This assignment and the next describe the basic organization of the cerebral cortex, the outer layer of the cerebral hemispheres. The cerebral cortex contains the majority of cell bodies in the human nervous system and the synapses formed axon terminals and dendrites. It is divided into three levels: primary sensory areas, sensory association areas, and higher order association areas. The assignment describes how the areas were identified and some main features of the lowest level, the primary sensory areas.

When you have completed this exercise, you should know something about the structure and organization of the cerebral cortex, and how it is divided. You should also understand how the primary sensory areas represent the senses from which they get their information.

Asgn2a claims that "From psychology's viewpoint, the most important question about the nervous system is: 'How does the nervous system code or represent psychological and behavioral processes?'". One basic codes is location: different parts of the brain are associated with different functions. Phrenology was the first attempt to relate different psychological processes to different areas in the brain.

At the end of the 19th century, Franz Gall (Figure 1-2d), a Viennese physician, and his disciple, Johan Spurzheim, proposed that the shape of a person's skull in the head reflected his/her mental traits. They named the study of the shape of the head phrenology (In Greek, "phren" = mind, "logy," from logos = study of). Gall claimed that each area of the cerebral cortex was associated with one of 27 mental "faculty" (~ trait, ability). If a faculty was strong, its brain area swelled up. Figure 2-2d shows a typical phrenological map of the head. The pictures represent the different mental and behavioral traits associated with the location of bulges on the skull. Phrenology made a fundamental contribution to the understanding of the brain and how it works. Phrenology introduced the idea that the mind could be divided into separate functions, which are linked to specific parts of the brain. Therefore, phrenology is quite similar to the dominant modern idea about brain organization, with one crucial exception: The data used to support phrenological ideas was very weak and unreliable. Modern behavioral neuroscience deals with many more and simpler, more specific mental processes. Link a description of phrenological theory.

The psychological concepts that phrenology used were faculties like benevolence, veneration (~worship), cunning, etc. Modern behavioral neuroscience deals with working memory (asgn3j) and its subdivisions, visual recognition of shapes and objects (asgn2x,t), perception of motion (asgn2r,s), etc. Also, many behavioral neuroscientists claim that specialized areas of the brain are parts of complex, interactive networks rather than isolated modules. The evidence on which phrenology was based was its downfall. Gall claimed that the outer surface of a skull reflected the shape of the brain underneath. Gall established the relation between mental faculties and skull shape with people he judged to show a faculty very strongly and measuring that person's skull. Unfortunately the mental assessment was much less carefully done than was the skull measurement, and the sample of skulls was quite small and biased.

Objective measurement of psychological processes (asgn1b) and random or representative sampling (asgn1j) were techniques that would first appear a century later. Finally, the evidence is quite clear that the skull’s surface does not reflect the shape of the brain inside, and the brain's outer shape is only very weakly related to its functions.

The flaws in phrenology made it a standard example of poor science. Nevertheless, it's contribution has been very important. Previously, philosophers and scientists believed that the brain worked as a whole, partly because of the apparent unity of conscious experience. Phrenology is the first clear statement of the idea that the brain does different things in different places. This idea is called localization of function, and it has been a dominant theme in behav-oral...
neuroscience for about a century and a half. For more about phrenology's contribution to modern behavioral neuroscience.

Unfortunately, the concept of localization is often taken too far. Like the phrenologists, some researchers seem to claim that a specific location in the brain is the specific place where a specific psychological function takes place. For example, one area generates grammar, another recognizes faces, a third guides attention, etc. A more likely view is that a specific area is an important, even crucial, part of a brain system for a psychological function. Furthermore, brain systems for different functions are interconnected and overlap.

Q1. The main contribution of phrenology to modern psychology and neuroscience was __.
A. the discovery of the main categories of personality and mental traits
B. the idea that skull shape reflects how developed the brain under it is
C. the idea that different parts of the brain were involved in different psychological functions
D. A, B, and C are all correct
E. none of the above are correct. Phrenology is a deeply flawed theory, so it contributed nothing

Cerebral Hemispheres

The cerebral hemispheres are the top level of the basic hierarchy in the Central Nervous System (CNS). They bulge off either side of the rostral (front) end of the brain stem, somewhat like two mushrooms.

The hemispheres have several different parts:

1. The cerebral cortex is the 1 cm-thick layer of grey matter that forms the outer surface of the cerebral hemispheres. Figure 3-2d shows it as a pink outer layer on the hemispheres. (In the living brain it is pale pink, which turns greyish tan in preserved brains.) It is the "mushroom's cap."

The cortex is highest level of the brain and is essential for higher levels of mental function. It contains roughly half of all neurons in the human brain. Figure 4-2d shows a highly magnified slice through the cortex. It is stained with a dye that colors only the cell bodies of neurons (and glia) blue. Note how densely packed neurons are in the cerebral cortex. It also shows that the cortex has six basic layers of neurons, each having its specialized functions.

The cerebral cortex is wrinkled in many mammals, especially in humans. The grooves that make these wrinkles are called sulci, and the ridges between them are called gyri. Figure 3-2d shows sulci in cross section as narrow valleys into the cortex. Figure 5-2d, shows them as curving lines on the surface of the cerebral hemispheres.

Wrinkling packs more grey matter into the limited space inside the skull, just as crumpling a piece of
paper fits it into a smaller space. Figure 5-2d shows the "typical" pattern of sulci as curving lines on the cerebral hemispheres. The sulci also divide the brain into five major subdivisions called lobes. The pattern varies among individual brains, so the sulci only rough landmarks.

2. White matter forms the inside cerebral hemispheres underneath the cerebral cortex. It is made of the axons that connect to and from each area of the cortex to other areas and to other parts of the brain. It is the "stem of the mushroom."

3. The basal ganglia are several large, interconnected clusters of grey matter inside the white matter of the hemispheres. They link most of the cerebral cortex to the motor system of the brain, to organize and execute complex movements smoothly and efficiently. They also play an important role in learning.

The cerebral cortex of humans (and many other mammals):
T F Q2A. has all the neurons in the cerebral hemispheres
T F Q2A. is wrinkled by ridges (gyri) and grooves (sulci) to pack more grey matter into the skull
T F Q2A. is the outer layer of the front end of the brain
T F Q2A. has two lobes, the anterior and the posterior

The cerebral cortex is divided into many different areas, each of which is closely associated with its own set mental and behavioral functions. These functions are nothing like the ones phrenology proposed, and they are based on much better evidence. This division is based on several different measures. Originally they were defined by differences in the pattern of the six layers of the cortex (Figure 4-2d). These correlate with measures of brain function, measured by methods described in asgn2a.

The relation between cortical area and function is not fixed by a genetic code. Rather, it depends on the interaction between genetic and environmental processes, early in development especially.

For example, in ferrets, the visual connections were rerouted experimentally to the auditory cortex, which developed the anatomical and functional characteristics of visual cortex (Roe et al., 1990; von Melchner et al., 2000, Merzenich, 2000). A similar reorganization also happens in humans who are blind at birth and learn to read Braille (touch-based printing). Their cortical visual areas become responsive to touch. Transcranial magnetic stimulation there disturbs their ability to read, whereas it has no effect when tested on sighted people who read Braille (Büchel et al., 1998; Cohen et al., 1997).

Brain organization can change in adults. For example, professional string players, who use their fingers a lot, have much more brain devoted to the fingers than do amateur players (Elbert et al., 1995). Simply practicing a touch task using fingers for several weeks will affect both the size and function of the brain devoted to the fingers.

The front part of the cortex is associated with movement, from planning an action to doing it. The back part of the cortex is associated with sensory perceptual function. Vision, hearing, somesthesia (body sense and "touch") are (mainly) associated with different parts of the back part of the cortex. Figure 6-2d illustrates the connections between these "main" senses and their primary areas, and between the primary area for motor control and muscles it controls.

Figure 6-2d shows that each sense (vision, hearing, etc.) sends information first and most directly to its own specialized area, called its primary sensory area. ! The visual pathway from the eyes projects (goes to, makes connections to) most directly to the primary visual cortex on the occipital lobe at the back of the brain.

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The diagram shows the projection (~connection) of each major sense to its primary area in the cerebral cortex.
The auditory pathway from the ear projects most directly to the primary auditory cortex on the top edge of the temporal lobe, which is located behind and just above the ears, where the temple pieces of a pair of glasses go.

The somatosensory (soma = body) or "touch" pathways go most directly to the primary somatosensory (touch) cortex on which it is represented (mapped). The type size shows relative size of each body part's representation.

Figure 7-2d. Match the experience that a patient reports, if s/he is stimulated at each of the numbered locations on Figure 7-2d. 1. 2. 3. 4. 5.
Q3A. touch Q3B. (involuntary) movement Q3C. visual Q3D. sound
Hint: What would a person report feeling when the primary touch area is stimulated?

Each primary sensory area contains a map of its sense organ. This is easiest to understand for the somatosensory system in Figure 8-2d. Figure 8-2d shows the place in the primary somatosensory cortex at which stimulation produces a sensory experience in the body part named at the right. The size of the lettering indicates the size of the somatosensory cortex from which such reactions can be produced.

For example, touching the feet activates the top end of the primary somatosensory area, so this part of the body map is called the representation of the foot. Below the foot representation, in order, are the representations of the legs, the back and chest, the arms, the hands, the face, and the mouth.

Damage in the primary somatosensory ("touch") cortex disturbs the sense of touch. The numbers on Figure 9-2d show different places on the cerebral cortex damaged in different patients. Match the number for each place with the part of the body where a patient would have defective touch perception. 1. 2. 3. 4. 5.
Q4A. hand Q4B. mouth Q4C. foot Q4D. face

Figure 10-2d. Penfield's classic maps of the human primary somatosensory and motor cortex, based on effects of weak electrical stimulation of the cortex during neurosurgery. The stimulation was done to identify areas of pathology to be removed and areas of function that must be avoided. Note how distorted the "homunculus" is. The hands and face are very large and the back is small relative to their real size. This difference is the basis of the high sensitivity to touch on the hands and face.

Every method described in asgn2a is used to study the organization of primary sensory and motor cortex. Most dramatic are the observations on human patients during brain surgery. In some kinds of brain surgery, the patient is awakened from anesthesia after the brain is exposed (Calvin and Ojemann, 1994; Penfield and Rasmussen, 1950). (The nerves from the head are blocked with local anesthetic.) The patient is awake because the neurosurgeon needs to locate accurately the pathological (sick) area to be removed and important healthy areas, such as the speech area, to avoid damaging them. The electrical stimulation identifies what each area is especially important by triggering some specific reaction. If the stimulation is in a speech area, it disturbs the patient's ability to speak. If the stimulation is in part of the primary somatosensory cortex, the patient reports tingling or buzzing on a part of his/her body. This means...
The map of the body is the way the brain codes location on the body. Touch on the foot makes neurons (nerve cells) at the top end of the somatosensory area respond. Touch to the face activates neurons at the bottom end of the somatosensory area. Touch on each finger activates cells in neighboring parts of the hand area of the cortex. Your mind interprets activity in these different parts of the somatosensory cortex as a sensory experience on the related body part.

The body map is an example of labeled line coding, also called anatomical coding. It gets this name because it is sort of like telephone lines going to the switchboard. The switchboard knows which phone is active because each line coming in is labeled with that phone number. Likewise, the brain can tell where a stimulus is on the skin, because a particular nerve "line" comes in from each skin area to a different location in the somatosensory cortex's "switchboard." Exercise asgn2d explains the idea of labeled line coding further.

**Q5.** The brain can tell the difference between a touch on the cheek and a touch on the hand because
A. different places on the somatosensory ("touch") area become active
B. it relates touch to vision which tells where the touch was
C. it feels the touch at different places
D. anatomical or labeled line coding signals where touch is
E. A and D are both correct
F. A, B, C, and D are both correct

The somatosensory map of the body is very distorted. Some small parts of the body take a lot of space on the map, and some big parts take only a small part of the map. The type size of the names of body parts illustrates the size of the area devoted to it. In Figure 8-2d above, the larger the type size, the larger the cortical areas for that body part. For example, "back" and "legs" are printed in small letters, because these parts of the body take up only a small part of the primary somatosensory cortex, even though the legs and back have a large part of the skin. In contrast, "hand" and "mouth" are printed in big letters, because these parts of the body take up a large part of the primary somatosensory cortex, even though they have a area of skin surface.

The size of the somatosensory area for each part of the body is correlated with touch sensitivity on that part of the body. Parts of the body that has a large area in the cortex are very sensitive to touch, and you can locate where to touch is on that part of the body quite accurately. For example, your fingers and mouth are very sensitive to touch, and you can locate quite accurately where on each finger or on the lip you get touched. In contrast your back is not very sensitive, and you can't locate accurately where you are touched there.
skin of your index finger. Start with them rather far apart, about 1 cm between the tips. Everyone will report detecting two separate touches, one from each tooth pick. Now have the person testing you bring the points closer and closer until you cannot tell whether you were touched with one or two tooth picks. Try this on several other parts of the body, and compare how far apart the points of the tooth picks must be to detect them reliably.

To test your ability to locate where you were touched, have someone briefly gently touch you with a ball point pen at different places on your skin. Then, without looking where the pen mark is, put a dot on the drawing in Figure 11-2d at the right. After you have done this for several places on your skin, compare the locations of the dots on your skin where you had been touched with the dots on the drawing where you perceived you had been touched. How do they compare at different places, the fingertip, the palm and the upper arm, for example?

Q6. Raccoons have five separate bulges in the lower part of its somatosensory cortex, one associated with each finger. Therefore you might expect raccoons __.  Hint
A. to be very sensitive to pain  B. to recognize things by touch (with fingers) quite well
C. not to connect information between the fingers  D. also to have large face and mouth areas in the somatosensory cortex

The map of your visual field (what you see) in your primary visual area has the same kind of features as the somatosensory (“touch”) map. You can think of the primary visual cortex as being sort of like a TV screen and your eye as being sort of like a TV camera. Light from different parts of your visual world activates corresponding parts of the “TV screen.” The TV screen analogy to the primary visual area models only one aspect of how the visual cortex works -- how location in the visual world is coded. The map of the visual world on the visual cortex is described in more detail in Exercise asgn2s.

Like the somatosensory area, the visual map is distorted. The part of the map devoted to the middle of the visual field is much larger than the part devoted to the periphery (edges). Look straight at the end of your thumb at arm's length; it takes up about 1% of your visual field. On the primary visual cortex, your thumb is activating about half of its total area.

This enlargement makes the small part in the middle of your visual field much more sensitive to fine detail; you can see fine detail only directly where you are looking; detail vision decreased rapidly as the visual target moves away from the very center of your visual field (asgn2s explains this effect in more detail). Figure 12-2d illustrates this fact.

Q7. (Select the best answer.) When the optometrist tests your eyes with the eye chart, s/he measures how good your best detail vision is. S/he measures how well information about the letter you are looking straight at gets to __.
A. the middle of the TV screen  B. the 1% of the visual cortex that gets information from the letter on the eye chart you are looking at
C. the whole visual cortex  D. the middle 50% of the visual cortex

Damage to the primary sensory areas of the cortex disturbs conscious perception of sensory experience. For example, damage in the somatosensory area disturbs the ability to recognize or locate touch to the affected part of the body. Damage to a part of the primary visual area on the occipital cortex results in a "blind spot" for the corresponding part of the visual world. Destroying all of the primary visual cortex results in cortical blindness: visual experience is unavailable to consciousness.
Q8. Helen Keller became blind (and deaf, as well) at age 2 as an aftereffect of measles, because the disease affected her brain. Because she had no conscious sense of vision, the damage responsible for her loss of sight probably destroyed entirely her
A. primary visual cortex   B. lenses   C. cerebral cortex   D. all primary sensory cortex

The primary motor area also has a map of the body surface. Stimulating the top end of the right motor cortex elicits (triggers) movement in the left foot. As the location of stimulation is moved down the motor cortex, the movements that the stimulation elicits move up the body. So stimulating the bottom end of the right motor cortex triggers movement on the left side of the face.

As in the sensory areas, the motor map of the body is distorted, enlarging the parts of your body that you can control most precisely, as is illustrated in Figure 13-2d. The size of the names of body parts indicates the size of the cortical areas to those parts. The fingers and mouth make precise movements and take up much more of the motor cortex than do areas like the trunk, where movement control is not precise.

More recent research shows that movements elicited (triggered) by stimulation underestimate the amount of motor cortex associated with movement in each part of the body (Baringa, 1995; J. Sanes et al., 1995). In this research, monkeys learn to make specific movements when signals tell them to respond. Neurons in many widely scattered parts of the motor cortex became active while monkeys make these specific movements.

This finding shows that a much broader area of the motor cortex participates in the control of specific muscles and movements. This organization makes sense when you consider the fact that even very simple movements require the coordinated action of many muscles and joints. The wide scattering allows more efficient coordination between muscles working at these different locations on the body.

A recent study using stimulation has confirmed the idea that the motor cortex is organized more by movements than as a map of the body (Helmuth, 2002). This work showed that monkeys make smooth, complex, well-directed movements when the motor cortex was stimulated with longer lasting (0.5 sec.) stimulation than was used in earlier studies.

Q9. Some new world monkeys can use their tails as an extra hand. You would expect that they have __. Hint
A. an enlarged area at the top of the motor cortex   B. an enlarged area in the motor cortex for the hand
C. a smaller hand area in motor cortex to make room for controlling the tail
D. an enlarged motor cortex, in which all parts are equally bigger   E. A and C are both correct
When you have finished the exercise you should be able to recognize the difference in functions of the association cortex and the primary cortex. You should be able to described the main features of limbic functions and recognize the main functions of the basal ganglia inside the cerebral hemispheres.

Association cortex is the cerebral cortex outside the primary areas (Figure 1-2e). In humans and other primates the association cortex is by far the most developed part of the brain. It is essential for more complex mental functions. For example, association areas are necessary for perceptual activities, like recognizing objects (toasters, horses, words, etc), rather than their simple features, like edges, color, or pitch, which depend on primary sensory cortex.

Association areas take up an increasingly larger percentage of the cerebral cortex as brain size increases among different species. As brains get bigger among different species of animals, the cerebral cortex gets bigger even more. The extra cortex is created by more and deeper wrinkling. Most of the added cortex is association cortex. Figure 1-2e compares the relative size of association cortex in rats and humans. Association cortex is the pink area outside the primary sensory areas.

The increasing size of association areas correlates with the complexity of behavior and mental functions. Big-brained primates -- monkeys, apes, and especially humans -- have complex behavior and mental function. Their wrinkled cortex is mostly association cortex. Animal species like horses and cats have less complex behaviors. Their medium-sized brains have less a wrinkled cortex, with a lower percentage of association cortex. Rats and rabbits have still less complex behaviors. Their smaller brains have few, shallow wrinkles in the cortex, and association cortex is a small percentage of the total area.

Q1. A biologist shows a class a brain that has rather large cerebral hemispheres. This brain probably
A. is wrinkled and swollen because it is preserved ("embalmed")
B. came from an animal that probably had fairly complex behaviors
C. probably has quite a lot of association cortex compared to primary areas
D. had a lot of grey matter       E. B, C, & D       F. A, B, C, & D

Recall from asgn2d that the sensory systems (vision, hearing, etc.) each have their own primary area on the cortex, which gets the most direct connections from its sense. Each primary sensory area sends information to its own cortical association areas, which is next to its primary area, as shown in Figure 2-2e. The arrows show the main direction of information flow, but association areas also connect back to their primary areas providing them feedback. The motor system is organized in the same way, but in the reverse direction: from motor association areas to the primary motor area to the motor systems in the brain stem and spinal cord.

Each sensory association area appears necessary for perception of objects and events for its sense. The information that each sensory association area gets from its primary area is about simple contours, boundaries, and qualities like color or pitch. Sensory association areas combine this kind of information to represent complex objects. For example, the visual association area on the lower part of the temporal lobe plays a primary role in your ability to recognize faces, dogs, cars, trees, etc., whereas the primary visual cortex is required for detecting basic features of the visual world: edges, light and dark, location, etc.

Many data support this idea. For example, people with damage to visual association cortex (on the lower part of the temporal lobe) often suffers from visual agnosia (a = without, gnosia = knowing) (Farah,
1990). Such people can see objects, but cannot recognize them. They may be able to describe the features of an object but still cannot name it by sight. They can recognize and name the same object placed in the hand, showing they know the word. This condition is described further in asgn2q.

Q2. A neurologist (physician who specializes in diseases of the nervous system) described a patient as "the man who mistook his wife for a hat" (Sacks, 1985). He could see his wife but perceived her head as a hat. This patient probably had damage in __.

A. all association areas of the cortex     B. primary visual cortex
C. visual association cortex           D. the sulci between the gyri where arrows cross them.

The activity of nerve cells in visual association cortex also shows that these areas are involved in a higher level of processing. For example, nerve cells in (a part of) the visual association area respond selectively to complex, patterned visual stimuli, like images of objects, abstract forms, hands, faces, or even specific faces (K. Tanaka et al., 1991). This means that when such cells respond, the brain has information telling that the specific stimulus object that triggers the active cells is getting to the sense organ.

For example, a group of neurons in a monkey's visual association area on the temporal lobe respond only when it looks at a specific person (Young & Yamane, 1992). This suggests that activity in those neurons tells the brain/mind that the monkey looks at that specific person. So the next time you see your best friend, remember that you can see him/her because a few thousand neurons in the visual association area of your temporal lobe have become active. Give them a pat on the back for the great job they do for you, without you even asking.

The somatosensory (touch) and auditory association areas show the same kind of processes. For example, damage to the auditory association cortex (around the primary auditory cortex on the top of the temporal lobe) leaves sensitivity to sound unaffected, but disturbs recognition of what sounds mean. In the auditory association areas, neurons respond much better to complex sound patterns like bird calls and speech sounds than to simple tones. Damage to the somatosensory association cortex (on the parietal lobe behind the primary somatosensory cortex) leaves sensitivity to touch unaffected, but disrupts ability to recognize objects by touch.

Q3. You can predict that neurons in auditory association areas are most likely to respond to

A. simple pure tones   B. complex meaningful sounds, like a door closing or a dog barking
C. speech sounds       D. B and C are both correct   E. A, B, and C are all correct

The information flow in the motor system is in the opposite direction from the flow in sensory systems. Information goes from the association area to the primary motor area, which directly and indirectly controls the motor systems in the brain stem and spinal cord. The motor association area is on the frontal lobe in front of the primary motor cortex. It is essential for effective planning for actions. To execute the plans it sends signals to the primary motor area, which is more directly related to the actual execution. Damage here disturbs planning and organization of movements (Goldman-Rackic, 1994).

Mark each item True or False. Association areas for each sense __.

T F  Q4A. receive information from their own sense's primary sensory area
T F  Q4B. are required for recognizing but not for detecting (seeing, hearing, etc)
T F  Q4C. have nerve cells that respond best to a pattern of stimulation
T F  Q4D. together with higher order association areas, takes up a much bigger per cent of a large, wrinkled cerebral cortex than of a small, smooth one.  HINT

Higher Order Association Areas

Higher order association cortex carries out complex mental processes not associated with any particular sense. Figure 3-2e shows the primary areas and their association areas in colors and the higher order association areas in grey. Each sensory and motor association areas sends signals to higher order association areas, which combine this information to form the basis of the highest mental processes, like language, thinking, and planning. These processes do not depend on any one specific kind of sensory information. For example, language can use vision (reading, sign language) and touch (Braille for the blind), as well as hearing. The arrows
show the flow of information from primary areas to sensory association areas to higher order association areas. 

Link to a story about Albert Einstein's brain and how it may differ from the average brain.

Figure 4-2e shows the higher order association areas in grey and points out the location of two parts that play a crucial role in language: Broca's area at the lower back of the left frontal lobe, and Wernicke's area, at the junction of the left temporal and parietal lobes. Both are shown on the left hemisphere, because it is dominant for phonetics (speech sounds) and for grammar in 99% of right-handed people and about 2/3 of left-handed people. (These are not the only brain areas that are important in language.)

These areas were first identified in the mid-19th century from the effects of brain damage on language function. Damage in Broca's area affects speech production and understanding more complex grammar. Damage in Wernicke's area affects understanding and using words. However, the exact location of these areas and what processes they carry out is still not settled (Lieberman, 2001).

Listening to spoken words automatically activates understanding the meaning, so Wernicke's area is activated. Saying words depends on precise control of the muscles of the face and mouth, so these areas are activated. Generating words depends on finding words and getting them ready to say, so Broca's area is activated.

Match the brain area to the best fitting items below.

1. Wernicke's area
2. Broca's area
3. both Wernicke's and Broca's areas

Q5A. left side of brain (for most people)  
Q5B. producing grammar  
Q5C. word understanding  
Q5D. higher order association area  
Q5E. frontal lobe

The higher order association areas on the right hemisphere's parietal and temporal lobes are part of a network of brain areas related to directing attention. Large lesions (~damage) on the back part of the right hemisphere (see Figure 6-2e) can make people completely ignore the left side of their world (Heilman, 1979). This condition
Figure 6-2e. A typical neglect-producing lesion (~damage) on the right hemisphere, showing the area on the top edge of the temporal lobe. Patients with this disorder ignore their left, so damage in this higher order association cortex can disturb many other functions indirectly: reading and writing, (they miss what is on the left side of the page); eating (ignoring food on left side of plate); getting dressed (failing to put left arm or leg into sleeve or pant leg).

This part of the right association areas also appears important in recognition and expression of emotion. This problem can lead to important problems in social communication. For example, damage here can make people unable to recognize or express emotion, such as anger, fear, or sarcasm (Bear, 1983; Ross & Mesulam, 1979). These social signals play an important part in effective social behavior.

Figure 7-2e illustrates how a patient with neglect might draw a car and a clock. It shows how the left side of the drawings are missing or squeezed into the right side.

Higher order non-sensory association areas ___.

Q6A T=A F=B take up much of the expanded cerebral cortex and brains get larger among species of animals
Q6B T=A F=B are important for mental functions that do not depend on information a single sense
Q6C T=A F=B are not involved with language, which is built on hearing
Q6D T=A F=B are not involved with attention which is closely tied to hearing
Q6E T=A F=B on the right side plays an important role in recognizing socially important signals

The higher order association area in the very front part of the frontal lobes appears to be essential for many different complex, psychological processes. It is especially important for planning and executing actions effectively and for anticipating their consequences. Evidence for this idea comes from many sources. For example, people with damage to the frontal lobes may have normal, even superior, IQs, but their inability to plan and recognize consequences in advance prevents them from using their "intelligence" for much of anything useful. They also have trouble changing plans when a change in the environment requires a new strategy. Like Phineas Gage, they often show major personality changes, becoming impulsive, superficial, and/or socially incompetent.
Damage in the frontal lobes can affect a specific behavioral process, but the loss of a specific function can show up in many different kinds of disturbed behavior. Damasio (1994) describes a remarkable case of frontal lobe damage as shown in Figure 8-2e. Elliot, the patient, could describe what he needed to do in social and business settings, but he could not do what he had just described. Otherwise, he was completely normal or above normal mental functioning.

Elliot was a successful lawyer and businessman when he developed a brain tumor in the orbital frontal cortex (orbit=eye socket), located on the bottom of the frontal lobes just above the eyes. The tumor was successfully removed with little damage to the surrounding brain, and Elliot recovered completely, except that he could not carry out correctly ordinary personal, business, or social activities, though he could describe correctly what he needed to do.

Elliot could analyze business deals but was totally unable to do what his analysis told him to do. He made very bad deals, which he never would have done before his tumor, and managed to lose his family as well as his money.

He could describe accurately what to do in different social situations, but he acted completely inappropriately in such social settings. Nevertheless, he passed virtually every test that was supposed to measure frontal lobe functioning.

Damasio finally figured out Elliot's problem from a casual remark he made. He had successfully done a test that asked him to explain what to do in different situations. Elliot said that although he could explain what to do he could not do what he had just said. Further testing showed that he could not do tasks that required him to follow a plan or learn from the consequence of doing it. He apparently had lost the connection from his brain’s planning system to its motivation system. His plans could no longer control his actions. For example, in a gambling task he chose plays with a few big wins, but in the long run it wiped out his stake. He could not switch to plays with smaller wins but was a winning strategy over the long run. People with intact orbitofrontal cortex often start on the losing play but switch to the successful play. They can inhibit their attraction to the bad plays that gave the large wins. (Interestingly their hands "knew" the winning play before they could consciously recognize it.)

Frontal lobe damage often affects personality. Damage in other parts of the frontal association areas makes personality much shallower and disturbs the ability to recognize what social situations require. (In contrast, Elliot's personality became very cool and distant. He understood, but could not make, the appropriate social response.) Brain scans show that patients with schizophrenia (a severe "mental" illness) have abnormally low activity in the frontal lobes. This is why many people with schizophrenia have difficulty monitoring what is important in their mental activity and behavior. As a result, many people with this devastating disease have trouble organizing even fairly simple activities, such as ordinary household chores. (Observations like these show that "mental illnesses" like schizophrenia and depression, are mental only in the sense that the main symptoms are mental. These diseases are based on abnormal brain function, just as are epilepsy, Alzheimer's disease, strokes, etc. Asgn5d,e, and f explain why schizophrenia is a brain disease in more detail.) Link to information about the role of abnormal frontal lobe function in schizophrenia.

Q7. Phineas Gage was one of the first people to survive a severe brain injury and have his behavior documented afterwards. Before the brain injury, he was a sober, responsible worker. Afterwards, he was not seriously disabled physically but was a completely different person: impulsive, emotional, unable to recognize the consequences of his actions, etc. These changes were the result of

A. Alzheimer's disease  
B. damage to the frontal lobes  
C. damage to the left hemisphere  
D. damage to the primary area of the cortex  
E. right parietal lobe

Link to a website devoted to Phineas Gage.

Other Parts of the Cerebral Hemispheres

This section briefly summarizes some of the functions of the limbic system (motivation and emotion, as well as conscious memory) and basal ganglia (movement organization and simple learning). (These are the primitive parts of the brain (Sarnat & Netsky, 1974), and they are essential for organizing and executing the most
basic functions of the nervous system: movement, motivation, and emotion. However, these basic systems have added other functions, which is quite new in evolution appearing only in mammals.) Filling in a table like this may help you remember the following information and do the next question.

<table>
<thead>
<tr>
<th>Brain Area</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limbic system</td>
<td></td>
</tr>
<tr>
<td>Hippocampus</td>
<td></td>
</tr>
<tr>
<td>Hypothalamus</td>
<td></td>
</tr>
<tr>
<td>Anterior Cingulate</td>
<td></td>
</tr>
<tr>
<td>Amygdala</td>
<td></td>
</tr>
</tbody>
</table>

The limbic system is especially important in motivation and emotion (see asgn4n, o, and z). It is mainly in the limbic lobe, which forms the inner surface of the cerebral hemisphere. The limbic lobe makes a ring around the white matter that connects between the cerebral hemisphere and the top end of the brain stem, as the rough underside of a mushroom cap circles the stem. Figure 10-2e shows the location of several parts of the limbic system on the inner surface of the left cerebral hemisphere.

The limbic system is does most of its control of behavior through the hypothalamus, at the top end of the brain stem. The hypothalamus controls the autonomic nervous system and many parts of the endocrine system through its control of the pituitary gland directly below it (see asgn4zd).

Evidence for the role of the limbic system in emotion and motivation comes from many sources. For example:

! Anatomical data show that the parts of the limbic system are connected to each other and to the hypothalamus.

! Damage to different areas in the limbic system disrupts different motivated and emotional behaviors. For example, damage in the lateral (~outside part, margin) hypothalamus makes rats unresponsive to most stimuli. They will even starve to death in the midst of plenty, because they do not make any effort to get food. However, these rats chew and swallow food put in their mouths. They act as if they like the food but don't "want" it or can't make voluntary movements to get it.

! Electrical stimulation in the hypothalamus can elicit motivated behavior, such as eating and drinking.

! Stimulation in the hypothalamus can also produce intense reward. Animals will repeatedly turn on electrical stimulation to these parts of the hypothalamus thousands of times per hour for many hours in a row, even at the expense of ordinary motives like eating. These areas in the hypothalamus are also activated by cocaine and amphetamine ("speed"), indicating that these areas are important links in the brain's reward or "wanting" system (see asgn4w.)

The hippocampus and related parts of the medial (inner, toward the middle) wall of the temporal lobe of the limbic system are crucial for the storage of new declarative (~conscious) memories (see asgn3l) (Squire, 1987). For example, human patients with damage to these structures cannot remember any new information consciously for

Figure 9-2e. Plan of the central nervous system showing the limbic lobe forming a ring around the bundle of white matter (greatly stretched) connecting the hemispheres to the top end of the brain stem. The limbic part of the brain stem is the hypothalamus.

Figure 10-2e. Inner surface of the left cerebral hemisphere and the brain stem cut through its length, showing the limbic lobe and specific limbic structures.
more than a few minutes. For example, patients cannot remember anything about a doctor or nurse who started working with them after the brain damage occurred, even after hundreds of visits with them. Mishkin and co-workers (Miskin & Appenzeller, 1987) have described an animal model of this amnesia. The role of the hippocampus and related structures in memory is described further in asgn3l.

The amygdala is important for recognizing and responding to emotional cues. This structure, deep in the temporal lobe (see Figure 11-2e), is a very important link in the limbic system. Damage to it disrupts emotional reactions, as shown in many studies with monkeys, humans, and rats. The amygdala plays a particularly important role in fear. For example, rats and other animals (including humans) with damage to the amygdala cannot learn fear reactions to signals that predict an aversive event (e.g., painful electric shock). It also plays an important role recognition of emotions, especially fear and sadness. (Hamann et al., 1996; Morris et al., 1996) People with damage in the amygdala have difficulty recognizing these emotions (Adolphs et al., 1994; Calder et al., 1996), and brain scans from normal volunteers show high activating in the amygdala while viewing faces showing emotional expressions, especially fear.

Tests of monkeys in social groups showed that removal of the amygdala makes them social outcasts from their troupe. They become social outcasts because they cannot recognize the meaning of emotionally and socially important signals from other monkeys. They can’t tell when to back off, so they get beaten up and kicked out of their troupe. For example, monkey with damage in the amygdala approach a normal monkey, even when it signals the test monkey to back off (Emery et al, 2001). Link to an article about the amygdala’s possible role in social function, depression, autism, etc.

The anterior cingulate cortex appears to play an important role in selecting and executing voluntary actions (Posner, 1994). Complex, high-level tasks activate this area, especially if they require high performance, coordinating several activities, dealing with novelty, and response monitoring. Such tasks put a heavy demand on attention and decision-making. This brain area is also activated by positive, attractive events, which enhance voluntary responding.

Match the behavioral processes below with the part of the brain to which they are most closely related

Q8A. increased activity here when you are memorizing the names of brain areas
Q8B. increased activity here when you watch a scary horror movie
Q8C. animals will work very hard to turn on weak electrical stimulation here
Q8D. increased activity here when you are successfully solving a complex task
Q8E. becomes more active when you get thirsty
Q8F. the system essential for normal motivation and emotion; it includes all the other brain areas in the list
1. limbic system 2. amygdala 3. hypothalamus 4. hippocampus and related areas 5. anterior cingulate

The basal ganglia are crucial areas for integrating (~combining) information from many different brain systems. They are several large areas of grey matter deep inside the cerebral hemispheres (see Figures 11-2e and 12-2e), separated from the cortex by white matter. They play an essential role in starting and executing behaviors smoothly, quickly, and efficiently. Damage to this system, disorganizes movement and make movements difficult to start or to stop.

For example, Parkinson’s disease is the result of losing of nigrostriatal bundle, a set of neurons that form a major pathway in the basal ganglia from the substantia nigra to the striatum. Some of you probably know an older person who suffers from Parkinson’s disease. The first sign of
Parkinson's disease is usually a slow shaking of the resting hand or foot. As the disease progresses, voluntary movement becomes harder to start, walking becomes a slow shuffle, and the face becomes mask-like and unexpressive. In its late stages, patients are unable to move voluntarily.

Surprisingly, patients with Parkinson's Disease can make quick, automatic reactions to specific triggering stimuli, especially under stress. For example, a former baseball player who was paralyzed this way could quickly raise his hands to catch a ball thrown at him unexpectedly. Mohammed Ali, the former heavyweight boxing champion, is one well known figure who suffers from it; his boxing career may have helped the disorder to develop. It usually appears later in life, but some young people developed devastating cases because of an impurity that can form in certain improperly prepared "recreational" street drugs. Link to information about Parkinson's Disease.

Parts of the basal ganglia also appear to be important in storing and retrieving automatic, non-conscious memories, like memory for motor skills and habits (Petri & Mishkin, 1994). For example, rats trained to find a goal in a water maze could not recall where to go 24 hours later, if the striatum of the basal ganglia was chemically blocked after training. In contrast, they showed no loss following this treatment on the same kind of task if it required recalling the spatial location of the goal, without any specific cue for it (Packard & Teather, 1997). The first task requires learning a specific association between cue for goal area and successful responding, which is a form of non-conscious, automatic memory of a habit (which uses unconscious memory called procedural memory). The second task requires learning a particular place, which depends on conscious memories, called declarative memory. These two memory systems are described further in asgn3l.

The basal ganglia also appear to play an important role in the emotion of disgust. People with damage in the basal ganglia show a selective defect in recognizing this emotion in pictures showing different emotions in facial expressions. (Calder et al., 2000, 2001)

Q9. Mark each of the following with T if it likely to be an effect of damage in the basal ganglia or F if it is not.

T F A. difficulty in consciously remembering new information for more than a few minutes
T F B. jerky, awkward, poorly timed movements, or slowed voluntary movements
T F C. problems falling asleep
T F D. failing to recognize the facial expression of disgust

Q9. Mark each of the following with T if it likely to be an effect of damage in the basal ganglia or F if it is not.

T F A. difficulty in consciously remembering new information for more than a few minutes
T F B. jerky, awkward, poorly timed movements, or slowed voluntary movements
T F C. problems falling asleep
T F D. failing to recognize the facial expression of disgust

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asgn2e -- CEREBRAL CORTEX: Association Cortex

asgn2f -- CELLS THAT MAKE UP THE NERVOUS SYSTEM

This exercise is an introduction to the way neurons in the brain work. Neurons are the brain cells that do (most of) the specialized functions of the nervous system: communication and integration. The exercise outlines:

- the codes that neurons use to signal excitation and inhibition
- the way one code integrates (combines) signals from 1,000s of other neurons
- the way the other code communicates (sends) that integrated signal to 1,000s of other neurons.

When you have finished the exercise, you should know

- the main parts of the neuron:
  - dendrites: the message-receiving part of the neuron
  - axon: the message-sending part of the neuron
  - cell body or soma: the metabolic (life process) center of the neuron
- the two main codes that neurons use, and how they work:
  - all-or-nothing impulse code on the axon, specialized for reliable transmission over distance: communication
  - graded response on the dendrites, specialized for combining signals from many other neurons: integration
Neurons carry out their specialized functions of communication and integration because their outer cell membrane has special properties. The cell membrane separates the inside of all cells (not just neurons) from the outside, and all chemicals that get into and out of the cell must go through it. As in all cells, the cell membrane of a neuron is polarized. This means that there is an electrical difference across the cell membrane.

To measure the polarization of a cell, a very thin electrode is put inside a cell and connected to a very sensitive voltmeter, as illustrated in Figure 1-2f. (The electrode is usually a thin glass tube filled with a conducting salt solution. The tube is tapered to a very fine point (about 1 um thick), which is barely visible with a light microscope.) The meter shows that the inside of the cell has a negative voltage relative to the outside. In a neuron that is neither excited nor inhibited, this electrical difference is called the resting potential. Figure 1-2f shows that the "typical" neuron has a resting potential of about -70 mV (about 1/20 of what a flashlight battery produces).

Q1. An electrode inside an unstimulated neuron records ___ of about -70 millivolts.
A. an electrical difference  B. a polarization  C. a resting potential  D. a cell membrane
E. A, B, and C are all correct  F. A, B, C, and D are all correct

To understand polarization, think of a flashlight battery. A battery is polarized: it has a + pole (the button at one end), which is positive relative to the - pole (the flat surface at the other end). Imagine that the cell membrane has lots of tiny batteries in it, as illustrated in Figure 2-2f. The positive button poles are on the outside of the cell membrane, and the flat negative pole are on inside. This would make the inside of the cell negative relative to the outside.

Of course, the cell membrane really does not have little batteries in it. The polarization is produced by chemically driven molecular "pumps." These "pumps" push Na+ (positive sodium ions: atoms of sodium with a + electric charge) out of the cell, leaving behind negative ions, especially Cl- (chloride ions). The excess of negative ions left inside the cell makes it negative. The Na+ gets back into the cell when the cell is excited. (Na+ and Cl- are the atoms that form table salt. Dissolving table salt in water breaks it up into these two ions.)

Q2. The polarization across the membrane of a neuron (and all other living cells) is caused by
A. putting electrodes through the neuron's cell membrane  B. tiny batteries in the cell membrane
C. pumping out positively charged atoms of sodium  D. combining positive sodium and negative chloride ions

Coding excitation and inhibition on dendrites

The cell membrane of neurons is modified to have special properties. These special properties let dendrites integrate information and let axons communicate the integrated information reliably to other neurons.

On dendrites:
1. Excitation (+) adds to the -70 mV resting potential, pushing it closer to 0.0 mV.
2. Inhibition (-) subtracts (= negative addition) from the -70 mV resting potential, pulling it further away from 0.0 mV.
3. All the excitation and inhibition the dendrites add up by a process called summation.
4. The total amount of + and - determines what the polarization across its membrane is.
   a. If the neuron gets more + (excitation) than -, the depolarization is small. If + is only a little more than -, the depolarization is small. If + is a lot more than -, the depolarization is large.
   b. If the neuron gets more - than +, then polarization shifts away from 0.0 mV. This is called hyperpolarization. If - is only a little more than +, the hyperpolarization is small; if - is a lot more than +, the hyperpolarization is large.
Match the following terms with what they mean.

**Q3A.** polarization on dendrites goes from -70 mV to -64 mV
**Q3B.** a dendrite gets 20 excitatory inputs and 20 inhibitory inputs, and its polarization shows no net change
**Q3B.** the input to a dendrite changes its polarization from -70 mV to -73 mV

1. excitation  
2. inhibition  
3. summation

The dendritic membrane varies smoothly, because summation on it adds up the small excitations (+) and inhibitions (-) from the many synaptic connections it gets from other neurons. Each synapse can produce a little depolarization or a little hyperpolarization. The dendritic membrane adds all of them up, and the total + and - = the membrane's polarization at that moment. Because the dendritic membrane adds up all these different excitations and inhibitions, its polarization changes smoothly with changes in excitation and inhibition. This kind of polarization changes called a **graded response**.

**Figure 6-2f.** measuring a graded electrical signal

![Image of six meters showing different graded responses from the dendrites, ranging from -95 mV to -45 mV.](image)

Figure 6-2f illustrates this with six meters showing different graded responses from the dendrites. The illustrated values range from -95 mV to -45 mV, but they could take any value: -57.7 mV, -73.4 mV, -66.1 mV, or any other. The dendritic membrane's polarization changes just a little when it sums (adds up) weak signals from a few other cells. It changes a lot when it sums strong signals from many other cells. Therefore, size of the change in polarization reflects how strong the signals from other neurons reaching the dendrites are.

A dimmer switch is an analogy to graded response coding on dendrites. Dimmers can vary the brightness of a light smoothly from very bright to very dim (not just on or off). In the same way, the dendritic membrane acts like a dimmer switch, because their polarization can vary smoothly in its response to signals from other neurons. Turning the dimmer in Figure 5-2f toward -45 mV (right) increases excitation. Turning it toward -95 mV (left) has the opposite effect by increasing inhibition.

**Q4.** The dendrite's response to excitation and inhibition is graded. This means that

A. its polarization varies smoothly with the amount of excitation and inhibition it gets from other cells
B. it grades excitations into inhibitions from many sources
C. it contains many dimmer switches
D. strong stimulation excites its polarization, and weak stimulation inhibits its polarization.

The combined signal that summation produces on dendrites must be sent to other neurons to have an effect. The axon of the neuron does this job. It is designed to communicate this information reliably over distances that can be 1.5 meters or more from the tips of the toes to the base of the brain.

To do this, the axon uses a "digital" or pulse code. The axon is either off or (briefly) on, as when you flick a light switch on and off. It generates brief pulses of electrical current called **action potentials** or all-or-nothing impulses (usually impulse, for short). All-or-nothing refers to the fact that the axon makes them all (about) the same size.

Because the all-or-nothing impulses on axons are all the same size, the size of the impulses does not transmit information. Instead, the axon uses the number of impulses per second (rate) as the code for stimulus intensity. Digital yes/no codes like this are very reliable (especially for transmission over long distances), because noise (~interference) does not affect the rate of a digital, pulse code signal.

Communications engineers discovered about 60 years ago what nature "discovered" through evolution at least 500 million years ago, when animals that probably had specialized nerve cells first appeared. Modern communications lines, like the cables that carry long-distance phone calls,
Figure 7-2f. The all-or-nothing code which axons use. The higher that rate of impulses (impulses/second), the stronger the excitation the axon got.

**Axon's All-Or-Nothing Action Potentials (impulses) to Increasing Excitation**

- E below threshold
- E at threshold
- E weak
- E medium
- E strong
- I (Inhibition)

Figure 7-2f summarizes this rate code. The horizontal axis is time (a few seconds). Each vertical line stands for an all-or-nothing impulse. The top line shows that the axon fires no impulses when the excitation is too weak to reach threshold. The next four lines show increasing numbers of impulses as intensity of excitation increases above threshold. The bottom line shows that inhibition generates no impulses.

When a neuron sends all-or-nothing impulses down its axon, neuroscientists often say that the neuron is firing. Think of the neuron as a machine gun and the all-or-nothing impulses traveling down the axon from the dendrites to the axon terminal as bullets it fires. In this machine gun, the tighter the trigger is squeezed (graded depolarization on dendrites), the more bullets it fires every second (all-or-nothing impulses on the axon). Therefore, the number of bullets that leave the machine gun every second reflects how strongly the dendrite trigger is being pulled. Link to more about the codes that dendrites and axons use.

Q5. Mo measures the activity of an axon in the optic nerve from the eye to the brain. When she shines a tiny spot of light on the eye, the rate of all-or-nothing impulses increases from 5/sec. to 10/sec. This means the light ____ the neuron. When she shines the light on a neighboring spot on the eye, the rate of all-or-nothing impulses decreases from 5/sec. to 1/sec. This means the light ____ the neuron. Hint: A. excited; excited B. excited; inhibited C. inhibited; inhibited D. inhibited; excited E. not enough information provided

asgn2g -- SIGNALS THAT NEURONS USE: Transmission at Synaptic Connections

This exercise describes the basic process of transmitting signals from one neuron to another: synaptic transmission. At most synapses in the brain, chemical messengers called neurotransmitters send signals from one neuron to the next. Synaptic transmission is particularly important for two reasons: ! Behavioral change is associated with synaptic change. Learning and all other behavioral change processes depend on changes in synaptic efficiency. ! Psychoactive drugs and medications have selective psychological effects because:

- They act on only one or a few of the many different types of synaptic transmission systems,
- Each brain system uses only one or a few chemical neurotransmitter systems at their synapses.

Therefore, if a medication or "recreational" drug affects one chemical transmitter system, then it also acts on only those few brain systems that use it.
When you have completed this exercise, you should be able

- to explain the steps in synaptic transmission.
- to explain why psychologically active chemicals can have selective effects on synaptic transmission and on behavior.
- to recognize a few major chemical neurotransmitters, their general behavioral functions, and chemicals that affect these neurotransmitters and the behavioral effects they have.

**Synapses** are the connections between neurons, where one neuron can affect the activity of another. The signals from one neuron travel down its axon (nerve fiber) to axon terminals (or terminal buttons). There, axon terminals *almost* touch the dendrite of another neuron to form a synapse. The "typical" synaptic connection sends signals from the axon terminal button of one neuron to the dendrite of another neuron. Figure 1-2g shows the main parts of a "typical" synapse.

Most synapses use **chemical neurotransmitters** (often called simply transmitters) to send signals from one neuron to the next. The nervous system has many more than 100 different identified chemicals that act or probably act as transmitters. It is estimated that perhaps hundreds more have yet to be identified. Some of them are called neuromodulators, because they only change the dendrites' sensitivity to other transmitters, but do not trigger signals themselves. I will ignore this difference and use only the term neurotransmitter.

**Q1.** Transmission from the axon terminal of one neuron to the dendritic membrane of another occurs by

- A. all-or-nothing impulses
- B. graded responses
- C. a chemical neurotransmitter
- D. psychologically active drugs and medications

**[Memorize and understand the next two paragraphs!]** These different neurotransmitters are very important psychologically. **Psychologically active drugs have selective effects on behavior because each drug affects only one or a few of the many neurotransmitter systems.** For example, opiates, like morphine (the "standard" for pain relief) and heroin, depress the brain and the body because they act on a specific set of transmitters. Cocaine and amphetamine stimulate the brain, because they act on a different set of transmitters. The strong hallucinogens, like LSD, affect a third systems, and sleep-inducing medications like barbiturates act on a fourth.

Synaptic transmission has five steps:

1. **synthesis:** making the chemical transmitter molecules.
2. **storage:** putting the transmitter molecules away to protect them till needed.
3. **release:** letting them out of the axon terminal into the tiny synaptic cleft, the submicroscopic gap between the axon terminal of one neuron and dendrite of another.
4. **binding:** attaching to and activating receptor molecules on the dendrite. This excites or inhibits the dendrite's membrane, depending on the kind of synapse.
5. **removal by reuptake or breakdown:** promptly getting rid of the transmitter molecules so they won't keep on stimulating the dendrite.

**Review:** These steps are very important to understand, because psychologically active drugs and medications act on one or more of these steps of a synaptic transmitter system.

For example, amphetamine ("speed") blocks the removal (by reuptake) of the transmitter dopamine. Therefore, it makes dopamine synapses act as if the presynaptic axon terminal [presynaptic = before the synaptic cleft] were releasing much more dopamine. Morphine and heroin mimic the action of a family of transmitters called endorphins, because they bind to their receptor molecules and activate them.
Q2. Chlorpromazine (Thorazine®) was the first medication discovered that helped relieve symptoms of schizophrenia, a severe "mental" illness. ["Mental" illness is mental only in its symptoms; it reflects abnormal brain function, just as strokes and brain tumors do.] Chlorpromazine works

A. in 5 steps: synthesis, storage, release, binding, removal
B. by changing the size of all-or-nothing impulses on axons
C. on the threshold for membrane polarization
D. by affecting a specific chemical neurotransmitter system

Review: Figure 3-2g summarizes the sequence of the steps in synaptic transmission. Link to a step-by-step summary of the stages of synaptic transmission.

The following briefly explains how each of the five steps in synaptic transmission works:

1. **Synthesis.** Neurons extract chemicals (often an amino acid from protein) from the blood and convert them into chemicals that serve as neurotransmitters. One or more specific enzymes (biological catalysts) convert the starting chemical into the neurotransmitter.

2. **Storage.** Neurons make extra neurotransmitter molecules, so that enough is quickly available if the neuron is strongly excited. This extra neurotransmitter is stored in little packets called **vesicles**.

3. **Release.** All-or-nothing impulses (or action potentials - see asgn2f on neurons) travel down the axon of a neuron and reach the **axon terminal** where synaptic transmission starts. There, impulses trigger the release of neurotransmitter molecules from the axon terminal into the **synaptic cleft**. (The synaptic cleft is the tiny gap between the axon terminal button and the dendritic postsynaptic membrane [postsynaptic = after the synaptic cleft]).

4. **Binding.** When neurotransmitters reach the dendritic membrane on the other side of the synaptic cleft, they can bind (attach) to receptor molecules specifically shaped to accept those neurotransmitter molecules. Binding activates several reactions, including a change in dendritic membrane polarization, producing **depolarization if it is an excitatory synapse and hyperpolarization if it is inhibitory** [depolarize = decrease in polarization; hyperpolarize = increase in polarization {hyper = extra, over}]. The binding is loose, so the neurotransmitter molecules soon are released back into the synaptic cleft.

5. **Removal.** **Neurotransmitter molecules in the synaptic cleft must be removed.** If they are not, transmitter molecules would accumulate in the synaptic cleft. These molecules would repeatedly bind with and be released from the receptor molecules. This would stimulate the dendrite repeatedly, as if many impulses were arriving on the axon. If this happens, the dendrite cannot tell the difference between low and high rates of firing on the axon (= weak and strong stimulation from the neuron). The transmitter molecules are either recycled or broken down into an inactive form.

   a) **Reuptake** recycles transmitter molecules back into the axon terminal button.

   b) **Breakdown** destroys them with enzymes that are specific for each kind of neurotransmitter molecule.

Match the following:

1. synthesis  2. storage  3. release  4. binding  5. removal by breakdown or reuptake
Q3A. destruction or recycling of released transmitter molecules
Q3B. extra transmitter molecules available when axon sends many impulses
Q3C. making transmitter molecules from precursor chemicals (raw materials)
Q3D. triggered by all-or-nothing impulses reaching axon terminal
Q3E. activation of dendritic membrane

**[Memorize and understand the next paragraph!]**

Psychologically active drugs and medications act on one (or a very few) of the more than 100 chemical neurotransmitter systems at some stage of synaptic transmission. Therefore, different psychologically active drugs and medications affect different psychological processes, because they affect different neurotransmitter systems. Different neurotransmitter systems affect different brain systems, which in turn control different behaviors.
The drugs and medications are not themselves transmitters, but some do mimic the action of transmitters. This table illustrates this idea:

<table>
<thead>
<tr>
<th>Drug A</th>
<th>neurotransmitter system K</th>
<th>brain system Q</th>
<th>behavior X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug B</td>
<td>neurotransmitter system L</td>
<td>brain system R</td>
<td>behavior Y</td>
</tr>
<tr>
<td>Drug C</td>
<td>neurotransmitter system M</td>
<td>brain system S</td>
<td>behavior Z</td>
</tr>
</tbody>
</table>

Q4. [Mark EACH item True (T) or False (F)] Chlorpromazine and barbiturates (older sleeping pills) are both classed as depressants. Chlorpromazine relieves symptoms of schizophrenia, whereas barbiturates do not. The reason these medications have different effects is that

T F A. they affect different neurotransmitters  
T F B. they change the order of the stages of synaptic transmission  
T F C. each brain system has its own behavioral function  
T F D. they are different neurotransmitters  
T F E. each brain system has its own neurotransmitter system

The following are examples of the relation between different recreational drugs and the neurotransmitter systems they affect. The main point is not to memorize this, but to use them to help understand the underlying principle: psychologically active chemicals produce their effects by changing how one (or a few) neurotransmitter systems work.

- **Alcohol** (among other effects) increases the effectiveness of GABA, the main inhibitory neurotransmitter in the brain. Other drugs and medication also increase the activity at synapses using GABA. These include barbiturates (older type of sleeping pills) and anti-anxiety medications (like Valium and Librium). These drugs and medications act at different sites, so their combined effect on GABA transmission is much stronger than the sum of their individual effects. This makes combining these drugs and medications with alcohol very dangerous.

- **Amphetamine** and **cocaine** increase the effectiveness of transmission at dopamine synapses, mainly by preventing removal by reuptake. Therefore, much more dopamine remains in the synaptic cleft and binds more with the receptor molecules. This has the effect of increasing the stimulation to the dendrites of the post-synaptic neuron. One brain system that uses dopamine as its neurotransmitter is the "reward system" of the brain, which is what makes these recreational drugs so popular (and so addictive, especially if used for any length of time).

- **Opiates** (drugs like morphine and heroin) mimic the action of a group of transmitter substances called **endorphins**. (These transmitters are sometimes called the brain's own "morphine.") These drugs bind to one or more types of endorphin receptors on the dendrites and activate them as if they were the natural endorphin. Some systems that use endorphins as transmitters inhibit pain systems. Others activate the dopamine-using reward system.

- **Nicotine** (in tobacco) binds to and stimulates one kind of receptor molecule for acetylcholine. This transmitter system has recently been found closely associated with the dopamine reward system, which is an important reason for nicotine's strong addictive properties.

Match the drug with the chemical transmitter it affects

1. GABA  
2. dopamine  
3. endorphins  
4. acetylcholine

Q5A. nicotine  
Q5B. cocaine  
Q5C. heroin  
Q5D. alcohol

Reminder: if you are not sure, go back and check the list above.

Link to an explanation about how caffeine works to keep you awake.

The following examples illustrate how some medications act to help relieve "mental" disorders.

- **Schizophrenia** is a very disruptive "mental" illness that severely disrupts people's ability to deal with even ordinary tasks of everyday life. The first effective medication, **CPZ (chlorpromazine)**, was introduced about 45 years ago. Many others, like **HAL (haloperidol)** have been developed. They appear to work by blocking one kind of dopamine receptor. They do so by binding to the receptor molecules without activating them. Therefore they prevent dopamine from binding to the receptors and activating them. This is like putting chewing gum into a lock, so the key can't fit in and open it. The more tightly a medication binds to the dopamine receptor, the lower the dose needed to be effective (Creese et al., 1971).
Depression often can be relieved quite successfully by one of several medications. Imipramine (Tofranil®) acts to block the reuptake of norepinephrine (NE) and serotonin (5HT). Fluoxetine (Prozac®) selectively blocks serotonin reuptake. MAO inhibitors like phenelzine (Nardil®) block the breakdown of serotonin, norepinephrine, and dopamine.

Anxiety is often helped by a group of chemicals called benzodiazepines, which include Librium® and Valium®. These act to increase effectiveness of the important inhibitory neurotransmitter, GABA. These medications can become addictive, especially if taken for a long time.

Match the chemical neurotransmitter system with the behavioral problem with which it seems associated:

1. dopamine  2. GABA  3. serotonin (and others)

Q6A. anxiety  Q6B. schizophrenia  Q6C. depression

Reminder: if you are not sure, go back and check the list above.

To go to a website with a more detailed description of synaptic transmission, click HERE.