Table 10.1 Main types of sensory modalities

| Sensory modality	Form of energy	Receptor organ	Receptor cell
Chemical			
common chemical	molecules	various	free nerve endings
arterial oxygen	O_2 tension	carotid body	cells and nerve endings
toxins (vomiting)	molecules	medulla	chemoreceptor cells
osmotic pressure	osmotic pressure	hypothalamus	osmoreceptors
glucose	glucose	hypothalamus	glucoreceptors
pH (cerebrospinal fluid)	ions	medulla	ventricle cells
Taste	ions and molecules	tongue and pharynx	taste bud cells
Smell	molecules	nose	olfactory receptors
Somatosensory			
touch	mechanical	skin	nerve terminals
pressure	mechanical	skin and deep tissue	encapsulated nerve endings
heat and cold	temperature	skin, hypothalamus	nerve terminals and central neurons
pain	various	skin and various organs	nerve terminals
Muscle			
vascular pressure	mechanical	blood vessels	nerve terminals
muscle stretch	mechanical	muscle spindle	nerve terminals
muscle tension	mechanical	tendon organs	nerve terminals
joint position	mechanical	joint capsule and ligaments	nerve terminals
Balance			
linear acceleration (gravity)	mechanical	vestibular organ	hair cells
angular acceleration	mechanical	vestibular organ	hair cells
Hearing	mechanical	inner ear (cochlea)	hair cells
Vision	electromagnetic (photons)	eye (retina)	photoreceptors

Modified from Ganong (1985)
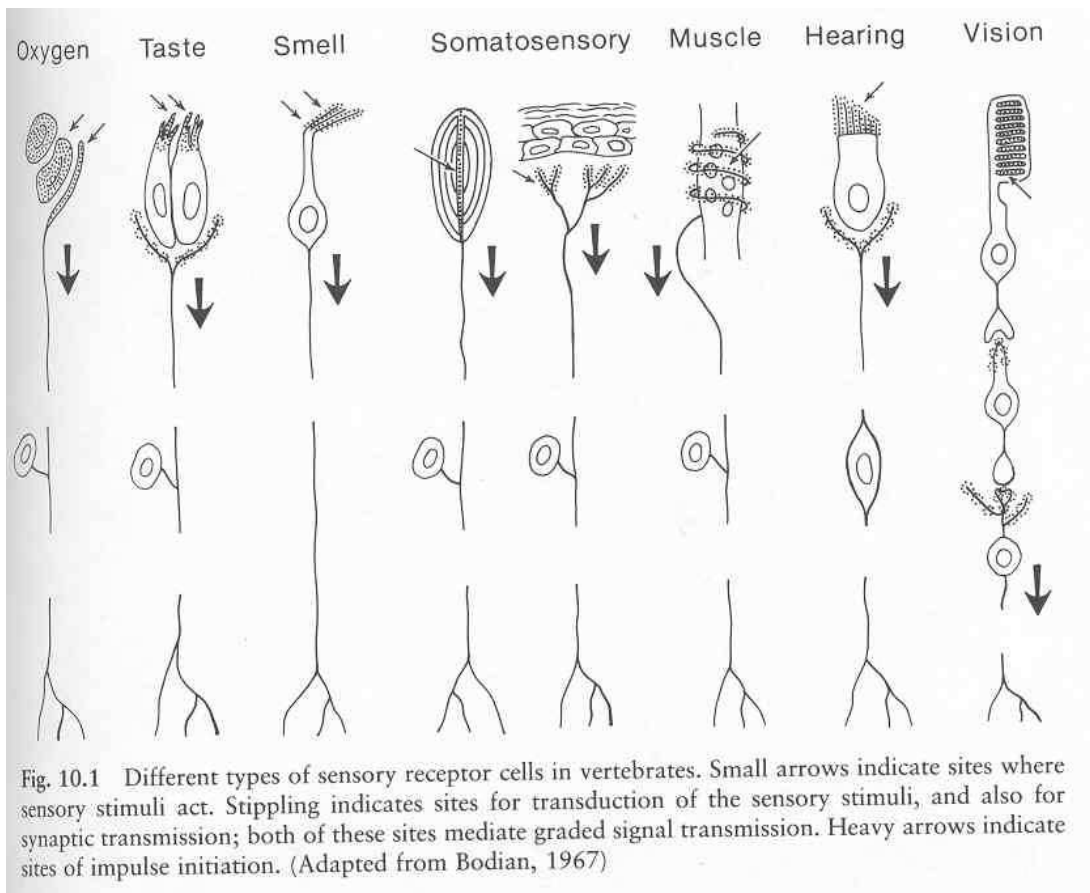
Fig. 10.1 Different types of sensory receptor cells in vertebrates. Small arrows indicate sites where sensory stimuli act. Stippling indicates sites for transduction of the sensory stimuli, and also for synaptic transmission; both of these sites mediate graded signal transmission. Heavy arrows indicate sites of impulse initiation. (Adapted from Bodian, 1967)

Table 10.2 Steps in sensory transduction

Transduction step	Vision	Olfaction	Taste Sweet/bitter amino acids	Salt/sour	Mechanoreception (hair cells)
Energy	Photons	Molecules	Molecules	Na^+, H^+	Displacement
Membrane receptor	7TD family: rhodopsin	7TD family: olfactory	7TD family: gustatory		
G protein	Transducin	G_{olf}	G_{gust}		
G-protein target	Phosphodiesterase	Adenylate cyclase III; phospholipase C	AC; PLC		
Second messenger	cGMP	cAMP; IP_3	cAMP; IP_3		
Protein kinase			Protein kinase Â?		
Membrane channel	Cationic; inward	Cationic; inward Anionic; inward	K^+	Na^+; K^+	Cationic; inward
Sensory response	Close channel	Open channel	Close channel	Open; close	Open channel
Adaptation mechanism	Ca^{2+}; phosphorylation?; arrestin	Ca^{2+}; protein kinases ?	?	?	Myosin/actin motor; Ca^{2+}?
Cell body output	Synapses	Impulses	Synapses	Synapses	Synapses

7TD family: 7 transmembrane domain receptor family.
From Shepherd (1991b)

Table 10.3 Common operations in sensory transduction

Transduction operations	Operations in single sensory cells	Operations in cell populations
Detection	Perireceptor mechanisms: filters: carriers: tuning; inactivation Sensitivity Rapidity	Perireceptor mechanisms: filters; carriers; tuning; inactivation Different thresholds
Amplification	Positive feedback Active processes Signal/noise enhancement	Positive feedback Signal/noise enhancement
Encoding/ discrimination	Intensity coding Quality coding Temporal differentiation	Different dynamic ranges Quality independent of intensity Center–surround antagonisms Opponent mechanisms Construction of maps
Adaptation and termination	Desensitization Negative feedback Temporal discrimination Repetitive responses	Temporal discrimination
Sensory channel gating	Open or close conductance gating	
Electrical response	Depolarization or hyperpolarization	
Transmission to brain	Electrotonic spread Active properties Synaptic output or impulse discharges	Spatial patterns: maps and image formation Temporal patterns: directional selectivity, etc.

From Shepherd (1991b)
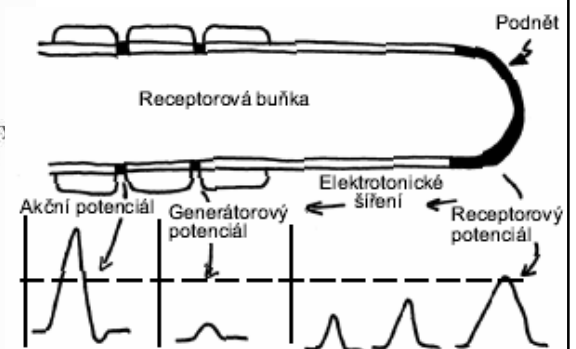
Obr. 4.13. Vstup informace do nervového systému (NS). Na podnět reaguje specializovaná receptorová membrána změnou iontové propustnosti a vzniká receptorový potenciál. Ten se pasivně šíří a překočí-li depolarizace (generátorový potenciál) prahovou hodnotu, vzniká na axonu akční potenciál. Ten pokračuje do NS.
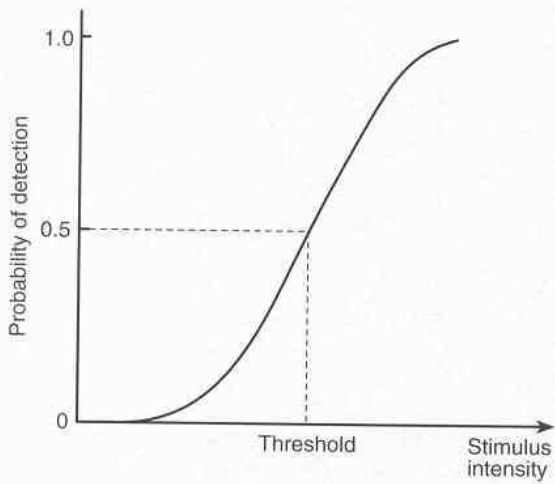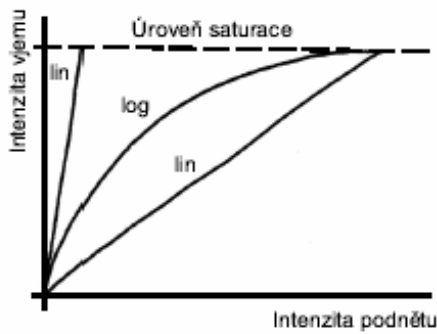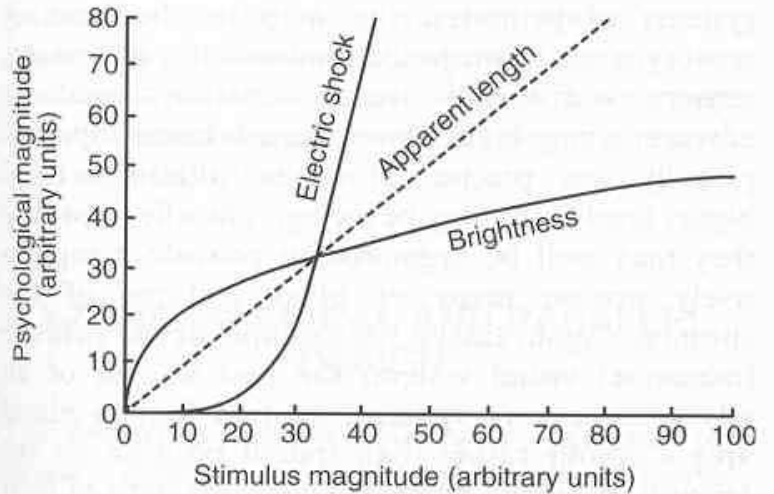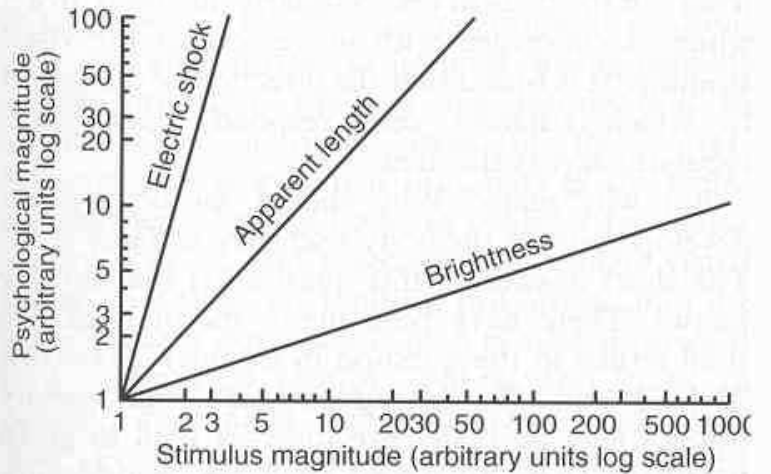
Figure 3.1 Psychometric curve. The threshold is defined as the intensity when half the responses are correct. The position of the curve on the ordinate is arbitrary. It will shift to the right or left according to circumstances


A

B

Figure 3.2 Psychophysical correlations. (a) When subjective magnitude is graphed against stimulus magnitude on linear coordinates the lines are frequently curved upwards or downwards. (b) When graphed against log–log coordinates straight lines are obtained whose gradients depend on the value of the exponent, 'n'. From Stevens, 1961

Obr. 4.15. Intenzita vjemu roste s intenzitou podnětu logaritmicky – ne lineárně. Tento kompromis mezi rozlišovací schopnosti a saturačním prahem (nasycením) receptorů umožňuje zachovat odstupňovanou reakci na velmi široký rozsah intenzit současně s velkou citlivostí pro slabé podněty.
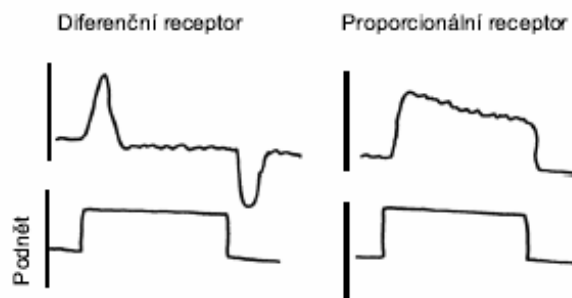
Obr. 4.16. Rozdíl v adaptaci D- (diferenčních) a P- (proporcionálních) receptorů. D-receptory reagují jen na časovou změnu podnětu. Odpověď P-receptorů trvá po celou dobu působení podnětu.
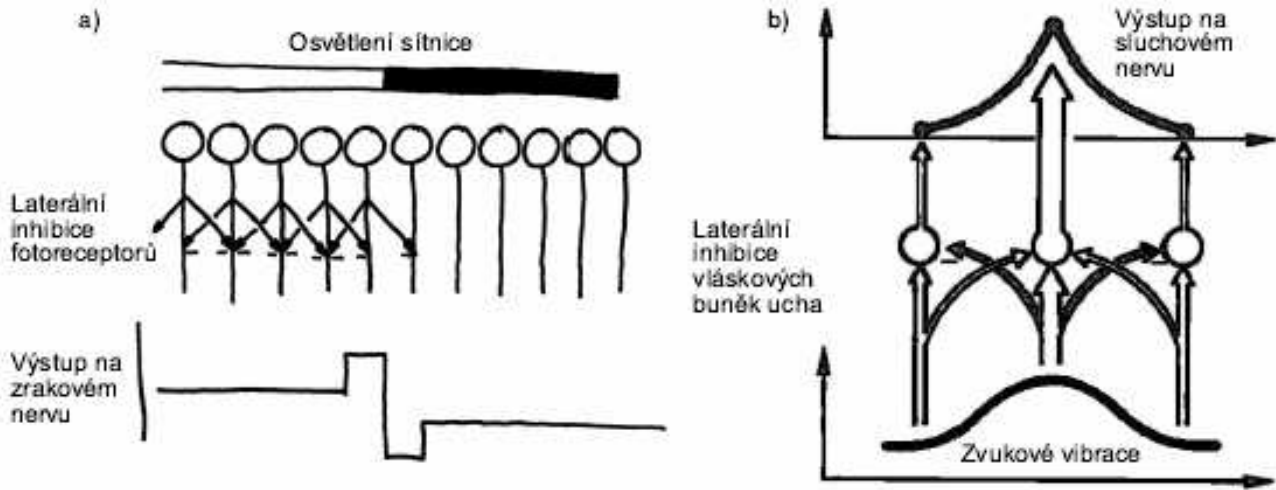
Obr. 4.17. Význam laterální inhibice při zpracování smyslových vstupů. a) Kontrastní přechod mezi osvětlenou a neosvětlenou sítnici je ještě více zvýrazněn. b) Místo sluchového aparátu (hlemýždě), kde jsou zvukové vibrace maximální, je zvýrazněno proti méně vibrujícimu okolí – kontrast je ještě ostřejší.

A. RETINA B. OLFACTORY BULB
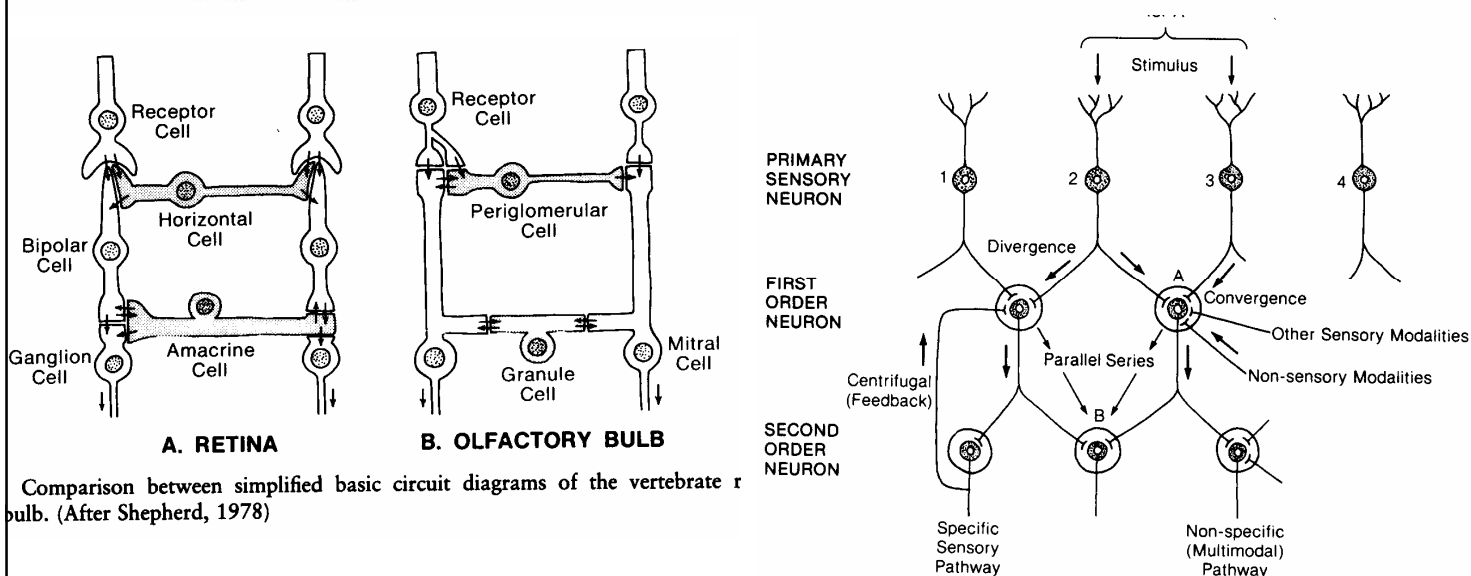
Comparison between simplified basic circuit diagrams of the vertebrate r
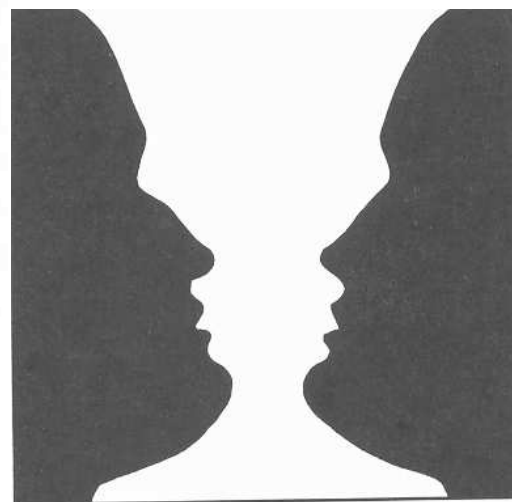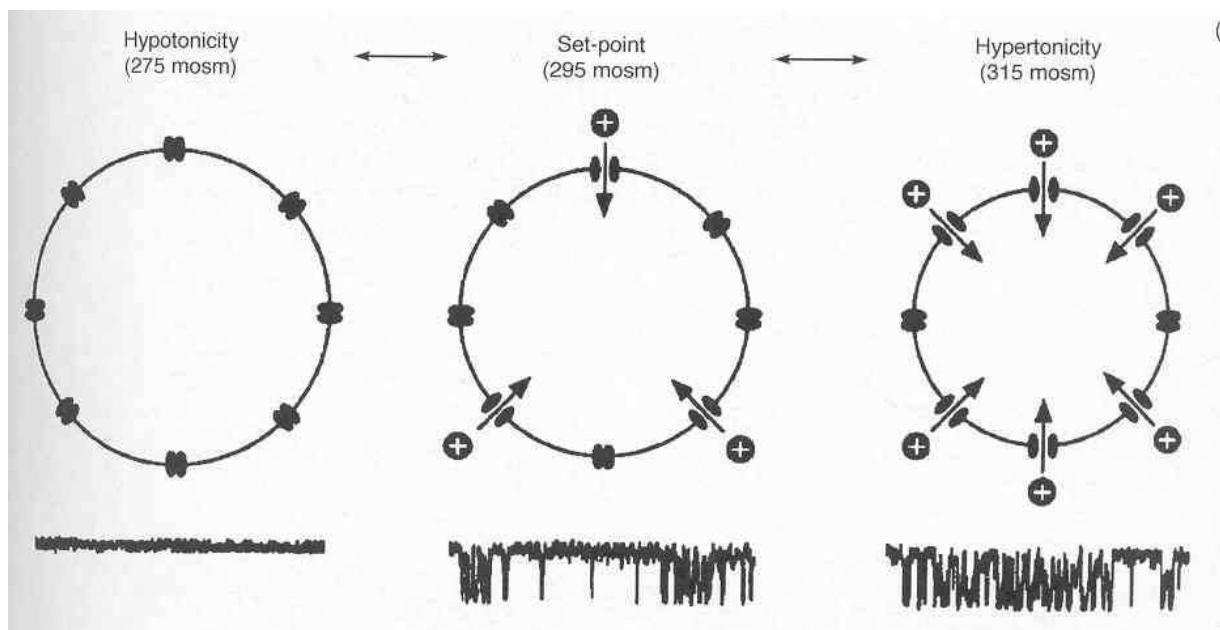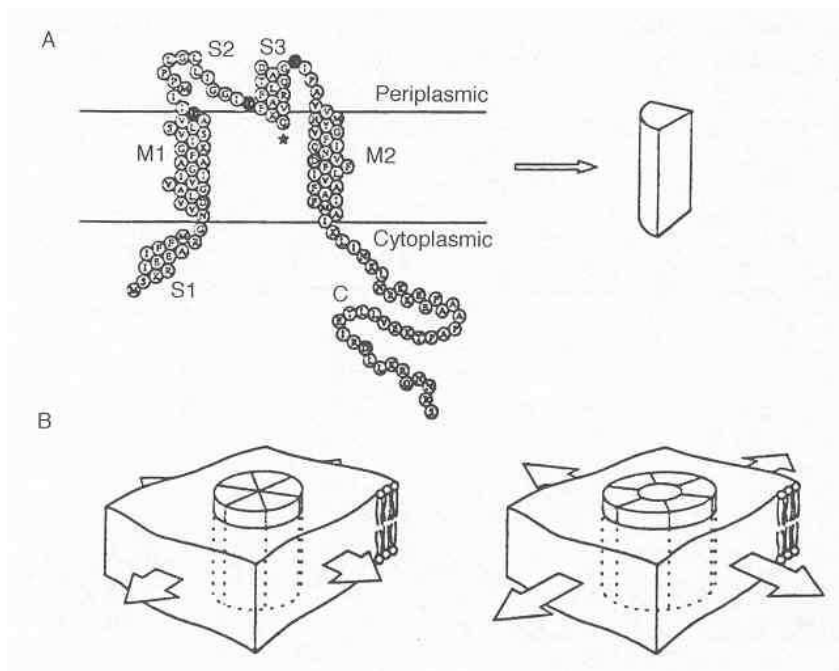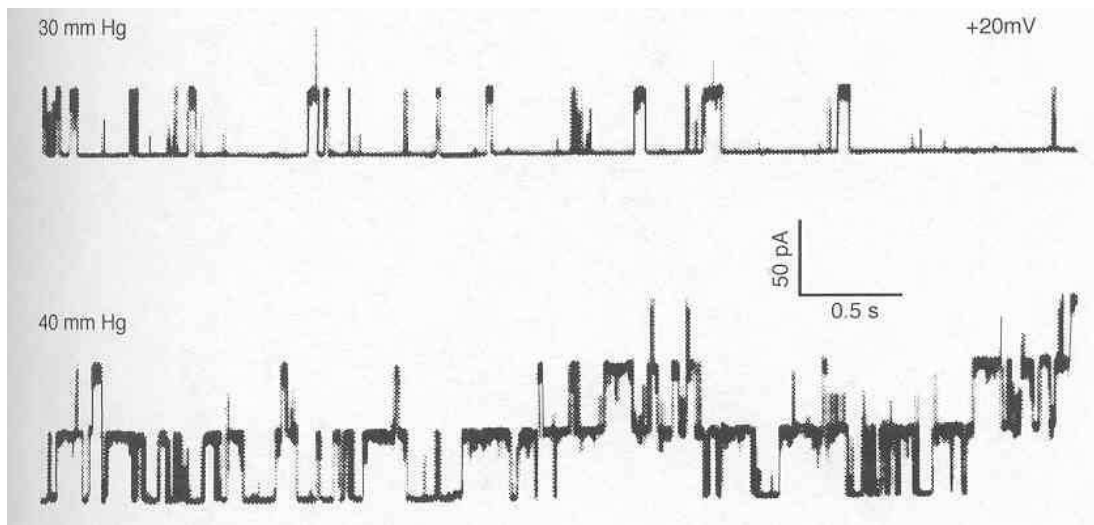bulb. (After Shepherd, 1978)
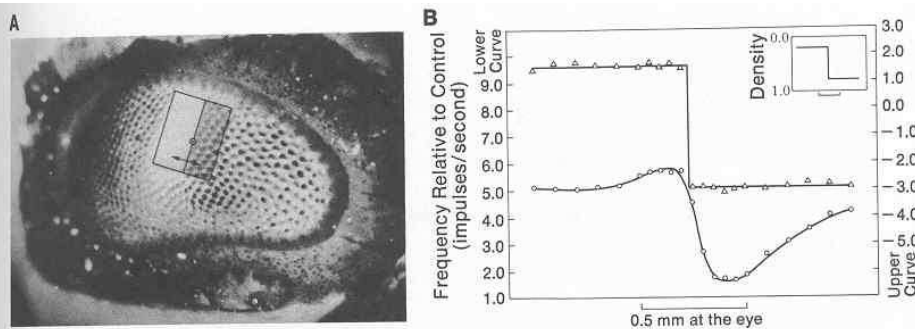
Fig. 10.6 Enhancement of spatial contrast in *Limulus* eye. A. Surface of *Limulus* eye, with superimposed rectangular stimulus pattern; pattern is divided into lighter (left) and darker (right) regions. Pattern is centered on test ommatidium (×). Arrows show directions in which the test pattern was displaced, to produce lower curve in graph in B. B. Recordings of spike frequency in axon from test ommatidium in A. *Lower curve:* responses to rectangular test pattern in A. *Upper curve:* responses to small spot of light, at high and low intensities corresponding to those of test pattern (see insert). The differences between the two curves illustrate that lateral inhibition enhances the response on the light side of an edge (because there is less inhibition from the more darkly lit neighbors to the right) and depresses the response on the dark side of an edge (because there is more inhibition from the brightly lit neighbors to the left). (From Ratliff, 1965)

Mechanorecepce

30 mm Hg   +20mV

50 pA
0.5 s

40 mm Hg

A

S2   S3
Periplasmic
M1   M2
Cytoplasmic
S1   C

B

Hypotonicity   Set-point   Hypertonicity
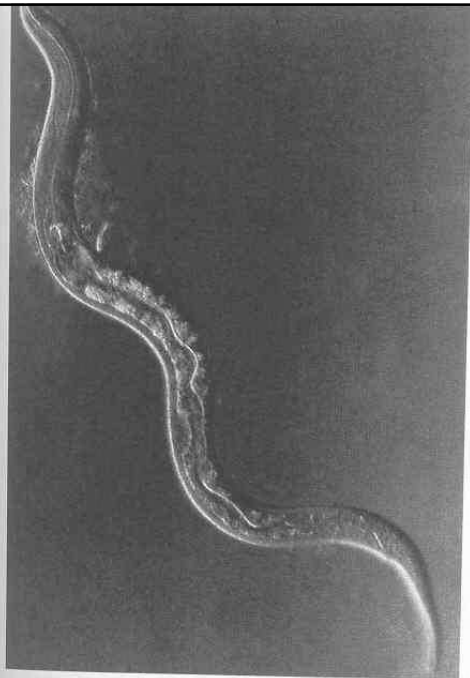(275 mosm)   (295 mosm)   (315 mosm)

Figure 7.1 *Caenorhabditis elegans*. This worm is about 200 mm in length. *C. elegans* consists of 959 somatic cells of which 302 constitute the nervous system. The body is translucent and many of its cells can be distinguished in the living animal. Reprinted from J. G. White, 1985, 'Neuronal connectivity in Caenorhabditis elegans', *Trends in Neurosciences* 8, 277 with permission from Elsevier Science
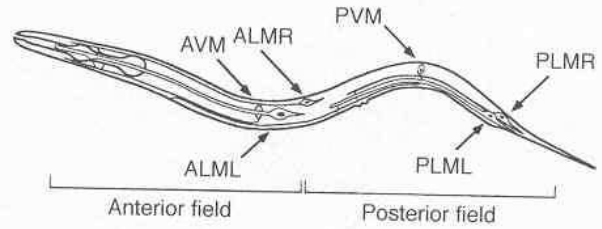

Figure 7.2 *C. elegans* touch receptor neurons. Note that there are two fields of touch sensitivity determined by the disposition of the neurons in the nematode's body. ALML = anterior lateral microtubule cell left; ALMR = anterior lateral microtubule cell right; PLML = posterior lateral microtubule cell left; PLMR = posterior lateral microtubule cell right; AVM = anterior ventral microtubule cell. From Tavernarakis and Driscoll, 1997, *Annual Review of Physiology*, **59**, 662. With permission, from the *Annual Review of Physiology*, Volume 59, ©1997, by Annual Reviews www.annualreviews.org
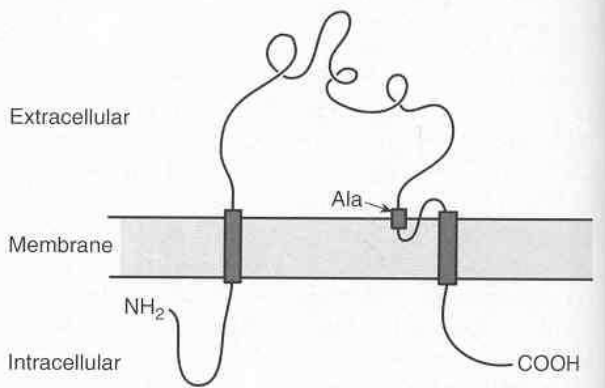

Figure 7.4 Transmembrane topology of the MEC-4 protein. There are two transmembrane domains and a small membrane insertion just before the second transmembrane helix. The bulk of the 768 residue protein is, as indicated, in the extracellular space. When Alanine$_{713}$ (Ala) is replaced by a bulkier amino acid cell death ensues. After Tavernarakis and Driscoll, 1997
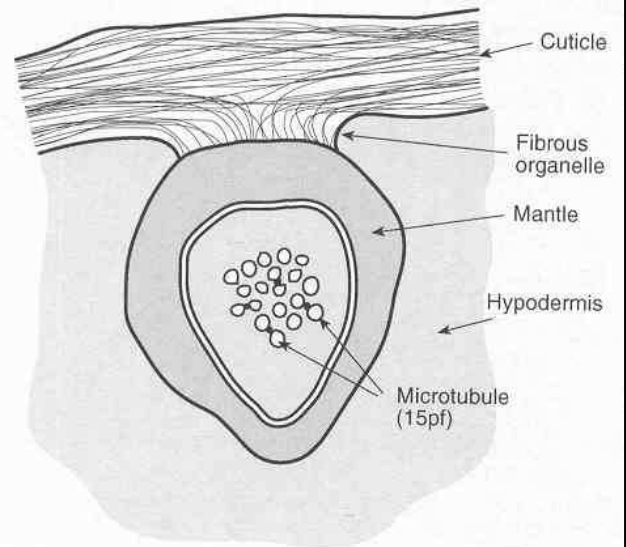

Figure 7.3 Ultrastructure of *C. elegans* touch receptor neuron in transverse section. The neuron is surrounded by a connective tissue mantle and is attached to the cuticle by a 'fibrous organelle'. It contains a bundle of microtubles (each composed of 15 protofilaments (pf)). After Tavernarakis and Driscoll, 1997
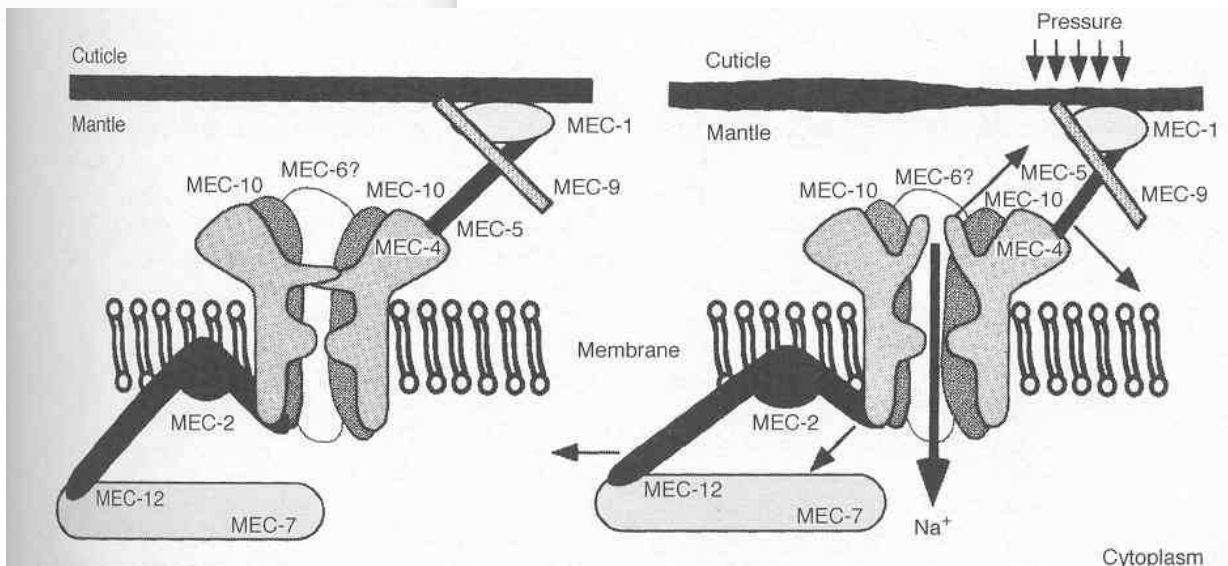

Figure 7.6 Conceptual model of *C. elegans* touch receptor. Explanation and nomenclature in text. From N. Tavernarakis and M. Driscoll, 1997, 'Molecular modelling of mechanotransduction in the nematode *Caenorhabditis elegans*', *Annual Review of Physiology*, **59**, 679. With permission, from the *Annual Review of Physiology*, Volume 59, ©1997, by Annual Reviews www.annualreviews.org
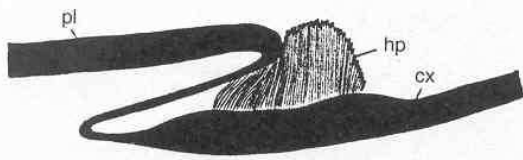
Figure 6.3 (a) The figure shows the brushwork of sensilla at the articulation of the second leg of the cockroach, *Periplaneta americana*. The thick cuticle of the pleuron (pl) thins to a delicate articular membrane and then thickens again to form the cuticle surrounding the coxa (cx), the first segment of the leg. The brush of sensilla forms a hairplate (hp). From Pringle, 1938

Figure 3 *Drosophila* bristle-receptor model. **a**, Lateral view of *D. melanogaster* showing the hundreds of bristles that cover the fly's cuticle. The expanded view of a single bristle indicates the locations of the stereotypical set of cells and structures associated with each mechanosensory organ. Movement of the bristle towards the cuticle of the fly (arrow) displaces the dendrite and elicits an excitatory response in the mechanosensory neuron. **b**, Transmission electron micrograph of an insect mechanosensory bristle showing the insertion of the dendrite at the base of the bristle. The bristle contacts the dendrite (arrowhead) so that movement of the shaft of the bristle will be detected by the neuron. **c**, Proposed molecular model of transduction for ciliated insect mechanoreceptors, with the locations of NompC and NompA indicated.
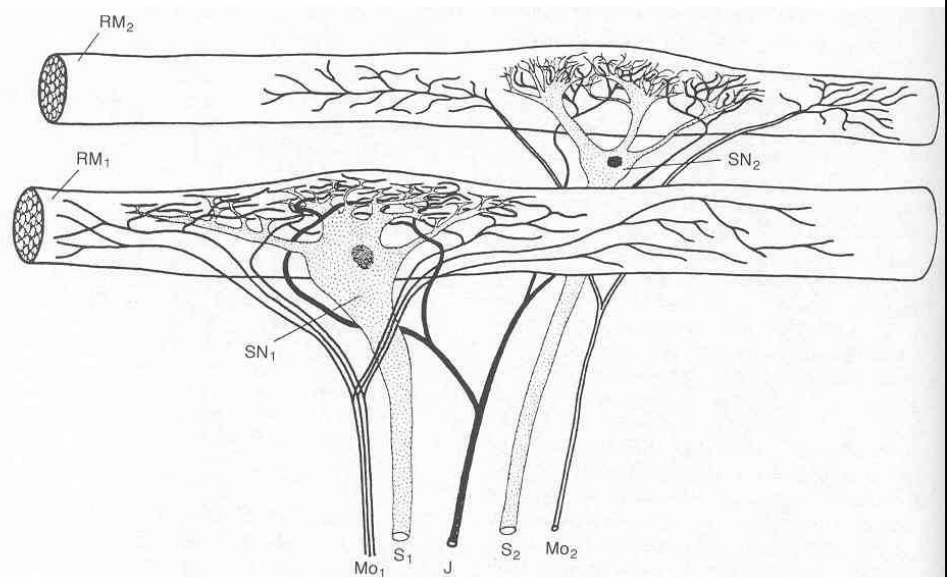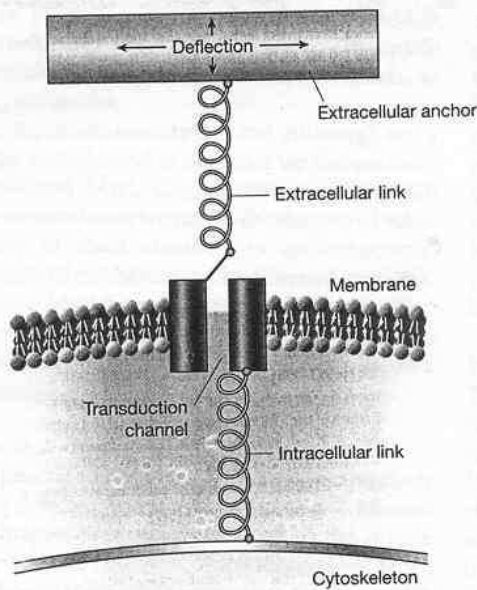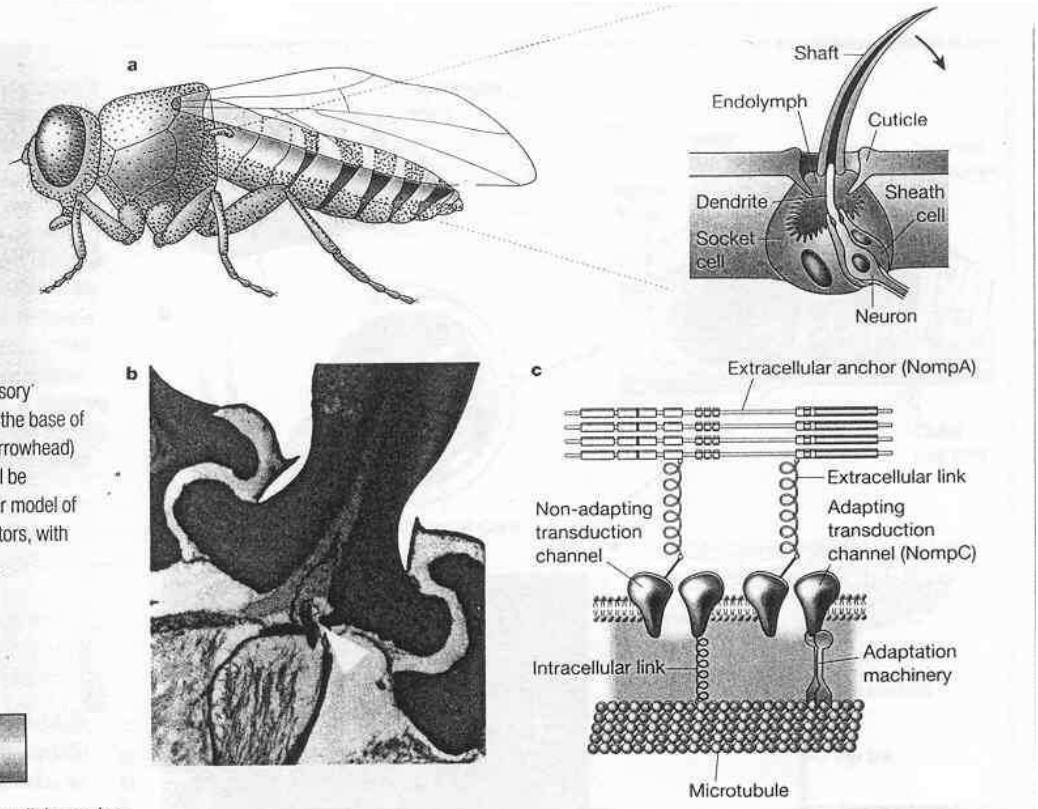

Figure 6.1 Schematic drawing of the stretch receptors in the abdominal segments of the crayfish, *Astacus fluviatilis*. RM1, RM2 = receptor muscles 1 and 2. SN1 = slow adapting sensory neuron; SN = fast adapting sensory neuron; S1, S2 = sensory fibres; Mo1 = three thin motor fibres to RM1; Mo2 = thick motor fibre to RM2; J = inhibitory fibre. From *Handbook of Physiology*, Section 1, Volume 1, *Neurophysiology* (1959), p. 378. Reproduced by permission of The American Physiological Society
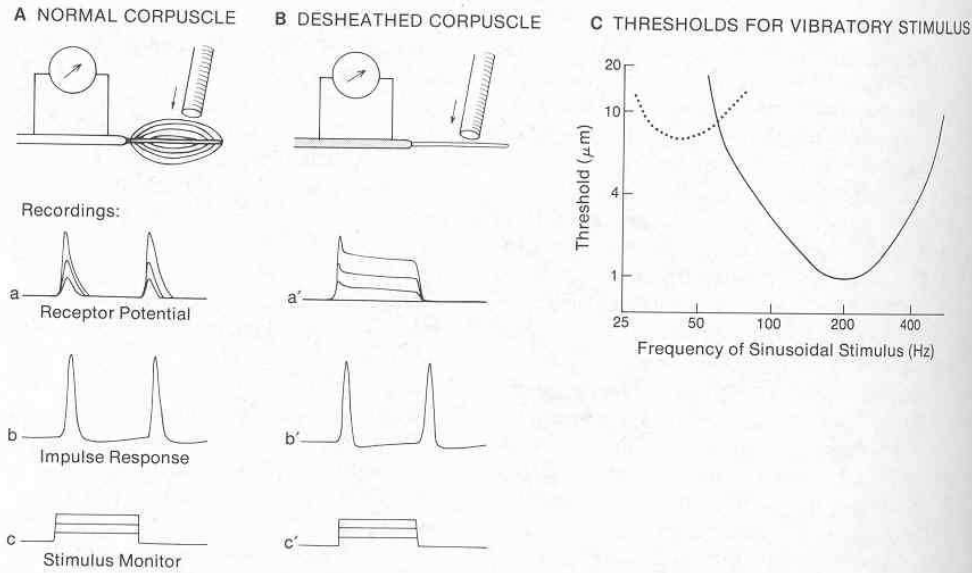
A NORMAL CORPUSCLE   **B** DESHEATHED CORPUSCLE   **C** THRESHOLDS FOR VIBRATORY STIMULUS

Recordings:

a   Receptor Potential   a′

b   Impulse Response   b′

c   Stimulus Monitor   c′

Fig. 12.5 Experimental analysis of transduction in the Pacinian corpuscle. **A.** Diagram showing probe for stimulating the intact corpuscle, and recording from the nerve. *(Below)* recordings of the receptor potential and impulse discharge. **B.** Repeat of experiment after removal of lamellae. **C.** Sensitivity of Pacinian corpuscle to vibratory stimulation at different frequencies. Sensitivity of Meissner's corpuscle is shown by dotted line. (A, B based on Loewenstein, 1971; C modified from Schmidt, 1978)
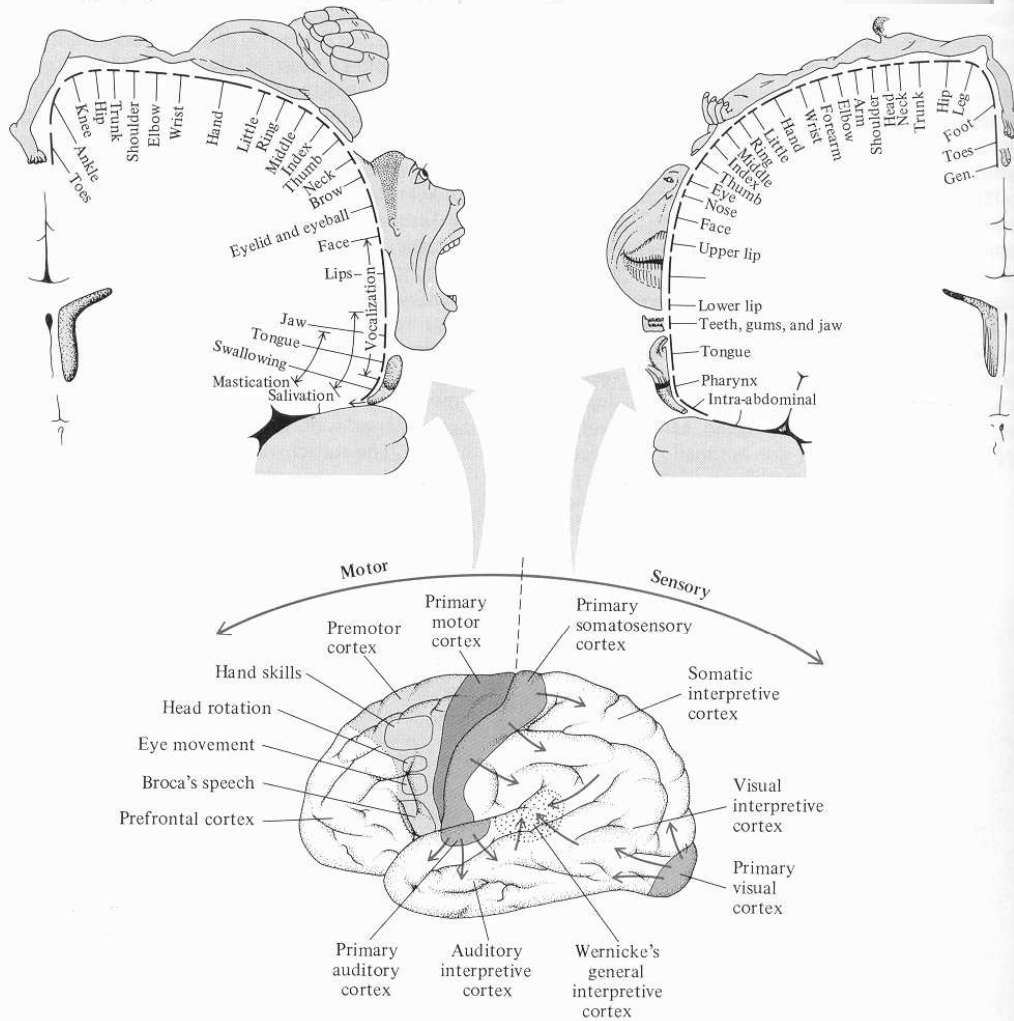
FIGURE 8–30 The human cerebral cortex is organized into areas with specific functions. The primary sensory areas include somatic sensation (e.g., tactile information), vision, and audition. The somatosensory cortex receives sensory information that is organized on the cortex as a map, or homunculus. The primary sensory areas relay information to their respective sensory interpretive areas, then to a general sensory interpretive area (Wernicke's cortex). Much of the motor output of the cortex is from the primary motor cortex, which has a highly organized map. The primary motor cortex receives information from the premotor cortex and other parts of the brain. The premotor cortex has specific areas for control of functions such as speech (Broca's area), eye movement, head rotation, and hand skills. It receives information from the sensory associative areas as well as other areas of the brain. The prefrontal cortex has more diffuse effects, affecting "depth of feeling" and "elaboration of thought."