The Psychophysics of Visual Perception

A. What is Psychophysics

From ancient times, observing our own sensations and perceptions has been the most important way of learning about our body and mind. At its most basic, this is how we observe that our eyes are essential for seeing, the ears for hearing and so on. More subtly, Aristotle (350BC) described several perceptual illusions, including retinal after-images and the motion after-effect, now a staple of psychology and neuroscience. But it was in the nineteenth century that this folk psychology became formalized into detailed measurements of human perception. Galileo, Kepler and Newton had demonstrated with stunning success that the physical world was subject to laws that explained the observed regularities in the cosmos. Scientists now began to search for similar laws governing human perception; in Fechner's bold phrase, "an exact science of the relations between body and soul" (Fechner, 1860).

As a physicist and philosopher, Fechner aimed at developing a method that relates matter to the mind, connecting the publicly observable world and a person's privately experienced impression of it. His ideas were inspired by experimental results on the sense of touch and light obtained in the early 1830s by the German physiologist Ernst Heinrich Weber in Leipzig, most notably those on the minimum discernible difference in intensity of stimuli of moderate strength which Weber had shown to be a constant fraction of the reference intensity, and which Fechner referred to as Weber's law. From this, Fechner derived his well-known logarithmic scale, now known as Fechner scale. Fechner's work was later studied and extended by Charles S. Peirce, who was aided by his student Joseph Jastrow, who soon became a distinguished experimental psychologist in his own right.

Much of modern psychophysics is still based on Fechner's work and uses thresholds to measure the relationship between stimuli and perception. In addition to measuring the difference threshold, researchers also gauge the value of an absolute threshold. An *absolute threshold* is the smallest perceptible amount of stimulus that will produce a response. For example, the dimmest amount of light or weakest amount of sound a subject can detect is the absolute threshold. Fechner devised three methods to determine threshold values; later researchers added others. Results from these methods can vary depending on the time it takes for a particular subject's nervous system to register a response, the intensity of the stimulus, or differing criteria used by the researchers.

Method of Limits: To measure absolute threshold using this method, a subject is presented with a series of stimuli in either ascending or descending order and is asked via a yes-or-no question to determine the smallest amount that is detectible. If the test begins with the brightest amount of light, for example, the light would be decreased incrementally until the subject determines he or she can no longer perceive it. One of the drawbacks of this method is that subjects can begin to anticipate a value and "predict" when they can perceive a stimulus.

Method of Adjustment: In this method, the subject controls the amount of stimulus and continually adjusts it until he or she finds the amount that is "just barely detectible." With sound, for example, a subject would turn a knob until the point when he or she can or cannot hear a sound. This method can pose problems for researchers because the level of perception can differ from person to person.

Method of Constant Stimuli: The method presents a series of five to nine stimuli in a random order and the subject is asked to detect the desired threshold value. A subject may be asked to choose the brightest in a series of shaded colored circles shown in a certain order. The test would be repeated with the circles shown in a different order. This method is generally considered the most accurate because it removes the possibility the subject can try to predict the outcome.

Staircase Method: This method was developed from later research and is most often used by modern psychologists. The Staircase Method is based on the Method of Limits in which a series of stimuli is presented in an alternating ascending or descending order. When the subject can detect the desired variable, the test is stopped and the "direction" of the staircase is reversed and the process repeated. The threshold is considered to be the intensity level at the point the staircase is stopped and reversed.

What we experience is greatly influenced by sensory analysis. As they process information, the senses divide the world into important perceptual features (basic stimulus patterns). For vision, such features include lines, shapes, edges, spots, colors, and other patterns. In some instances, the senses act as *feature detectors* because they are attuned to very specific stimuli. After they have selected and analyzed information, sensory systems must *code* it. Sensory coding refers to changing important features of the world into messages understood by the brain. Also important is *sensory localization* in the brain meaning that the type of sensation you experience depends on which brain area is activated as some brain areas receive visual information, others receive auditory information, and still others receive taste or touch. Knowing which brain areas are active tells us, in general, what kinds of sensations you are feeling.

B. Structure of The Eye & Visual Pathways

In its front part, there are ligaments, which hold the lens, and the iris, which is controlling the amount of light entering in the eye. With a diameter ranging from 2 to 8 mm and located in the center of the iris, the pupil lets in more or less light, depending on the fact that it is dilated or contracted. The light rays entering the eye are first bent by a curved membrane, the cornea, before crossing the pupil where they are bent again. Another adjustment of rays is done through an automatic mechanism called accommodation, which consists of a more or less pronounced flattening of the lens. The lens becomes rather round if the object on which we try to focus on is close or very flat if the object is far. Thus, if an object is near, the muscles contract; the lens becomes thicker and the light rays are bent even more.

The outermost part of the eye is the sclera. The sclera is resistant and maintains the shape of the eye. In its anterior part, it is transparent and covered by a thin membrane, the conjunctiva, which has a protecting role. Between the sclera and the retina, there is an intermediate membrane, the choroid, or choroid membrane, which allows to avoid the presence of light reflection (internal) by absorbing light. Highly vascularized, the choroid has a nutritive function for retinal cells. Note that the spherical shape of the eye is made possible by the presence of two types of fluid. In the anterior part, between the cornea and the lens, this fluid is called the aqueous humor. In the back part, there is a large space filled with a rather gelatinous substance called the vitreous humor.

In the posterior part of the eye, there is a blind spot (or optic disk) caused by the presence of the optic nerve. This spot covers approximately 7.5° on the vertical axis and 5° on the horizontal axis (approximately 2.1 mm × 1.5 mm). The brain manages to compensate for the loss of vision caused by the blind spot. The innermost layer of the eye's posterior part is the retina. It is on the retina that the image is formed. On the retina is a point having a diameter of about 1°, the fovea. It is at the fovea that we have the sharpest vision. The fovea is located 2 mm from the blind spot in a small area, the macula lutea (or yellow spot). In this area, there is a high concentration of cones. In fact, at the center of the fovea, there are only cones.

Finally, each eyeball is provided with three pairs of muscles that direct the eye in all directions of the visual fi eld. These pairs have actually antagonistic roles. The superior and inferior lower rectus muscles allow the eye to make movements in the vertical direction, from top to bottom and from bottom to top; the lateral and medial rectus muscles make possible the horizontal movements, to the left or to the right; and the inferior (which is smaller) and superior (which is larger) oblique muscles are responsible for torsional movements and are involved in the vertical movements.

We distinguish two major pathways in the processing of visual information. Their name refers to the origin of the stimulation and where it ends up. Thus, the first pathway is called magnoparietal. It is also referred to as the median temporal pathway or dorsal pathway (or even *geniculostriate*). This pathway provides information about the "where" and "how" aspects of vision and requires the contribution of 10 % of ganglion cells. As this pathway passes through V5, it is not surprising that it is associated with motion perception. The other pathway is called parvotemporal or ventral (*tectopulvinar*). It is also known as the "what" pathway. This pathway requires the contribution of areas V2 and V4, the latter indicating that it involves color processing. In fact, this pathway allows to scrutinize images or objects for identifying them correctly.

C. Theories of Color Vision

Two major views have long been opposed when attempting to explain color vision. A first view point, supported by Thomas Young in the early nineteenth century and also by Hermann von Helmholtz a few decades later, is known as trichromatic theory of Young- Helmholtz . Essentially, this theory states that color vision depends on the presence of three types of receptors in the eye. It is postulated that these receptors are sensitive to all wavelengths, with a maximal sensitivity for a given length. These receptor types are more sensitive to blue, green, and red. In fact, Young and Helmholtz knew that, for a person having no color vision deficit, an additive mixture of red and green gives yellow. So they explained the vision of yellow by the excitation of the receptors of red and receptors of green. Indeed, according to them, any color could be explained by different excitation levels of the three receptor types.

Later in the nineteenth century, various observations not compatible with the trichromatic theory led Ewald Hering to develop another theory of color vision. In particular, Hering observed that people asked to choose colors that do not seem to be a mixture tend to discern four, and not three, primary colors: blue, green, red, and yellow. He also observed that people never report perceiving a greenish red or a yellowish blue. Moreover, the fact that people perceiving neither red nor green can perceive yellow was also a major objection to the trichromatic theory of Young- Helmholtz. Finally, Hering also knew that prolonged exposure to a color can create a strange effect, as discussed below. Thus, Hering rather proposed the *opponent process* theory to account for the wide range of perceived colors. This theory states that color perception is based on the operation of pairs of opponent colors. These pairs are red and green, blue and yellow, and white and black to reflect brightness perception. In this way, if a neuron is excited by the presence of a color, it will be inhibited by the presence of the opposite color.

Interestingly, contemporary data from physiology provide support for both theories and color vision can be explained with a system that is somewhat of a compromise between the theories of Young-Helmholtz and Hering and consists of three types of cones transmitting information to a more central level of processing. Based on the De Valois and DeValois (1993) multi-stage color model, the visual system transforms the signals from three cone types (S-cones, M-cones, and L-cones) into two separate opponent-color channels: red-green (RG) and blue-yellow (BY), and an achromatic (luminance) channel. This is achieved through a two-stage process: the first stage involves retinal ganglion cells creating receptive fields that are "opponent" (e.g., an L-cone center with M-cone surround), and the second stage involves the cortex combining these signals to isolate RG and BY channels and separate color from luminance.

A. What is Psychophysics?

1. What is the primary focus of the passage?
A) The evolution of physics from Galileo to Newton
B) The development of psychophysics and the study of human perception
C) The historical development of the study of light
D) The work of Charles S. Peirce in philosophy

2. Who first demonstrated that the physical world was governed by laws that explained observed regularities?
A) Ernst Heinrich Weber
B) Aristotle
C) Galileo, Kepler, and Newton
D) Fechner

3. What law did Fechner base his work on, which relates the intensity of stimuli to the perceptible differences in sensation?
A) The absolute threshold law
B) The Weber-Frechner law
C) Weber's law
D) The threshold of sensation

4. What is the purpose of psychophysics as described in the passage?
A) To explore the relationship between the brain and the body
B) To measure how the brain interprets physical stimuli
C) To study the laws governing the cosmos
D) To observe the sensory perceptions in animals

5. What is an absolute threshold?
A) The point at which a subject can no longer detect a stimulus
B) The smallest perceptible amount of stimulus that produces a response
C) The difference between two stimuli
D) The method used to measure the perception of brightness

6. What is one limitation of the Method of Limits?
A) It is too complicated for most subjects to understand.
B) It does not account for individual differences in perception.
C) Subjects may predict when they can perceive a stimulus, skewing results.
D) It is too fast to be accurate.

7. Which method is considered the most accurate for determining perceptual thresholds?
A) Method of Constant Stimuli
B) Method of Adjustment
C) Staircase Method
D) Method of Limits

8. What is sensory coding?
A) The process of turning sensory information into a mental image
B) The process of dividing the world into perceptual features
C) The process of converting features of the world into messages the brain can understand
D) The process of perceiving a stimulus at its maximum intensity

B. Structure of The Eye & Visual Pathways

1. The iris controls the amount of light entering the eye by adjusting the size of the pupil. **T**

2. The cornea is located behind the lens and is responsible for most of the eye's internal reflections. **F**
(The cornea is in front of the lens and bends light entering the eye; the choroid prevents internal reflections.)

3. The fovea, located in the macula lutea, contains only cones and provides the sharpest vision. **T**

4. The aqueous humor fills the large posterior space of the eye, while the vitreous humor is found between the cornea and lens. **F**
(It's the reverse: the aqueous humor is in the anterior part, between cornea and lens; the vitreous humor fills the large posterior space.)

5. The dorsal (magnoparietal) visual pathway is mainly involved in motion and spatial perception. **T**

6. The ventral (parvotemporal) visual pathway processes information about the color and identity of objects. **T**

C. Theories of Color Vision

1. According to the trichromatic theory proposed by Young and Helmholtz, how is color vision produced in the human eye?
Color vision depends on three types of receptors (cones) sensitive to blue, green, and red wavelengths, and all colors are perceived by different combinations of excitation in these three receptor types.

2. What evidence led Ewald Hering to propose an alternative to the trichromatic theory?
Hering noted that people perceive four primary colors (red, green, blue, yellow) rather than three, never see greenish red or yellowish blue, and that some people lacking red or green perception can still see yellow.

3. What is the main idea of Hering's opponent process theory of color vision?
Color perception is based on pairs of opposing colors—red-green, blue-yellow, and white-black—where excitation by one color inhibits the response to its opposite.

4. How does the opponent process theory explain why we do not perceive colors like "greenish red"?
Because red and green are opponent colors that inhibit each other; activation of one suppresses the other, making simultaneous perception impossible.

5. How do modern physiological findings reconcile the trichromatic and opponent process theories?
Modern research shows that the visual system uses three types of cones (supporting trichromatic theory) whose signals are then combined into opponent-color channels (supporting Hering's theory), forming a two-stage color processing system.

6. According to the De Valois and DeValois (1993) model, what are the three channels that process visual information, and what does each represent?
The three channels are the red-green (RG) channel and blue-yellow (BY) channel for color processing, and an achromatic (luminance) channel for brightness perception.