EINDHOVEN
UNIVERSITY OF
TECHNOLOGY

Perception

Citation for published version (APA):
Bouma, H., Bouwhuis, D. G., Koester, E. P., Kroeze, J. H. A., Eijkman, E. G. G., Engel, F. L., Hart, 't, J., Houtsma, A. J. M., Nes, van, F. L., & Roufs, J. A. J. (1997). Perception. In R. Dulbecco (Ed.), *Encyclopedia of human biology* (Vol. 6, pp. 627-639). Academic Press Inc..

Document status and date:
Published: 01/01/1997

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 05. Oct. 2023

Perception

H. BOUMA and D. G. BOUWHUIS
Institute for Perception Research/IPO in Eindhoven

E. P. KÖSTER and J. H. A. KROEZE
Utrecht University

E. G. G. EIJKMAN
Nijmegen University

F. L. ENGEL, J. 'T HART, A. J. M. HOUTSMA, F. L. VAN NES, and J. A. J. ROUFS
Institute for Perception Research/IPO in Eindhoven

GLOSSARY

Attention Selective perception of certain objects or events out of many possible ones

Hearing Perception mediated by certain acoustical vibration impinging upon the ear

Kinesthetic perception Perception mediated by mechanical and thermal stimulation outside or inside the body

Perception Interface between the outside world and the human brain, as regards the intake of sensory data, the processing into sensory attributes, and the recognition as objects or events

Smell Perception mediated by certain volatile chemical substances impinging upon the sensory surfaces of the nose

Taste Perception mediated by certain chemical substances impinging upon the tongue

Vision Perception mediated by certain electromagnetic radiation impinging upon the eye

HUMAN PERCEPTION IS TAKEN HERE AS THE physicochemical interface between the outside world and the human brain, plus the sensory and cognitive processing of the data transforming these into information. Each sense organ is generally activated by its specialized type of stimulation and gives rise to its specific set of sensory attributes. Senses that take in stimulation from distant sources are hearing, through certain acoustical vibration, vision, through certain electromagnetic radiation, and smell, by a number of volatile chemical substances. Sense organs that react to stimulation from close sources are taste, by certain chemical substances in the mouth, and the skin senses (and kinesthetic senses), from mechanical stimulation at the outside or inside of the body. Next, the sensory attributes and their dynamic variations are subjected to processes of recognition, that is, interpreted within a framework of evolved experience and recent context. An important special case is the recognition of spoken language (speech) through the ear or written language (reading) through the eye, where the language elements are symbolic carriers of information between humans. In the overwhelmingly rich sensory stimulation to which humans are exposed, powerful perceptual selection processes make the chaotic input

ENCYCLOPEDIA OF HUMAN BIOLOGY, Second Edition, VOLUME 6.

amenable. All perceptual functions are far from constant because they are in active development over life from one's earliest to final moment.

I. GENERAL

A. Transduction

Transducers are located in the sense organs, which, after initial filtering, map the physical data to neural data. So in the eye, imaging is an optical filtering process and the rod and cone receptors of the retina are the transducers proper. In the ear, the ear canal, the chain of middle ear bones, and basilar membrane provide filtering, and the hair cells act as transducers. When physical parameters are outside the range of filters and transducers, no perception results, even if perceptual terms are commonly used (infrared, ultrasound).

B. Sensory Attributes

After transducers, neural processing takes over. This is quite complex and leads to (1) largely or partly automatic reflexes in muscles and glands and (2) impressions and interpretations about the outside world (perception). The two categories are interdependent, and active perception, in which movements of the observer occur, may be different from passive perception. Sensory attributes are coupled to physical stimuli and reflect direct processing, which may be of a complex nature; examples in vision are brightness and color as coupled to spatial luminance distribution and wavelength composition; examples in hearing are loudness and sound direction as dependent on physical spectral intensities and differences in intensity and time of the signals for the two ears, respectively. For the sense organs, with the possible exception of smell, the number of sensory attributes is relatively small. Constant stimulation need not produce constant sensation (adaptation). The field of study that relates sensory attributes to physical stimuli is called psychophysics.

C. Recognition

Another type of processing is the interpretation of the sensory attributes of one or more senses by mapping them onto internal concepts of the outer world that have developed earlier. The central term here is recognition, because learning has been involved, perceptual experience is relevant, and interpretation may well differ among observers. The activated concepts imply meaning to the observer, which relates to networks of relevant associations. Examples are recognition of faces and of musical sounds. Associations may sometimes be described in physical terms, that is, in terms of physical stimuli, which would produce similar activations. The recognition and associations form a basis for further cognitive evaluation and for intended movements, which bring about changes in the physical world. Natural language is concerned with the manipulation of symbolic information. The symbols themselves, speech or print, are coupled to meaning by language conventions rather than by physical attributes. Units are called "words," and their ordering rules are described by the syntax. Natural language permits an incredibly rich gamut of expressions from a similarly rich gamut of inner worlds. Subtlety and ambiguity lie close together. Speech perception and reading are the two perceptual components.

D. Selection

Perception is usually quite robust and stable in the presence of wide variations of physical stimuli (perceptual constancies). This should perhaps be attributed to the types of processing involved and to priorities in processing (selection). Priorities in processing are dependent both on sensory attributes coupled to external physical stimuli (conspicuity) and on internal factors relating to the search of specific information by the subject (directed attention). As the relevant distribution of sensory attributes becomes more complex, priorities in processing are more pertinent. Conspicuity and directed attention may be in mutual conflict; however, the rule seems to be that the two processes are cooperative in a sense that the desired information is coded in terms of its most conspicuous attributes.

Robustness and stability of perception are prerequisites for integrating the perceiving subject in each of the many physical environments, thus preventing perceptual chaos. The basis for this seems to be that the subjects act on an internal model of the physical world and incoming data are interpreted in terms of shifts and changes in this internal model. Components of such internal models reside, as we say, in long-term memory and are revived as required in the internal model of the world "here and now." Language data are coded as internal speech in a short-term buffer. It holds some five to nine words or word combinations. Several other memory components are short term as well, but properties of the former language type are best known.

E. Development

Because it is brought about by physical stimuli, perception depends on the physical environment. However, the great amount of learning involved in perception makes perceptual processes themselves also very much dependent on the world around us. In this sense, human perception bears the marks of the environment that we live in. Much of the present environment has been brought about by technology and consequently both our internal concepts as built up in the preceptual process and the perceptual processes themselves are geared to this technological world.

II. HEARING

A. Transduction

The human hearing organ consists of an acoustical–mechanical part comprising outer, middle, and inner ear and an electrochemical part, which includes a variety of neural structures that run from the 8th (auditory) nerve to the temporal lobe of the brain's cortex. The outer ear (pinna, ear canal) mainly transmits sound waves from the outside air to the eardrum. In the middle ear, three small bones (malleus, incus, stapes) with attached ligaments and muscles connect outer ear (eardrum) and inner ear (oval window). The lever action of these bones and the area reduction of eardrum to oval window form a mechanical transformer between the low impedance of air in the ear canal and the much higher impedance of the fluid inside the inner ear. Automatic stiffening of the middle ear muscles when the ear is exposed to intense sound (middle ear reflex) causes sound attenuation, which protects the inner ear. The inner ear (cochlea) is a rolled-up tube partitioned almost over its entire length (35 mm) by the basilar membrane. This membrane assumes different resonance patterns, dependent on the vibration frequency of the stapes. Thousands of (inner) hair cells, situated along this membrane and innervated by fibers of the 8th nerve, convert the mechanical motion of the membrane into electrical pulses, which propagate along 8th nerve fibers to other nuclei of the auditory nervous system. The actual processing of those nerve pulses, which results in the sensation of hearing, may occur at many neural levels anywhere between the termination of the 8th nerve (cochlear nucleus) and the auditory cortex. [*See* Cochlear Chemical Neurotransmission; Ears and Hearing.]

The sensitivity range of the human ear is on the one hand limited by the hearing threshold, which is shown in Fig. 1. On the other hand, our hearing range is limited by the discomfort or pain threshold, which is typically around 130 dB, independent of frequency. For long-duration sound exposures, a hearing-damage threshold can be as low as 90 dB.

B. Auditory Attributes

Relationships between perceptual, subjective attributes of sound and its physically measurable, objective characteristics are well established. Perceived loudness of a tone is a power function of its sound pressure (exponent 0.6). Perceived pitch has a simple monotonic relationship with frequency (tone height) but also a cyclic one (tone chroma). This causes pitches of successive octaves to sound similar. Perceived timber depends primarily on the spectral profile of a sound but also on temporal features such as attack and decay. Perceived location of sound depends systematically on interaural arrival-time differences (low frequencies) and interaural intensity differences (high frequencies). There are also many cross-relationships. Loudness and timber both depend on frequency, and the pitch of a tone can change when only its intensity changes.

C. Recognition

What we hear is determined not only by the absolute or differential sensitivity of our ears but also by our

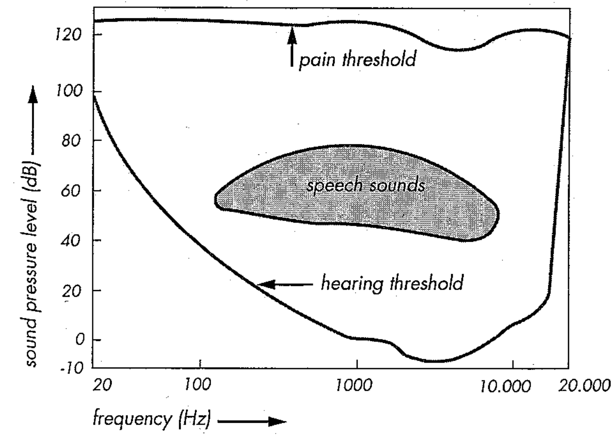

FIGURE 1 Region of sound pressure level and sound frequency in which normal hearing occurs.

memory capacity for sound. Roughly speaking, we can barely distinguish tones that differ by 1 dB in intensity (i.e., 12% in sound pressure) or 0.2% in frequency. Integrating this over the entire intensity and frequency ranges of our ear, we find that we can distinguish about 340,000 different tones. However, if we have to recognize or identify every one of those tones, we end up making mistakes. In fact, the largest number of different tones that we can reliably identify is about seven. Identification performance is primarily limited by memory capacity and not so much by differential sensitivity of our ears. Memory capacity for sound can grow with training. During infancy and childhood, we learn to recognize and handle many different speech sounds of the language (categorical perception). Trained musicians, especially those who have absolute pitch, can recognize considerably more than seven notes.

D. Hearing Impairments

Hearing impairments are first of all those associated with upward threshold shifts. They can be broadly divided into conductive and sensori-neural hearing losses. The former are broadband and exhibit simultaneous upward shifts of hearing and pain thresholds. The latter are often frequency-specific and generally show a mere increase in hearing threshold without an equivalent rise in pain threshold. Reduction of dynamic range by a sensori-neural disorder often causes an abnormal growth of perceived loudness with sound intensity, called recruitment. Some other hearing disorders, not necessarily connected with hearing loss, are tinnitus (hearing a constant tone when there is no sound) and monaural diplacusis (hearing several tones or noise when the sound is a pure tone). Binaural diplacusis (hearing slightly different pitches in each ear when they receive the same tone) is a common phenomenon but can become excessive in pathological cases. Noise-induced temporary threshold shifts recover with time. However, when exposure levels are too high (gun shots, disco) or the ears have been exposed for many years to sound pressure levels of 90 dB or higher (factory noise), permanent threshold shifts may result.

Current technology has given us virtually unlimited control over the sounds we can produce (computer music) and over means of encoding or decoding sound (telephone communication). Often, one can save communication costs or sound storage space by simply not encoding those portions of a sound that our ears would not perceive anyway (perceptual entropy). For the hearing-impaired it is sometimes useful to process the sound of a hearing aid so that it will match the person's residual hearing. Finally, for those who suffer from total bilateral cochlear hearing loss, various cochlear electrode implant techniques are available through which the 8th nerve can be stimulated by electrical transformations of sound, resulting in sensations that resemble hearing.

III. SPEECH

Speech is the sound produced by the vocal mechanism of humans as a carrier of meaningful messages that are coded according to the rules of language.

A. Production

The energy is provided by a stream of air from the lungs; the various speech organs convert it into a source sound and shape it into the many different speech sounds. For most speech sounds, the source consists of vocal cord vibration, which gives rise to a quasi-periodic sound with many overtones. Varying the repetition frequency results in changes in perceived pitch.

B. Vowels and Consonants

The source sound is shaped in the vocal tract. This consists of the pharyngeal and oral cavities (and the nasal cavity, which is only relevant for nasal sounds, such as the first and last sounds in "man"). The vocal tract has a flexible form, mainly determined by the movability of the tongue body and tip. At many different places in the oral cavity, a reduction of its cross-sectional area can be made, which gives rise to as many differences in timber, noticeable in, for example, the 12 vowels of English in the words "heat," "hit," "head," "hat," "hard," "hot," "hod," "hook," "hoot," "hut," "herd," and "the."

If somewhere in the vocal tract a sufficiently narrow constriction is made, or a closure followed by a release, the airstream from the lungs may become turbulent. This causes noise and, in these cases, the sound source is situated in the vocal tract itself. Examples are "s" and "t." Again, the position of the constriction determines the nature of the speech sound [e.g., "k" (back) and "t" (front)].

The articulatory characteristics mentioned thus far are reflected in acoustic properties: Figs. 2a and 2b show the waveforms of the vowels in "heat" and "hoot." The energy distribution as a function of frequency (the spectrum) appears to be specific for each

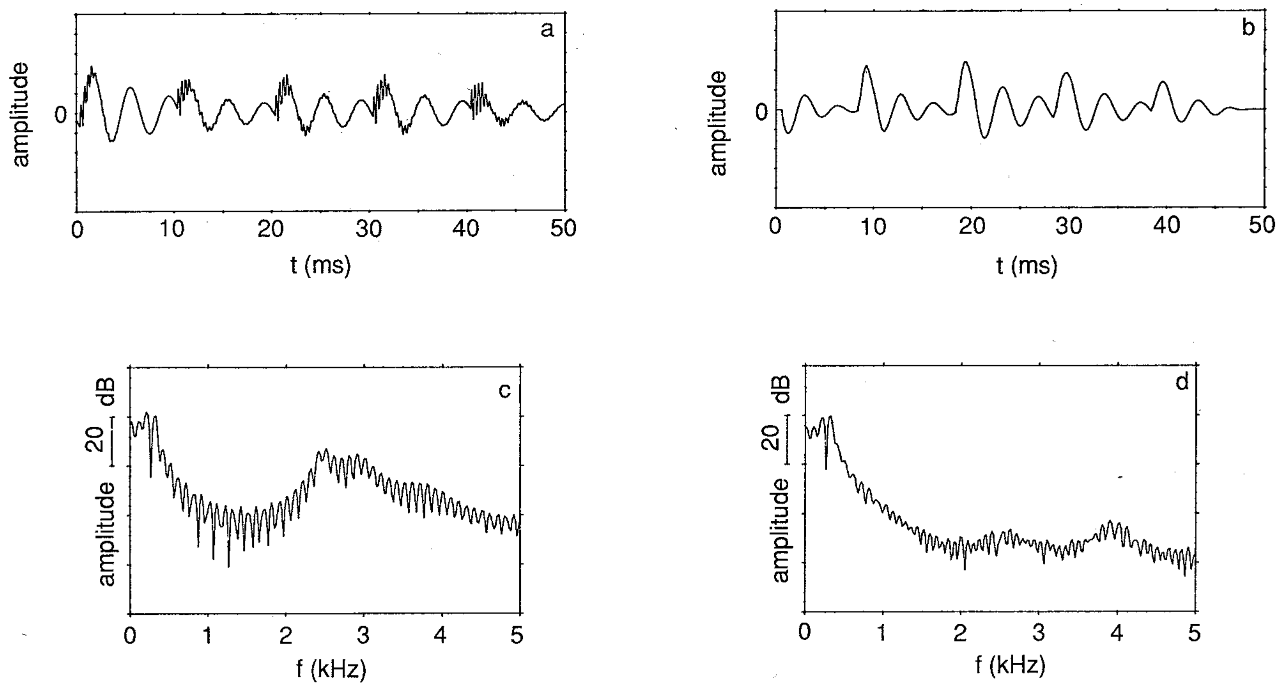

FIGURE 2 (a) Waveform of the vowel in "heat." (b) Waveform of the vowel in "hoot." (c) Spectrum of the vowels in "heat." (d) Spectrum of the vowel in "hoot."

speech sound. Figures 2c and 2d show examples for the same speech sounds as in Figs. 2a and 2b.

Many of the acoustic features give rise to distinct auditory attributes, such as hissing sounds ("s") versus sounds with pitch ("m"), high ("heat") versus low ("hoot") timber, and short ("t") versus long ("s") sounds. But this does not imply that normal speech perception is based on the identification of all the auditory attributes for each of the successively incoming speech sounds. Indeed, isolated speech sounds can only be recognized with about 70% certainty.

C. Recognition

Cognitive attributes must also be taken into account: we should consider that the listener largely bases his or her interpretation on stored knowledge. An appeal to cognition can take place at different levels of abstraction. For instance, it has become apparent that in a word recognition task, the number of perceived syllables together with the location of the word stress strongly reduces the number of candidate words. Nevertheless, only the low level of speech sound recognition is decisive in distinguishing between, for example, "elegant," "element," and "elephant." On the other hand, if the word is presented in a syntactically correct sentence, its status as either a noun or an adjective may be revealed, and this will help to separate the first word from the other two (e.g., the context "That's an . . . solution" only allows "elegant").

Clearly, in normal discourse the contextual information is of great help in these situations. But a truly complicating factor is that in fluent speech there are practically no pauses between words (like spacings in print). Our impression is that we can nevertheless process the continuous stream of speech as if it were segmented into words. This can hardly be understood without the assumption that a constant, intensive appeal is made to an internally represented dictionary. Thus, speech perception is a very complicated activity, in which knowledge of the language plays an important part, on levels ranging from phonology (sound structure) to semantics (meaning). There is an enormous gap between the abundant information available in the speech signal and the restricted amount of it the listener can cope with. Therefore, speech perception must be considered to be a highly selective process. [*See* Language.]

D. Speech Technology

Speech perception can be studied by means of measuring the acceptability of artificial speech. An interesting by-product of this method is that, in the end, it may lead to reliable acoustic specifications for speech synthesis-by-rule. This is, in fact, one of the objectives of speech technology, which furthermore is concerned with—parsimoniously coded—speech transmission, with automatic speech recognition, and with speaker identification. The products of these efforts are beginning to find their way in a world that becomes increasingly technical: computer systems that respond to spoken commands or queries, in artificial speech rather than in orthographic form on a screen, are already one of the possibilities. But also communicatively disabled persons may benefit from these facilities: a reading machine for the visually impaired or a keyboard-to-speech device for vocally handicapped people. Mention may be made of semiautomatic devices as well, such as the intonable electrolarynx for laryngectomees or those who lack the use of their voice temporarily.

IV. VISION

A. The Eye and Visual Pathways

The eye consists of a bulb-like transparent body (vitreous body) that is enveloped by the sclera. At the front side of the eye bulb, a clear window enables light to enter the eye, through a hole in the iris diaphragm (pupil), and fall onto the retina. The optics of the eye (cornea and lens) create an image of the outside world on the receptor mosaic within the retina. There are two kinds of photoreceptors: rods and cones, with rods operating at night and cones at daylight. They transduce the light distribution into a stream of nervous activity, which is modified at different retinal cell layers and guided into the optic tract. Eventually, the information stream of the left half of the retinas reaches the left part of the visual cortex of the brain, the right retinas feeding the right part of the cortex, both passing a crossover (optic chiasm) and a neural nucleus (lateral geniculate nucleus). [*See* Eye, Anatomy; Vision, Physiology; Visual System.]

B. Physical Stimuli

Light, emitted by a natural or artificial light source, is reflected by object surfaces and projected onto the retina. It enables a human being to obtain information from the outside world and to orient and act accordingly. The relevant physical magnitude of the reflected light is luminance, which can be characterized as light density. The illumination pattern at the retina caused by the properties of the visible surround is proportional to its luminance pattern. Spectral components of this light stimulate three kinds of cone differently, which causes color vision. [*See* Retina.]

C. Visual Attributes

Variations in luminance and spectral content evoke the visual attributes brightness, brightness contrast, sharpness, and color. Details can be detected by differences in brightness and color. Visual acuity characterizes the ability to see small details. Generally, the visual attributes are not trivially linked to the physical stimuli. The luminance distribution evokes, for instance, an internal image of the outside world that is largely determined by object properties such as surface reflectance, whereas the light source properties and observer position are relatively unimportant. Other visual attributes that also mainly reflect object properties are depth, movement, and texture.

D. Cognitive Aspects

It is commonly acknowledged that the main goal of vision is to derive three-dimensional object shape from the information contained in the retinal luminance distribution. In other words, the visual system aims at reconstructing the outside world from the light density variations.

Visual attributes such as brightness, color, movement, and depth can be regarded as lower-level interpretations that form the input to higher-level interpretations. These involve the grouping of related items within the visual field to larger wholes, and exchanges with memory items. For instance, features of body shape, color of hair, and movement enable us to identify an individual.

In visual recognition, in search, and in reading, the eyes normally move over the text in irregular jumps (saccades), each eye pause giving rise to recognition of objects in the fixation area. Integration across eye saccades occurs smoothly in an unknown way.

E. Visual Disorders

Defects may occur anywhere in the visual pathways. Optical defects may result in a retinal image that is not optimal. Lens errors, for instance, may evoke blurred imaging on the retina, whereas light straying at particles in the optic media diminishes contrast. Neural defects may already occur at lower processing levels, such as color weakness. A typical example of malfunctioning at higher levels is word blindness (dyslexia), better referred to as reading weakness.

F. Vision in a Technical World

Luminance distributions of pictures displayed on film and television are intended to evoke the same perceptual sensations as the corresponding luminance distributions that occur in real scenes. This does not imply that they should be identical. In fact, the displayed images are often far more parsimonious than the real ones. Generally, it is sufficient if the differences cannot be seen. A typical example is the apparent continuity of a television image, which in fact is a line-type image that is periodically refreshed.

V. READING

Reading concerns the visual perception of language signs. The signs are coupled to meaning by convention, either directly as in ideographs or by alphabetic or syllabic code (characters), which relates to speech sounds. [*See* Reading Processes and Comprehension.]

A. Eye Movement Control

Generally, the process of reading is preceded by searching for the desired part of a text on a page. During search, the eyes skim over the page, their motion being guided by certain text attributes. Just as in other static visual situations, the eyes move stepwise so that in a series of fixations of about 250 msec the successive characters can be imaged on the central part of both retinas. Saccades between fixations are 8 ± 4 letter spaces in alphabetic languages. Other saccades are necessary from the end of a line or column to the beginning of the next one, and back to previous parts of the text. [*See* Eye Movements.]

B. Word Recognition

During fixation pauses, information is extracted from the visual reading field, which measures 10–20 letter positions of alphabetic text or 1–3 ideographs. Both character recognition and word contour recognition contribute to this process. Luminance contrast and discriminability between characters of similar configuration are important.

C. Temporal Integration

Time is a crucial factor in reading: if the reading speed is too low, it takes too long to absorb the full content of a sentence and, therefore, its context, thus preventing integration. There is a minimum reading rate of 20 words per minute. Reading rate is the result of a complex interplay between necessary recognition time and the prevention of backward masking, saccade length, and accruing comprehension.

D. Reading and Language

A reader's knowledge of the language interacts with all components of reading. Visual patterns are decoded as characters and words, in turn representing sounds of speech and semantic units. Characters in a prescribed order and orientation represent words of the language, with a different sound pattern, and a specific grammatical function and meaning. Fluent reading requires extensive use of redundancy of the printed text at graphical, orthographic, lexical, syntactic, and semantic levels.

E. Reading Disorders

In many cultures that depend so much on the printed text, a reading disorder is a considerable handicap. Reading disorders may be due to insufficient intellectual development or a visual impairment. A specific reading disorder—dyslexia—occurs in about 6% of the male population. Its origin is now sought in the chain of cognitive processes following vision. [*See* Dyslexia–Dysgraphia.]

F. Reading in a Technical World

An increasing part of what people read now is presented with electronic means on electronic displays. Reading proceeds basically in the same way for paper-based as for screen-based texts, but negative effects may result from display properties. The presentation of bright text on a dark background, for instance, together with the presence of a reflecting glass sheet in front of the screen, may hamper reading if the surrounding luminance is high. With proper care, many such negative effects may be avoided. Also sharpness, color, contrast, and character configuration are relevant.

VI. SMELL

A. Transduction

The olfactory epithelia, two pigmented areas of 2–4 cm^2 in the olfactory clefts on both sides of the nose, consist of receptor cells, sustentacular cells, and Bowman's glands, which secrete the watery olfactory mucus (composition unknown) in which the odor-receptive cilia (80) sprouting from the protruding knobs of the bipolar receptor cells are bathed. The axons of these cells (neurons that are replaced by new ones from a basal cell layer during life) reach the olfactory bulb, where they form synapses. In this layered structure, many interconnections are found. The mitral cells (secondary neurons) form the olfactory tract to central parts of the brain. Granular cells receive afferent and centrifugal input and exert inhibitive influences on other cell types in the bulb. Odorous molecules can reach the receptors via ortho-nasal (sniffing) or retro-nasal (exhalation of vapors from the mouth) stimulation. The nature of the receptive mechanism is unknown, but receptor proteins are involved. On average, the olfactory receptor responds to 30% of the odors presented, but different receptors respond to different sets of odors and correlations between the sensitivities to odors are low (average $r = \pm 0.30$), suggesting a fair degree of independence and specificity. [*See* Olfactory Information Processing.]

Human olfactory sensitivity strongly varies among odors and among individuals. Adaptation (reduction of sensitivity during stimulation) is strong and recovery after adaptation slow. Odors often suppress each other in mixtures.

B. Chemical Stimuli

The physicochemical properties determining the odor of a molecule are unknown. Volatility is a prerequisite, and water and lipid solubility, molecular shape, and functional groups are important. Enantiomers can have distinguishable odors.

C. Sensory and Cognitive Attributes

Odors warn (fire, cadavers), convey pleasure (food), and play a role in sex (perfume, body odors). Odorous quality is quite varied: many thousands of odors can be distinguished, but not verbally labeled. Odor memory is predominantly episodic. Odors have (inborn) or acquire strong affective values. Pleasant odors become unpleasant when strong.

D. Olfactory Disorders

Specific anosmia (i.e., insensitivity to one odor or a group of closely related odors in otherwise normally sensitive persons) is not exceptional. General anosmia (complete insensitivity), hyposmia (reduced sensitivity), parosmia (disturbed perception of the nature of the stimulus), and kakosmia (perceiving all odors as putrid) can be caused by head traumata, viral infections, hormone or neurotransmitter deficiencies, or obstructions in the nasal pathways. Recovery prospects depend on the nature of the cause. Parosmia can occur as a transient stage in the regrowth of olfactory receptors after destruction of the epithelium. Olfactory hallucinations are sometimes caused by brain tumors.

E. Odors in a Technical World

Industry, intensive agriculture, waste treatment, and traffic frequently cause malodors. Direct scaling methods for odor nuisance have been developed. Malodors may cause social problems, sleeplessness, and nausea.

VII. TASTE

A. Transduction

Taste is a part of complex oral sensations, to which touch, pain, and temperature may also contribute. Transductors are the taste buds in the lingual papilla or in the soft palate and epiglottis. They consist of 50–150 elongated epithelial cells with microvilli projecting outward into a "taste pore" in the epithelial layer. Taste cells on the anterior tongue are innervated by the chorda tympani (CT), those on the tongue's edges by the CT and glossopharyngeal nerve (GN), and taste buds on the back of the tongue by the GN only. The vagal nerve (VN) innervates the epiglottis. Gustatory nerve targets include the neocortex, required for associations such as the retention of learned taste aversions, and the limbic system, serving hedonic aspects. Stimulus intensity, reflected by neural response magnitude, predicts sensation strength, whereas qualities (sweet, salty, sour, bitter) are associated with four nerve fiber groups. Most stimuli activate fibers of all groups, leading to distinct across-fiber patterns. In suprathreshold mixtures, mutual suppression may occur. Weak stimuli sometimes show mixture-enhancement. With prolonged stimulation, taste declines and water may take on a different after-taste (adaptation). Recovery occurs after stimulus cessation. Cross-adaptation between different taste substances occurs mainly within and not between taste qualities. Only small regional sensitivity differences between qualities exist on the tongue. Bitterness is stronger on the back of the tongue than on the tip; however, on the tip, bitterness recognition is superior. [*See* Tongue and Taste.]

B. Taste Stimuli and Sensory Attributes

Sweet is initiated by binding to complementary proteinaceous sites. In addition to sugars, many sweeteners are known. One is the protein thaumatin, equisweet to a 3000-fold sucrose weight. Aspartame, equisweet to a 200-fold sucrose weight, is widely used in foods and drinks. Sensitivity to bitter-tasting urea is bimodally distributed in the population, suggesting a genetically controlled receptor substance. Acids taste sour. Many salts taste salty, but they often are predominantly bitter. [*See* Sweetness, Stereochemistry.]

C. Taste Disorders

Taste complaints, in most cases, can be ascribed to misperceived olfactory disturbances. Except for slow decline in the elderly, taste rarely causes complaints. The decline of taste in the elderly is not uniform across compounds, so the receptor composition on the tongue may not be uniformly altered. Localized loss or change of taste may be associated with destruction of tongue tissue, nerve damage (e.g., a tumor), or central pathology.

D. Taste Technology

Taste substances are used in many products. Often sugars are replaced by noncaloric or noncariogenic sweeteners. Low-sodium diets and low-energy drinks require carefully balanced substitutes so as to maintain their hedonic value. Industrial and consumer taste panels assist in psychophysical assessment of most foods and beverages.

VIII. SKIN SENSES

A. Transduction

The skin senses (or somatic senses) subserve the perceptions of touch, pressure, warmth, cold, pain, and also electric current. Their main purpose is to explore form and roughness of surfaces, to search for comfort with respect to temperature, to avoid painful contacts that could do harm, and to inform about movement and position of the body and the limbs. In the evolutionary process, they are probably among the oldest senses whereby animals tried to probe their environment. In two different layers of the skin, the dermis and the epidermis, a manifold of nervous structures can be discovered, which support the skin sensitivity. Their supposedly specialized functions are still a matter of debate. In the dermis, there are rather large so-called Pacinian corpuscles. They are internally shaped like an onion and are almost certainly subserving the sense of touch. Also in the dermis, fluid-filled compartments containing collagen fibrils with nerve endings are found, called Ruffini organs. In the epidermis, one finds Meissner's corpuscles, consisting of laminar cells interwoven with nerve endings, and also disc-like Merkel's corpuscles. Some of these corpuscles are believed to function in a network of touch and pressure-sensitive transducers. There is also an abundance of free nerve endings in the skin, the function of which is most difficult to establish. Somehow, their responses elicit different sensations of warmth, cold, and pain, which are very well discernible. Finally, in the hairy skin one finds hair follicle nerve end organs responding to the bending of hairs. [*See* Proprioceptors and Proprioception; Skin and Touch.]

The large number (on the order of 10^6) of nerve fibers ending in the skin layers are distributed very unevenly over the body surface. The sparse distribution on the back in contrast to the dense distribution on the fingertips, mouth, and tongue reflects the different sensitivities in these areas.

One form of perception, located deeper in the body, is kinesthesis, the sense of movement and of posture; this will not be treated here.

B. Sensitivity to Physical Stimuli

Because the sensitivity over the skin area varies considerably, only approximate indications can be given here. Sensations of the sense of touch (also often referred to as the sense of vibration) requires an amplitude of indentation of the skin of >0.1–$10\ \mu$m in the frequency range of 20–1000 Hz. A feeling of pressure can be elicited by placing weights of >10–100 mg on the skin. Warmth can be felt by temperature rises of >0.1–0.2°C over a sufficiently large area within a sufficiently short time interval. Cold sensations begin to arise at a smaller temperature drop (-0.05°C) under approximately similar conditions. Pain can be evoked under a variety of conditions: by damaging the skin mechanically, by applying an aggressive chemical to the skin surface, by exposing the skin to temperatures of >45°C, or by sending an electric current in the milliamp range through the skin.

Sensations of itch and itchy skin ("alloknesis") can be evoked by intracutaneous injection of chemicals such as histamine. For instance, a dose of 1 μg histamine applied intracutaneously produces alloknesis with a latency of about 10 sec and a duration of about 25 min.

C. Sensory Attributes

A conspicuous property of the skin senses is the fact that, except for pain, they all show a marked decrease in perceived "strength of sensation" when a stimulus remains constant over time. For instance, the pressure of a coin placed on the skin is felt for only a short time. Plunging in cold or warm water gives initially an overwhelming sensation of cold or warmth, but this sensation wears off rather quickly. The sense of vibration escapes the prevailing adaptation by the nature of its stimulus, which is a rapid change of indentation of the skin. A further important aspect of skin sensation is the fact that its magnitude increases as the stimulus area is enlarged up to an upper bound. This is called the summation area. The summation area of touch, pressure, pain, cold, and warmth gets larger in this order. The summation area is also approximately inversely related to the density of nerve fibers and is therefore smallest for the tongue and the fingertips. Finally, the summation area is related to the so-called two-point threshold, which is the minimum distance of two point-like stimuli that are just perceived separately.

D. Cognitive Attributes

In exploring the environment, touch among the skin senses is dominant. It is amazing how many different textures of solid surfaces can be recognized. Even the nature of fluids may be felt by moving the hand in the fluid.

The touch sense also can have an important signaling function in interpersonal relationships as the way of touching one another can have an emotional content. The senses of warmth and cold do not seem to carry more specific conscious information than is related to comfort. The alarm function of the sense of pain is evident; many fast retraction reflexes depend on this sense. Intractable pain causes patients suffering from this pathological condition to experience an unbearable pain in the skin (often in the face) for which no adequate external reason can be found.

E. Technical Use of the Skin Senses

Of the human's sensory systems, the skin senses play a restricted role in communication. It is not until the visual or the auditive sense is impaired or overloaded that the tactile sense is called upon for extra communication. In the past, many ingenious devices employing the sense of touch have been put to use for the visually handicapped. The temperature senses are not commonly thought of as useful for communication purposes owing to their relatively slower response, their poorer localizability, and their fast adaptation. Attempts have been made to enlarge the information capacity of the human operator by recruiting the skin senses in a so-called "skin vision" system, whereby information from the outside world is "projected" onto the skin. The interpretation of such "projections" will have to be learned. Up until the present, only blind people have been applying such projection systems with limited success.

IX. PERCEPTUAL SELECTION

A. Reduction of Complex Data

A drastic reduction occurs in the amount of perceptual data impinging on the observer. This occurs through body, head, and eye movements and through sensory and cognitively controlled selective processes.

B. Object and Subject Factors

We classify the factors that control the selective processes into object and subject factors. The object factors are of external origin and relate to properties of the stimuli (conspicuity). The subject factors are of internal cognitive origin and derive from the subject's motives, desires, and expectations (directed attention). The two factors are also named involuntary and voluntary determinants of selective attention, respectively.

Voluntary selection may be precategorical (i.e., directed at expected stimulus location) or postcategorical (i.e., depending on stimulus recognition). Benefit primarily exists in the neglect of nonattended stimuli. Also, some direct benefit of selective attention can be demonstrated. An example of precategorical voluntary attention is the neglect of messages to one ear when the two ears receive different speech messages. The "cocktail party effect" is related in fact to both precategorical selection (sound direction) and postcategorical selection (speech content). Visually, only certain attributes can be effectively selected among other attributes present. Selection also occurs among signals coming simultaneously from different senses. So pain may be sometimes reduced by shifting attention toward other perceptual information.

Figure 3a demonstrates how the conspicuity of a target (center) depends on differences with neighboring distractors. Figure 3b indicates that a high conspicuity corresponds to a large visual field in which the stimulus will be detected. Selection develops with aging in a subtle way.

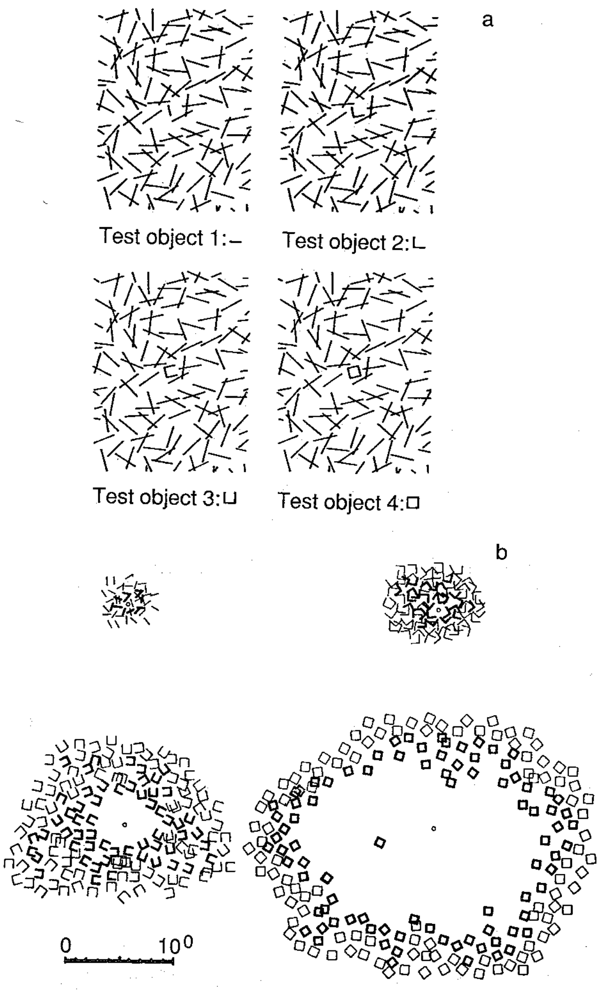

FIGURE 3 (a) Differential conspicuity as a result of target–background differences for test objects 1–4. In each case, the target object is in the center. (b) Areas around the fixation point in which targets 1–4 can be detected in a single glance in the same background as in (a). Target objects in bold were detected; the others were not discovered.

C. Selection in a Technical World

Research on auditory attention was initiated in the early 1950s through a need to understand the performance difficulties faced by air traffic controllers and pilots who were required to respond quickly and accurately to a range of visual and auditory inputs. However, how to catch and hold attention is also a very practical problem for the advertiser, the road sign designer, the newspaper make-up editor, and, nowadays, the designer of multimodal human–computer interfaces.

X. DEVELOPMENT OF PERCEPTUAL FUNCTIONS

When during a person's lifetime unchanged stimuli gradually give rise to different sensations and cognitive percepts, we speak of perceptual development. Changes in perception are brought about by maturation, sensory development, perceptual learning, and physiological changes, which ultimately may also lead to deterioration of perceptual functions.

A. Infancy

In infants, the components of the visual system mature in the order in which visual information is processed. With the retina maturing first and the cortex last, elementary stimulus variables can be handled better than complex patterns in infancy. A corollary of this is that during the first 2 months, both foveas are not consistently aligned for binocular fixation. A sensory limit on blur detection amounts to ±1.4 diopters, while convergence may vary in a 3° range in 1-month-old infants. Stereoacuity develops rapidly from 3 months of age onward, and near space perception after 4–5 months is similar to that of adults, but visual space seems to be confined to some 1.5 m.

Although newborns might be color-deficient, as the lateral geniculate nucleus and the prestriate cortex are not yet mature then, no evidence indicates this. At 4 months, infants can perceive hues and do so categorically, in much the same fashion as normal trichromatic adults. By then, myelinization of the optic radiations is complete.

Visual acuity is moderate at birth; at <1 month of age, resolution is just <1°, but at 2 months, acuity is good for distances at least between 30 cm and 1.5 m. At 6 months, acuity is about 5 min of arc, and at 1 year it is comparable with that of adults (at least 1 min of arc). Shape perception shows a gradual development too. At 1 month, infants prefer to look at a face-like pattern rather than a plain geometrical one, but they scan details only at 2 months. Whether or not infants up to 6 months of age have the same kind of size and shape constancy as adults is unknown; stimulus invariance seems to involve much perceptual learning and not to be a direct consequence of maturation.

Hearing, coupled with localization, can be shown to exist at birth but is more sensitive to complex sounds than to pure tones. Recognition of the mother's voice may happen early but is probably fully evolved at 1 or 2 months. Ample evidence indicates that 1- to 4-month-olds can easily distinguish between many different speech sounds and categorize them.

One-year-old infants can recognize objects by touch alone, but little is known about earlier touch perception, which is strongly linked to unconditioned reflexes.

A surprising ability, present at 3 weeks, is to imitate adults' facial gestures. Full control of facial gestures also provides evidence of the ability to recognize smells (6 weeks) or tastes. Apparently, preference for sweets is not learned or modified by experience.

B. Childhood

Although young children can distinguish detailed visual features quite well, at 5 years of age they are still unable to grasp fully the relation between the whole and the parts. Only well after 10 years of age are they able to complete an embedded figure test at adult speed. They are also less sensitive to figure orientation. Size constancy is much better than that of infants but is restricted largely to distances of 3 m. When growing up, children are increasingly better able to confine their attention to specific information-bearing parts of the stimulus pattern as a whole and use their attention strategically for perceptual tasks.

C. Learning

The simplest kinds of learning consist of habituation and sensitization. Habituation occurs when repeated presentations of a stimulus evoke increasingly lower sensation levels. Sensitization, on the contrary, increases sensation level after sufficient stimulus repetition but, in general, requires cognitive effort. Both concepts are to be distinguished from adaptation, which may encompass both effects. Adaptation is operative in a short time range (minutes or less), and its effects are completely reversible. Habituation and sensitization, however, have enduring effects, up to weeks or months or even longer, and may not be reversible at all. Practice is a common means to induce sensitization and is effective in a large range of psychophysical tasks. [*See* Learning and Memory.]

The human perceptual world derives a great deal from extensive experience with the objective physical environment (e.g., resulting in the perception of the world as upright). Perceptual learning is said to occur when basic stimulus features are interpreted on a higher abstract level to represent a different unit. This procedure may be repeated many times, whereby the stimulus is residing over a hierarchy of ever more detailed subordinate feature categories. Thus, abstraction becomes a means for perceptual efficiency when dealing with masses of environmental stimulation. Conversely, attention is increasingly employed to select wanted information and to cancel or suppress irrelevant perceptual information. Reading is a good example of cumulative and abstract perceptual learning; from visual features to characters, symbols or words, phrases, sentences, and thematic and semantic units. The ability to recognize words routinely takes years of practice; at 10 years of age, normal readers are some 150 msec slower than adults to name shortly presented words and about 10% less accurate. Text redundancy (e.g., residing at the orthographic, lexical, and syntactic level) can be employed only after extensive practice; both sensitization and perceptual learning, as well as selective attention, must take place.

Most stimulus patterns, for reasons of efficiency, tend to be perceived as instances of categories; the latter are obtained by continuous exposure and learning and depend heavily on human perceptual experience. Perceptual categories form the framework of the recognition process.

D. Physiological Changes

One of the best-documented cases of physiological change is that of decreased accommodation range of the eye, known as presbyopia. Due to continuous growth of fibrous tissue within the lens capsule, it becomes less elastic and transparent. Whereas the accommodation range at 8 years of age may span up to 19 diopters, it decreases almost linearly until the age of 50 years, after which it stabilizes at a range of 1 diopter on average. The presence of fibers and particles within the lens and the eyeball fluid will scatter incoming light and cause glare, resulting in reduced subjective contrast and acuity. Yellowing of the lens causes a slight reduction of sensitivity to green, blue, and violet for older people. In addition, they have more difficulty in ignoring irrelevant visual stimulation, thus needing more time to process information.

A common aging form in hearing is presbyacusis, involving a progressive hearing loss for high frequencies. This goes together with a decrease in speech intelligibility from the 30th year onward.

During a person's lifetime, changes occur in the anatomical structure, the neural pathways, and physiological functioning of all sensory systems; in general, this implies reduced sensitivity and performance levels. In many cases, however, sensory sensitivity of older people is hardly or not at all impaired compared with that of younger people, the elderly generally employ a stricter criterion for perception and recognition, which means their sensitivity only seems affected, but it is actually equally effective. This appears also to be the case for touch sensitivity and pain. Little is known about age-related changes in taste and smell.

BIBLIOGRAPHY

Aslin, R. N., Alberts, J. R., and Peterson, M. R. (eds.) (1981). "Development of Perception," Vol. 2. Academic Press, New York.

Bartoshuk, L. M. (1988). Taste. *In* "Stevens' Handbook of Experimental Psychology" (R. C. Atkinson, R. J. Herrnstein, and G. Lindzey, eds.), 2nd Ed., Vol. 1, Chap. 9, "Perception and Motivation" (R. D. Luce), pp. 461–499. John Wiley & Sons, New York.

Boff, K. R., Kaufman, L., and Thomas, J. P. (1986). "Handbook of Perception and Human Performance." John Wiley & Sons, New York.

Borden, G. J., Harris, K. S., and Raphael L. J. (1994). "Speech Science Primer; Physiology; Acoustics and Perception of Speech," 3rd Ed. Williams & Wilkins, Baltimore.

Charness, N. (ed.) (1985). "Aging and Human Performance." John Wiley & Sons, Chichester, England.

Singer, H., and Ruddell, R. B. (eds.) (1985). "Theoretical Models and Processes of Reading," 3rd Ed. Lawrence Erlbaum Associates, International Reading Association, Newark, Delaware.

Thomas, E. F., and Silver, W. L. (eds.) (1987). "Neurobiology of Taste and Smell." John Wiley & Sons, New York.

Tinker, M. A. (1964). "Legibility of Print." Iowa State Univ. Press, Ames.