TÜRK NÖROLOJİ DERGİSİ TURKISH JOURNAL OF NEUROLOGY

II. Ulusal Kognitif Sempozyumu / *II. National Cognitive Symposium*

Türk Nöroloji Dergisi 2005; Cilt:11 Sayı:4 Ek:1 Sayfa:40-41

26 MAYIS 2005 PERŞEMBE / 26 MAY 2005 THURSDAY

09.40-10.40

Association Cortex and Cognitive Networks

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The cerebral cortex of the human brain contains approximately 20 billion neurons spread over an area of 2.5 m2. The cerebral cortex is engaged in 3 major operations: (1) reception of sensory stimuli from outside and from within (input); (2) execution of motor acts (output); and (3) intermediary processing interposed between input and output. Thought, language, memory, self-awareness, and even many aspects of mood and affect constitute different manifestations of intermediary processing. The neural substrates for these intermediary processes are located in regions that are collectively known as association cortex. From a behavioral point of view, therefore, the cerebral hemispheres can be divided into 3 major components: primary sensory cortex, primary motor cortex, and association cortex. The primary sensory areas provide an obligatory portal for the entry of sensory information into cortical circuitry, whereas the primary motor areas provide a final common pathway for coordinating complex motor acts. The primary sensory and motor areas constitute 10% of the cerebral cortex. The rest is subsumed by unimodal, heteromodal, paralimbic, and limbic areas, collectively known as the association cortex. The limbic and paralimbic components are involved predominantly in the modulation of mood, motivation and memory, whereas the heteromodal and unimodal components are involved predominantly in perceptual elaboration and motor planning.

The hypothalamus is the head ganglion of the internal milieu and the chief repository of neural programs for instincts and drives. Among cortical structures, only limbic regions have substantial monosynaptic interconnections with the hypothalamus. The limbic system is therefore polarized toward the internal environment and its requirements. In contrast, the primary sensory and motor areas are polarized toward the outside world: the sensory areas provide portals for the entry of information about extrapersonal events, and the motor areas coordinate the movements through which the environment is manipulated. Hypothalamic nuclei have very few direct connections with primary sensory and motor cortical areas. This arrangement ensures that motor proficiency and perceptual accuracy are not unduly influenced by sudden shifts in the emotional state of the individual. Communications between the sensorimotor apparatus and the hypothalamus occur through obligatory relays within association cortex. Association regions therefore provide neural bridges that mediate between the inner urges of the individual and the contingencies of the extrapersonal environment.

Intermediary processing increases the flexibility of behavior so that drives can be satisfied according to the limitations and opportunities that exist within the extrapersonal world. Animals comparatively lower in the phylogenetic scale have relatively underdeveloped association cortex and display remarkable behavioral rigidity. In these animals specific stimuli can automatically trigger predetermined responses that are described as instinctive. The neural substrate for flexibility is provided by the interposition of association areas between stimuli and responses, between hypothalamic urges and external reality. These intermediary areas of the brain act as and gates and or gates in a programming board. Hence identical stimuli can trigger vastly different responses depending on situational context, past experience, and present needs. It is the phylogenetic development of this intermediary processing that is responsible for choice among options, flexible shifts away from unsuccessful responses, adaptation to new situations, delay of premature gratification, and even for self-awareness, thought, and play behavior. As in so many other areas of biology, however, advantages rarely come without special vulnerabilities. In this case intermediary processing could be said to bring with it the susceptibility for apprehension, doubt, rumination, and excessive inhibition.

The relationships between mental function and brain structure are complex. There are no dedicated centers for memory, emotion or language. According to current thinking, there are no centers for "hearing words," "perceiving space," or "storing memories." Cognitive and behavioral functions (domains) are coordinated by intersecting large-scale neural networks that contain interconnected cortical and subcortical components. The network approach to higher cerebral function has at least four implications of clinical relevance: (1) a single domain such as language or memory can be disrupted by damage to any one of several areas, as long as these areas belong to the same network; (2) damage confined to a single area can give rise to multiple deficits, involving the functions of all networks that intersect in that region; (3) damage to a network component may give rise to minimal or transient deficits if other parts of the network undergo compensatory reorganization; and (4) individual anatomic sites within a network display a relative (but not absolute) specialization for different behavioral aspects of the relevant function. Five anatomically defined large-scale networks are most relevant to clinical practice: a perisylvian network for language; a parietofrontal network for spatial cognition; an occipitotemporal network for face and object recognition; a limbic network for retentive memory; and a prefrontal network for attention and behavior.

This conceptualization of behavioral neuroanatomy helps to understand the clinical manifestations of brain damage and the neurobiological foundations of mental function.