Chapter 2: Cognitive Neuroscience and Cognitive Science

2.0 Chapter Overview

The chapter covers basic issues of cognitive neuroscience and how neural processing relates to cognition.

2.1 Chapter Contents

Cognitive Neuroscience

Neurons: The Basic Building Blocks

- Basic Neurology
- Neurons
- Neural Communication
- Neurons and Learning

Neuroanatomy: Important Parts of the Brain

- Brain Anatomy
- Principles of Functioning
- Split-Brain Research and Lateralization
- Cortical Specialization
- Levels of Explanation and Embodied Cognition

Neuroimaging: Looking at the Brain

- Structural Measures
- Electrical Measures
- Metabolic Measures
- Other Measures

Neural Net Models: Connectionism

2.2 Chapter Summary

Cognition does not exist in a vacuum, but depends intimately on various neurological brain states. This can be seen clearly in patients, such as K.C., who have brain damage that then disrupts their ability to engage in certain types of cognition, perhaps illustrating dissociation.

The basic building blocks of the nervous system are the neurons, which students should be familiar with, including their component parts. Neural communication involves action potentials, which are changes in the electrical charge within a neuron. These action potentials follow the all or none principle. At the synapse, neurotransmitters are released which can affect the dendrites and cell membrane of the next neuron. There are a number of neurotransmitters that are involved in neural communication, and that can also influence the flow of cognition. During learning, neurons can be altered during long-term potentiation and consolidation.

In addition to the basic functioning of neurons, a thorough understanding of modern cognitive sciences must include an understanding of brain anatomy. Part of this involves understanding the roles of such brain structures as the thalamus, corpus callosum, hippocampus, and amygdala, as well as the cortex itself. The cortex is divided into a number of regions, each of which is critical for different types of mental activities. Two important principles of brain function and architecture: contralaterality and hemispheric specialization. Hemispheric specialization refers to the fact that specific types of processes(e.g., language) tend to be represented in and controlled by separate, lateralized regions of the brain. Further localization of function is found in the cortex with the sensory and motor cortices, with special types of neurons, such as mirror neurons, and certain pathways through the cortex for processing different kinds of information, such as the dorsal and ventral pathways.

While understanding underlying neurophysiology is important, in some sense, cognitive processes can be thought of as emergent properties from the operation of the neurons themselves. These emergent properties build from the parts that underlay them. Similarly, more abstract cognitive processes may be built and emerge from the embodied sensory and motor processes in which they began.

There are various neuroimaging methods for understanding brain structure and processes. In terms of the structure of the brain itself, two of the most popular methods are CT scans, which use x-rays, and MRI scans, which use the resonant frequencies of molecules. MRI scans are more detailed. To look at mental processes, some techniques use electrical measures, such as single cell recording, EEG(and ERP), and TMS techniques.

Another approach is to look at metabolic changes, as with PET and fMRI images. Finally, there are also other techniques available to cognitive science, including lesion studies, direct cortical stimulation, and the use of special populations.

The notion that human cognition is analogous to processing in a computer system has been abandoned at the detailed level, especially because of evidence of widespread parallel processing in humans. Connectionist(neural net, PDP) models can simulate such parallel processes, however, and therefore may be an excellent way of modeling human cognitive processes.

2.3 Key Terms

Acetylcholine: a neurotransmitter that may be involved in strengthening neural connections during long-term potentiation. (p. 38)

Action Potential: the change in electrical charge that occurs when a neuron fires. Neural firing follows the all or none principle, resulting in all action potentials being the same. (p. 36)

All or None Principle: the idea that either a neuron fires or it does not, with all action potentials being the same. (p. 37)

Amygdala: an almond-shaped structure adjacent to one end of the hippocampus; often involved in emotion processing. (p. 42)

Axon: the long, extended portion of the neuron. (p. 34)

Axon Terminals: the branchlike endings of the axon in the neuron; contain neurotransmitters. (p. 34)

BOLD Signal: Blood oxygenation level-dependent signal that informs the researcher about the relative level of activity in a region of the brain. (p. 54)

Brodmann's Areas: these are numbered areas of the cortex that were identified by an analysis of physical differences in different parts of the brain. These numbers are useful in locating general areas of the cortex. (p. 43)

Cerebral Cortex (Neocortex): the top layer of the brain; responsible for higher-level mental processes (nearly surrounds the "old brain" or brainstem). (p. 42)

Cerebral Hemispheres (Left and Right): The two major structures in the neocortex. In most people, the left cerebral hemisphere is especially responsible for language and other symbolic processing, and the right is especially responsible for nonverbal, perceptual processing. (p. 42)

Cerebral Lateralization: specialization of function between the left and right hemispheres(e.g., 90 percent of male, right-handed subjects who write with their hand right-side up have most of their language functions served by the left hemisphere). Different functions or actions within the brain tend to rely more heavily on one hemisphere or the other or tend to be performed differently in the two hemispheres. (p. 45)

Cognitive Neuroscience:(a.k.a. neurocognition/cognitive neuropsychology) a hybrid term applied to the analysis of those handicaps in human cognitive functioning which result from brain injury and other neurophysiological effects on cognition. (p. 32)

Connectionist Models: a computer-based technique for modeling complex systems. Knowledge is represented by the strength of the excitatory or inhibitory connections between massively interconnected nodes. (p. 57)

Consolidation: the slow process of making memories permanent; this process can last days, week, month, or years. (p. 40)

Contralaterality: receptive and control centers for one side of the body are in the opposite hemisphere of the brain(*contra* = against). (p. 44)

Corpus Callosum: broad band of fibers that constitute the primary bridge between the right and left hemispheres of the neocortex. (p. 42)

CT Scan: computed axial tomography; x-rays(of the head) that can be used to provide detailed 3-D information about the physical structure of the brain. (p. 51)

Dendrites: the branching input structures of the neuron (p. 34)

Direct Stimulation: The direct application of electrical current to the surface of the cortex; used by Penfield and others to map the cortex, such as the sensory and motor homunculi. (p. 56)

Dissociation: a disruption in one component of mental functioning but no impairment of another. (p. 32)

Dorsal Pathway: the neural pathway across the top of the cortex, stemming from visual-processing areas in the occipital lobe, primarily responsible for processing information about where things are in the world. (p. 49)

Emergent Properties: the properties that emerge from collections of elements (e.g., neurons) working together to create a new process of property that the individual elements lack (e.g., reasoning). (p. 50)

EEG (Electroencephalogram): electrodes on a person's scalp pick up brain waves. (p. 52)

ERP (Event-Related Potentials): the momentary changes in electrical activity of the brain when a particular stimulus is presented to the subject (e.g., changes in N400 for semantic anomalies, changes in P600 for syntactic anomalies). (p. 52)

fMRI: functional MRI; uses signature metabolic activity to capture both general structure of the brain and to indicate which areas of the brain are used to perform some particular task. Minimally invasive but shows some time lag, since the increase in metabolic activity can lag anywhere from several hundred milliseconds to several seconds behind the cognitive activity. Such scans are called "functional" because they show the brain as it is functioning. (p. 54)

Frontal Lobe: most forward part of cortex, and important for the control of thought and action. (p. 43)

GABA: an inhibitory neurotransmitter involved in weakening connections between neurons during learning. (p. 39)

Glutamate: an excitatory neurotransmitter involved in strengthening connections between neurons during learning. (p. 38)

Hemispheric Specialization: the principle that each cerebral hemisphere has specialized functions and abilities. (p. 45)

Hippocampus: "sea horse"; located immediately interior to the temporal lobes, important for (episodic) memory consolidation. (p. 42)

Lesion: a change in the structure of a tissue or an organ due to injury or disease, usually resulting in impairment of normal function (e.g., surgery, head injury, etc.). (p. 56)

Lobes(of the Brain): frontal, parietal, occipital, and temporal. (p. 43)

Long-Term Potentiation (LTP): the temporary (days, weeks, or months) strengthening of connections between neurons as a temporary storage of memories prior to consolidation. (p. 39)

Magnetic Resonance Imaging (MRI): a medical scanning technology that uses electrical signatures of metabolic change to compute the structure of the brain. (p. 41)

Mirror Neurons: neurons in the cortex specialized for planning and executing one's own movement, as well as simulating the movement of others that are being observed. (p. 49)

Motor Cortex: the band of cortex at the back of the frontal lobe responsible for processing information about voluntary muscle movements throughout the body. (p. 48)

Myelin Sheath: the fatty coating on a neuron's axon that can facilitate neural communication. (p. 34)

Neocortex: cerebral cortex. (p. 41)

Neural Net Models: connectionist models. (p. 57)

Neuron: the cell that is specialized for receiving and transmitting a neural impulse (dendrites [input structures], soma [cell body], axon terminals [output structures]). (p. 34)

Neurotransmitter: the chemical substance released into the synapse between two neurons; responsible for activating (type I neurons) or inhibiting (type II neurons) the next neuron in sequence. (p. 38)

Nodes of Ranvier: gaps along the myelin sheath that allow the action potential to jump from one point to another, thereby speeding neural communication. (p. 36)

Norepinephrine: a neurotransmitter that is involved in the creation of new memories. (p. 38)

Occipital Lobe: the lobe at the back of the brain that is most heavily involved in vision. (p43)

Parallel Distributed Processing: thoroughly parallel (simultaneous) processing distributed across wide areas of the system (e.g., brain). With this kind of parallel processing, the architecture can turn to distributed, rather than localist, representation. In a distributed representation system, the correlations (regularities) between representations get encoded into a network of connections. One feature of distributed representations is that their use can lead to achieving a "solution" for ambiguous inputs as the input is "cleaned up." (p. 57)

Parietal Lobe: portion of the cortex on the top, behind the frontal lobe and in front of the occipital lobe. This part of the cortex is important for sensory processing, spatial processing, and working memory. (p. 43)

Positron Emission Tomography (PET) Scan: this technique yields images of the functioning of the brain based on cerebral blood flow. (p. 54)

Propagation: the movement of an action potential from the dendrites, through the soma, and down the axon. (p. 36)

Sensory Cortex: the band of cortex at the front of the parietal lobes responsible for processing sensory information from throughout the body. (p. 48)

Single Cell Recording: the measurement of firing rating from an individual neuron using an electrode implanted in vivo. (p.52)

Soma: the cell body of a neuron. (p. 34)

Special Populations: populations of people that have some consistent alteration of brain structure or activity, such as older adults or Korsakoff's patients. (p. 56)
Split Brain: patients with a severed corpus callosum; performance can be examined to reveal various hemispheric specializations. (p. 46)
Synapse: connection point between neurons where neural transmission takes place; the transmission itself. (p. 37)
Temporal Lobe: the lobe of the cortex on the sides, below the frontal and parietal lobes. This lobe is important for audition and memory. (p. 43)
Thalamus: ("inner room"; "inner chamber"); "gateway to the cortex"; major relay station from the sensory systems of the body to the cortex; almost all messages entering the cortex come through the thalamus. (p. 42)
Transcranial Magnetic Stimulation (TMS): the use of magnetic coils to affect the activity of targeted assemblies of neurons in the cortex to either increase their activation or give a person a temporary lesion. (p. 54)
Ventral Pathway: the neural pathway across the side of the cortex, stemming from visual-processing areas in the occipital lobe; primarily responsible for processing information about what things are in the world. (p. 49)

2.4 Key People

Brodmann: identified separate areas of the cortex (p. 43)
K.C.: a patient (described by Tulving [p. 54]) who sustained a brain injury due to a motorcycle accident yielding a pervasive disruption of LTM: "He cannot remember, in the sense of bringing back to conscious awareness, a single thing he has ever done in the past." His intelligence, language, and knowledge were otherwise normal. (p32)
McClelland and Rumelhart: connectionist modeling (p. 58)
Penfield: pioneer of direct stimulation techniques for investigating brain function (p. 56)
Sperry: split-brain research (surgical intervention for epilepsy) (p. 46)

2.5.1 Lecture Suggestions (Effectiveness/Student Reactions)

- This chapter covers a lot of information. Be sure to indicate what your desired level of to-be-retained knowledge is.
- Request (and respond to) feedback. In the third hour of class time, hand out a sheet of paper and have each student (anonymously, if they wish) answer each of four preprinted questions:

1) What would you like to learn in this course?
2) Which course requirements are of most concern to you? (e.g., interpreting data, technical writing, etc.)
3) What is most likely to prevent you from performing at a level of excellence?
4) What can be done to enable you to meet these challenges?

2.5.2 Lecture Suggestions (Content)

Basic Tools

- Illustrate (via example or video) lesion/imaging techniques and their associated behavioral observations.
- To make it clear that the mind depends on the brain, discuss cases in which brain damage has affected thinking in some form or another.

2.6 Research Project Ideas

- Given unlimited resources, how might neuroimaging tools be used in the work place or other aspects of real-world life? Be creative.
- New ways of assessing neural activity are being developed all the time. Find one of these and design a study of how it may be used to study one aspect of cognition.
- What utility, if any, do developments in neurocognition and connectionist modeling have for developments in artificial intelligence? Are there any existing technologies that use principles of cognitive science in one form or another?