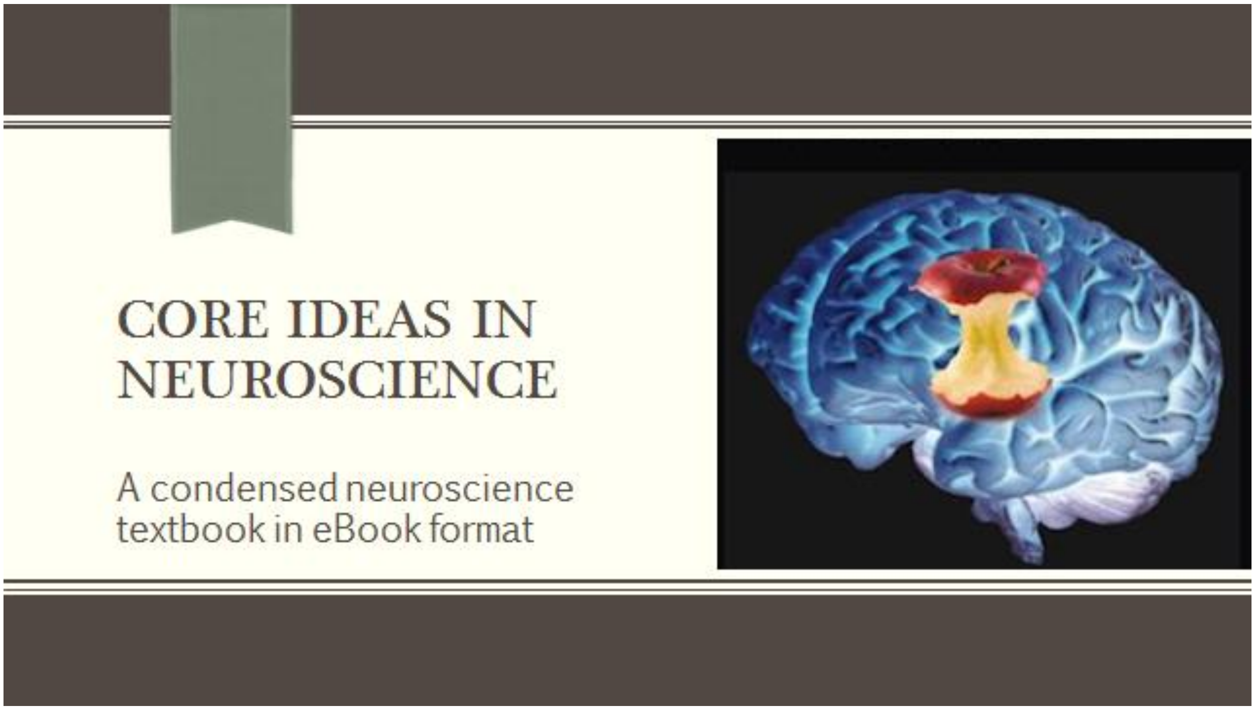

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Free sample modules:

Topographical Mapping   Readiness Response

Topographical Mapping

Core Idea

> Major sensory and motor systems are topographically mapped. That is, the body, both inside and out, is mapped by the nervous system. Major sensory systems map the external world within their own circuitry. Likewise, the nervous system contains a mapped control over the muscles of the body. Mapped regions may have different inputs or outputs or may share the same ones. Maps are interconnected so that projections from one map to another trigger a back projection to the first map. Mapping can persist at all levels in a given pathway.

Terms

Basal ganglia: several clusters of neurons beneath the cerebral cortex that collectively modulate and help to coordinate body movements, as well as having other, non-motor functions.

Body (spinal) segment: the body can be mapped according to the neuronal pathways to and from specific zones of the spinal cord. For example, both sensory and motor pathways of certain muscles reside in specific regions of the spinal cord.

Hippocampus: a phylogenetically old kind of cortex, folded in under the neocortex, that is especially involved in emotional behavior and in memory formation.
Hypothalamus: a small zone on the ventral surface of the brain. This area contains several distinct clusters of neurons that are important for regulating visceral and hormonal functions.

Mapping: maps are neuronal representations (sometimes highly abstracted) of the real world. A map is a point-to-point representation of the real-world environment in which an animal lives.

Thalamus: a group of many neuronal clusters along the midline of the brain, lying just in front of the brainstem and underneath the cerebral cortex. These clusters generally are topographically segregated for various sensations from specific parts of the body.

Topographical: a spatial representation of information in the environment (can include internal environment of the body) is projected onto neuronal circuitry. The representation of the environment cannot be “graphed” in the usual sense of the word, but can be revealed and studied by various physiological measures such as electrical recordings from various regions within the mapped areas.

Explanation

The body, both inside and out, is mapped by the nervous system in terms of specific body parts and where they are located. Major sensory systems, such as vision and hearing, map the external world within their own circuitry. Locations in a three-dimensional sensory world are represented in the central nervous system neurons in such a way that neighboring locations in the sensory world also are represented in neighboring neurons in the nervous system. Major motor systems direct which body parts are to move and how they should move in three-dimensional space. Motor neurons activate certain muscles have neighboring neurons that activate neighboring muscles. These topographical maps constitute an inner model of the body, creating in effect a sense of self. In primates and humans especially, this sense of self is partly represented in conscious awareness.
What we sense is:

> an *IMPLEMENTATION* (in topographical maps) of
> a *REPRESENTATION* (as nerve impulse patterns)
> of an *ABSTRACTION* (via selective receptive fields, feature extraction, transduction events, and binding)
> of the actual *REALITY* (physical stimuli)

What we believe and think is based on:

> … *how that sensory representation is processed,*
> *remembered, and altered by feedback from our actions*.

Note that it is not so obvious what the “reality” basis is for motor programs. The underlying reality must include some kind of combination of muscle and bone anatomy, neural circuitry, and various degrees of intentionality.

We know that topographical maps exist because with appropriate monitoring techniques, such as microelectrodes that can record responses at various points along a sensory or motor pathway, an observer can witness the point-to-point projections of activity. Conversely, if one knows, from electrical recordings for example, the anatomical locus of a projection, the information flow along the pathway can be mimicked by electrical stimulation or be abolished by a lesion that is strategically placed in the topographical mapped area.

Not all parts of the brain have clear topographical mapping. Such less-mapped areas include the hippocampus, hypothalamus, and basal ganglia. How these regions interact with the mapped systems remains among the great enigmas of neuroscience.

Such mapping constitutes the “hard wiring” of the nervous system. Many of the known mapped pathways in brain are indeed created under genetic control during early development of the brain. These seem to be largely independent of any influence of learning, and this is certainly true for pathways in the spinal cord and brainstem. However, many studies have shown that depriving young developing animals of a specific kind of stimulus can prevent them from developing the neural pathways in higher brain areas such as cerebral cortex for detecting such stimuli. The corollary is that sensory experience in early stages of development must be involve the selection of circuitry used to process those kinds of stimuli. Over time and repetition, these circuits can become permanently dedicated to that particular function.

Examples

The simplest example of mapping is found within the spinal cord (Fig. 1.9). A restricted portion of the body is mapped by a few specific neurons in the part of the spinal cord that is part of the same body segment. The projections from the cord into the brain retain a topographic segregation in the first relation station in the subcortical part of the brain known as the thalamus. The bodily mapped representations in the thalamus are maintained in the projections to the sensory cortex. As mentioned earlier, the sensory information is also routed in parallel in a non-topographically mapped form via the central core of the brainstem. From there, projections go to diffuse areas of the cortex other than the sensory cortex.

This has substantial clinical application. From knowing the topography of a sensory projection, for example, one can predict the clinical effects of a lesion at a particular point in the spinal cord. Conversely, from careful observation of clinical signs, particularly spinal reflexes, one can predict the locus of a lesion.

Readiness Response

Core Idea

Widespread populations of neurons in the brainstem govern the responsiveness to sensory input, the state of consciousness and alertness, activation of many visceral and emotive systems, the tone of postural muscles, and the orchestration of primitive and locomotor reflexes. The brainstem mobilizes a host of sensory, motor, and visceral responses to biologically significant stimuli to produce a generalized “readiness response.”

Terms

Affect (noun): more or less equivalent to emotions. A term that is often reserved for animals, in order to seem less anthropomorphic.

Autonomic nervous system: that subdivision of the nervous system that regulates (unconsciously) visceral activities. This includes regulation of the cardiovascular, respiratory, and digestive systems.

Brainstem: that part of the brain that is interposed between the spinal cord and the forebrain. It is generally considered to include the medulla, pons, midbrain, and some people would also include the hypothalamus.

EEG (electroencephalogram): electrical potentials recorded from a population of neurons, typically recorded from electrodes placed on the scalp.

Limbic system: a collection of neuronal groups in the brain that collectively act to govern emotions. Important structural areas include the hypothalamus, hippocampus, septum, amygdala, and parts of the cerebral cortex (cingulate, piriform, entorhinal).

Periaqueductal grey: the brainstem has a central canal ("aqueduct") that contains cerebrospinal fluid. The pool of neurons immediately surrounding this canal is called the periaqueductal grey. It is also known as the central grey.

Reticular formation: a massive collection of neurons in the central core of the brainstem. Many of these neurons are small with only local interactions, while others have long ascending and descending fiber projections.

Thalamus: a mass of neuronal clusters along the midline of the brain, lying underneath the cerebral cortex. Many of these neuronal clusters are topographically mapped specific sensory pathways. Here, we are talking about the reticular portion of the thalamus, which is the anterior extension of the brainstem reticular formation. This part of the thalamus projects nonspecifically to widespread areas of the cortex.

Explanation

Various populations of neurons in the brainstem are nodal points between sensory input and motor output. These populations govern the responsiveness to sensory input, the state of consciousness and alertness, activation of many visceral and emotive systems, the tone of postural muscles, and the orchestration of primitive and locomotor reflexes. Collectively, these effects permit an adaptive response to biologically significant stimuli: in short, a "readiness response." Activation of the brainstem, particularly the reticular formation and periaqueductal grey, is seen to engage a constellation of sensory, integrative, and motor responses for adaptive response to novel or intense stimuli. Also engaged during activation are brainstem nuclei whose neurons release specific neurotransmitters: raphe (serotonin), locus ceruleus (norepinephrine), and substantia nigra (dopamine).

We can think of a readiness response as including behavioral and mental arousal. When the animal is aroused by sensory input, all relevant systems are activated by reflex action. Behavioral readiness is a state of preparedness for making appropriate behavioral responses to environmental contingencies. The brainstem, particularly its reticular formation, has long been accepted as mediating such components of readiness as arousal and orienting. The brainstem also mediates most of the other components of readiness by generating a global mobilization that includes enhanced capability for selective attention, cognition, affect, learning and memory, defense, flight, attack, pain control, sensory perception, autonomic "fight or flight," neuroendocrine stress responses, visuomotor and vestibular reflexes, muscle and postural tone, and locomotion.

In a readiness response, the cerebral cortex is excited, enhancing consciousness and arousal level. Concurrently, muscle tone is enhanced, preparing the body for forthcoming movement instructions. Simultaneously, the limbic system is activated, which allows new stimuli to be evaluated in the context of memories. Also at the same time, neurons of the hypothalamus and the autonomic nervous system mobilize the heart and other visceral organs for the so-called fight-or-flight situations. This conglomeration of responses makes an animal ready to respond rapidly and vigorously to biologically significant stimuli. These multiple reflex-like responses are for the most part very obvious during startle reactions of either animals or humans. Less intense stimuli may not evoke a full-blown readiness reflex because the brain can quickly determine whether or not a response of great intensity is appropriate to the stimuli.
Brainstem reticular formation (BSRF) cells receive collateral sensory inputs from all levels of the spinal cord, including such diverse sources as cutaneous receptors of the body and head, Golgi tendon organs, aortic and carotid sinuses, several cranial nerves, olfactory organs, eyes, and ears, in addition to extensive inputs from other brainstem areas, the cerebellum, and the cerebral cortex. Thus, the BSRF is ideally situated to monitor and respond to a variety of stimuli that can be biologically significant (Fig. 5.2).

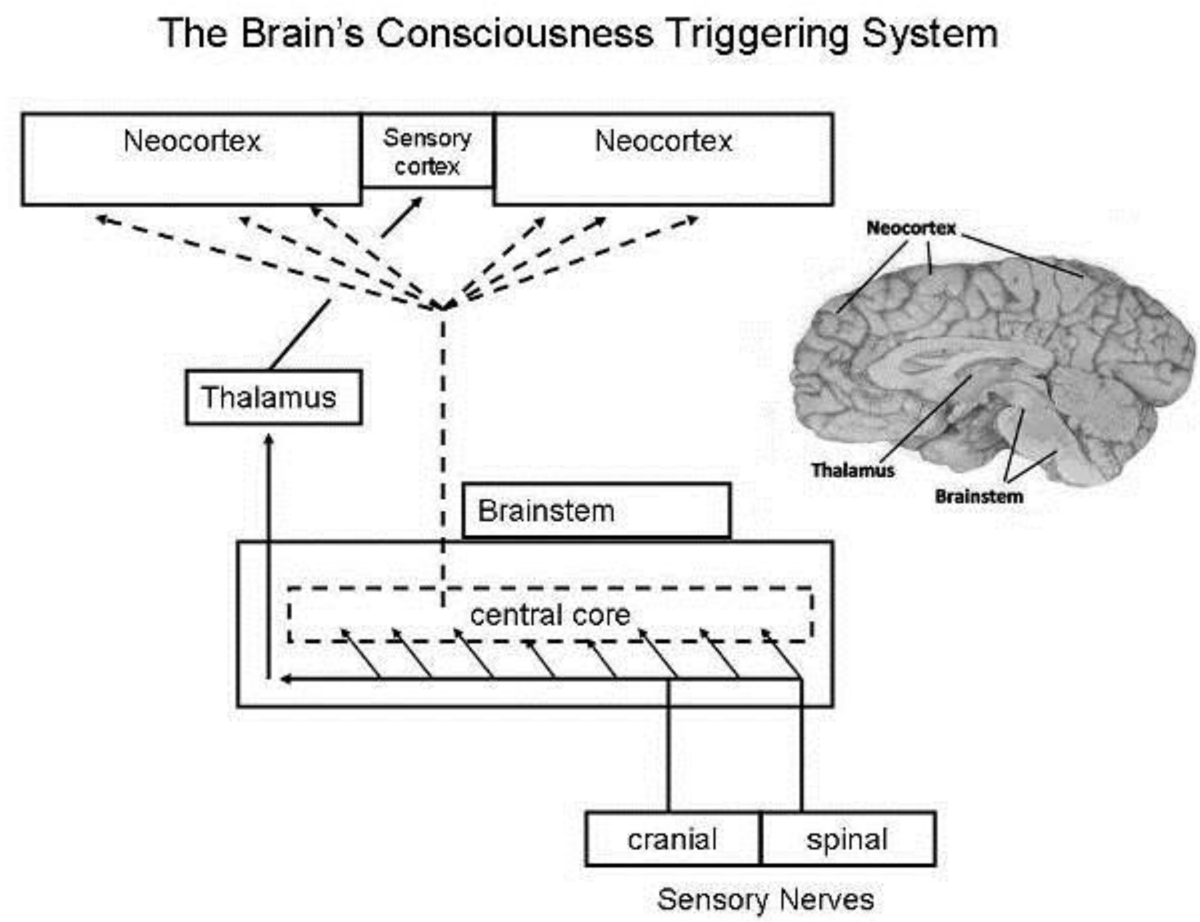


Fig. 5.2 Diagram of the physiological components of the readiness response. The central core of the brainstem provides an activating (or disinhibiting) drive of

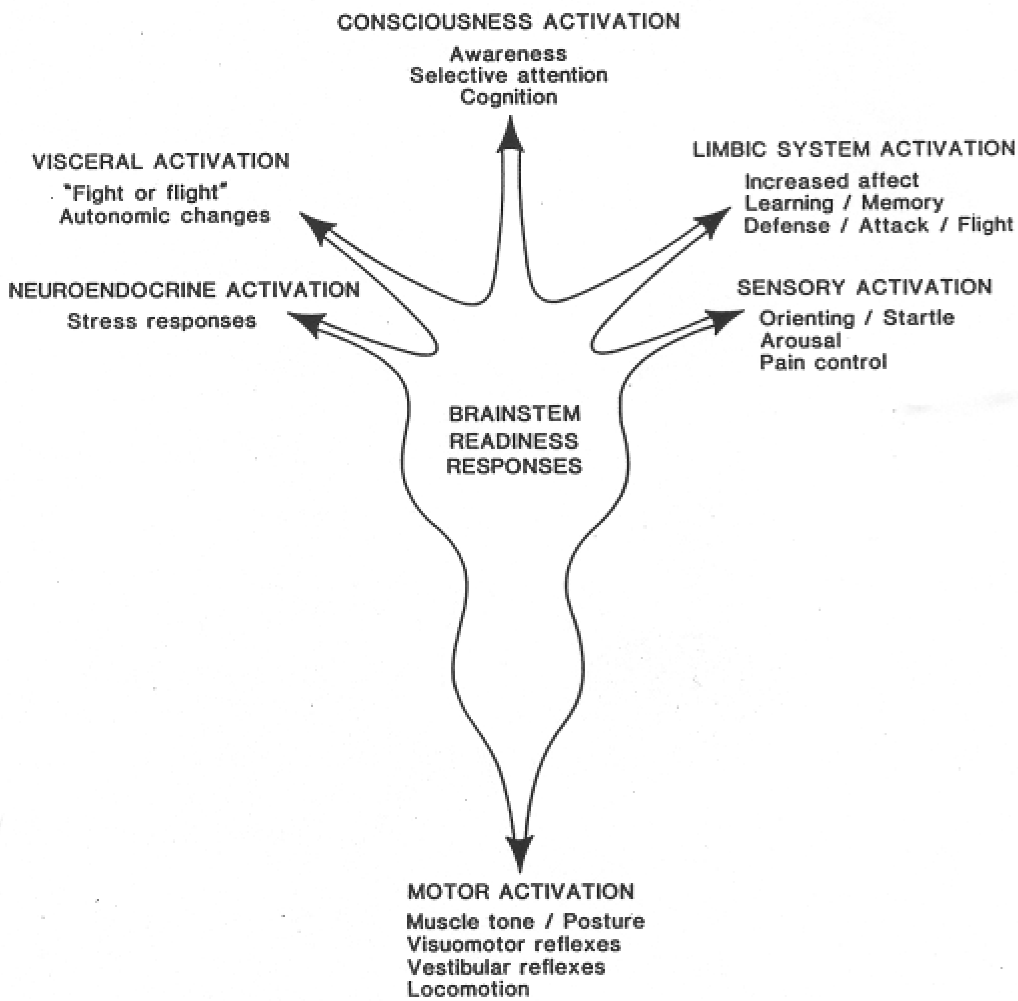
widespread regions of the neocortex to trigger and sustain consciousness. Sensory information from cranial and spinal nerves send topographically organized information to the sensory cortical map of the body, while at the same time sending collateral stimulus to activate the central core of the brainstem. From Klemm, 2011.

When BSRF neurons are stimulated by sensory input of any kind, they relay excitation through numerous reticular synapses and finally activate widespread zones of the cerebral cortex. In contrast, sensory information that arrives in the cortex via the main sensory paths passes through relatively few synapses and arrives at specific and very discrete zones of the cortex.

The BSRF responds in similar ways to any sensory stimulus, whether from the skin, eyes, ears, or whatever, to “awaken” the cerebral cortex so that it can respond to and process stimuli.

While the obvious conclusion is that the reticular formation creates arousal by direct excitation of higher centers, one cannot yet rule out the possibility that the excitation is indirect and results from a release from inhibition.

The readiness response does more than just activate the cerebral cortex and the EEG. It produces a more complete brain and body readiness that includes activation of emotions, memory capability, “fight or flight” responses in viscera and neuroendocrine activity, and muscle tone (Fig. 5.3)



. Fig. 5.3 Diagram of the physiological components of the readiness response.

Examples

Some components of the readiness response are more evident than others. Consider orienting. If you hear a sudden, loud noise, most likely you will reflexly turn your head toward the sound and become tense. You may not be aware of many visceral changes that also occur, such as an immediate rise in pulse rate and blood pressure.
Another good example to which most people can relate is found in a sleeping cat who is suddenly startled into arousal by a dog barking nearby. The cat leaps to its feet, orients to the dog, becomes extremely tense (including arching of the back and extension of the limbs). The hair will rise and the cat will hiss and prepare to lash out its claws toward the dog. Clearly, the cat is mobilized for total body response to the threat.

One reason that the readiness response is a total body response is that the BSRF gets extensive input from various brain regions, particularly the neocortex and limbic system.

Such input can be a major influence on behavior. For example, the cortical and limbic-system activities that are associated with the distress of a newly weaned puppy probably supply a continuous barrage of impulses to the BSRF, which in turn continually excites the cortex to keep the pup awake and howling all night.

The role of the BSRF in these arousing responses can be demonstrated by direct electrical stimulation at many points within the brain- stem reticulum. Such stimulation activates the neocortex (indicated by LVFA in the EEG), the limbic system (rhythmic theta activity in the hippocampus), and postural tone (increased electrical activity of muscles). Additionally, many visceral activities are activated via spread of BSRF excitation into the hypothalamus.

All readiness response components seem to be triggered from the BSRF, the central core of the brainstem. Evidence that the BSRF performs an important function in readiness includes: (1) humans with lesions in the BSRF area are lethargic or even comatose, (2) surgical isolation of the forebrain of experimental animals causes the cortex to generate an EEG resembling that seen in sleep. 3) Direct electrical stimulation of the BSRF has unique abilities to awaken sleeping animals and to cause hyperarousal in awake animals. (4) BSRF neurons develop a sustained increase in discharge just before behavioral and EEG signs of arousal.

Some recent studies have implicated cholinergic neurons in the pons in the EEG arousal component of the readiness response. These neurons appear to be under tonic inhibitory control of adenosine, a neuromodulator that is released during brain metabolism. This may relate to the mental stimulating properties of caffeine and theophylline, which act by blocking adenosine receptors.

Related Ideas

Conscious Awareness
Neurotransmission (Cell Biology)
Neurohormonal Control (Overview)
Pain Perception
Receptive fields (Senses)
Selective Attention
Reflex Action (Information Processing)

Table of Contents

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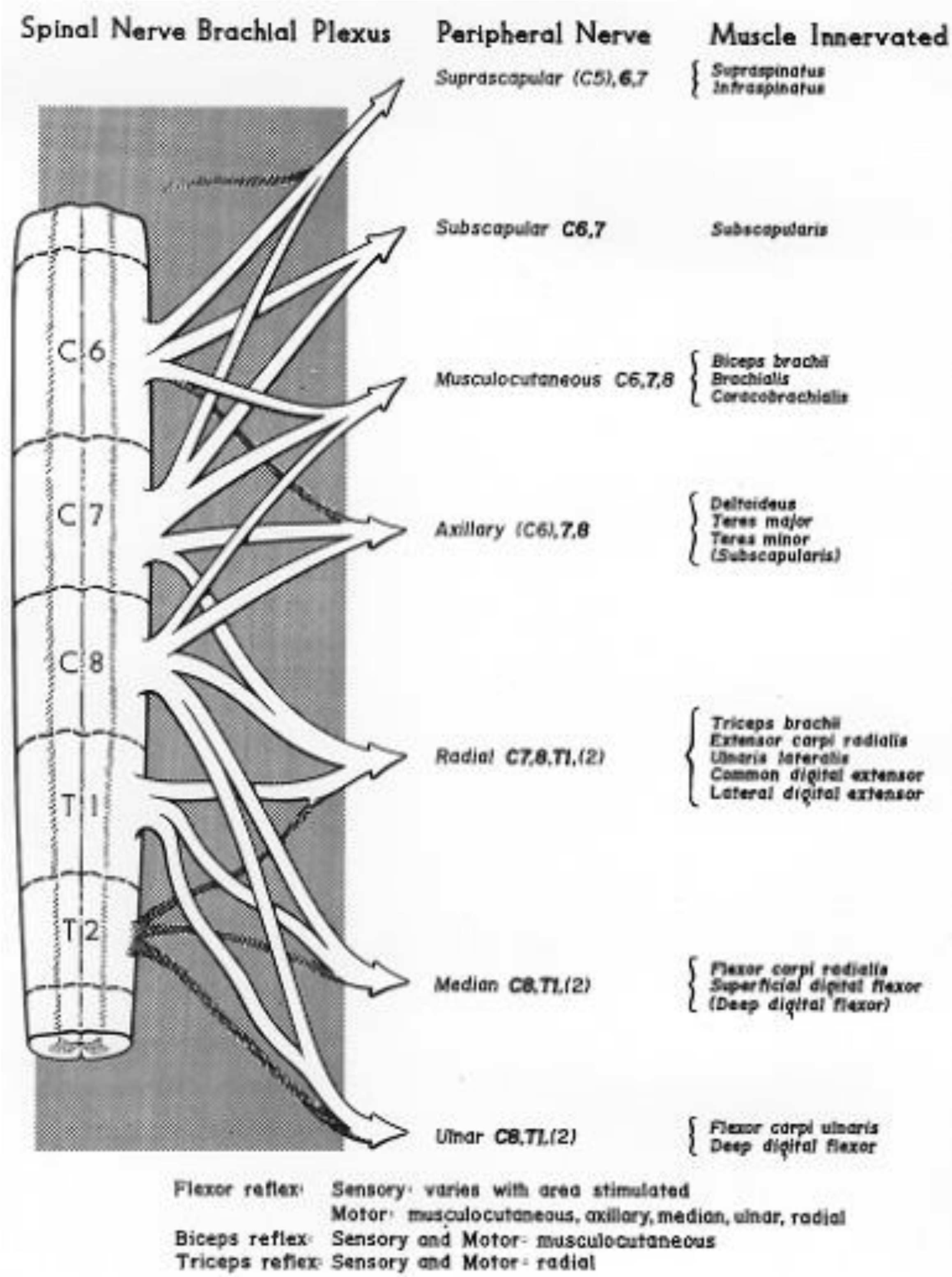

Fig. 1-9. Segmental innervation from the regions of thespinal cord that give rise to the brachial plexus in dogs. Note that specifilc regions of the cord specifically innervate different muscle groups. (From DeLahunta, 1983).

The projections from the cord into the brain retain a topographic segregation in the first relay station in the subcortical part of the brain known as the thalamus. The bodily mapped representations in the thalamus are maintained in the projections to the sensory cortex.

Topographic mapping is also a prominent part of the architecture of the higher parts of the nervous system, including much of the cerebral cortex. However, the clinical applications of this knowledge are not as straightforward as in the case of spinal pathways. In the bodily mapped parts of the cerebral cortex, there are specially located neurons for both sensations and motor control. The precision of sensation or motor control is more or less proportional to the amount of map and number of neurons that participate in that function (Fig. 1-10).

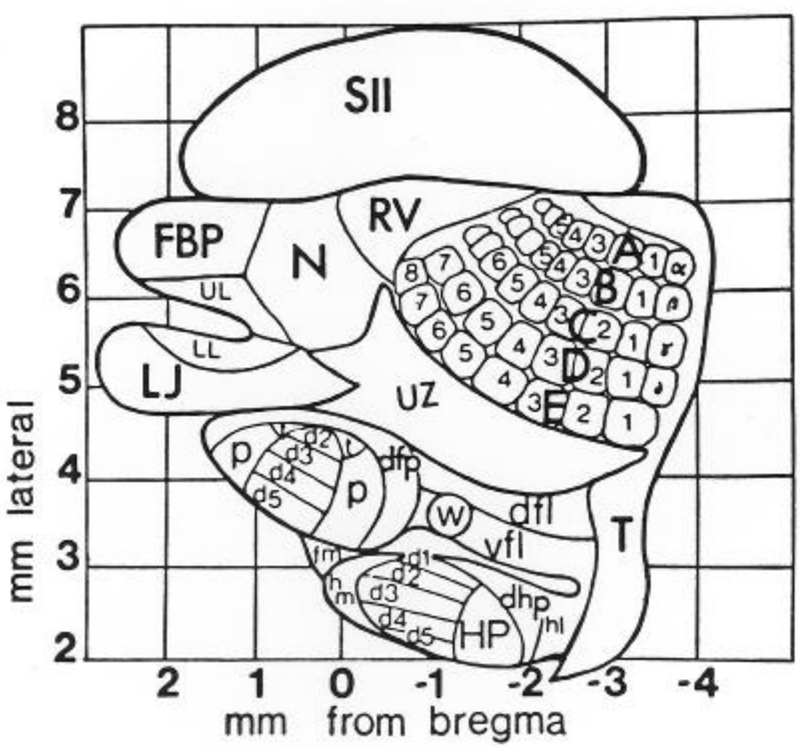

Fig. 1-10.Topographically detailed representation of the various parts of skin of anesthetized rats in the primary sensory cortex. Map was constructed by microelectrode recording from neurons in the sensory cortex while simultaneously stimulating different regions of skin. There is disproportionate representation of the vibrissae (A, 1-8) and the skin of the paws (dhp, dfl, P) and digits (d1-d5). Less well-represented areas include the trunkm (T), nose (N), lips (UL, LL) lower jaw (I, J). Zone UZ was unresponsilve in anesthetized rats. SII=secondary sensory cortex, which was not tested for mapping. (From Chapin and Llin, 1984).

Taken at face value, the idea of mapping can be very misleading. Take, for example, the observation from magnetic imaging studies on monkeys that indicate the presence of three patches of neocortex in the left hemisphere that a monkey uses to discriminate among pictures of faces of other monkeys. Electrical recording from individual neurons in these cortical patches revealed a high degree of face-response selectivity, with face-sensitive neurons in these areas being some 50 times less responsive to non-face stimuli. Magnetic resonance imaging of human brains indicate a small face-selective area in the bottom posterior region of the right hemisphere, while other small areas are selective for seeing bodies or scenes or visually presented words. These findings tempt us to conclude that the cortex is broken down into modules, with one patch dealing with faces, another with bodies, and so on. Yet, we must realize that the imaging technology available only allows us to see the "sweet spots" of such processing. Each of these cortical areas is connected to many widespread regions in both hemispheres and these are no doubt engaged in the processing associated with the respective sweet spots, but have not been detected because of limited sensitivity and resolution of current imaging technology.

A more compelling example of how we can overemphasize topographical mapping comes from what we have learned about the two well-known "speech centers" in the left cerebral cortex. Each is about the size of a half dollar coin, with one center controlling the tongue and lip movements needed for speech and the other controlling semantic interpretation of language. Destruction of these centers, as sometimes occurs for example with stroke, can render a person incapable of speech. Magnetic resonance imaging of bilungual people even indicates that the areas are engaged irrespective of which language a bilingual speaker chooses to use. It does not, however, necessarily follow that speech capability is confined to these small areas. Indeed, it seems highly unlikely that all the memory store associated with language can be held in just these small areas of cortex, especially in people who speak many languages. Brain imaging studies in bilinguals show that neurons in the left caudate nucleus, one of the basal ganglia located deep within the forebrain, is activated during language processing and is sensitive to which particular language a bilingual chooses to use at any given moment. Study of a person with damage in the left caudate nucleus revealed that even a trilingual patient retained comprehension of all of her languages. However, her spontaneous use of the languages was corrupted, characterized by inability to control which language was used, with spontaneous and uncontrollable choice of language.

Thus, it would appear that the caudate normally helps to monitor and control the use of neuronal populations in the language center. It is still not clear where all the information associated with language, such as grammar and vocabulary, is stored. Most likely, language is a process widely distributed throughout many areas of the brain. In such a case, the language centers should be thought of as perhaps crucial nodal points in multiple distributed circuits.

Related Ideas

Ensembles of Dynamic Neural Networks (Learning & Memory)
Modularity
Parallel, Multi-level Processing (Information Processing)
Emergent Properties (Information Processing)

Sensory Modalities & Channels (Senses)
Plasticity (Development)

Table of Contents

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