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Important Note: The following set of materials is organized around a particular theme, or "special focus," that reflects important topics in the AP Psychology course. The materials are intended to provide teachers with resources and classroom ideas relating to that focus. The special focus, as well as the specific content of the materials, cannot and should not be taken as an indication that a particular topic will appear on the AP Exam.

Special Focus: The Brain, the Nervous System, and Behavior

Introduction

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The articles that follow are organized around the theme of "The Brain, the Nervous System, and Behavior." I chose this theme because, based on personal experience and my interactions with fellow high school psychology teachers, I've found that many of us feel unprepared to teach the concepts of neural and brain functioning. Over the years, independent study and practice have improved my presentation of these topics, but the support of my fellow educators has also been invaluable. The purpose of these materials is to provide you with that type of support. What follows are wonderful teaching activities that you can readily implement in your classes and articles that provide background information, helpful hints on how to teach certain concepts, and images and data that will supplement your course lectures.

The collection begins with an article entitled "The Brain and Your Students: How to Explain Why Neuroscience Is Relevant to Psychology," by Stephen M. Kosslyn and Robin S. Rosenberg of Harvard University. Sometimes it is a challenge for teachers to help students understand why studying biology in a psychology course is important. Kosslyn and Rosenberg believe that helping students learn more about recent findings in neuroscience enables them to better "establish the reality of psychological phenomena" and to understand cognitive processes more fully. The authors provide illustrative examples and ideas about how to incorporate biological research into the classroom.

Brennis Lucero-Wagoner of California State University: Northridge contributed "Active Learning: Engaging the Entire Brain to Construct Meaning." She has developed active-learning activities centered on teaching the parts and functions of the neuron and the brain. Lucero-Wagoner focuses on a learning model developed by David Kolb that suggests that genuine learning occurs in a cycle of experience, reflection, abstraction, and active testing. James Zull has adopted Kolb's ideas and applied them to current research in neuroscience. Lucero-Wagoner has created activities based on Zull's model to help students become more fully engaged in their own learning of neuroscience.

In his article "Basic Neuroscience," David G. Thomas of Oklahoma State University provides clear, concrete examples about how neurons do their jobs. He explains that students need to understand these neural functions because neurons are the building blocks from which students can understand more complex psychological processes.

Thomas not only explains these basic processes but also provides an interesting application in a hypothetical psychological experiment demonstrating the connection between neural functioning and goal-directed behavior.

To supplement the teaching of the neuron, Jessica Habashi has provided valuable resources in “Neurons in the Real World.” For most teachers of introductory psychology, the images of neurons provided in textbooks and overheads are artists’ drawings of the various structures. Habashi provides links to histological slides of neuronal structures typically discussed in introductory psychology classes. To accompany the slides, Habashi provides detailed descriptions of each as well as hand-drawn, black-and-white images for students to color and label.

Finally, I developed an additional teaching activity investigating another aspect of the physical basis of behavior and cognition. In “Memory, Memory Loss, and the Brain,” I explore the physical aspects of memory and the role of the hippocampus, as well as the consequences of life without memory, through the case studies of H.M., Clive Wearing, and Jimmie G.

By integrating the articles and teaching activities contained in this book into your own syllabus, you will give students valuable insight into the biological and technological bases of behavior that transcends the information normally included in an AP-level textbook. I hope you will find these many resources useful in your courses and the teaching activities engaging for your students.

The Brain and Your Students: How to Explain Why Neuroscience Is Relevant to Psychology

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Note: This article first appeared in *Voices of Experience: Memorable Talks from the National Institute on the Teaching of Psychology by* Perlman, Baron. Copyright 2005 by American Psychological Society. Reproduced with permission of American Psychological Society in the format Other Book via Copyright Clearance Center.

Barely a week goes by without an announcement of some new advance in neuroscience research. Often the new research findings arise from neuroimaging studies, which may use techniques like positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) to show that certain brain areas are activated when people perform specific tasks. Many of these advances directly bear on the nature of psychological phenomena, but it is often not clear how to teach this information in a way that is meaningful and interesting to psychology students. Not being neuroscientists, many students do not feel motivated to learn the results of brain studies because, from their point of view, associations between a particular task and where the brain happens to be activated when that task is performed seem arbitrary and irrelevant.

To counter this attitude, teachers of psychology need to show students how understanding the brain is relevant to psychology. The brain, after all, is the seat of cognition, affect, and consciousness—and thus its characteristics surely affect the nature of our thoughts, feelings, and behavior.

We have developed two related approaches to integrating neuroscience into psychology, which we illustrate in this chapter. First, we show how discoveries about the brain can help us to establish the reality of psychological phenomena and distinguish among them, and help us understand mental processes more deeply. Second, we take a step back and exploit an important general principle: Any psychological phenomenon can be addressed from multiple levels of analysis. The brain does not exist in a vacuum, and putting it in context—seeing its role in our thoughts, feelings, and behavior, alone and in groups—allows students to see how the brain affects everyday phenomena.

Facts about the Brain Inform Psychology

In this section we discuss how findings about the brain illuminate three general types of psychological questions: (a) whether a psychological phenomenon actually exists; (b) whether two phenomena are distinct or instead are different facets of the same thing; and, (c) why people think, feel, or behave in specific ways in specific circumstances.

Psychological Reality?

Facts about the brain can tell us whether a phenomenon is "psychologically real." Introspection, or even behavioral data, may not prove sufficient to implicate a specific mental phenomenon; such data can often be explained in many different ways (e.g., Anderson, 1978). Facts about the brain can play a decisive role in documenting that a mental phenomenon actually exists.

Do Mental Images Exist?

Consider this quote from John B. Watson, founder of behaviorism:

> What does a person mean when he closes his eyes or ears (figuratively speaking) and says, "I see the house where I was born, the trundle bed in my mother's room where I used to sleep—I can even see my mother as she comes to tuck me in and I can even hear her voice as she softly says good night"? Touching, of course, but sheer bunk. We are merely dramatizing. The behaviorist finds no proof of imagery in all this. *We have put all these things in words long, long ago* . . . (Watson, 1928, pp. 76-77)

Pylyshyn (1973, 1981, 2003) and others echoed this view years later, conceptualizing cognition as analogous to programs running on a computer. In their view, such programs use language-like internal representations (lists of facts, tables of information, and so on), and do not involve images in any sense. According to this view, the "picture-like" aspects of mental imagery are purely epiphenomenal. Like the heat from a light bulb when one is reading, these characteristics do not play a role in information processing. Are reports of using images in reasoning and recall to be taken as simply figures of speech, or do they reflect fundamental facts about how the mind works?

Visual mental images have been shown to exhibit three kinds of properties (for reviews, see Kosslyn, 1980, 1994). Try this (or have your students try it): Count, from memory, how many windows are in your living room. Most people report that they visualize the room and mentally scan along the walls, counting the windows. Did you notice the locks on the windows? Go back and try to "see" what they look like in your image. If you watch someone else doing this, you will probably see their eyes move to the side, and often jerk as they "fixate" on successive windows. This demonstration suggests that visual mental images have three properties: (a) spatial extent (objects in images appear to embody distance, like the walls in your image of your living room); (b) limits on spatial extent (objects in images do not extend indefinitely; just as you cannot see behind your head during perception, you "see" only a limited slice of the room in imagery); and, (c) grain (if objects are too small, they are hard to "see," as the window locks probably were the first time you counted the windows). These introspections were initially supported by behavioral findings (for distance, see Kosslyn, 1973; Kosslyn, Ball, & Reiser, 1978; for limited extent, see Kosslyn, 1978; for grain, see Kosslyn, 1975, 1976). However, these results proved controversial, and did little to convince skeptics of the psychological reality of imagery (e.g., see Kosslyn, 1980, 1994; Pylyshyn, 1981, 2003; Tye, 1991).

Enter the brain. In the monkey brain, 32 cortical areas have now been shown to play a role in visual perception (Felleman & Van Essen, 1991). Fifteen of these areas are *topographically organized*—that is, they preserve the spatial structure of the retina. When a monkey is shown a pattern, the pattern falling on the retina is literally preserved by the pattern of neurons firing in these cortical areas (e.g., see Tootell et al., 1982). These topographically mapped areas have three relevant properties: They have spatial extent; they evolved only to process the input from the eyes and hence have *limited* spatial extent; and they have grain (conferred by *spatial summation*—the fact that stimuli that are close enough together will be averaged by a given visual neuron, which blurs the distinction between the stimuli).

Thus, it is of great interest that visual mental imagery typically activates some of these areas in the human brain. The majority of both PET and fMRI studies have documented such activation (for reviews, see Kosslyn & Thompson, 2003; Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998; Thompson & Kosslyn, 2000). In addition, the spatial properties of visualized objects affect the specific pattern of activation in these areas, and do so in much the same ways in perception (when people see the objects). In perception, objects that stimulate the fovea activate the very back parts of the primary visual cortex, and increasingly larger objects stimulate increasingly anterior parts of this structure (Fox et al., 1986). The same is true in visual mental imagery, even when people have their eyes closed (Kosslyn, Thompson, Kim, & Alpert, 1995).

But these findings—like all neuroimaging findings—are purely correlational; they only show that activation in a brain area accompanies a particular kind of mental processing. In order to establish that the brain areas play a causal role in such processing, a different method is required. For example, magnetic stimulation can temporarily impair the functioning of part of the cortex. If that part of the cortex plays a causal role in performing a particular kind of task, then participants should perform the task more poorly following such magnetic stimulation. Relying on this logic, researchers first asked participants to memorize sets of stripes, and later asked them to close their eyes and visualize pairs of stripes in order to compare them (e.g., in terms of their relative length or width), This task not only activated the primary visual cortex, but also was impaired when magnetic stimulation had temporarily disrupted this cortex. Moreover, the magnetic stimulation had much the same effects in the corresponding perceptual task, when the participants viewed the stripes instead of visualizing them (Kosslyn et al., 1999). Thus, neuroscience research has been able to help answer the question of whether mental images exist: They do.

Is Hypnosis Just Playacting?

Some researchers and theorists have claimed that hypnosis is a distinct psychological state that allows one to focus attention very precisely (e.g., Hilgard, 1965; Hilgard & Hilgard, 1975; Kihlstrom, 1987; Spiegel & Spiegel, 1987), whereas others have claimed that hypnosis is nothing more than a role in which people cooperate with the wishes of the hypnotist (e.g., Barber, 1961; Spanos, 1986).

One way to judge the merits of these two claims is to study the neural correlates of hypnosis. The key idea is that people cannot voluntarily alter the neural mechanisms that signal a particular mental state. Thus, if hypnosis is accompanied by distinct brain states, it cannot be ascribed simply to playacting. To test this, Kosslyn, Thompson, Costantini-Ferrando, Alpert, and Spiegel (2000) selected a group of highly hypnotizable people (as measured by standard scales) and showed them colored and grayscale patterns while scanning their brains with PET. In brief, researchers presented the pattern in color or grayscale, and asked the participants to alter their perception (if needed) in order to see each version either in color (even if it was actually gray) or in grayscale (even if it was actually in color). Finally, the participants performed these tasks while being hypnotized or while not being hypnotized.

Kosslyn et al. (2000) first located the classic “color area” of the brain in the fusiform/ lingual region (in the back, underside of the brain) by examining the results when participants were told to perceive the colored display as being in color versus when they were told to perceive the grayscale display as gray. Two regions within the color area (as identified earlier by other laboratories, e.g., Lueck et al., 1989) were activated, one in the left cerebral hemisphere and one in the right. Kosslyn et al. (2000) then examined how hypnosis affected activation in these areas. Both the left- and right-hemisphere color areas were activated when the participants were hypnotized and were asked to perceive color—whether or not they were actually shown the color or the grayscale stimulus. In fact, these areas were activated to comparable degrees when hypnotized participants mentally added color to grayscale stimuli as when they were presented with actual color stimuli. Similarly, these areas were "turned down" when hypnotized participants were asked to see gray—whether or not they were actually shown the color or grayscale stimulus. All that mattered to hypnotized participants is what they experienced seeing, not the actual nature of the stimulus.

For the left-hemisphere color area, these results were obtained only when the participants were hypnotized. When they were not hypnotized, the actual nature of the stimulus determined how the area responded. In contrast, for the right-hemisphere color area, activation was always determined by what the participants were told to perceive. If they were asked to perceive color, the area was activated—both when the participants had been hypnotized and when they were not hypnotized but were asked to visualize the appropriate colors or grayscale.

In short, hypnosis can alter the state of brain areas. What the participants *experienced* seeing overrode the actual stimulus input when they were hypnotized. The right-hemisphere color area apparently is more sensitive than the left to the effects of mental imagery per se, but the left required hypnosis in order to be modulated by experience.

Thus, results from neuroscience research are helping supply answers to questions about whether certain psychological phenomena exist. At least with regard to mental imagery and hypnosis, the answer appears to be yes.

Same or Different?

Relatively recent research in neuroscience has also enabled behavioral scientists to resolve old questions about whether two different psychological phenomena are in fact distinct from each other, or whether they simply reflect different facets of the same underlying mechanism. For example, we consider whether classical conditioning and operant conditioning are really different forms of learning, and whether behavior therapy works the same as medication in the treatment of a disorder.

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Classical Versus Operant Conditioning

Classical and operant conditioning both establish an association—the former between a stimulus and a response, the latter often between a discriminative stimulus and a response, which rests on an additional association between the response and a consequence. Moreover they both have several elements in common: extinction and spontaneous recovery; generalization and discrimination; moderating factors that affect response acquisition, such as time (e.g., the length of time between the conditioned stimulus and the unconditioned stimulus, or immediate versus delayed reinforcement); and both are subject to constraints on what can be learned easily. However, with classical conditioning, the response must be elicited, and thus the types of behaviors amenable to classical conditioning are generally limited to involuntary behaviors. In contrast, with operant conditioning the learner gives responses that are not necessarily elicited, which are then followed by a reinforcer that increases the probability that the learner will make that response in that setting in the future.

Given the similarities between the two types of conditioning, some researchers (e.g., Kosslyn, Ganis, & Thompson, 2003; Pylyshyn, 2003) have debated whether they really are different, or are just different procedures that produce a similar end. Researchers have shown that voluntary movements can be shaped via classical conditioning (Brown & Jenkins, 1968), and "involuntary" responses can be operantly conditioned (such as learning to control tense jaw muscles to decrease facial pain, Dohrmann & Laskin, 1978). However, the fact that the same ends can be reached does not imply that the means to those ends are the same; by analogy, bats, birds, and helicopters fly, but in different ways.

Perhaps the best evidence that the two kinds of conditioning are distinct is the fact that they rely on different neural systems. Indeed, when we looked at the brain systems underlying learning, we realized that posing the question in terms of classical versus operant conditioning was misleading. Not only do classical and operant conditioning clearly draw on different mechanisms, but different types of classical conditioning themselves rely on different systems. For example, whereas classical conditioning of fear draws on the amygdala (e.g., LeDoux, 1996), classical conditioning of eye blinks relies heavily on the cerebellum (Thompson & Krupa, 1994). In contrast, operant conditioning does not rely on either structure, but does make use of the dopamine-based "reward system" that relies on a part of the brain called the nucleus accumbens (e.g., see Robbins & Everitt, 1998). Neuroscience is able to show that different systems are used in the different types of learning.

Behavior Therapy Versus Medication

Another example in which neuroscience research helps sort out whether two phenomena are the same or different can be found in the success of two treatments for obsessive-compulsive disorder (OCD): medication (fluoxetine, better known as Prozac) and behavior therapy. Both treatments can be helpful in reducing symptoms, but do they accomplish this end in the same way? To address this question, Baxter et al. (1992) used PET to examine the brain function of OCD patients in two conditions, either before and after behavior therapy or before and after receiving fluoxetine. The scans revealed that behavior therapy and fluoxetine both resulted in decreased activity in a part of the brain called the right caudate (part of the basal ganglia, which is involved in producing "automatic behaviors"). Schwartz, Stoessel, Baxter, Martin, and Phelps (1996) replicated the effects of behavior therapy on the brain. Thus, evidence shows that behavior therapy and the drug alter the function of one area in common.

However, the drug also affected two other areas, the anterior cingulate and thalamus, both of which are involved in attention. The effects of the two treatments on the brain are not identical. When we come to understand better what different parts of the brain do, we can understand why drugs and behavior therapy have some similar effects but also have different effects. Moreover, simply because the drug affected more areas does not necessarily imply that it is better. The activation of these additional brain areas may reflect side effects. Depending on what these additional areas do, behavior therapy might turn out to be the more focused, appropriate intervention. Neuroscience research sheds light on the nonidentical effects of the two treatments.

Explanations of Phenomena

Perhaps the most general use of data about the brain is to help us understand how a particular psychological event occurs. Students are more likely to become interested in neuroscience research when the research explains psychological experiences of which they have firsthand knowledge. To illustrate this approach, we focus on common events: emotion-modulated startle and "hunches."

Emotion-Modulated Startle

If you are like most people, you have experienced walking down a street alone late at night and suddenly hearing a noise behind you. The realization that it was probably just a cat knocking over a trash can probably came well after you were startled by the sound and your heart started racing. When in a state of nervousness, fear, or in some other intense emotional state, people are prone to being startled (e.g., see LeDoux, 1996). A large body of research has shown that the amygdala plays a crucial role in this sort of emotion-modulated startle; the structure is activated in startling situations, and patients who have impaired amygdalae do not show this startle reaction (see Damasio, 1994; LeDoux, 1996).

Emotion-modulated startle can be induced if one hears a scary story (e.g., a campfire ghost story late at night) followed by a loud sound. Students often get a lot more out of a discussion about emotion-modulated startle when they themselves experience such a response. To try this with your students, invite students to close their eyes while you read aloud a short scary story in a soft theatrical voice; at some point near the end of the story, create a loud noise by slamming a book on the table. (Note that we suggest you let students know in advance that the goal of the demonstration is to startle them, and that students who don't want to be startled should keep their eyes open.) This sort of demonstration is interesting to students (and teachers) because it shows that the amygdala can be modulated by the cognitive systems based in the cortex. Listening to a scary story can make us become anxious—which in turn makes us prone to being startled. This phenomenon clearly highlights the close link between emotion and cognition, which is interesting because our teaching experience suggests that many students intuitively feel that emotion and cognition have nothing to do with one another.

Hunches

A hunch is a belief, not based on explicit reasoning, that a problem can be solved in a certain way or that a situation will develop in a certain way. Hunches arise prior to conscious reasoning and usually cannot be justified rationally. To study the development of hunches, Bechara, Damasio, Tranel, and Damasio (1997) asked people to play a gambling game that involved taking cards from different decks. Participants were given a sum of play money at the outset, and drew cards that either awarded them additional money or penalized them. Cards were arranged into four decks, and some decks were "riskier" than others. Cards from the riskier decks could result in large losses. Participants were not warned that the decks differed in how risky they were, but after drawing many cards they typically figured this out. However, before they were consciously aware of the differences among the decks, they usually had a hunch. This hunch was not only a subjective feeling but also was the source of a skin-conductance response (SCR), which occurred right before the participants drew a card from a risky deck. Such responses occurred when the brain sent signals to the body that certain choices were risky, even before the participants consciously realized it.

Perhaps the most interesting results concern the contrast between the normal participants and patients who had damage to the ventral medial frontal lobes, part of the brain known to play a crucial role in using emotional information to guide behavior (see Damasio, 1994). These patients never showed skin-conductance responses prior to making a choice, and never expressed having a hunch. Moreover, by the end of the game, even the normal people who never consciously figured out the situation still chose properly, but the patients never did. In fact, the three patients who did figure out how the decks were set up still chose incorrectly! These patients never produced skin conductance responses, and continued to choose poorly even though they understood the situation.

According to Damasio, hunches are based on covert signals that arise before a person has thought through a situation, and these signals are based on a kind of "implicit memory." Without such emotional nudges, people do not choose wisely. In daily life, patients with damage to the ventral medial frontal lobes squander their money, have erratic personal lives, and may fight with coworkers.

Whether or not Damasio's views are correct, the exciting aspect of this finding is that once we know that a certain brain area is crucial to the phenomenon, we have a lever to understand the phenomenon in greater detail. The vague problem, "what is a hunch?" now can be recast as, "how does this brain area function so that we have hunches?"

Neuroscience and Levels of Analysis

As we hope we have just shown, neuroscience can become more interesting when it illuminates psychological phenomena. A single principle underlies this approach, which rests on exploiting the concept of *levels of analysis*. The idea is simply to put the brain in a broader context, allowing facts about the brain to illuminate facets of phenomena at other levels of analysis. We can focus on three levels: First, the *level of the brain* is concerned with biological mechanisms, such as neural circuits, functions of lobes, and the effects of hormones. It is also concerned with the effects of genes on those mechanisms. Second, the *level of the person* is concerned with the content of people's mental processes. The content of mental processes includes beliefs (e.g., ideas, knowledge, expectations), desires (e.g., hopes, goals, needs), and feelings (e.g., fears, guilt, love). Whereas the level of the brain focuses on mechanisms for their own sake, independent of any particular content, the level of the person focuses on the content per se. Third, we focus on the *level of the group*. This includes the physical and social world. The physical world is our material environment, both natural and manmade. The social world is our interactions with other people, ranging from our relationships to our culture. Moreover, groups—like individuals—have their own behavior and mental processes (shared identity, beliefs, normative behaviors). Thus, the level of the group refers to the influence that other people and the physical environment have on us and that we have on other people.

A key part of the levels approach is an emphasis on the fact that *events at each of the levels affect events at the other levels.* Events at the different levels are constantly interacting. For example, right this minute your brain is processing these swiggly black lines in front of you, interpreting them as conveying meaning (level of the brain). These lines were created by others (specifically, we authors—level of the group) in order to convey specific ideas (level of the person). If we have successfully conveyed that information, your beliefs will change (level of the person), which in turn will affect not only how your brain organizes and stores information in the future, but possibly even how you interact with other people. By emphasizing the key role of the brain in such interactions, students can immediately see why the brain can speak to important issues in psychology.

When we ask whether mental images exist, for example, we use events in the brain to help us understand events at the level of the person, in this case the contents of conscious experience and beliefs about properties of objects. Facts about the brain inform us why we have particular experiences (level of the person), why we are aware of some aspects of objects with some kinds of images (e.g., tiny ones) and other aspects with other kinds of images (e.g., large ones). Thus, this example can be used to illustrate how events at the different levels are constantly interacting, and why understanding events at the level of the brain is relevant to understanding events at the other levels—such as the nature of conscious experience. Indeed, if we ask you to visualize a particular object, that social interaction can lead your brain to produce a specific experience (which involves interactions among events at all three levels)—and depending on the nature of the image, you will report different things to us.

When asking about hypnosis, we not only use events in the brain to explain aspects of experience and knowledge (level of the person), but we can also see how the very act of being hypnotized—which is a social encounter—affects the brain (and in turn affects one's experiences). Thus, all three levels of analysis are involved in this example.

In our example of classical versus operant conditioning, we saw how facts about brain mechanisms allow us to distinguish among different kinds of learning. Because they are different systems, a given person might be good at one kind of learning but not another, and vice versa for another person. Thus, knowledge that the systems are distinct can tell us something about how people differ in their abilities to acquire certain knowledge—allowing us, again, to draw a link between the level of the brain and the level of the person.

People who have acquired different knowledge behave differently, including when interacting with other people. For instance, some people are more prone to experiencing conditioned fear responses than are other people. Such people are likely to have more fears and phobias, and interact differently with people and their environment than individuals whose brains are less likely to acquire such conditioned emotional responses.

In the example of treatments for OCD, the social interactions underlying behavior therapy were found to change the metabolism of a certain part of the brain, and to do so in the same way that a drug does. It suggests that whatever the two types of therapy have in common may be mediated by that part of the brain. Events in the brain not only affect beliefs (helping the patient to overcome his or her disruptive beliefs), but also affect how these patients interact with others (at the level of the group) because they are less restricted in their daily activities.

Our example of emotion-modulated startle also involves all three levels of analysis. Consider again a campfire ghost story, which leads everyone to jerk when a loud noise is produced at the end. The state of the amygdala is affected by one's comprehension of the story, which involves tapping into stored knowledge and beliefs at the level of the person. One aspect of being a skillful storyteller is being able to tap into that knowledge, thus knowing how to make the listener tense and ripe for the coup de grace at the end of the story. Thus, to understand emotion-modulated startle, one must understand the dynamics of the social situation—and to understand those dynamics (i.e., why someone is telling a particular story in a particular way), one must understand the mechanisms that underlie the phenomenon.

Hunches are another example: They clearly play a key role in gambling, for instance, and gambling is a social activity. The discoveries about the brain-bases of hunches allow us to understand how the roulette player may sense a "winning streak"—and a detailed understanding of how this brain area works (effectively or not so effectively) perhaps someday can help to explain why some people seem to gamble foolishly, not learning from experience. Such behavior can have a devastating effect on the gambler's life, and the lives of members of the gambler's family.

Implications for Students and Teachers

Students can be fascinated by facts about the brain when they are brought to bear on topics in which they are interested, and are used in a way that illustrates how events in the brain affect the person and the group—and vice versa. The illustrations presented here are merely examples of ways in which facts about the brain can come alive for students. The general principle at work is that putting findings about the brain in a broader context helps students better understand and appreciate the material. Our experience has been that students become interested in findings about the brain when a controversy or question about a psychological phenomenon is illuminated. In addition, simply showing how the brain is not isolated from the person, the group, or the rest of the world can be eye-opening for students; they come to understand that understanding the brain can help them understand the nature of their feelings, thoughts, goals, relationships with others, and interactions with the environment—topics about which students typically are very curious. To draw facts about the brain clearly into the domain of psychology *as the student conceives of it*, teachers need to consider how specific brain events inform events at other levels of analysis. By integrating the brain into a larger context, it should become clear why learning about the brain informs us about key characteristics of psychology.

Here are some guidelines for providing such a context for findings and theories about the brain:

- Do the findings and theories about the brain help determine whether a psychological phenomenon exists? If so, explain both the phenomenon and the debate, providing demonstrations, video clips, or other material to illustrate the phenomenon or aspects of a key study.
- Do the findings and theories help make distinctions among similar phenomena or provide evidence that similar phenomena are facets of the same things? If so, explain the phenomena and why it matters whether or not they are distinct. If possible, provide demonstrations, video clips, or other material to demonstrate the phenomena.
- Explain to students how researchers progressed from general questions about a psychological phenomenon or process to the particulars of the specific task they used in their neuroimaging study. Explain how the task relates to the phenomenon under investigation.
- Explain to students how the findings about the brain provide insight into the origins or operation of a phenomenon. Generalize from the tasks used in specific studies to real-world situations or phenomena of interest to students.
- Using a levels-of-analysis framework, point out specific ways that findings about the brain do not exist in a vacuum: Neural processing affects, and can be affected by, an individual's beliefs, thoughts, feelings, goals (level of the person), and his or her interactions with other people and the environment (level of the group). Always bring the brain back to the world, and back to phenomena that grab the students' interest.

Acknowledgements

We thank Christine Souter for valuable comments on an earlier draft, and generations of Sophomore Tutors at Harvard University for trying out these ideas and for providing valuable feedback. Preparation of this chapter was supported by National Science Foundation under grant REC-0106760 and NIH Grant 5 R01 MH60734-03.

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Active Learning: Activities Engaging the Entire Brain to Construct Meaning

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In an influential book on educational theory, David Kolb (1984) asserted that deep learning, genuine comprehension, develops from a sequence of **experience**, **reflection**, **abstraction**, and **active testing** that he called the cycle of learning. More recently, in a very readable and thought-provoking book, *The Art of Changing the Brain: Enriching the Practice of Teaching by Exploring the Biology of Learning*, James Zull (2002) has taken Kolb's cycle of learning and grounded it in emerging brain research to provide teachers with a foundation for teaching based in brain science that not only can improve student learning but also, as a bonus, shifts the control for learning from the teacher to the student. For Zull, a professor of biology and director of the University Center for Innovation in Teaching and Education at Case Western Reserve, understanding how the brain works has direct application for teaching. "Eventually," he states, "teaching would become the applied science of the brain" (p. 4).

Zull presents his ideas with a clarity that makes the information easily accessible to readers without a background in either biology or neuroscience. According to Zull, the brain is designed to sense, integrate, and act. These functions are not accidental, he states, but rather are found in the nervous systems of both simple animals and humans. In Zull's framework, there are the sensory cortices that receive signals from the outside world, the motor cortex for the generation of movement (action), and two integrative cortical areas, which will be differentiated momentarily. I caution that Zull's work is greatly oversimplified here. Zull takes an entire book to explicate his ideas, and he provides considerable supportive evidence for his conclusions that is not represented here.

Zull (2002) separates the cortex of the brain into four main regions, each with different functions that are congruent with the processes described in Kolb's cycle of learning. I caution that there are many important cortical and subcortical structures and connections within these divisions, but those structures are not elaborated in this brief summary. Zull's four divisions of cortex are sensory cortex, posterior integrative cortex, frontal integrative cortex, and motor cortex. The sensory cortices receive information from the outside world through sight, touch, hearing, smell, taste, and position. These sensory events correspond to Kolb's first stage in the learning cycle, **concrete experience**.

Once sensory signals have entered the brain, they flow to the integrative part of the brain nearest that cortical sensory receiving site. Zull refers to this integrative area as the posterior integrative cortex, the collective structures of which are concerned with the development of memory, language comprehension, visuo-spatial relationships, and the identification of objects and faces, among other processes. This region of cortex connects and combines sensory experiences to create images and meaning. These processes, performed by the posterior integrative cortex, correspond to Kolb's second stage in the learning cycle, **reflection**. During this phase, insights are developed, associations are made, and experiences are recalled and analyzed.

From the posterior integrative cortex, signals course forward to the frontal integrative cortex, an area whose combined elements are responsible for short-term memory, problem solving, planning, decision making, organizing, and directing actions. Here ideas are manipulated, past experiences are recalled, and plans for future action are formulated. These activities correspond to the development of **abstractions** in Kolb's cycle. Zull's fourth cortical division is the motor cortex, which is responsible for directing all voluntary bodily movements. The motor cortex executes the plans and ideas generated by the frontal integrative cortex; these actions correspond to Kolb's active testing (Zull 2002).

While sensing (experience) and information are the necessary building blocks for learning, receiving and remembering aren't the same as understanding. All teachers have experienced students who have diligently completed an assigned reading and have carefully committed the information to memory, but they are unable to apply what they have "learned." Zull (and Kolb) would argue that the student did not complete the cycle of learning. While they achieved the stages of sensing and reflection, they did not proceed to abstraction and the formation of their own ideas and explanations. Thus they have no ideas on which to act or to test, and they are unable to apply the concepts that they have committed to memory.

True learning involves acting: connecting new information to what is already known and creating and testing new ideas. The foundation for learning is present in the brain of each and every student; our challenge as teachers is to be creative in designing learning situations that are compatible with how our brains are structured to learn. No one can force a brain to learn, but we can structure assignments to foster the use of the complete brain, which, Zull avers, is wired to proceed from sensing and reflecting to planning for action, hypothesizing, explaining, and demonstrating. Teachers who provide experiences and assignments that engage all four areas of cortex and who make time for students to think, write, and discuss key concepts in class can foster deeper learning, a transformative experience in which the source of knowledge comes not from the outside, but from the inside—from the self, from one's own brain. The learner becomes the constructor of his or her own knowledge!

In a typical day in the classroom, we introduce our students to new ideas through a lecture, an assigned reading, or, perhaps, a video. This is analogous to Kolb's concrete experience. Oftentimes, students go no farther in the cycle of learning, that is, they neglect to reflect on the information presented or to make attempts to assign meaning to new ideas. They internalize inert information, information that is memorized but absent of understanding (Paul and Elder 2001). Here is a set of "entire brain" assignments designed to build on concrete experience and to foster reflection, abstraction, and active testing while addressing several of the concepts concerning the relationship between biology and behavior that might be covered in an AP Psychology course. Among the topics that, according to the *AP Psychology Course Description*, students should understand are: (1) the structure and function of neurons; (2) the anatomical and functional relationship among the central, somatic, and autonomic nervous system; and (3) the brain as a key part of the nervous system. (The Course Description is available on the AP Psychology Course Home Page: apcentral.collegeboard.com/psych.)

Assignment 1: Identify the Structure and Function of a Neuron

Materials: You will need one neuron-building kit for each group of three or four students. Use your imagination in collecting items for your kits. The following suggested items can be easily gathered:

- Two lengths of string: 36 inches and 24 inches
- Eight paper clips of varying size or color
- 12 bottle caps of two different types or colors (plastic water bottle caps, metal mineral water or cola caps)
- 18 small buttons of three different colors
- Six medium-sized buttons in two different colors
- Clear plastic drinking straws cut into one-half-inch pieces
- Wrapped candy (enough for two pieces for each member of the group for a reward at the completion of their work)
- Ziploc® bags to hold the kits

Part 1: Concrete Experience

The assignment assumes that students have completed readings and received lectures on neuronal structure and function.

Part 2: Reflection
After completing their reading, ask students to imagine that, as AP students, they have been invited to return to their elementary school to speak to a science class about neurons. To prepare for the visit, they are to begin to organize their thoughts by making a list of important principles and concepts associated with neurons that should be conveyed to the elementary school students in their talk. They do not need to elaborate their ideas at this point; they should merely construct a list of points to be covered in their speech. (See appendix A, "Sample List of Concepts Associated with Neurons," for possible concepts to be considered.)

Part 3: Abstraction
Instruct students to bring their list of concepts to class in duplicate. One copy is submitted to the instructor at the beginning of class to ensure that students have thought about the important things to know about neurons and to ensure that they are prepared for the group work to follow. Assign students to small groups of three or four students each. Using their lists as reference, the groups are to construct the ideal or complete list of concepts to be covered in their elementary school presentation. Inform them that they have a fixed amount of time to complete their list and to elaborate it. At the end of the allotted time period, call the class to attention. Ask each group to state and describe two important concepts on their list. Write their answers on the board and repeat this process until all groups have exhausted their lists and all key concepts that you think should be addressed have been offered.

Part 4: Action
Distribute a "neuron-building" kit to each group of students and instruct them that they have a fixed amount of time to construct a synapse that contains one complete neuron (axon, dendrite, soma) and a postsynaptic dendrite. Inform them that this synapse will serve as a model to help them demonstrate their key concepts to their elementary school audience. Circle the room and have each group explain and demonstrate as many of the various concepts and principles to you as they are able. (See appendix B for an image of a possible synapse constructed with the aforementioned objects.)

Assignment 2: Describe and Explain the Organization of the Nervous System

Materials: Obtain a figure depicting the autonomic nervous system (ANS) with the muscles, glands, and organs innervated. You can find many images on the Web through an Internet search for "autonomic nervous system."

Part 1: Concrete Experience
The assignment assumes that students have completed a reading or received a lecture on nervous system structure and function.

Part 2: Reflection
Have students construct and complete a table illustrating the divisions of the nervous system (see appendix C, "Divisions of the Nervous System"). Instruct students to generate a drawing of the central nervous system depicting the brain, brain stem, cerebellum, and spinal cord. If you have introduced sensory and motor roots of the spinal cord, have the students draw a cross section of the spinal cord as well.

Part 3: Abstraction
Distribute the figure of the autonomic nervous system and instruct students to write the effect of the sympathetic and parasympathetic nervous system next to the picture of each target organ.

Part 4: Action
Assign students to groups of three and distribute the scenarios presented in appendix D, "The Ups and Downs of the Autonomic Nervous System." Potential responses to the scenarios are also found in appendix D.

Assignment 3: Review the Structure and Function of the Brain

Part 1: Concrete Experience
The assignment assumes that students have completed a reading or received a lecture on brain structure and function and hemispheric specialization.

Part 2: Reflection
Tell students that they are to begin to construct a study guide for an upcoming exam on brain structure and function. Instruct them to list the four lobes of neocortex and to describe the functions of each. Next have them fold a sheet of paper lengthwise. Have them list the special functions of the left hemisphere in the left column and the special functions of the right hemisphere in the right column.

Part 3: Abstraction
As a homework assignment, have students draw left and right lateral and superior views of the cerebral hemispheres. Have students identify and label the four lobes of neocortex and the location of the motor and somatosensory cortices. If it has been covered, have students draw the limbic cortex within the temporal lobe. Alternatively, you can

download appropriate images for labeling from this Web site: http://staff.washington.edu/chudler/colorbook.html. Once they have labeled the lobes, students should describe at least two functions associated with each.

Part 4: Action

Assign students to create a collage that depicts the special functions of the two hemispheres, using their lists and drawings as guides. They can use images cut from magazines, draw the images themselves, or use clip art. (See appendix E for a very simple example constructed on the computer using clip art. The image shows thinking and movement in the frontal lobe, somatosensation in the parietal lobe, and sight and hearing in the occipital and temporal lobes respectively. These functions are common to both hemispheres.) To complete the assignment properly, the students should present left and right lateral views of the hemispheres. They should utilize images that depict the special functions of the left and right hemispheres; for example, the left hemisphere is dominant for language and speech for the majority of people. It is also superior for reading, writing, and mathematical calculations. The right hemisphere is superior at spatial relationships, recognition of faces, and attentional skills. It is also dominant for perceiving and interpreting facial expressions and mood and the perception of nonverbal acoustic stimuli.

Assignment 4: A Culminating Exercise

This assignment asks students to draw upon all they have learned about nervous system structure and function.

Place students in groups of three and distribute the assignment shown in appendix F, "Show Me What You Know!" Sample answers are included in appendix F.

Conclusion

These exercises are meant to spark ideas. They can be modified to suit the emphases of your course. The underlying principle is to structure assignments so they ensure that the ideas you want students to remember are registered in their brains by engaging their posterior integrative cortex through the process of reflection. Students may not attach meaning to their ideas at this stage. Subsequent assignments, designed to activate the frontal integrative cortex, should require students to elaborate what they "learned" in the first phase. Finally, help students to act on their ideas with an assignment that requires that they use their motor cortex to write, describe, explain, or construct. This last step can lead to new ideas and new experiences that can renew the cycle.

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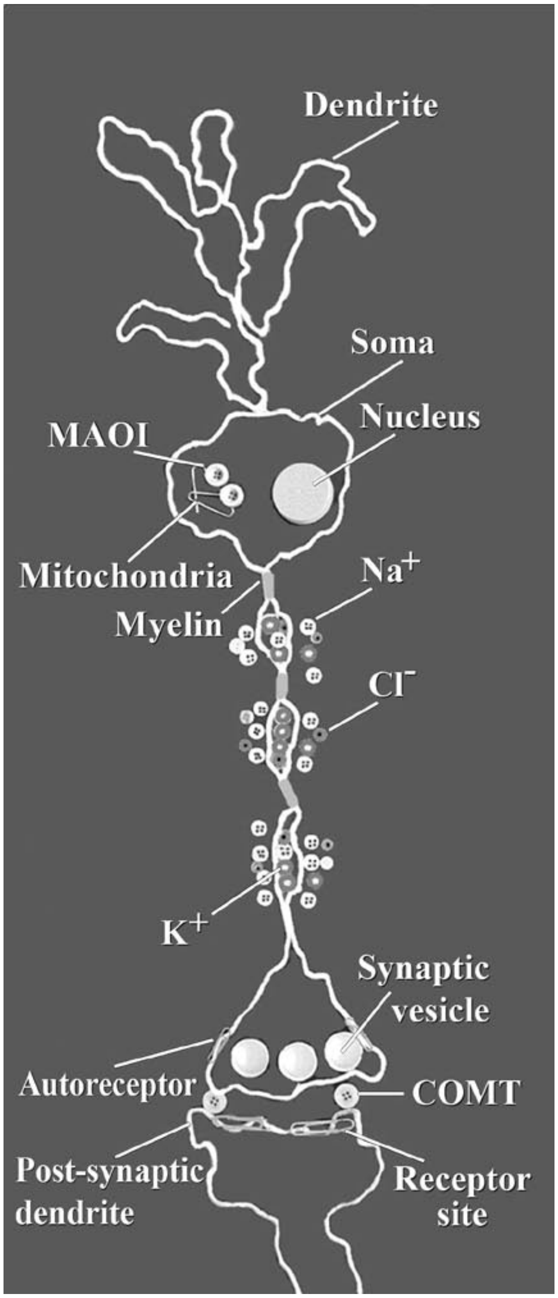
Appendix A: Sample List of Concepts Associated with Neurons

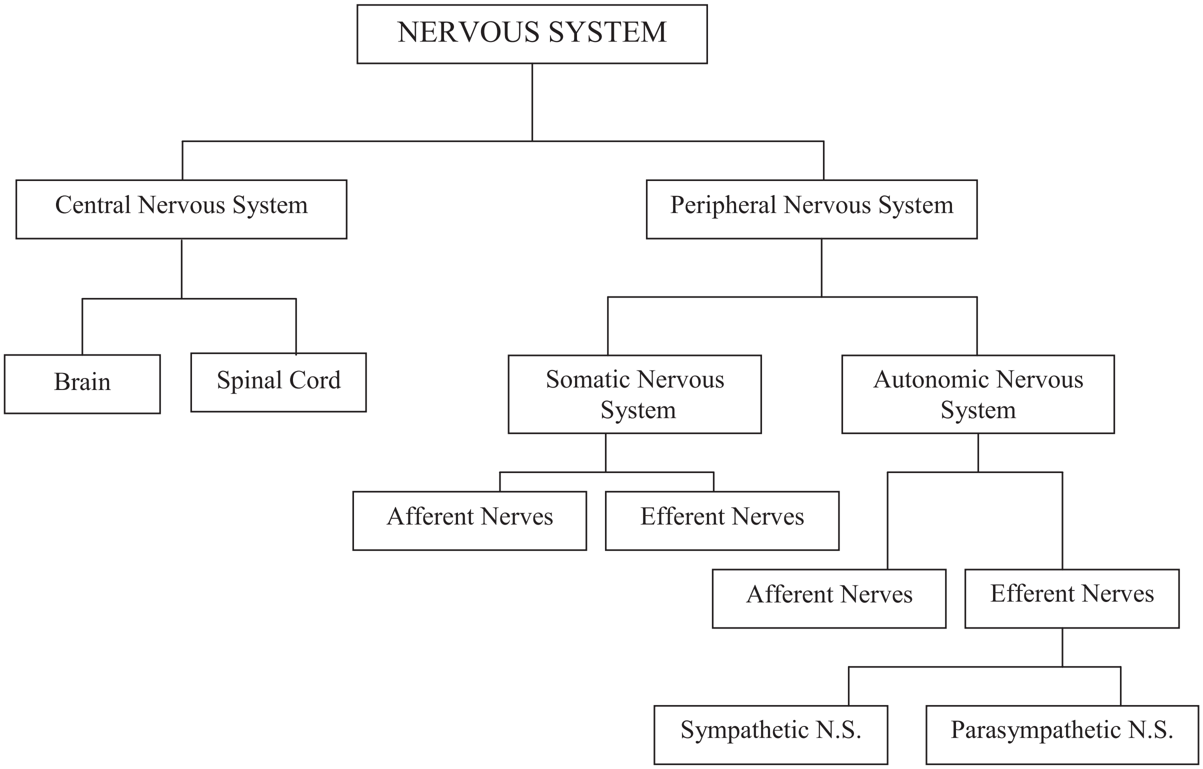
- All neurons have three parts: dendrite, axon, and soma.
- Neurons communicate with one another at functional junctions called synapses.
- The flow of information across the synapse is unidirectional.
- Neurons undergo electrical events called action potentials.
- Neurotransmitters are released following an action potential.
- Neurotransmitters produce excitatory postsynaptic potentials (EPSPs) or inhibitory postsynaptic potentials (IPSPs) in the postsynaptic cell.
- The effects of the neurotransmitter on the postsynaptic cell are terminated by enzymatic action or uptake processes.
- EPSPs and IPSPs are capable of temporal and spatial summation.

Appendix B: An Example of a Neuron and Synapse Constructed with the Neuron Kit



This image and the other images in this article were created by the author, Brennis Lucero-Wagoner.

Appendix C: Divisions of the Nervous System



Appendix D: The Ups and Downs of the Autonomic Nervous System

1. While walking home from school, J. is chased by a large, barking dog that has escaped from its owner's yard. Describe the bodily sensations that J. will experience as a result of this incident. Once J. is home and safe, will those sensations change? If so, how will they change?
2. T. has just joined the track-and-field team at school. Practice begins right after school, and T.'s usual habit is to have a big peanut-butter-and-jelly sandwich as soon as school is over. According to what you know about the autonomic nervous system, should T. continue with this habit and eat just before going to practice? Why, or why not?
3. Z.'s mother practices yoga, and she often encourages Z. to join her. On the day of exams, Z. usually awakens feeling anxious. By the time she gets to school, her mouth is dry, her hands are sweaty, and she has the sensation that she needs to urinate, although her bladder isn't full. Z.'s mom advises her to practice yoga before going to school on those mornings. Given what you know about yoga and the autonomic nervous system, is this good advice? Why, or why not?

Sample Answers to "Ups and Downs of the Autonomic Nervous System"

1. While walking home from school, J. is chased by a large, barking dog that has escaped from its owner's yard. Describe the bodily sensations that J. will experience as a result of this incident. Once J. is home and safe, will those sensations change? If so, how will they change?

   Possible answer: J.'s sympathetic nervous system will be activated during his "flight" response. Heart rate will accelerate, pupils may dilate, breathing (respiration) will increase, perspiration will ensue, and digestive processes will slow to conserve energy. There will be increased oxygen uptake, and blood sugar will rise. Once home and safe, the parasympathetic nervous system will begin to override the sympathetic nervous system to return the body to a resting state. Heart rate will return to normal, J. will cease perspiring, digestive processes will resume, the pupils of the eye will return to normal size, and respiration will slow.

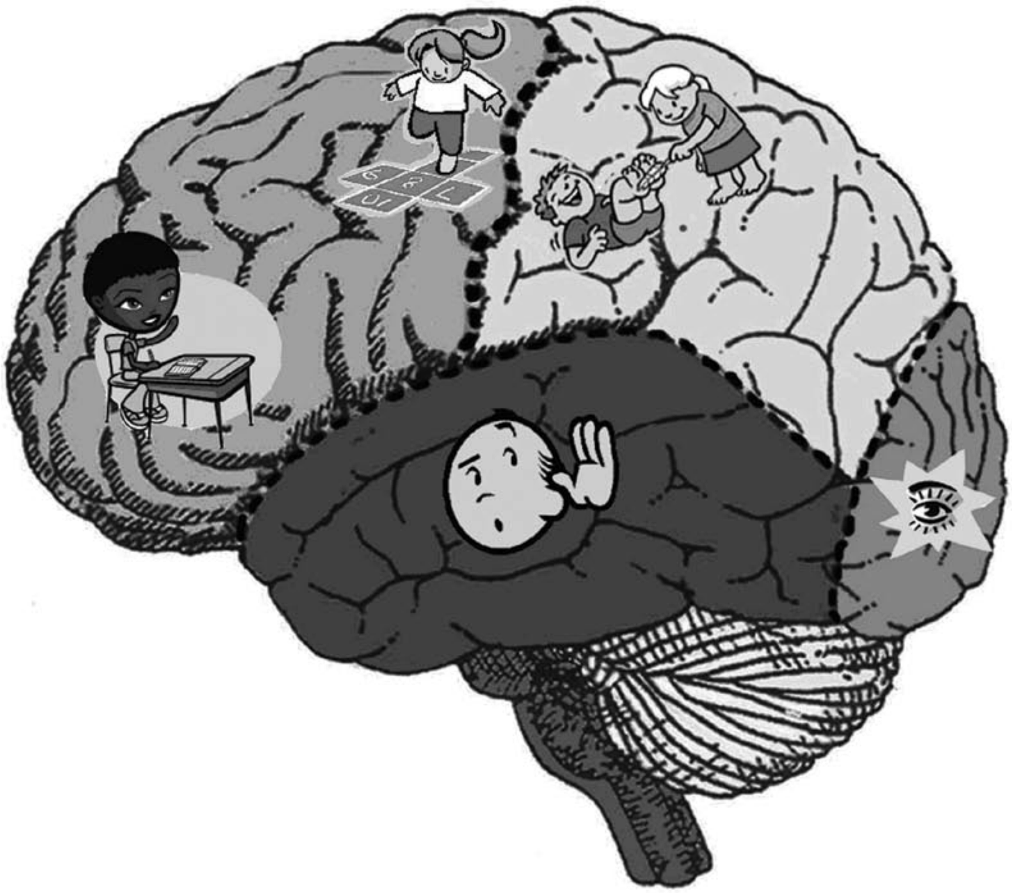
2. T. has just joined the track-and-field team at school. Practice begins right after school, and T.'s usual habit is to have a big peanut-butter-and-jelly sandwich as soon as school is over. According to what you know about the autonomic nervous system, should T. continue with this habit and eat just before going to practice? Why, or why not?

   Possible answer: T.'s sympathetic nervous system will be activated to prepare for the actions of running laps and especially for the competitive time trials run against T.'s teammates. Because the sympathetic nervous system slows the digestive activity of the stomach and intestines and reduces blood flow to those organs while increasing blood flow to the skeletal muscles of the legs, T.'s peanut-butter-and-jelly sandwich may sit like a lump and not be easily digested. As a result, T. may not get much benefit from that sandwich.

3. Z.'s mother practices yoga, and she often encourages Z. to join her. On the day of exams, Z. usually awakens feeling anxious. By the time she gets to school, her mouth is dry, her hands are sweaty, and she has the sensation that she needs to urinate, although her bladder isn't full. Z.'s mom advises her to practice yoga before going to school on those mornings. Given what you know about yoga and the autonomic nervous system, is this good advice? Why, or why not?

Possible answer: Z.'s bodily sensations indicate sympathetic nervous system arousal: dry mouth, sweaty palms, and the feeling that she needs to urinate, although her bladder isn't full. Individuals who practice yoga can learn to slow their heart and respiration rates. Individuals who practice yoga can learn to quiet their sympathetic nervous system and shift toward an increase in parasympathetic activity. Z. wishes to increase the activity of her parasympathetic nervous system and decrease the arousal responses of her sympathetic nervous system. Therefore the practice of yoga or meditation exercises might be a good thing for Z. to try, especially on stressful exam days.

Appendix E: Sample Figure Depicting Functions of the Four Lobes of Neocortex



Appendix F: Show Me What You Know!

You've just completed reading the chapter describing the structure and function of the nervous system. At first, this material may seem daunting. If you merely memorize the names of structures and their definitions, it's pretty boring, but if you try to think about how the nervous system is involved in producing behavior, thought, emotion, and memories, well, then it may seem more relevant and can even be fun.

Here is your challenge: Use your newly acquired knowledge of the anatomy and workings of the nervous system to describe which parts of the nervous system are activated in the individuals described in the three scenarios below. I'll get you started on each scenario with an example.

This is a contest. The group that lists the most structures with the correct explanation wins three points to be applied to any assignment or exam of their choosing.

1. Q., an architect, is constructing a drawing of a building she has designed. With a drawing pen in her right hand, Q. sips a cup of tea and hungrily eats an apple and some nuts with her left hand. As Q. works, a favorite techno-pop musical group can be heard in the background. She takes in the view out the office window, which overlooks a park that is resplendent with colorful flowers in bloom. The sky appears cobalt blue and is dotted with cumulus clouds.

   Sample answer: The left motor cortex is activated to control movement of her drawing hand.

2. Crazy E., a star basketball player, is competing with his team in an important basketball tournament. The player he is guarding is constantly "trash talking," and it makes him angry. Crazy E. is perspiring heavily, and his heart beats rapidly. With an angry look on his face, he yells back at his opponent. Suddenly, a teammate passes him the ball; he fakes his opponent and dribbles past him to make a beautiful left-handed jump shot. He hears the crowd roar as he turns and runs toward the center circle.

   Sample answer: The sympathetic nervous system is activated, producing perspiration.

3. T. has been studying hard in preparation for an important AP Psychology Exam. She repeats the divisions of the nervous system aloud several times and tries to recall the three parts of a neuron. She makes a drawing of the brain, labels the lobes, and uses colored pens to distinguish one lobe from the other. She has a lot more studying to do, but she's getting tired and sleepy. She tries to decide whether to continue studying or to stop for a while. She curls up on the bed, listens to music on an iPod®, relaxes, and dozes off to sleep. Soon she is dreaming about neural transmitters that look like M&Ms® being carried across a synapse in tiny SUVs.

   Sample answer: The frontal lobes are activated during decision making.

Sample Answers to "Show Me What You Know!"

Students are often quite insightful and creative in the answers they generate. It is important that they justify or explain their answers. These are some possible answers.

1. Q., an architect, is constructing a drawing of a building she has designed. With a drawing pen in her right hand, Q. sips a cup of tea and hungrily eats an apple and some nuts with her left hand. As Q. works, a favorite techno-pop musical group can be heard in the background. She takes in the view out the office window, which overlooks a park that is resplendent with colorful flowers in bloom. The sky appears cobalt blue and is dotted with cumulus clouds.

Suggested answers:

- The left motor cortex is activated to control movement of her drawing hand.
- The right motor cortex guides movement of the left hand.
- The hypothalamus is involved in the perception of hunger and thirst.
- The occipital cortex processes the visual scene.
- Retinal cone cells are activated by the colorful blooms and sky.
- The right hemisphere is involved in the visuo-spatial task of drawing.
- The right hemisphere processes the nonverbal acoustic sounds of the music.

2. Crazy E., a star basketball player, is competing with his team in an important basketball tournament. The player he is guarding is constantly "trash talking," and it makes him angry. Crazy E. is perspiring heavily, and his heart beats rapidly. With an angry look on his face, he yells back at his opponent. Suddenly, a teammate passes him the ball; he fakes his opponent and dribbles past him to make a beautiful left-handed jump shot. He hears the crowd roar as he turns and runs toward the center circle.

Suggested answers:

- The sympathetic nervous system is activated, producing perspiration and an accelerated heart rate.
- The left hemisphere processes the opponent's "trash talking."
- The left hemisphere produces Crazy E.'s verbal responses to his opponent.
- The right hemisphere processes the roar of the crowd.
- The right motor cortex guides the left-handed jump shot.
- The right hemisphere is involved in the development of Crazy E.'s angry facial expression.
- The cerebellum guides the direction, force, and velocity of Crazy E.'s movements in making the jump shot.

3. T. has been studying hard in preparation for an important AP Psychology Exam. She repeats the divisions of the nervous system aloud several times and tries to recall the three parts of a neuron. She makes a drawing of the brain, labels the lobes, and uses colored pens to distinguish one lobe from the other. She has a lot more studying to do, but she's getting tired and sleepy. She tries to decide whether to continue studying or to stop for a while. She curls up on the bed, listens to music on an iPod®, relaxes, and dozes off to sleep. Soon she is dreaming about neural transmitters that look like M&Ms® being carried across a synapse in tiny SUVs.

Suggested answers:

- The frontal lobes are activated during decision making.
- The left hemisphere (Broca's area) is involved in the production of speech.
- REM sleep is controlled by various sites in the reticular formation.
- The right hemisphere is involved in the appreciation of music.
- The right hemisphere guides her drawing.
- The parasympathetic nervous system becomes dominant as T. relaxes.
- The temporal lobe is involved in the development of T.'s explicit and semantic memories of the nervous system.
- The hippocampus is involved in the consolidation of T.'s long-term memory of the nervous system.

Basic Neuroscience

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Stillwater, Oklahoma

The human brain is certainly one of the most complex biological systems on earth and, it's safe to say, in our entire solar system. As students of this amazing creation, our task is to use the human brain to understand itself. The endeavor may be less paradoxical than it sounds, for each of us has firsthand knowledge of at least some of the brain's functions.

Nevertheless, the task is a daunting one, so let me describe the small part of it to be addressed here: the functioning of the basic unit of the nervous system, namely, the individual neuron. Students of psychology may wonder why they must understand neural functioning to understand human behavior. They may easily see the relevance of certain functional systems, for example, learning to fear a stimulus as Little Albert did with his white rat. Similarly, it is of great and obvious import to study the memory functions of the hippocampus and the sensory functions of the thalamus. But why study individual neurons? From my perspective, there are two primary reasons for this—one theoretical and one quite practical. The theoretical reason is that, to really understand how fear responses can be learned and how the hippocampus processes memories, we must know how individual neurons work because they are the bricks from which these edifices are built.

The practical reason for studying the functioning of individual neurons is that psychological disorders are increasingly being treated with psychoactive drugs. The effects of most of these drugs take place through the alteration of the physiological activity of neurons. To understand how drugs work (as well as nutrients and neurotoxicants), we must understand these neural effects.

What Neurons Do

The function of a neuron is to take in information from the environment or from other neurons, integrate that information, and then send information along to other neurons. Even if we disregard environmental input (as we will do in this article), this statement seems highly abstract and thus may cause our eyeballs to roll back into our heads. But let us substitute **chemical messenger** for the word **information**. Now the statement becomes suddenly very concrete. We could really wrap our brains around it if only that word **integrate** were not there. We think, "**Integrate** has a number of meanings, none of which we can plug into this sentence, can we?" For our purposes here, I define integration as the adding together of those chemical messages that excite a neuron and those chemical messages that inhibit it. If that summation of excitatory and inhibitory messages within the neuron results in a certain net level of excitation, the neuron will pass information—chemical messengers—along to other neurons. With these definitions, our statement becomes: "The function of a neuron is to take in the chemical messengers that other neurons send it, add together the excitatory and inhibitory messages they carry, and pass on chemical messengers to other neurons if the excitation is great enough." This now sounds comprehensible, and I hope this discussion of the processes involved proves to be just that.

A Brief Tutorial

The first step in understanding neural function takes us back to our fifth-grade arithmetic class, where we learned how to add and subtract negative numbers. If we start at 0 and subtract +2, we arrive at –2. Now shift from thinking of this as subtracting +2 to thinking of it instead as adding –2. If we are now at –2 and we add –3, the result is –5. We can add +4 to this amount to equal –1, then **subtract** –1 to bring us back to zero.

This little exercise refreshed our memories on four arithmetic operations: subtracting positive values, adding negative values, adding positive values, and subtracting negative values. The next hypothetical situation also uses these operations as an analogy for neural function. Say you are the treasurer of an organization, and to aid your bookkeeping you keep a cash box. In that box are two types of paper slips. Some represent debits and are thus negative numbers; others represent deposits and are positive numbers.

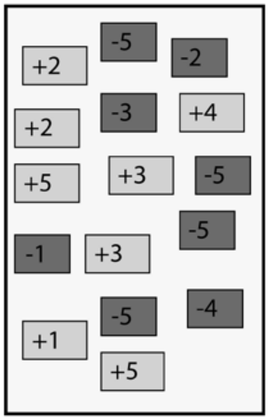

Figure 1: Treasury Box Analogy
This and the other images in this article were created by the author, David G. Thomas.

Figure 1 shows the contents of your treasury box with a net value of –5 dollars. A potential donor has said that, if your club can reach a net value of +5 dollars, she will provide a gift of $1,000. Therefore, adding a deposit slip of +2 dollars nudges you toward that **threshold** value of +5, while adding a debit slip of −1 or subtracting a deposit slip of +1 pushes you away from the threshold.

The Resting Potential

Now let us map our treasury box onto neural function. The box represents a neuron that is a living cell. The debit slips represent molecules within the neuron that carry a negative electrical charge. In real neurons, these negatively charged **ions** are mostly large protein molecules that cannot move out of the neuron. We will use the symbol −P to refer to these. The deposit slips represent positively charged ions, which can be either potassium or sodium. Potassium ions (which we will abbreviate as +K) are concentrated inside of neurons; sodium ions (+Na) are concentrated outside of neurons. Also concentrated outside are negatively charged chloride ions (−Cl). Although the −P ions always stay inside the neuron, the other three ions can pass through the wall, or **membrane**, of the cell. Analogous to the treasury box, adding and subtracting these ions will influence the net value, or **potential,** within the cell. And, as with the treasury box, if that potential becomes positive enough and the threshold value is met, a major event occurs.

The delicate balance of these four ions—+K, −P, +Na, and −Cl—creates what is called the **resting potential** inside the neuron. This means that when no information (no excitatory or inhibitory chemical messenger) is picked up by the neuron, the four ions are in equilibrium. The value of this resting potential is −70 millivolts. We will switch our analogy now from a treasury box to a battery, say the 12-volt battery in an automobile. The negative terminal of the car battery has a 12-volt electrical difference between it and the positive terminal. This means that a 12-volt charge is built up between the two terminals that can be released to do work, like power the car's starter motor. The electrical difference between the inside and the outside of the neuron is only 70 millivolts, with a millivolt (abbreviated mV) being 1/1,000 of volt, but this nevertheless makes that neuron a little battery with a 70 mV charge ready to be released. That release occurs when the neuron's threshold value is reached, which in this case is −65 mV, but we will discuss that later.

For now, let us continue discussing the resting potential, which we said was the result of an equilibrium among the four ions. Actually, we should call this a **dynamic** equilibrium because three major forces are at work here that produce the delicate balance. The first force we are all familiar with. It is called **electrostatic pressure** and can best be described as "opposites attract," meaning that areas of negative charge, like the −70 mV charge inside the neuron, attract positively charged ions like +Na. Conversely, charges that are alike repel each other. The −70 mV resting potential within the neuron repels the negatively charged chloride ions (−Cl).

The second force of this dynamic equilibrium is the tendency for molecules to move from areas of high concentration to areas of lower concentration. Therefore, since –Cl ions are concentrated outside of the neuron, they will tend to move into the cell where there are few –Cl ions.

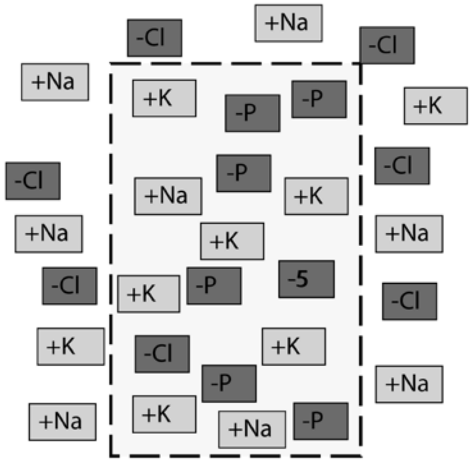

Figure 2: The Four Ions That Determine the Resting Potential

If we look at Figure 2, we can consider these two forces and how they act on each type of ion. Notice first, though, that the cell membrane of the neuron is drawn as a broken line. This is to represent the concept of **permeability**, that is, ions can pass through this membrane. (I already mentioned above that –P ions cannot pass through this membrane, so the effects of the two forces on them are irrelevant. The –P ions are locked within the cell.) Chloride ions (–Cl) are concentrated outside the neuron, so they will tend to move through the membrane into the cell. However, –Cl ions are negatively charged, so the negative charge inside the neuron will repel them. In fact, these two forces exactly balance each other such that –Cl ions do not cross the cell membrane when the neuron is at its resting potential. Similarly, the two forces act in opposite directions for +K: it tends to move out of the neuron because it is concentrated inside, but the negative charge inside tends to attract these positive ions. For +K, the concentration force is a little stronger than the electrostatic force, and therefore some +K ions "leak" from the neuron when it is at the resting potential.

Notice now +Na. We can see that both forces are acting on +Na ions to push them into the neuron. Why, then, is our –70 mV electrical potential not quickly drained in a manner similar to what would occur if the two terminals of a car battery were connected by a wire? The answer is that the permeability of the membrane at rest is very low for Na+ ions, while it is relatively high for +K (and –Cl). Permeability does not mean simply that the cell membrane has holes in it. Rather, embedded in the cell membrane are channels that are specific to each ion. These are called **passive channels**, and ions can pass freely through them, but each channel allows only one type of ion to pass. There are a great many passive channels for +K but very few for +Na. Therefore, the slight net force pushes a few +K ions out of many channels, while only a small number of passive channels allow +Na ions into the cell despite the very strong net force trying to push them in.

This is where the third force that helps maintain the resting potential comes in. This third force is called the **sodium-potassium pump**, and it does just that. This tiny mechanism pumps those few escaping +K ions back into the neuron and the few intruding +Na ions back out.

Our tiny battery is charged and ready to do its work, which is to communicate with other neurons. To do so, the neuron must be excited (or inhibited) by the information it receives from other neurons.

Excitation and Inhibition

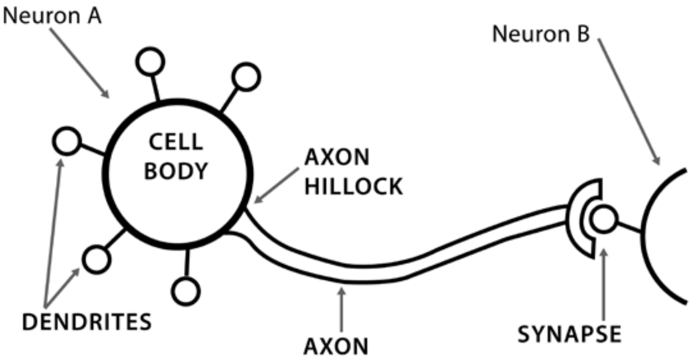

Figure 3: Schematic Diagram of a Neuron

Figure 3 is a schematic diagram of a neuron with its four primary parts labeled: the **dendrites**, which receive the chemical messengers from other neurons; the **cell body**, which maintains the vital functions of the neuron; the **axon hillock**, where the integration of incoming messages takes place; and the **axon**, which sends a signal down its length to release chemical messengers to other neurons. The neuron in Figure 3 is also shown to make a connection with a dendrite of another neuron. This connection is called a **synapse** and is shown in more detail in Figure 4. Only one synapse is shown in Figure 3, but a single axon may branch many times to form several synapses, either with one neuron or with many others.

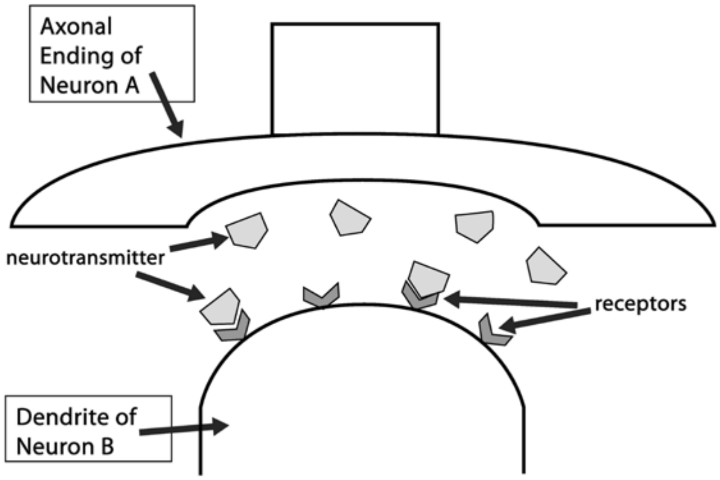

Figure 4: A Synapse

In Figure 4, we can see that Neuron A has released its neurotransmitter into the gap between its axonal ending and the dendrite of Neuron B. I will first describe the process of excitation; therefore this neurotransmitter is likely to be glutamate, which is the most common excitatory neurotransmitter in the brain. Glutamate molecules will cross the tiny gap between the point of their release from the axonal ending of Neuron A and the dendrites of Neuron B. **Receptors** for the neurotransmitter are shown on the dendrite. These receptors will only **bind** (that is, pick up) molecules of a certain shape, in this case, that of the glutamate molecule. The glutamate molecule fits into the receptor like a key into a lock. These receptors are connected to another type of channel, which are called **neurotransmitter-gated channels**. In essence, these channels can be thought of as doors that open when they are unlocked by the key that is the glutamate molecule.

In our current scenario where excitatory glutamate is involved, these channels open briefly and allow +Na ions to pass into the neuron. Recall that both the concentration and the electrostatic forces are attempting to push +Na ions into the neuron, so when sodium channels are opened, these ions will readily rush in. Since +Na carries a positive charge, we are adding positivity (deposit slips to our treasury box) to the –70 mV within the neuron. This drives the voltage within the neuron to, say, –67 mV. This driving of the internal voltage closer to zero is called **depolarization**, and it serves to excite the neuron a tiny bit. We call these small, positive charges created by the entering +Na ions **excitatory postsynaptic potentials**, or EPSPs.

If the neuron is depolarized enough such that the threshold value of –65 mV is achieved, the major event that I alluded to earlier occurs: the neuron fires an action potential, which is basically a spark of electricity that travels down the length of the axon and causes the release of the neuron's own neurotransmitter. However, this is not as easy as it sounds. The threshold value of –65 mV has to occur at the **axon hillock**, which is where the action potential is initiated. The inrushing +Na ions do not change the voltage value of the entire neuron but only at the locale where these ions entered. That local excitation must travel all the way to the axon hillock in order to fire the action potential. This is difficult because that excitation dissipates along the way. The farther the distance between the opened +Na channels and the axon hillock, the more dissipation will occur. To help visualize this process, think of the neuron as a large circular basin of water. Mentally mark a Point X anywhere on the rim of the basin. This will be analogous to the axon hillock. Now take an eyedropper filled with red dye and release a single drop of it into the basin at Point Y, the farthest point possible from Point X. The drop reddens the water at Point Y and begins to dissipate. If any of the red color reaches Point X, it is so diluted that we cannot see it. This is what happens to the EPSPs that occur as +Na ions enter the neuron. They move toward the axon hillock but quickly dissipate.

Now release several drops of red dye from your mental eyedropper at Point Y. If enough red dye is released, some of it will appear at Point X. An analogous process occurs in neurons. If the +Na channels are opened several times, EPSPs travel the distance to the axon hillock such that sufficient depolarization occurs there to reach the threshold value. However, this opening of the same set of +Na channels must be done in rapid succession, a process called **temporal summation**. Why? Because, unlike our basin of water, the neuron has a sodium-potassium pump that will remove the +Na ions. Of course, a neuron could be excited by glutamate at several synapses simultaneously (analogous to adding drops of red dye at several places around the basin's rim). Again, we have the adding together all of these inputs in what is called **spatial summation**.

Not all synapses involve the excitatory neurotransmitter glutamate. By some estimates, up to 80 percent of the synapses in the brain do not involve excitation at all but serve instead to inhibit neurons. The most common inhibitory neurotransmitter is **gamma-amino-butyric acid**, or GABA for short. GABA is released by axonal endings in the same way that glutamate is released, and GABA also traverses the synaptic gap and binds to receptors on dendrites. GABA, too, fits into these receptors like a key in a lock and opens neurotransmitter-gated channels. However, instead of opening +Na channels, GABA opens either –Cl channels or +K channels. From our discussion of the resting potential, we know that the net effect of the forces working on +K ions is to push them out of the neuron. When this occurs, we are subtracting deposit slips from the treasury box that represents our neuron. The resulting effect is to make the –70 mV potential inside the neuron even more negative, say to –72, –75, or even –80 mV. A moment's thought allows us to deduce the ramifications. This process pushes the neuron's voltage level further away from its threshold of –65 mV. Therefore more excitation is now required to fire an action potential: the greater the outflow of +K ions, the more the inhibition and with it the decreased likelihood that the neuron will fire. The outflow of +K ions creates **inhibitory postsynaptic potentials** (IPSPs). The inside of the neuron is pushed away from its threshold, that is, it is **hyperpolarized**.

Integration of EPSPs and IPSPs

With something like 10 to 100 billion neurons in the brain, it is quite likely that at any given moment, a neuron is receiving information (that is, neurotransmitters) from several other neurons. Some of this information will be excitatory in the form of glutamate and some inhibitory in the form of GABA. If the net voltage—the sum of all of the resultant EPSPs and IPSPs—reaches the –65 mV threshold, the neuron will fire an action potential. But let us remember that this threshold voltage cannot occur just anywhere in the neuron. It must occur at the axon hillock. In other words, it is at the axon hillock where the integration of input takes place. It is as if a little man with a calculator resides at the axon hillock, adding EPSPs and subtracting IPSPs. If and when his calculator reaches –65, the little man presses a button that starts a cascade of events that results in the action potential.

The Action Potential

Of course, there is no little man residing in each neuron. Instead, there are **voltage-gated sodium channels**, which open when the threshold voltage of –65 mV is achieved at the axon hillock. These voltage-gated sodium channels are located all along the length of the axon, but initially only those at the axon hillock open. A great many positively charged +Na ions rush into the neuron at this location, causing the voltage to go from –65 up to +50 mV. This spike of positive voltage is the action potential.

However, as I mentioned earlier, the action potential travels down the length of the axon, the result of which is the release of neurotransmitter. This process of the propagation of the action potential down the axon is shown in Figure 5.

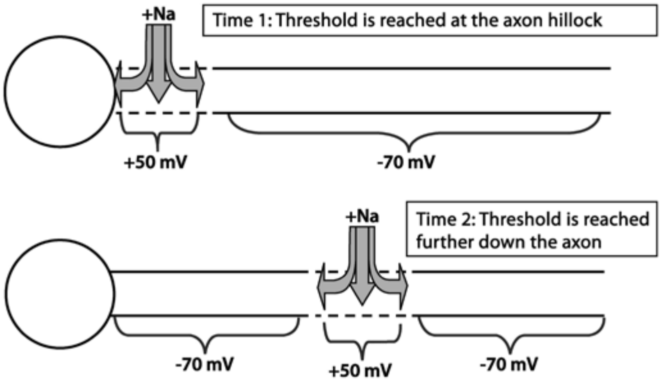

Figure 5: The Action Potential and Its Propagation Down the Axon

When threshold is reached at the axon hillock at Time 1, local sodium channels open (represented by the dashed line), +Na ions enter, and the voltage rises to +50 mV. However, the entrance of those +Na ions causes depolarization of the neighboring segment of the axon, resulting in this adjacent area reaching threshold. Consequently, its voltage-gated sodium channels open, and the action potential now occurs here (at Time 2 in Figure 5). This process occurs continuously down the length of the axon until the action potential reaches the axonal endings.

I need to point out that the size of the action potential stays at +50 mV down the whole length of the axon, regardless of how long the axon is. Thus we say that action potentials are **nondecremental**—unlike EPSPs and IPSPs, which lose their intensity as they move through the dendrites and cell body. Action potentials are nondecremental because they self-perpetuate in the manner shown in Figure 5. This holds true even for axons that branch many times. At the end of each branch, when the action potential arrives, it is still +50 mV. Action potentials are always the same size: if they occur, they are +50 mV, not +20 on some occasions and +80 on others. This is to say that action potentials are **all or none**.

Another subtle point shown in Figure 5 is that, at Time 2, the local environment near the axon hillock has returned to its resting potential as the action potential travels down the axon. Two processes are primarily responsible for returning the axon to –70 mV. The first is that shortly after +Na ions begin to flow into the axon, the depolarization they produce triggers voltage-gated **potassium** channels. These channels have a somewhat higher threshold than sodium channels, so they open after the action potential is well under way. Consequently, +K ions begin to flow **out** of the axon. This removal of positively charged ions begins to push the voltage down toward zero and back into the negative range.

The second process that serves to reset the local environment to −70 mV is that the voltage-gated sodium channels close when the action potential reaches its peak, stopping the flow of positively charged ions into the neuron. The potassium channels remain open after the sodium channels close, and thus the outflow of +K ions continues until the voltage reaches the resting potential, thus "recharging the battery" so that the axon hillock is ready to initiate another action potential. The entire process from the time sodium channels open until potassium channels close is approximately one millisecond (one-thousandth of a second). During this time, another action potential cannot be initiated at the axon hillock, and thus this duration is referred to as the **absolute refractory period**. This puts a limit on the firing rate of a neuron to about 1,000 times per second.

Neurotransmitter Release

Our action potential has finally reached the end of the axon. As mentioned above, a single axon may branch many times, and consequently action potentials travel down, and to the end of, each branch. At each axonal ending are more voltage-gated channels, but these are for **calcium**. I have not yet mentioned calcium, but it, too, is concentrated outside of neurons. The high voltage level of the action potential opens these calcium channels, causing these ions to flow into the axonal ending. Here we find neurotransmitter molecules packaged in what are called **synaptic vesicles**. The influx of calcium causes these vesicles to release their contents into the synaptic gap. This neurotransmitter might be glutamate, which will bind to receptors on the receiving neuron and cause EPSPs within it. If the neurotransmitter is GABA, IPSPs will occur. This brings us full circle back to where we started.

Putting Neurons to Work

Before ending the discussion of basic neural function, let me try to put this knowledge into context to show how neurons work together to allow us to interact with our environment. We will put ourselves in what might be a typical psychology experiment. We sit at a computer with the index finger of our right hand on the space bar. For starters, our task is to simply look at an X in the middle of the screen and press the space bar whenever that X changes from red to green. When we perceive this color change, our frontal lobes initiate a message that eventually tells that right index finger to move. This message is relayed through the motor cortex and sent down to the brain stem and spinal cord and finally through the axons of neurons that signal the proper muscles to contract. These signals are relayed through a chain of neurons, with each one depolarizing the next through the release and binding of glutamate. It is not difficult to imagine how these excitatory signals might spread to nearby neurons and thus cause other muscles to contract, especially muscles close to those that are causing our index finger to flex downward. If this were to occur, perhaps all of our fingers would move. Or perhaps none of them would, even the index finger we wanted to move, because another muscle pulled the finger in the opposite direction. Obviously, this does not happen, and the reason it does not is because some of those excitatory signals are causing the depolarization and firing of neurons that release the neurotransmitter GABA. This neurotransmitter inhibits nearby neurons that activate these adjacent muscles, keeping them silent and allowing only those needed for the index finger flexion to fire. Thus the simple flexion of our index finger requires a finely orchestrated interplay of excitatory and inhibitory messages.

Now let us make our experiment more complicated. We will still be looking at the X, but our task is to press the F key when a small square appears briefly to the far left of the screen and the J key when it appears to the far right. Before the black square (to which we are to respond) appears, a small red circle flashes briefly to the left or to the right to warn us where the black square will appear. This warning, though, is correct only 80 percent of the time. So, while looking at the center X, a red circle flashes on one side of the screen, followed some variable interval later by the black square, and we press the correct key as quickly as possible. When we do this experiment, we find that our reaction time to the square that is accurately predicted by the red circle is considerably faster than when the red circle cues the wrong side. It makes intuitive sense that this would happen, but why? When we see the red circle, it focuses our attention to the side on which it appears. This attention primes our brain to expect, albeit with some uncertainty, the black square to appear there. This attentional prime gives a head start to the visual area of the brain monitoring that side as well as the appropriate response hand. The result is a reaction time that is faster to a correct red circle cue because the incorrect ones deliver these priming effects of attention to the wrong parts of the brain.

As our final task in this long lesson on neural function, let us build a model of how the brain might do this. To keep it simple, we will focus only on the attentional priming of the left and right index finger responses. (Similar processes would also occur for the visual system.) When the left index finger responds, the signals are sent from the right motor cortex; when the right finger responds, the signals come from the left motor cortex. At this point, I need to introduce one final concept. This concept is not often taught in undergraduate courses, even those devoted entirely to neurobiological psychology, but it is not a difficult one and goes a long way toward understanding how brains produce behavior. This concept is **neuromodulaton**, which can be thought of as the mechanism that provides the head start of attentional priming.

Neuromodulation involves neurons that release chemical messengers, which in this case are called **neuromodulators**. These do not affect just a few neurons at local synaptic sites as neurotransmitter do. Rather, neuromodulators are released by neurons and diffuse through the extracellular space to bind to receptors on large groups of neurons. In our case, suppose that the red circle cue appears on the right. The areas of the frontal lobe that control attention release a neuromodulator in the hand area of the left motor cortex. This neuromodulator affects all of these neurons, perhaps depolarizing them from their –70 mV resting potential to –67 mV. This depolarization is the head start that attention provides. Now when the signal arrives that the black square occurred on the right side, the already depolarized neurons controlling the right index finger are more easily brought to threshold and thus fire sooner. The result is a faster reaction thanks to the neuromodulator provided by the frontal areas in response to the cue. The neuromodulator does not provide specific information for specific neurons to act; those specific signals come in the form of neurotransmitters at local synapses. The neuromodulator provides a "ready and waiting state" that allows for faster responding when the specific signals do come.

From these examples, we can get a glimpse of how the brain interacts with its environment through the complex interplay of many types of neurons. Some provide a background state such as the attentional priming of neuromodulators. Other neurons communicate specific messages within this background state, messages that are both excitatory and inhibitory. The excitation is finely guided through to its destination by inhibitory signals that keep the excitation under control.

Summary

In this short primer, we have covered the basic processes by which neurons carry out their primary function, that is, communication. By starting with the analogy of the neuron as a treasury box, we saw how adding and subtracting positive (excitatory) and negative (inhibitory) ions influence the cell. We then learned about the forces that balance these ions into a state of dynamic equilibrium called the resting potential. From there, we saw how information—that is, neurotransmitters—from other neurons pushed this resting potential either toward threshold or further away from it. If the excitatory postsynaptic potentials were large enough to reach this threshold at the axon hillock, a cascade of processes occurred that resulted in a large positive potential—the action potential—moving down the axon and causing the release of that neuron's own neurotransmitter. We then explored two ways in which neurons can work together as systems to produce intelligent, goal-directed behavior. I hope the explanations provided here have been sufficiently clear to allow a full understanding by those brains trying to comprehend it.

Teaching Resource: Neurons in the Real World

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Introduction

The typical images of neurons found in most introductory psychology textbooks are an artist's rendering of the various neuronal structures. While these drawings are helpful and illustrate key ideas, few introductory students have been exposed to the neuron in the "real world." Powerful microscopes and various staining techniques have opened this incredibly small and detailed world to the naked eye. Students of psychology should be exposed to the beauty and intricacy of the neuron while they are learning about its basic structures and functions. In addition to giving students a view of neurons in their natural environments, exposing students to these images will likely stimulate further interest in the biological basis of behavior.

This teaching resource provides AP Psychology teachers with images of the neuron that they can easily implement into their course lectures. The images have been selected for the clarity and contrast of the stain, the level of detail, and student interest. The images are of neuronal types and structures typically covered in AP Psychology courses and can be used for instruction and to supplement traditional overheads or PowerPoint slides.

I have provided Web links to the various images. Teachers can easily access these slides for use in the classroom. I have also included hand-drawn pictures of the slides, along with a brief description of each, to provide teachers with references for the different drawings.

Equipment Needed

- Teachers will need a connection to the Internet to access each Web image for personal use.
- The hand-drawn pictures of each image may be enlarged and copied for lecture.
- Colored pencils or crayons may be used to color and label each image.

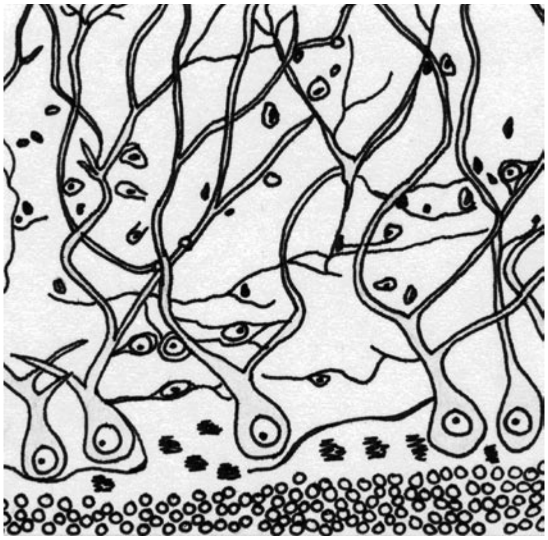
For further study, teachers can visit numerous histology Web sites, such as Histology-World (www.histology-world.com). Additionally, histology textbooks—such as *Wheater's Functional Histology: A Text and Colour Atlas*, 4th ed. (edited by Barbara Young and John W. Heath, Churchill Livingstone: Edinburgh, UK, 2000)—contain a wealth of knowledge regarding staining techniques and provide other ideal images.

Method

Teachers can use these slides to supplement a lecture on the function and structure of the neuron. After explaining and illustrating each neuronal structure with more traditional textbook images or PowerPoint slides, the following images could be used.

In addition, for an assignment, teachers could ask students to color and label the different structures of the neurons, or to identify different types of neurons, and to provide a brief explanation of how each functions.

Dendrites



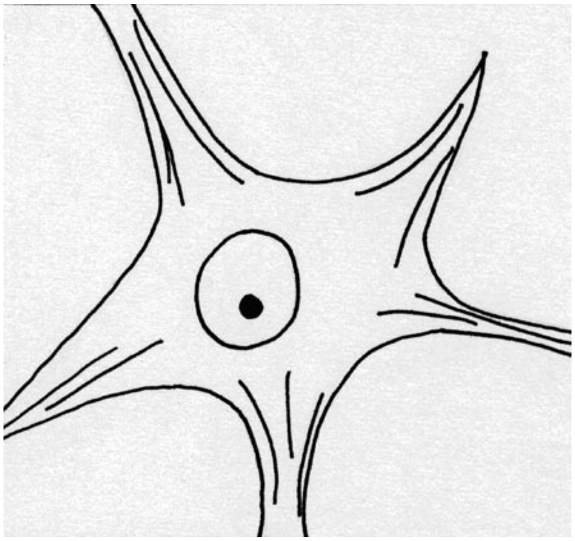
Slide 1: Purkinje Cells Dendritic Trees

Original slide: www.udel.edu/Biology/Wags/histopage/colorpage/cne/cnepcdt.GIF

This image and the other images in this article were created by the author, Jessica Habashi.

Description of slide: This high-contrast image clearly demonstrates the intricately branched network established between neighboring neurons, in this case the Purkinje cells of the cerebral cortex (cell bodies in bottom third, dendritic trees in upper two-thirds). You can ask students to identify the large cell bodies and dendrites (the axons are not visible). Encourage students to follow the path of the dendrites emanating from one neuron to reinforce the complexity and possibility for neural networking that arise as each dendrite branches. Should students become interested in the other cells that are visible in this image, explain that the cerebral cortex has three layers: the granular layer (below the Purkinje cell bodies), the Purkinje layer (at the level of the Purkinje cell bodies), and the molecular layer (above the Purkinje cell bodies).

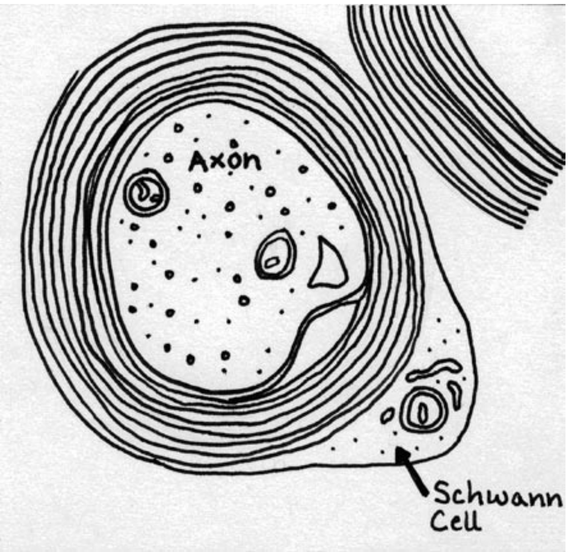
Cell Body



Slide 2: Motor Neuron
Original slide: www.udel.edu/Biology/Wags/histopage/colorpage/cne/cnemnn.GIF

Description of slide: This slide shows a single neuron. In the online version, the cell body is stained pink, while the nucleus of the cell, which houses the DNA, is a clear, round body with a dark dot in the center. This dot is the nucleolus, a part of the nucleus that is involved in producing ribosomes. Ribosomes are cell components that are necessary for protein production and should be familiar to students taking biology. Many common histological stains do not allow for direct observation of the axon; however, this image shows at least four dendrites (6, 8, 11, and 1 o'clock) and a probable axon (roughly 4 o'clock).

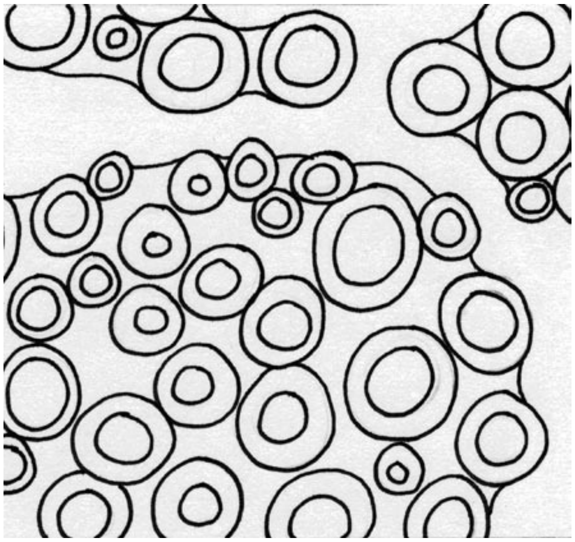
Axon



Slide 3: Myelinated Axon (A)

Original slide: www.udel.edu/Biology/Wags/histopage/empage/en/en3.gif

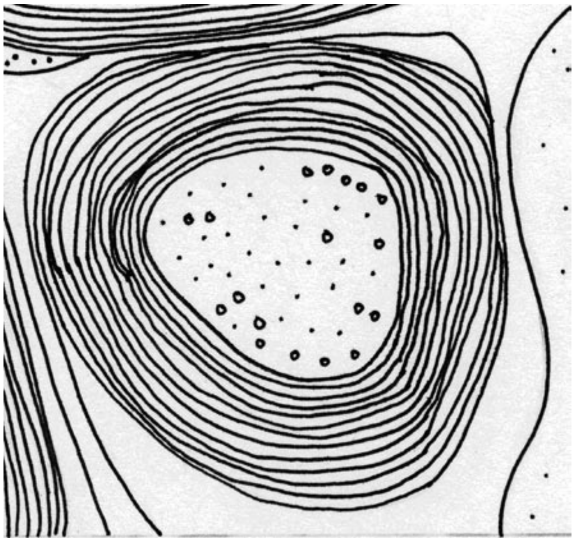
Description of slide: This image was produced from a section of neuronal tissue using an electron microscope. The resulting images, termed electron micrographs, allow us to visualize structures that are far too small to be seen using a common light microscope. The axon of this neuron has been cut in transverse (cross) section, such that the axon would come from behind the screen and outward toward the viewer. The small dots within the axon are the cytoskeleton of the cell, and they are involved in transporting such things as neurotransmitters from their site of production (the cell body) to their point of release (the axon terminals). The concentric rings are the myelin sheath. For neurons in the peripheral nervous system, Schwann cells produce the myelin sheath, which, in the online image, is marked with an arrow at 5 o’clock.



Slide 4: Myelinated Axons, Osmic Acid Stain

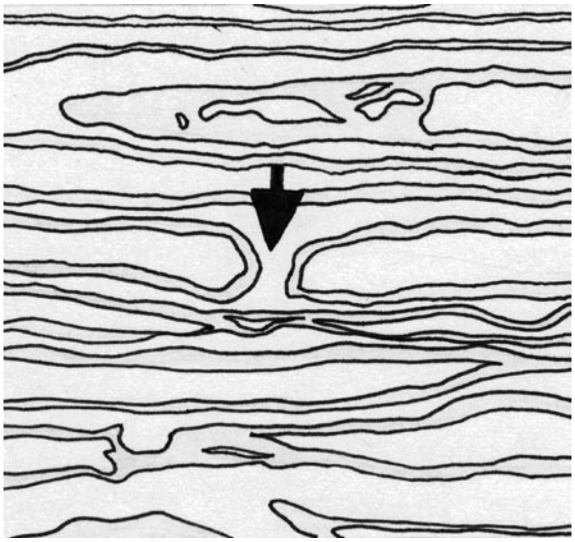
Original slide: www.udel.edu/Biology/Wags/histopage/colorpage/cne/cnemaoa.GIF

Description of slide: This highly magnified image of a nerve shows explicitly how the axons of individual neurons are bundled together in nerve tracts. The special osmic acid stain allows visualization of membranes, while other cellular structures are dissolved away. The nerve in this image has been cut in transverse (cross) section, such that the nerve is coming from behind the screen and would continue outward toward the viewer. The cut and stain of this tissue allow the myelin sheaths to be visualized as dark, donutlike structures. It is worth reminding students that deterioration of myelin is the hallmark of multiple sclerosis, a disease with various symptoms, including impaired coordination, mobility, and speech.



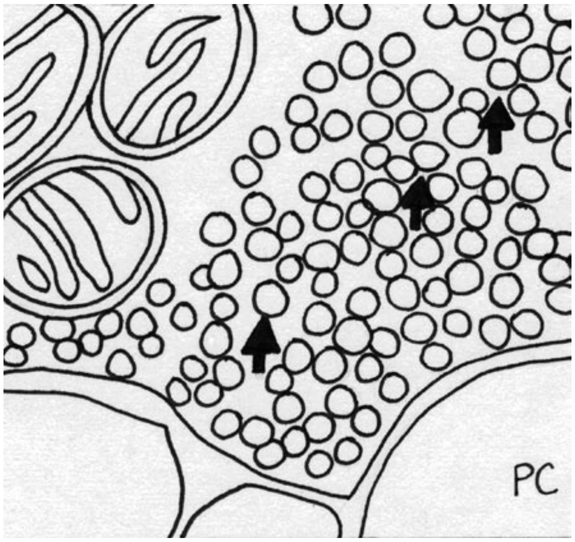
Slide 5: Myelinated Axon (B)
Original slide: www.bu.edu/histology/p/21302oca.htm

Description of slide: This electron micrograph is similar to the myelinated axon (A) shown in slide 3. The concentric rings of myelin surround the axon, and the small dots are transverse cuts through the cytoskeleton of the neuron. The cytoskeleton components are termed neurofibrils, and they run along the length of the axon like slender microscopic rods. Their functions include supporting the cell structure and acting as conveyor belts for delivery of products produced in the neuron cell body (that is, neurotransmitter vesicle components) to the sites of release (axon terminals).



Slide 6: Node of Ranvier
Original slide: www.udel.edu/Biology/Wags/histopage/colorpage/cne/cnenr.GIF

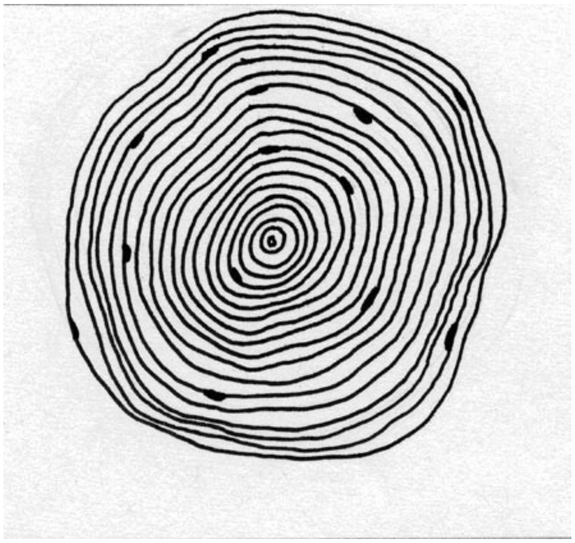
Description of slide: This image shows a number of axons cut in longitudinal section (along the length of the axons, instead of cross section). The stain allows direct visualization of the myelin sheaths in pink (visible online). The arrow denotes a site of discontinuity in the myelination of one of the axons, otherwise known as a node of Ranvier.



Slide 7: Synaptic Vesicles
Original slide: www.udel.edu/Biology/Wags/histopage/empage/en/en5.gif

Description of slide: This electron micrograph shows sections of three neurons—one presynaptic and two postsynaptic (PC) cells. The presynaptic cell is full of vesicles containing neurotransmitter (see arrows). The trio of larger, round structures in the upper-left corner is mitochondria, cellular components that produce energy for various cell processes, including the release of neurotransmitter (students who have taken biology should be acquainted with mitochondria).

Sensory Neuron

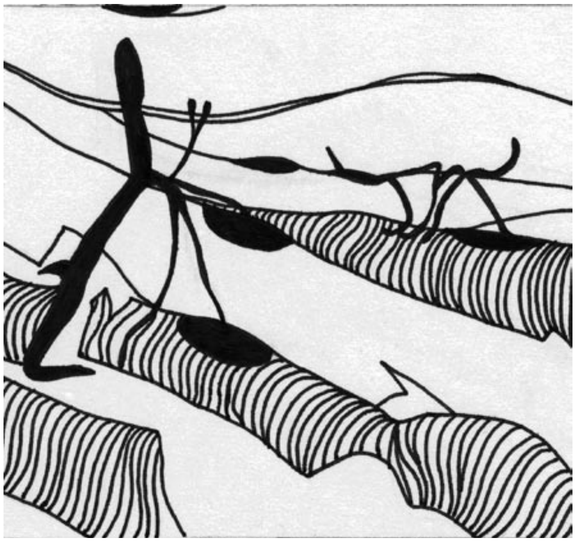


Slide 8: Pacinian Corpuscle

Original slide: www.udel.edu/Biology/Wags/histopage/colorpage/cne/cnepc.GIF

Description of slide: In addition to such traditionally discussed sensory neurons as the rods and cones of the eye, or the hair cells of the inner ear, there are structures that lie deep in the skin and sense pressure changes (not constant pressure) and vibrations. These are called Pacinian corpuscles, and their concentric appearance in cross section resembles a cut onion. The dark, oval-shaped structures that lie within the concentric rings of the corpuscle are nuclei of cells called fibroblasts. These produce connective tissue that supports the corpuscle structure. Also seen (in the online version) within the concentric layers of the corpuscle are small, red dots, which are red blood cells running through capillaries that lie between the layers of the corpuscle. Finally, there are the layers of the corpuscle of flattened and thin, highly modified Schwann cells. At the center of this structure is a single, unmyelinated afferent axon. Students may be interested to know that the cluster of large, white irregular spaces at the bottom right (5 o'clock) are actually sites of fat storage. In this preparation, the white is actually not the fat itself since the fat has been removed, but the spaces once occupied by the fat are still visible.

Motor Neuron



Slide 9: Motor End Plates

Original slide: www.udel.edu/Biology/Wags/histopage/colorpage/cne/cnemep.GIF

Description of slide: Motor end plates, also called neuromuscular junctions, are sites of communication between the nervous system and the muscles of the body. The muscle cells that are under voluntary control (also called skeletal muscle) are long, cylindrical cells, seen here in longitudinal view. The striped appearance of these cells is due to repeating rows of contractile proteins. When the signal for movement is relayed from the axon terminals, acetylcholine in this case, these contractile proteins slide past each other, causing the muscle cells to shorten in length. As this occurs in the muscle cells along the length of an entire muscle, the whole structure shortens, producing what we know as muscle contraction. Students may already be familiar with this process, since impairment of acetylcholine release by the botulism toxin, as used in cosmetic treatments, results in muscle paralysis.

Teaching Activity: Memory, Memory Loss, and the Brain

Kristin H. Whitlock
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Introduction

Researchers can learn more about the brain by studying cases of individuals whose normal brain functioning has been disrupted by injury, surgery, or disease. In this activity, students will focus on specific cases where a patient's hippocampus has been damaged, resulting in defective memory formation. Many introductory psychology textbooks describe such cases. This activity provides references for three case studies: Clive Wearing, H.M., and Jimmie G. Such stories are intriguing to students and provide an interesting context in which to discuss the workings of the brain in relation to ourselves.

This activity is best presented after students have completed background reading on brain structures and functioning or have received such information in class lecture. This activity allows teachers to review general content as well as focus on the role of the hippocampus in permanent memory storage.

Supplies Needed

Blank paper, pencil, and crayons or colored pencils

The Mind: Teaching Module 10, "Life Without Memory: The Case of Clive Wearing, Part 1" (14 minutes, 25 seconds). You can view a streaming clip at www.learner.org/resources/series150.html or purchase *The Mind* series, including 35 teaching modules, at 1-800-LEARNER or www.learner.org (ISBN 1-57680-180-2).

Or:
"The Lost Mariner" from Oliver W. Sacks, *The Man Who Mistook His Wife for a Hat* (New York: Harper Perennial, 1985, ISBN: 0060970790), pp. 23-42.

Or:
"The Man Who Lives for the Present: The Story of H.M." from Geoff Rolls, *Classic Case Studies in Psychology* (London: Hodder Arnold, 2005, ISBN: 0340886927), pp. 51-60.

Method

Have students draw the left hemisphere, placing the four lobes (frontal, parietal, temporal, and occipital) in the correct locations. Students should include a brief description of the function of each lobe. These drawings can be done individually or with a partner.

When finished, discuss with students which lobes of their own brains they used for which aspect of this assignment. List their answers on the board.

If students do not mention memory, ask, "What role might memory have played in this assignment?" Students may discuss they had to remember facts about the functioning of the different lobes and the locations of the lobes from either reading or lecture. Students may also discuss they had to know how to draw.

Introduce the concept of **explicit** (declarative) and **implicit** (nondeclarative) memories. Write each term on the board. Instruct students that explicit memories include general knowledge (also called **semantic memory**) and knowledge for events they have personally experienced (also called **episodic memory**). These types of memory require conscious recall. Give students examples of each (for example, July 4, 1776, as the signing date of the American Declaration of Independence for semantic memory and their memory of what they did over summer vacation for episodic memory).

Implicit memories are accessed without conscious recall and include memory for motor and cognitive skills, also called **procedural memories**. Give examples or elicit student examples (for example, riding a bike). Refer to David G. Myers, *Psychology*, 7th ed., (Worth Publishers: New York, 2004).

Teachers can download a free PowerPoint image to accompany this discussion at the Worth Publishers Image & Lecture Gallery for Psychology at www.worthpublishers.com/exploring/content/instructor/index.htm. Select the following sequence of links:

1. "Access the Image and Lecture Gallery here"
2. "Browse"
3. "Psychology: Introductory Psychology"
4. "Myers, *Psychology, 7e*"
5. "Chapter 09: Memory"
6. "Figure 9.12 - Memory subsystems"

After establishing the difference between explicit memories as the "things we know" and implicit memories as the "things we do," refer back to the student's brain drawings. What aspects of the assignment reflected implicit memory? Explicit memory?

Ask students, "Where is memory stored?" Discuss how the type of memory determines where memory is stored in the brain. Implicit memories seem to be stored in the cerebellum. Display an overhead or drawing of the cerebellum. Have students add the cerebellum to their drawings.

Teachers can download a free PowerPoint image to accompany this discussion at the Worth Publishers Image & Lecture Gallery for Psychology at www.worthpublishers.com/exploring/content/instructor/index.htm. Select the following sequence of links:
1. "Access the Image and Lecture Gallery Here"
2. "Browse"
3. "Psychology: Introductory Psychology"
4. "Myers, *Psychology, 7e*"
5. "Chapter 02: Neuroscience and Behavior"
6. "Figure 2.14 - The brain's organ of agility"

Explicit memories seem to be stored in the cortex in whichever area they are processed. Explicit information is handled by the limbic system, in a specialized area called the hippocampus. Display an overhead or drawing of the hippocampus. Have students add this structure to their drawings.

Teachers can download a free PowerPoint image to accompany this discussion at the Worth Publishers Image & Lecture Gallery for Psychology at www.worthpublishers.com/exploring/content/instructor/index.htm. Select the following sequence of links:
1. "Access the Image and Lecture Gallery here"
2. "Browse"
3. "Psychology: Introductory Psychology"
4. "Hockenbury, *Psychology, 3e*"
5. "Chapter 06: Memory"
6. "Figure 6.14 - Brain Structures Involved in Human Memory"

Explain that the hippocampus is a part of the limbic system, which includes the amygdala and hypothalamus, and is buried deep within the temporal lobes. The task of the hippocampus is to encode new explicit memories and transfer them to the cortex for permanent storage of long-term memory.

Ask students what they think would happen to memory if the hippocampus was damaged or destroyed through injury, surgery, or disease. Discuss how, by studying the case histories of such individuals, researchers have been able to learn more about the role of the hippocampus in memory formation.

Discuss the differences between retrograde and anterograde amnesia. **Retrograde amnesia** is the inability to recall events that took place before the trauma. **Anterograde amnesia** is the inability to form new memories after trauma.

Option 1

Show *The Mind*: Teaching Module 10, "Life Without Memory: The Case of Clive Wearing, Part 1" (14 minutes, 25 seconds).

This clip introduces students to Clive Wearing, an accomplished English conductor and musician who, after contracting viral encephalitis, lost his ability to form new explicit memories. The virus destroyed the hippocampus as well as other areas related to memory formation, limiting his memory span to three minutes.

After watching the clip, ask students why Clive can play and conduct music for longer than three minutes when his hippocampus has been destroyed. Students should refer to the fact that playing music, for Clive, is an automatic skill stored in the cerebellum. Deborah, Clive's wife, refers to Clive's musical abilities as being "as automatic as riding a bicycle or eating a meal . . . it is an ingrained skill." This area was evidently not damaged by the virus, and he has maintained these procedural memories. Discuss if Clive's case illustrates retrograde or anterograde amnesia.

Read the following quotation by Luis Buñuel, from Oliver W. Sacks, *The Man Who Mistook His Wife for a Hat* (New York: Harper Perennial, 1985), p. 23.

> You have to begin to lose your memory, if only in bits and pieces, to realize that memory is what makes our lives. Life without memory is no life at all. . . . Our memory is our coherence, our reason, our feelings, even our action. Without it, we are nothing.

Discuss with students the meaning of this paragraph and how memory is related to being human. Alternatively, ask students to write a reaction to this statement in the context of Clive's story for discussion.

Optional Activity

You can update Clive's case by showing *The Mind*: Teaching Module 11, "Clive Wearing, Part 2: Living Without Memory" (32 minutes, 44 seconds). This module shows more recent footage of Clive's case. Dr. Erin D. Bigler of Brigham Young University presents

Clive's scans, revealing extensive brain damage. Teachers may wish to save this clip until the unit on memory.

Additional Reading

Wearing, Deborah. *Forever Today: A True Story of Lost Memory and Never-Ending Love*. London: Corgi, 2006.

Option 2

If time allows, have students read chapter 6, "The Man Who Lives for the Present: The Story of H.M." from Geoff Rolls, *Classic Case Studies in Psychology* (2005), pp. 51-60, or assign the reading as homework.

This chapter introduces students to H.M. (Henry M.), who had brain surgery in an attempt to treat epilepsy. Dr. William Scoville drilled a hole in H.M.'s skull and removed most of his hippocampus along with the amygdala and other areas in the temporal lobes, severely affecting his ability to form new memory. Dr. Brenda Milner documented H.M.'s case for 20 years. Among the many instances of memory loss she recorded is an account of how H.M. was able to remember how to cut the lawn but if interrupted would become unaware that he was in the middle of cutting the lawn.

Discuss H.M.'s case with students. Discuss whether this case illustrates retrograde or anterograde amnesia. Have students generate examples of explicit and implicit memory from the article. Discuss how H.M.'s life was altered by this surgery.

Read the following quotation by Luis Buñuel, from Oliver W. Sacks, *The Man Who Mistook His Wife for a Hat* (New York: Harper Perennial, 1985), p. 23.

> You have to begin to lose your memory, if only in bits and pieces, to realize that memory is what makes our lives. Life without memory is no life at all. . . . Our memory is our coherence, our reason, our feelings, even our action. Without it, we are nothing.

Discuss with students the meaning of this paragraph and how memory is related to being human. Alternatively, ask students to write a reaction to this statement in the context of H.M.'s story for discussion.

Optional Activity: Mirror Tracing Task

The mirror tracing task involves tracing the outline of a star while looking at its reversed image in the mirror. H.M. demonstrated improvement on this task over repeated trials, while he could not remember having done the task before.

Instructions for this activity can be found at the University of Texas at San Antonio, Howard Hughes Medical Institute, Teachers Summer Institute in Neurobiology, www.utsa.edu/tsi/assign/learning/learning1/mirror.htm.

You can find PowerPoint images that illustrate this task and H.M.'s results at the Worth Publishers Image & Lecture Gallery for Psychology at: www.worthpublishers.com/exploring/content/instructor/index.htm. Select the following sequence of links:

1. "Access the Image and Lecture Gallery here"
2. "Browse"
3. "Psychology: Introductory Psychology"
4. "Gray, *Psychology, 4e*"
5. "Chapter 09: Memory and Consciousness"
6. "Figure 9.19-Brain area involved in temporal-lobe amnesia"
7. "Figure 9.20(1)-Implicit memory without explicit memory"
8. "Figure 9.20(2)-Implicit memory without explicit memory"

Option 3

Discuss with students what life would be like with a damaged hippocampus. Assign as reading chapter 2, "The Lost Mariner," from Oliver W. Sacks, *The Man Who Mistook His Wife for a Hat,* pp. 23-42.

In the "The Lost Mariner," Oliver Sacks relates the story of Jimmie G., who was 49 years old and could relate in great detail stories about his childhood, his high school days, and his time serving in the United States Navy during World War II. Yet Jimmie was unable to recall the current year and believed himself to be 19 years old. When asked to look in a mirror at his graying appearance, Jimmie was bewildered. Jimmie's memory impairment was due to Korsakov's (also spelled "Korsakoff's") syndrome. In this illness, the mammillary bodies, which form part of the limbic system, are damaged. The damage in Jimmie's case was due to severe alcoholism.

Have students record examples of implicit and explicit memories from the reading. In addition, ask students to write a reaction to the following quotation from Luis Buñuel, quoted in Oliver Sacks, *The Man Who Mistook His Wife for a Hat*, (New York: Harper Perennial, 1985), p. 23.

> You have to begin to lose your memory, if only in bits and pieces, to realize that memory is what makes our lives. Life without memory is no life at all. . . . Our memory is our coherence, our reason, our feelings, even our action. Without it, we are nothing.

After students have read about Jimmie, elicit examples of explicit and implicit memory and list on the board. Discuss if Jimmie's memory loss illustrates retrograde or anterograde amnesia. Also, discuss with students the meaning of the quotation from Luis Buñuel. Discuss how memory is related to being human.

Special Focus: The Brain, the Nervous System, and Behavior

Contributors

About the Editor

Kristin Whitlock has taught AP Psychology at Viewmont High School in Bountiful, Utah, since 1992. She was the 2005 Moffet Memorial High School Award winner from the Society for the Teaching of Psychology. She also received a Presidential Citation from the American Psychological Association (APA) in 2005. She currently serves as chair of the APA's High School Psychology Standards Working Group and has served on the AP Psychology Development Committee.

Jessica Habashi received a Master of Philosophy degree from Yale University in 2004 and a Doctor of Philosophy degree in cell biology from Yale University in 2006. Her thesis research involved the identification and characterization of *fhy4-1*, an *Arabidopsis thaliana* phytochrome A pathway mutant. Habashi served as a teaching fellow in histology at the Yale University School of Medicine from 2000 to 2005.

Stephen M. Kosslyn is a professor of psychology at Harvard University. He has published numerous papers on the nature of visual mental imagery and is the author of books including *Image and Mind*, *Ghosts in the Mind's Machine*, and (with Robin S. Rosenberg) *Psychology: The Brain, the Person, the World*. The article in this collection he cowrote with Robin S. Rosenberg appeared in *Voices of Experience: Memorable Talks from the National Institute on the Teaching of Psychology*, vol. 1, published by the Association for Psychological Science in 2005.

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David G. Thomas received his Ph.D. in developmental psychology from the University of Denver in 1981. After receiving his degree, he worked in the Brain Sciences Laboratories at the National Jewish Medical and Research Center in Denver until 1985, when he joined the faculty of the Department of Psychology at Oklahoma State University (OSU), where he is professor and associate department head. At OSU he has received numerous teaching awards, including the Outstanding Faculty Award in the College of Arts and Sciences in 1992 and the Regents' Distinguished Teaching Award in 1999. His research involves the study of electrical brain activity in infants and children, the role of nutrients in cognitive development, and the perception of time.

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