VISION: TEMPORAL FACTORS

Perception is modified by changes in visual stimuli that take place over time. For example, the apparent brightness of a stimulus may vary as a function of duration, even if its luminance is constant. Further, the appearance of a stimulus is affected by its timing with respect to other stimuli. For example, a flash of light may not appear to be a flash at all if it is embedded in a series of flashes (a phenomenon called *flicker fusion,* described further in the entry). Also described in this entry are the roles of temporal factors in brightness perception and factors in visual physiology and stimulus visibility.

Roles of Temporal Factors in Brightness Perception

The perceived brightness of a stimulus is not only determined by physical intensity but is also affected by duration. That is, a stimulus can be perceived as more intense by increasing either its physical intensity or its duration. Thus, the literature often refers to the time-integrated contrast energy, c, of a stimulus instead of its physical intensity.

One such relationship is conveyed in Bloch's law. Bloch's law (also called the time-intensity reciprocity law) states that a short-duration visual stimulus that is high in physical intensity (I) can appear as bright as a longer-duration stimulus of lower intensity (so long as both stimuli are of a duration, t, that is shorter than a critical duration, τ): for $t \leq \tau$, $c = I \times t$. The critical duration that temporally limits Bloch's law, τ, becomes shorter as the overall intensity of the stimuli increases. Bloch's law presumably operates due to integrative action of the visual system. However, the neural correlates are not currently known. Some reports suggest that a simple decay of neural activity can account for the effect.

In the Broca-Sulzer effect, perceived brightness also depends on stimulus duration. As the duration of a flashed stimulus increases, so does its perceived brightness, but then it decreases. Brücke and Bartley individually reported that the brightness of a flickering stimulus varies as a function of flash duration (an effect now referred to as the Brücke-Bartley effect). Later studies also investigated the role of flicker rate on the perceived brightness of flickering stimuli. Taken together, flicker rate, stimulus duration, interstimulus interval, and flicker on–off ratio (duty cycle) are all temporal factors that impinge upon the perceived brightness of a stimulus.

Flicker Fusion

The temporal factors that affect the appearance of a stimulus include the stimulus duration, but also its temporal interactions with other stimuli. Flicker fusion is the perceived continuous appearance of a flickering light. Although artificial electric lights appear to be stable light sources, in fact their light emission turns on and off cyclically at a rate of 50 to 60 Hz. Movies, computer monitors, TVs, and other presentation devices similarly flicker, despite the fact that they appear continuous. The apparent continuity of these devices is of central interest to the field of temporal visual processing, as well as to understanding how humans interact with the many devices and environments that make up modern society. For flicker fusion to occur, the rate of flicker of the source must be higher than the "critical flicker fusion threshold." This rate is typically 30 Hz or more, but it may vary as a function of context and lighting conditions.

Flicker fusion is thought to occur as a result of a process called "persistence of vision." In 1824, Peter Mark Roget (who also wrote the famous thesaurus) first presented the concept of "persistence of vision" to the Royal Society of London, as the ability of the retina to retain an image of an object for 1/20 to 1/5 a second after its removal from the field of vision. A second principle—the "phi phenomenon" or stroboscopic effect—is closely related to flicker fusion. The effect was first studied between 1912 and 1916 by Max Wertheimer (the founder of Gestalt psychology) and Hugo Munsterberg, who found that subjects perceptually bridge the temporal gap between two consecutive stimulus presentations, allowing them to perceive a series of static images as continuous movement.

Role of Temporal Factors in Visual Physiology and Stimulus Visibility

Temporal factors in visual perception are a function of the response dynamics of neurons in the visual system. Thus, to understand how temporal factors

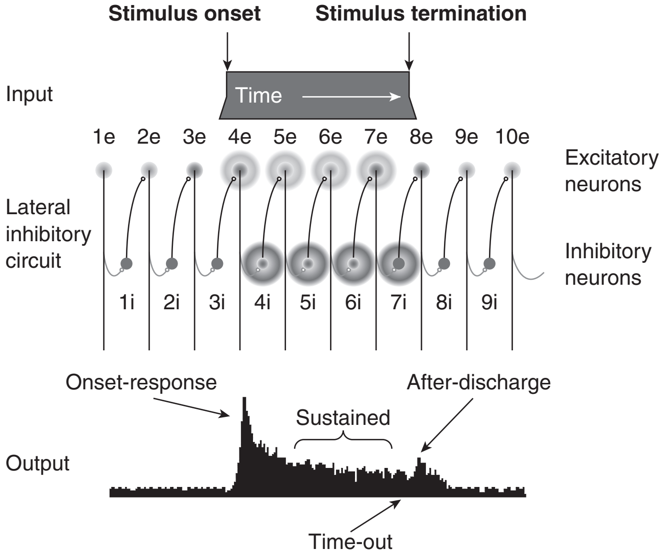

Figure 1 Temporal Response Dynamics and Response to Presentation of a Visual Stimulus

Notes: Temporal response dynamics of one excitatory and one inhibitory visual neuron, followed before, during, and after the presentation of a stimulus in which the stimulus is off (times 1, 2, and 3), on (times 4, 5, 6, and 7), and then off (times 8, 9, and 10). The neuronal response histogram of the excitatory neuron at the bottom shows the average response from 28 neurons in primate area V1 when visually stimulated for 500 milliseconds.

modulate perception, we must determine how visual neurons dynamically respond to stimuli.

Visual cortical neurons follow a stereotypical four-part temporal response dynamic in response to the presentation of stimuli (Figure 1): one excitatory neuron (at times 1e through 10e) and its connected inhibitory neuron (at times 1i through 9i). At times 1e, 2e, and 3e (before the stimulus is presented), there is no excitatory input, so the output remains flat. At time 4e (just after the stimulus, such as a bar of light, is presented), the neuron is excited, causing an onset-response. This leads to the activation of the inhibitory neuron at time 4i, after a slight delay. The inhibitory neuron then feeds back on the excitatory neuron and causes its activity to be suppressed at time 5e. This state of excitatory-inhibitory equilibrium is called the sustained period, which continues through time 7e, after which the stimulus is extinguished. Despite the stimulus having been terminated, the neuron at time 7i is nevertheless activated by the excitatory neuron at time 7e, due to the delayed effect of inhibition. Thus, the excitatory neuron at time 8e is inhibited while not being excited by visual input, and so is in a state of deep suppression called the time-out period, which in turn causes the inhibitory neuron at time 8i to be deeply suppressed due to lack of input. The excitatory neuron at time 9e then exhibits a disinhibitory rebound called the after-discharge due to lack of baseline inhibition (despite the fact that there is no excitatory input).

The Nobel laureate Edgar Adrian and his colleague Rachel Mathews, in the first microelectrode recordings from any visual system (eel optic nerve), found this temporal pattern of activity in response to the presentation of a disk of light. This response dynamic has been replicated in numerous animal models, including primates. Its perceptual consequence is that a visual stimulus appears more salient when it turns on and off than during its midlife.

Flicker fusion is also explained by these dynamics. When two stimuli are presented in close succession, the physiological after-discharge from the first stimulus and the onset-responses from the second stimulus may inhibit each other, thus generating perceptual flicker fusion.

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See also Contrast Enhancement at Borders; Lateral Inhibition; Visual Illusions; Visual Masking

Further Readings

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VISUAL ACUITY

Visual acuity is a measure of the keenness of sight. It has been studied, measured, and analyzed for thousands of years because it represents a fundamental limit in our ability to see. Consequently, visual acuity has been used as a criterion for military service and various other occupations, driving, and for receiving social security benefits. Visual acuity is limited primarily by the optics of the eye and by the anatomy and physiology of the visual system. Eye doctors assess visual acuity to assess the optical and physiological state of the eye and visual pathways. This entry concentrates on defining and specifying visual acuity, including minimum visible, resolvable, recognizable, and discriminable acuity.

Defining and Specifying Visual Acuity

How do we define the keenness of sight? Over the centuries, there have been a large number of different ideas about how to define and measure visual acuity, and these can be distilled down to four widely accepted criteria:

1. Minimum visible acuity—detection of a feature.
2. Minimum resolvable acuity—resolution of two features.
3. Minimum recognizable acuity—identification of a feature.
4. Minimum discriminable acuity—discrimination of a change in a feature (e.g., a change in size, position, or orientation).

These different criteria actually represent different limits and are determined by different aspects of the visual pathway.

Minimum Visible Acuity

Minimum visible acuity refers to the smallest object that one can detect. How small would that be? Visual acuity is generally specified in terms of the angular size of the image of the target at the retina. Under ideal conditions, humans can detect a long, dark wire (like the cables of the Golden Gate bridge) against a very bright background (like the sky on a bright sunny day) when they subtend an angle of just 0.00014°. As a comparison, your thumb, when viewed at arm's length, subtends an angle of about 2° on your retina, assuming your thumb is about 2 cm across and your outstretched arm is around 57 cm from your eye. It is widely accepted that the minimum visible acuity is so small because the optics of the eye spread the image of the thin line, so that on the retina it is much wider, and the fuzzy retinal image of the wire casts a shadow that reduces the light on a row of cones to a level that is just detectably less than the light on the row of cones on either side. In other words, although we specify the minimum visible acuity in terms of the angular size of the target at the retina, it is actually limited by our ability to discriminate the intensity of the target relative to its background. Increasing the target size, up to a point, is equivalent to increasing its relative intensity.

Minimum Resolvable Acuity

Minimum resolvable acuity refers to the smallest angular separation between neighboring objects that one can resolve. More than 5,000 years ago, the Egyptians assessed visual acuity by the ability of an observer to resolve double stars. There is currently still debate about how best to define and measure resolution. Today, however, the minimum resolvable acuity is much more likely to be assessed by determining the finest black and white stripes that can be resolved. Under ideal conditions, humans with good vision can resolve black and white stripes when one cycle subtends an angle of approximately 0.017° (1 minute of arc). This minimum resolvable acuity represents one of the fundamental limits of spatial vision: It is the finest high-contrast detail that can be resolved. In foveal vision, the limit is determined primarily by the spacing of photoreceptors in the retina. The visual system "samples" the stripes discretely, through the array of receptors at the back