176. https://doi.org/10.1155/2015/138176

Lim, A. (2021). Sensation and Perception: The Visual System. In D. Simmons & A. Morales (Eds.), *Open Neuroscience Initiative*. https://www.austinlim.com/open-neuroscience-initiative?msclkid=eace2a59c69411ecbf6348d5d4d5d27e

Lotto, R. B., & Purves, D. (2000). An empirical explanation of color contrast. *Proceedings of the National Academy of Sciences*, *97*(23), 12834–12839. https://doi.org/10.1073/pnas.210369597

Meinhardt, G., Persike, M., Mesenholl, B., & Hagemann, C. (2006). Cue combination in a combined feature contrast detection and figure identification task. *Vision Research, 46*(23), 3977–3993. https://doi.org/10.1016/j.visres.2006.07.009

Scott, A. W., Bressler, N. M., Ffolkes, S., Wittenborn, J. S., & Jorkasky, J. (2016). Public attitudes about eye and vision health. *JAMA ophthalmology, 134*(10), 1111-1118.

Smith, W. J. (1979, October). A review of literature relating to visual fatigue. In *Proceedings of the Human Factors Society Annual Meeting* (Vol. 23, No. 1, pp. 362-366). Sage CA: Los Angeles, CA: SAGE Publications.

Still, J. D., & Masciocchi, C. M. (2012). Considering the influence of visual saliency during interface searches. In *Cognitively informed intelligent interfaces: Systems design and development* (pp. 84-97). IGI Global.

Wade, N., & Swanston, M. (2013). *Visual Perception : an Introduction, 3rd Edition*. Taylor and Francis.

Wagner, W. F. 1985. Round Table: Lighting — an art supported by a technology. *Architectural Record.* 173 (No. 4).