Chapter 2: Cognitive Neuroscience

Overview

Cognitive neuroscience is a growing, exciting area of cognition studies (and of psychology in general). Recently-developed neuroimaging techniques are providing intriguing links between the brain and behaviour. The field of psychology (and, more specifically, the sub-field of cognitive psychology) is not nearly old enough to be an exact science. We just don't know enough about human beings to be certain about things but that's what is exciting about psychology! Cognitive neuroscience researchers are on the ground floor of learning how the brain works and what, scientifically, is the connection between the brain and the mind and our behaviour. Mathematics, physics, chemistry. . . they have had their day. Today, the excitement is in cognitive neuroscience.

A description of the methods of cognitive neuroscience is important to give students a sense of *how* we are learning about brain function. Animal models are useful for an understanding of low-level brain function—the basic properties of neuronal transmission are equivalent across species. Animal models are, of course, insufficient for informing us of uniquely human abilities. Studies of individuals with brain damage provide clues to brain function but, as the damage is not confined to controlled areas, we are given a complicated picture of how things work. Sperry's work on **split brain** individuals is a fascinating demonstration of the importance of hemispheric transfer and the relative strengths of each hemisphere. Use of functional imaging techniques, such as **MEG**, **fMRI**, and **PET**, provide a unique opportunity to look at brain functioning in healthy humans. **Connectionist** models offer a useful analogy to **neural networks**.

Students have a tendency to assume that the brain is very modular: "this area is in charge of this." It is a challenge to conceptualize the way we believe things actually are: some areas are relatively more important for some tasks but most abilities are not strictly localized. It is probably not accurate to say that any one region of the brain *controls* any one thing. A sophisticated knowledge of the way parts of the brain work together is far beyond our understanding at this point; it is the lofty aim of cognitive neuroscientists.

Learning Objectives

In this chapter students will:

- Examine the key issues in the localization of function debate.
- Outline the theoretical issues surrounding the relationship between the mind and the brain.
- Explain approaches to studying that relationship.

- Identify the advantages and limitations of the various methods used to localize cognitive processes in the brain.

Key Concepts with Illustrative Examples

aphasia (see page 33, 34)

Aphasias are associated with damage to Broca's area or Wernicke's area of the brain. Individuals with aphasia have great difficulty producing and/or comprehending speech. The distinction between these two types of aphasia is apparent from speech samples.

A Broca's aphasic explaining his trip to the hospital for dental surgery:
"Yes. . . ah. . . Monday. . . er. . . Dad and Peter H. . . and Dad. . . er. . . hospital. . . and ah. . . Wednesday. . . Wednesday, nine o'clock. . . and oh. . . Thursday. . . ten o'clock, ah doctors. . . two. . . an' doctors. . . and er. . . teeth. . . yah."

A Wernicke's aphasic, asked how he is today:
"Gossiping OK and Lords and cricket and England and Scotland battles. I don't know. Hypertension and two won cricket, bowling, batting, and catch, poor old things, cancellations maybe gossiping, cancellations, arm and argument, finishing bowling."

It is obvious that the Broca's aphasic has trouble getting words out. He does, however, produce some approximation of a reasonable answer so it seems clear that he understood the question. Individuals with Wernicke's aphasia typically find it easier to produce words but show little comprehension.

connectionism and neural networks (see pages 42)

Connectionist models attempt to capture the essence of neural networks as they exist in the brain. The brain consists of units (neurons) and connections between them. Both connectionist models and neural networks learn by strengthening connections.

Hebb rule (see page 42)

Hebb rule stipulates that two neurons develop a connection if they repeatedly "fire" at the same time. This simple but critically important principle provides a basis for the explanation of how the brain "learns."

interactionism (see page 28)

Interactionism is the idea that the mind and brain are separate substances that interact with and influence one another. According to Sperry, consciousness occurs because of activity in the brain, but it also causes brain activity.

interhemispheric transfer (see page 34)

The two hemispheres of the brain are connected by the corpus callosum. This connection allows the two hemispheres, which have different relative strengths, to exchange information. When the corpus callosum is severed, there are interesting implications (see Roger Sperry's work on split brain patients).

localization of function (see page 26)

The idea that there are specific parts of the brain involved in specific cognitive processes is called localization of function. This is particularly prevalent when one examines the different functions attributed to each hemisphere of the brain. For example, in most right handed persons, language functions are localized in the left hemisphere, whereas non-verbal functions, such as the recognition of emotions, are localized in the right hemisphere.

module (see page 26)

Cognitive neuroscientists generally agree that the brain is composed of modules, or parts, that specialize in particular cognitive operations. A language module, for example, may be responsible for learning to speak. One area of debate is the number of modules and the functions of each module.

parallel processing (see page 43)

Parallel processing is the underlying assumption of connectionist models that many neural connections are active at the same time. For example, when we look at an object, our brain processes all characteristics (i.e., colour, shape, motion, etc.) simultaneously allowing us to process the object as a single object rather than having to combine the separate characteristics.

Phrenology (see page 26)

Franz Joseph Gall and his student, J. G. Spurzheim, believed that differences in the shape of a person's skull indicated differences in the location of various brain functions. This belief led to phrenology, which was the study of the shape, size, and protrusions of the cranium in an attempt to discover the relationships between parts of the brain and various mental activities and abilities. Phrenologists believed that each bump on the skull indicated the presence of a cerebral "organ" that was responsible for intellectual and personality characteristics.

serial processing (see page 43)

Serial processing is the suggestion that only one neural activity occurs in the brain at a time. Therefore, when multiple components of an object have to be processed, each component would be processed sequentially.

Discussion and Debate Ideas

1. The cases of Phineas Gage and Eduardo Leite suggest that major brain trauma can, in some cases, result in few obvious cognitive deficits. Have students consider how that's possible. In both

cases, the damage was limited to the front part of the brain. It is important to point out that, while frontal lobe damage may not result in major losses in terms of memory and language, it does impact very high-level processing (decision-making, for example).

What if the rod had entered the brain in a different spot? What if Gage or Leite had been much younger or much older? This may provide a useful starting point for a discussion of localization and plasticity.

2. Have the class discuss the limitations of using individuals with brain injuries to assess brain functioning. Be sure to stress the lack of control (brain damage will never be tailor-made to answer your research questions). As well, consider the likely confounding variables (overall health problems, for example).

3. Encourage students to think about what bits of phrenology are still apparent in neuroscience. While obviously outdated in methodology, the underlying localization hypothesis is at the core of modern cognitive neuroscience.

4. Ask students to think about the brain–mind–behaviour connection. Very often, there are straightforward connections linking things that are going on in the brain to thoughts and actions. For example, it is activity in the brain (directed by the "mind"?) that causes you to be able to move your hand to grasp something. But what about a very complex set of characteristics like Attention Deficit Hyperactivity Disorder? Or (if you are comfortable moving farther away from cognitive psychology) what about Antisocial Personality Disorder? Is psychopathy best thought of as a product of "the mind" (i.e., choices made, issues of anxiety or self-esteem, etc.) or a product of "the brain" (patterns of electrical activity and blood flow to different regions)? Functional brain differences have been found in individuals with Antisocial Personality Disorder when compared to a control group: their brains react differently to emotional stimuli. If their brain works differently, should they be held to the same standards as those with "normal" brains?

5. Discuss how media portrays topics in cognitive science, in particular how they contribute to popular misunderstandings or truths about cognitive processes. Some examples would be the movie *Lucy*, which is based on the idea that humans only use 10% of their brain, or *Eternal Sunshine of the Spotless Mind*, in which the main character deliberately has his memory of his former girlfriend erased.

6. Students often find some of the earlier methods of studying the brain humorous (e.g., phrenology). Discuss the concept of philosophical presentism—the tendency to interpret the past within the context of modern values, as opposed to historicism, where findings are evaluated within the context of the period in which they are made. Have students suggest other historical findings that, although they were incorrect, contributed to current day understanding.

7. Although brain imaging techniques have greatly advanced our understanding of the brain, there are also some applications of brain imaging being explored that could have serious implications. An example of this is the use of brain imaging as a lie detection test. Have students discuss the possible positive and negative applications of the interpretation of brain imaging.

8. Discuss the reasons for keeping patients awake during brain surgery. Of particular relevance would be a discussion surrounding the variability in localization of function as well as the desire to preserve function.

9. Discuss the advantages and disadvantages of localization of function. If each function were localized to only one area, what would be the cognitive implications should damage occur?

Further Reading, Media Suggestions, and Teaching Aids

1. **Twomey, S. 2010. Phineas Gate: Neuroscience's most famous patient. *Smithsonian*. Available from http://www.smithsonianmag.com/history-archaeology/Phineas-Gage-Neurosciences-Most-Famous-Patient.html**

   This article provides an overview of the fascinating story of the recent discovery of a photograph of Phineas Gage.

2. **Gazzaniga, M.S. 2005. Forty-five years of split-brain research and still going strong. *Nature Reviews Neuroscience, 6,* 653–659.**

   This article provides a review of the split-brain literature by one of the pioneers of the subject.

3. **The Implicit Associations Test:**
   https://implicit.harvard.edu/implicit/demo/takeatest.html

   Participate in an Implicit Associations Test. This Harvard University website hosts a variety of interesting IATs. There is also a link to Project Implicit, a network of researchers "investigating the gap between intentions and actions."

4. **Comparing Neuroimaging Techniques:**
   http://www.g2conline.org/#Neuroimaging?aid=2089&cid=699

   This video discusses the different neuroimaging techniques used to study the brain, including PET and MEG.

5. **The Brain from Top to Bottom:**
   http://thebrain.mcgill.ca/

   This is an excellent website by McGill University that allows students and Instructors to interactively explore the brain.

Homework or Study Questions

1. **What are the two laws formulated from Lashley's rat lesion experiments?**

The law of mass action: learning and memory depend on the total mass of brain tissue remaining and not on the properties of individual cells.

The law of equipotentiality: although some cortical areas may become task-specialized, any part of an area can (within limits) do the job of any other part of that area.

2. **Interactionism, epiphenomenalism, parallelism, and isomorphism are all ways of conceptualizing the relationship between the mind and the brain. How are they different from one another?**

   Interactionism proposes that the mind and the brain are separate, but interacting, constructs. The claim of epiphenomenalism is that brain processes *produce* what goes on in the mind. The consciousness of the mind, then, is best thought of as a symptom of brain activity rather than a cause. Parallelism maintains that there is a correspondence between mind and brain; they are two components of the same reality. Isomorphism argues that there is a similarity in structural characteristics between mental events and what goes on in the brain.

3. **What are the relevant strengths and weakness of using event-related potentials (ERP), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI) to examine brain functioning?**

   ERP, which measures electrical activity in the brain, can provide very detailed information about the *timing* of brain activity. Since electrical activity is practically instantaneous, ERP offers very high temporal resolution. Because ERP measures electrical activity at the level of the scalp, it offers no great detail in terms of the location of activity in the brain. PET and fMRI, which measure blood flow, offer much more spatial resolution. It is possible to get a very detailed picture of *where* exactly activity is taking place. In addition, fMRI has the advantage over PET of avoiding the use of radioactive material.

4. **Why is "connectionism" so-named?**

   Unlike information-processing theories, connectionist theory focuses on *connections* between elementary units. Connections don't simply link bits of information; in fact, they themselves embody knowledge. The fundamental assumptions of connectionism are concerned with connections: strengthening of connections occurs according to the Hebb rule (units that are active in concert tend to develop a stronger connection) and processing is parallel, meaning that many connections can be active at one time.

5. **Describe the most recent research on the localization of language function.**

   Although Broca's and Wernicke's areas are certainly involved in language, more current research suggests the involvement of multiple other areas outside those originally described.

6. **Compare epiphenomenalism to Sperry's concept of consciousness as an emergent property.**

Epiphenomenalism and Sperry both viewed consciousness as a result of brain function. Sperry also believed that once the mind emerged from the brain it could both influence lower level processes and, in return, be influenced by those processes.

7. **Describe the key advantage that ERP has as a research tool over CT and MRI.**

   CT and MRI provide information about brain structures; however, they do not provide a measure of brain activity.

8. **Discuss the advantages and limitations of magnetoencephalography (MEG).**

   The advantages of MEG are that 1) it has better temporal resolution than fMRI, 2) it provides a direct measurement of neural activity, and 3) it is not influenced by irregularities of the head. It is limited, however, in that it can only detect activity near the cortical surface, it is not widely available, and is not cost effective.

9. **What does diffusion tensor imaging (DTI) tell us about the brain that other imaging techniques do not?**

   Other imaging techniques provide us with information about structure and changes in activity; however, DTI provides us with information about neural connections and interactions in the brain.

Suggestions for Research Paper Topics

1. Choose a research article that uses an animal model and describe what it may tell us about *human* cognition. Detail the limitations of animal models. For which component of human cognition would animal models be *least* useful?

2. There is a popular myth in the mainstream media that people are "left-brained" or "right-brained." With reference to Sperry's work, propose an experiment that could be done with split-brain patients to debunk the myth.

3. It could be argued that mind-reading is no longer science fiction; it's just (cognitive) science. With reference to recent literature, make the case that mind-reading is possible with the technology that exists today.

4. Drawing on the strengths of all the brain imaging techniques, hypothetically design the perfect brain scanner. What questions could it answer that current techniques cannot?

5. Investigate individual factors that influence lateralization of function such as gender and handedness.

6. With the exception of smell, sensory information is processed in the contralateral hemisphere. Explore why this might be so and what advantage this might serve?

7. The “brain training” games that are advertised suggest that they improve cognitive abilities. Research the validity of these claims. Are there actually benefits to these games?

8. With advances in brain imaging techniques, is animal research still necessary? Support your view with research on the gaps that still exist in studying the brain.

9. As knowledge about the brain becomes more accessible to the public, it is being applied to many areas of life, such as the education system. Which areas of cognitive neuroscience do you think would be most relevant to a new teacher entering the classroom? Justify your advice with research.