the ability to orient one's body to the complex and dynamic three-dimensional properties of one's own clothing.

Neuropsychology of Other Perceptual Modalities

After vision, the next most studied perceptual modality in neuropsychology is audition. Just as there is a primary visual area, there is also a primary auditory cortical area, in the temporal lobe, and damage to this region causes *cortical deafness*. This disorder is rare, presumably because auditory information from each ear is distributed to both hemispheres, and damage to both temporal lobes is a far more infrequent occurrence than bilateral occipital lesions that cause cortical blindness. There are also blindsight-like issues with cortical deafness, regarding what sorts of auditory abilities might still be present. Beyond primary auditory areas, damage to the auditory association cortex may lead to *auditory agnosia,* in which subjects can still perceive frequency, intensity, and duration of sounds, but cannot recognize sounds, speech, or music. More selective auditory agnosias include *word-deafness,* in which subjects are unable to comprehend speech, and *amusia,* in which subjects cannot recognize music, most likely through loss of the ability to process melody. Neuropsychological studies have gone further to suggest that there may be selective deficits in recognizing musical contour versus musical intervals in amusia.

In the somatosensory modality (touch), there are also deficits linked to damage to the primary sensory cortex in the precentral gyrus. As well, there are patients with *tactile agnosia,* who have intact perception of shape and texture, who cannot recognize objects by touch. This too has been fractionated into an apperceptive (or integrative) form and an associative form.

For the modalities of taste (gustatory system) and smell (olfactory system), there is much less information. It has long been known that damage to the orbitofrontal cortex or anterior and medial temporal lobe can impair the sense of smell, but further classification of central olfactory disorders has not yet been attempted. The primary gustatory cortex is located in the insula and adjacent inner operculum, which project to the orbitofrontal cortex, allowing for an integration of smell and taste. There is even less neuropsychological data on cerebral disorders of taste than there is for smell.

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See also Agnosia: Visual; Attention: Disorders; Brain Imaging; Consciousness: Disorders; Vision: Developmental Disorders

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Nonveridical Perception

A person's entire life experience—everyone, everything, every experience he or she has ever known—exists to that person only as a function of his or her brain's activity. As such, it does not necessarily reproduce the physical reality of the world with high fidelity. *Nonveridical perception* is the sensory or cognitive discrepancy between the subjective perception and the physical world. Of course, many experiences in daily life reflect the physical stimuli that fall into one's eyes, ears, skin, nose, and tongue. Otherwise, action or navigation in the physical world would be impossible. But the same neural machinery that interprets veridical sensory inputs is also responsible for one's dreams, imaginings, and failings of memory. Thus, the real and the illusory or misperceived have the same physical basis in a person's brain.

Types of Misperceptions

Misperceptions (that is, perceptions that do not match the physical or veridical world) can arise from both normal and pathological processes. Everyday perception in the normal brain includes numerous sensory, multisensory, and cognitive misperceptions and illusions. But these may also result from abnormal brain processes or physiological conditions, such as hypoxia, drug consumption, brain trauma, and neurological diseases, among others. This entry explores some types of misperceptions that occur in the healthy brain in standard physiological conditions.

Sensory Misperceptions

Sensory misperceptions are phenomena in which the subjective perception of a stimulus does not match the physical reality. Sensory misperceptions occur because neural circuits in the brain amplify, suppress, converge, and diverge sensory information in a fashion that ultimately leaves the observer with a subjective perception that is different from the reality. For example, lateral inhibitory circuits in the early visual system enhance the apparent contrast of edges and corners so that these visual features appear to be more salient than they truly are.

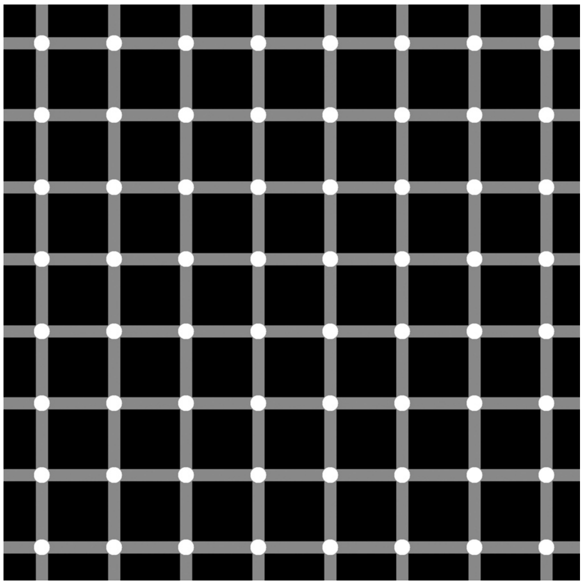

Figure 1 The Scintillating Grid Illusion

Source: Modified from Schrauf et al., 1997.

Notes: As you move your gaze around the image, observe the white circles on the intersections of the grey bars. Illusory dark dots seem to appear and disappear on top of the white circles, except for the one that you focus your gaze on at any given time.

Visual Misperceptions

In a visual illusion, the observer may perceive a visual object or scene that is different from the veridical one. Alternatively, the observer may perceive an object that is not physically present, or fail to perceive an object that is extant in the world. In the scintillating grid illusion (a type of brightness illusion; Figure 1), the subject perceives an illusory darkening of veridical white circles at the intersections of a grid.

Another well-known visual illusion is the perception of apparent movement. In this illusion, one object turns off while another object, in a separate spatial location, turns on. The perception is of a moving object that travels from the location of the first object to that of the second object. Movie marquees and motion pictures are practical applications of this principle.

Size illusions exemplify the importance of context in visual perception. In the Ebbinghaus illusion, a central circle will appear larger or smaller depending on the size of the circles surrounding it (the central circle will look large when the surrounding circles are small, and vice versa).

Errors in the perception of distance are another common type of visual misperception. Distances may be underestimated or overestimated, depending on various contextual cues. Dennis Proffitt and colleagues showed that people wearing backpacks consistently estimated distances as longer than people not wearing packs. More recently, Russell Jackson and Lawrence Cormack found that observers judged a cliff as higher when looking down from the top than when looking up from its base. Scientists have speculated that errors in distance perception such as these may have an adaptive value: For instance, a subject that overestimates the vertical drop of a steep cliff may descend it with great care, thus improving his or her chances of survival.

Auditory Misperceptions

In an auditory illusion, the listener may perceive sounds that are not present or that are different from those physically present. Auditory misperceptions are common while listening to speech embedded in noise (this is especially true for nonmeaningful speech; meaningful speech is easier to hear in noise). Other misperceptions involve speech segmentation. For example, consider the following two phrases: "How to recognize speech," and "How to wreck a nice beach." Although both sound patterns are almost identical, the context usually helps determine the correct perception.

The phantom words illusion, demonstrated by Diana Deutsch, is also related to speech perception. Here, the subject listens to recorded overlapping sequences of repeating words or syllables with different sounds presented in the left and right speakers. Even though the same exact sounds are repeated over and over, the listener will pick up specific phrases that appear to change from time to time. In one specific demonstration, the following phrases were heard by various speakers "no way," "when oh when," "mango," and "window." None of the perceived phrases were real, however, the listeners' brains simply made them up, as if trying to make sense out of meaningless speech.

Tactile and Pain Misperceptions

In tactile and pain illusions, the sensation of touch or pain differs in important ways from the physical stimulus. The thermal grill is an example of a powerful pain illusion, created by a grill of warm and cool interleaving bars. When a subject rests a hand against the grill, he or she experiences a sensation of burning pain. However, neither the warm nor the cool bars are painful to the touch when experienced in isolation. Thus, the thermal grill illusion further demonstrates that sensory perception does not work in absolute terms, but it is context dependent.

The cutaneous rabbit is a well-known tactile illusion. In the cutaneous rabbit, the subject's skin is sequentially tapped in two different locations. The subject's perception is that intervening (and nonstimulated) skin locations were also tapped, perhaps reflecting a kind of tactile "filling-in" process.

A number of tactile misperceptions are based on neural adaptation, that is, the decrease in responsiveness of sensory neurons when exposed to unchanging stimulation. To experience a tactile misallocation effect based on adaptation, close your eyes and try to touch the edge of one of your socks with your fingertips. It is very likely that you will fail to pinpoint the exact location of the sock's edge. The reason is that, in the absence of change, the somatosensory receptors signaling the edge of the sock get adapted (that is, they cease to respond). The perceptual consequence of such neural adaptation is a decrease in sensitivity. Adaptation effects are also common in other sensory modalities, such as vision, taste, and olfaction. For instance, adaptation helps explains why an unpleasant odor is more tolerable after a few minutes of exposure, or why the 10th bite of a delicious dish is never as good as the first one.

Gustatory and Olfactory Misperceptions

Except for those effects that are adaptation-based, taste and smell misperceptions appear to be less frequent than those of other sensory modalities. One powerful example of a taste illusion is the perceived localization of flavor (caused by olfactory input combining with taste) as occurring in the mouth. Tastants entering the mouth stimulate taste buds on the tongue, and vapors also reach the olfactory receptors through a passage that connects the mouth and nasal cavity. The stimulation of the olfactory receptors combined with stimulation of the taste buds create "flavor." However, we usually call this "taste" and associate it solely with stimulation of the tongue, presumably because of tactile sensations on the tongue. Another commonly experienced taste misallocation effect is the (incorrect) sensation of taste in areas of the mouth that have no taste receptors (for instance the roof of the mouth). This illusion may arise because the brain misinterprets the touch sensations of the food inside the mouth as the sensation of taste.

Multisensory Misperceptions

Multisensory misperceptions result from the interaction of two or more sensory modalities. The McGurk effect, or McGurk illusion, demonstrates that speech perception results from integrating both auditory and visual information. In this illusion, the visual stimulus is a video of a speaker making the lip and face movements for producing a sound such as /ga/. The auditory stimulus is a different sound, such as /ba/. However, a person watching the lip and face movements for /ga/ while receiving the auditory stimulus /ba/ actually hears a different sound, such as /da/.

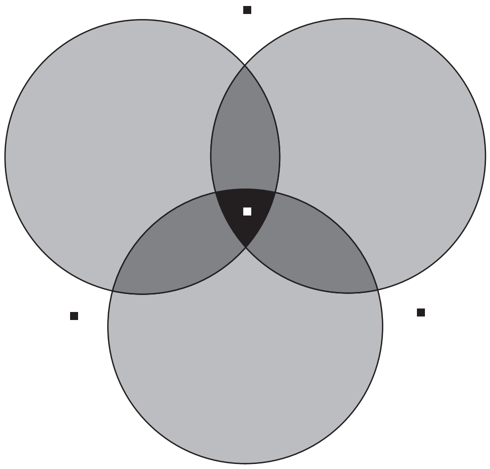

Figure 2 Perceived Brightness Is Affected by Voluntary Attention

Source: Modified from Tse, 2005.

Notes: Fixate your gaze on one of the fixation dots and direct your attention to one disk or another. The attended disk appears to darken in an illusory fashion, whereas the unattended ones appear unchanged.

Cognitive Misperceptions

Cognitive misperceptions involve higher-level cognitive functions, such as attention, memory, and causal inference.

Misperceptions Due to (In)attention

Attended objects may appear to be more salient or to have higher contrast than unattended objects (Figure 2); these perceptual effects have well-documented neural correlates in the visual system. Also, there are several cognitive neuroscience paradigms in which the allocation (or misallocation) of attention plays a critical role. These are described in the following sections.

Change Blindness. This is a phenomenon in which an observer fails to notice a large (and often dramatic) change within a visual scene. Such unnoticed changes usually take place during a transient interruption, such as a blink, a saccadic eye movement, or a flicker of the scene. Daniel Simons and Daniel Levin conducted a classical change blindness study, in which an experimenter approached a naïve pedestrian to ask for directions. While the pedestrian was providing directions, two additional experimenters carrying a door between them, rudely passed between the initial experimenter and the pedestrian. During this brief interruption, the original experimenter switched places with one of the door-carrying experimenters and continued the conversation with the pedestrian. Although the two experimenters looked different from each other and were dressed in different clothes, about half of the pedestrians failed to notice the switch. Change blindness is also common during changes that are introduced during cuts or pans in movies. Indeed, motion pictures often contain continuity errors (for instance, a glass of wine that is empty in one scene will be full in the next scene), despite very careful editing. Such continuity mistakes are usually unnoticed by spectators.

Inattentional Blindness. This is a phenomenon in which observers fail to notice an object that is fully visible in the display. Inattentional blindness differs from change blindness in that no memory comparison between the prechange state and the postchange state is needed: The missed object is fully visible at a single point in time. In a famous example of inattentional blindness, Daniel Simons and Christopher Chabris asked observers to watch a video showing people passing a basketball and to count how many times the members of a basketball team passed a ball to one another, while ignoring the passes made by members of a different team. While concentrating on the counting task, most observers failed to notice a person wearing a gorilla suit walking across the scene (the gorilla even stops briefly at the very center of the scene and beats its chest!). In this situation, no interruption or distraction was necessary, as the assigned task of counting passes was absorbing. Further, the observers had to keep their eyes on the scene at all times in order to accurately perform the task. Daniel Memmert showed, using eye-tracking recordings, that many observers did not notice the gorilla even when they were looking directly at it.

Memory Illusions

A large variety of memory illusions are commonly experienced by most people, such as déjà vu—the feeling that a novel situation has been previously experienced, or jamais vu (the opposite of déjà vu)—the illusion that a familiar situation has not been previously experienced. Another memory illusion is known in cognitive science as the *misinformation effect,* that is, the tendency for misleading information presented after the event to reduce one's memory accuracy for the original event. In a classic experiment, Elizabeth Loftus and John Palmer asked observers to estimate the speed of a car hitting another, after watching a video recording of a car accident. Observers that were asked how fast the car was going when it *hit* the other car gave lower speed estimates than observers that were asked how fast the car was going when it *smashed into* the other car. Experiments such as this demonstrate that memory illusions are critical to consider in the context of eyewitness testimonies. Eyewitnesses also generally report scenarios that are consistent with their expectations, a phenomenon known as *confirmation bias*. Such confirmation bias could also be responsible for some gross and tragic misperceptions, for instance in the police shootings of unarmed black subjects (the police officers declared to have "seen" a weapon, rather than a harmless object or an empty hand), possibly due to racial stereotypes associating blacks with violence and gun possession.

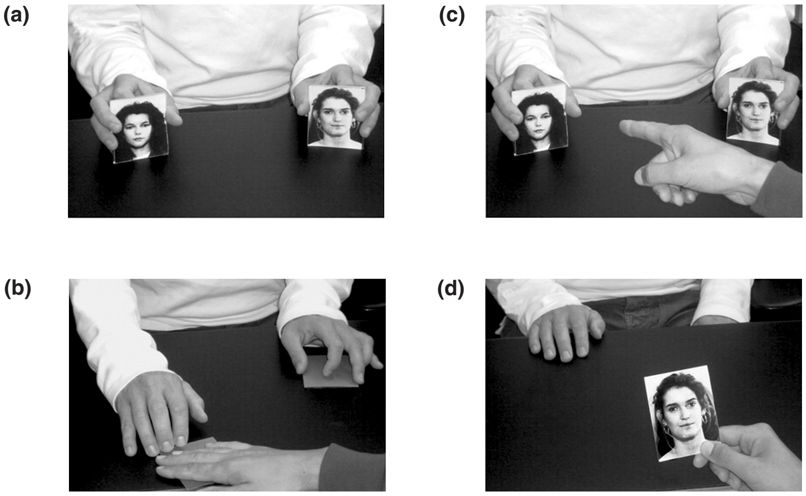

Figure 3 A Manipulated Trial During a Choice Blindness Experiment

Source: From Johansson, P., Hall, L., Sikström, S., & Olsson, A. (2005). Failure to detect mismatches between intention and outcome in a simple decision task. *Science, 310,* 116–119. Reprinted with permission from AAAS.

Notes: (a) Subjects are presented with two female faces and asked to choose the most attractive one. Unknown to the subjects, a second card with the opposite face is hidden behind each of the visible faces. (b) The subjects indicate their choice by pointing at the preferred face. (c) The experimenter flips down the pictures and slides the hidden picture over to the participant, covering the original picture with the sleeve of his moving arm. (d) Participants pick up the picture and are immediately asked to explain why they chose the way they did.

Illusory Correlations

We infer cause and effect in everyday life. When A precedes B, we often conclude that A *causes* B. This causal inference is integral to our perception of magic tricks, many of which involve apparent violations of causality. A skilled magician will link two unrelated events, A and B, by making sure that event A (pouring water on a ball) always precedes event B (the ball disappearing). Although A does not *actually* cause B, the spectators will perceive the events as causally related. This type of illusion—seeing a correlation that is not there—is termed an illusory correlation.

Free Will and the Illusion of Choice

We live our lives under the practical assumption that we are free to make our own choices. However, the existence of free will is debatable. More often than not, we are unaware of the exogenous and endogenous constraints that explain our choices. Thus, our experience of free will may be no more than a sophisticated cognitive illusion. A recent experimental paradigm moreover demonstrates that we can be blind to the outcomes of our choices. In this paradigm, developed by Petter Johansson and colleagues, the relationship between a subject's choice and its outcome is surreptitiously manipulated. Subjects were shown picture pairs of female faces (Figure 3a) and asked to choose which face in each pair they found most attractive (Figure 3b). On some trials, participants were also asked to verbally describe the reasons behind their choice. Unknown to the subjects, the researchers occasionally switched one face for the other (Figure 3c), after the subjects made their choice. During manipulated trials, the picture revealed by the experimenter as the one that had been chosen became the opposite of the subject's initial choice (Figure 3d). Interestingly, only 26% of all manipulated trials were caught by the subjects. But even more surprisingly: When the subjects were asked to state the reasons behind their choice in the manipulated trials, they confabulated to justify the outcome, which was opposite to their actual choice. Johansson and colleagues called this phenomenon *choice blindness*. Choice blindness shows that there are certain situations in which we do not perceive the difference between what we get and what we originally asked for. The potential implications of this phenomenon for everyday life are intriguing, especially as follow-up experiments have started to show that choice blindness is not restricted to vision, but it extends to other sensory modalities.

Is Everything an Illusion?

In the *Matrix* movie, Morpheus explains to Neo that everything we consider "real"—that is, all that we perceive through the senses—is the product of neural activity in the brain. But what the movie does not say is that, even when Neo awakens from the illusory world of the Matrix into the veridical world, his brain will continue to construct his subjective experience—as all of our brains do—and this experience may or may not match reality, to varying degrees. Thus, in a way, we all live in the illusory "matrix" created by our brains. Years before the *Matrix* movie, neurologist and Nobel laureate Sir John Eccles wrote that the natural world contains no color, sound, textures, patterns, beauty, or scent. Thus, color, brightness, smell, and sound are not absolute terms, but subjective, relative experiences that are actively created by complicated brain circuits. This is true not only of sensory perceptions, but of any other experience. Whether we feel the sensation of "redness," the appearance of "squareness," or emotions such as love or hate, these are constructs that result from electrochemical impulses in our brain.

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See also Aftereffects; Atmospheric Phenomena; Attention: Effect on Perception; Attention and Consciousness; Attractiveness; Auditory Illusions; Change Detection; Contrast Enhancement at Borders; Consciousness; Consciousness: Disorders; Cultural Effects on Visual Perception; Emotional Influences on Perception; Hallucinations and Altered Perceptions; Lateral Inhibition; Multimodal Interactions: Visual–Auditory; Out-of-Body Experience; Phantom Limb; Vision: Developmental Disorders; Visual Illusions

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