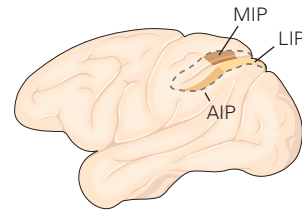


to the difference,  $f_2 - f_1$ . This is challenging to study because the decision variable does not evolve over a long time scale. There is no need to acquire many samples of evidence. All that is needed is an estimate of  $f_2$  and the application of a threshold. The flutter-vibration task complements the motion decision task by demonstrating the diverse functions of persistent activity. In the motion task, the persistence supports the computation of the decision variable—the accumulated evidence bearing on the decision alternatives. In the flutter-vibration task, the persistent activity represents

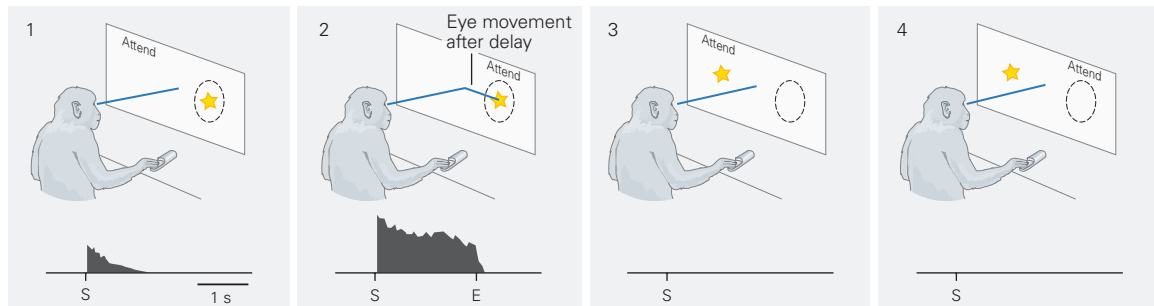
a sensory quality—the frequency of the reference stimulus—through a delay period.

### Perceptual Decision-Making Is a Model for Reasoning From Samples of Evidence

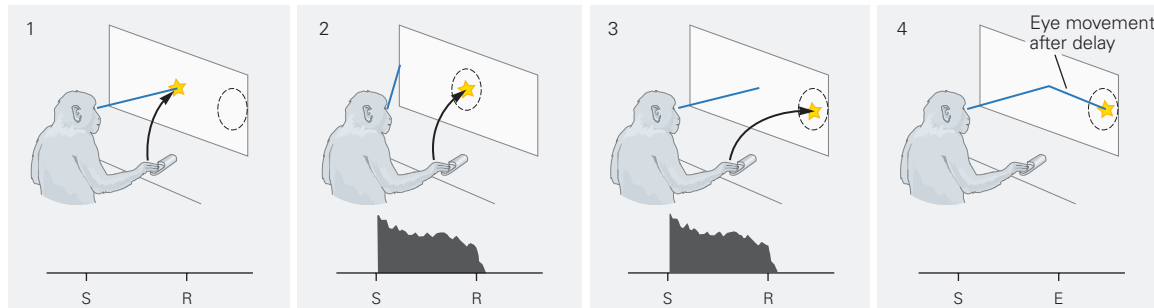
Most of the decisions animals and humans make are not about weak or noisy sensory stimuli. They are about activities, purchases, propositions, and menu items. They are informed by knowledge and



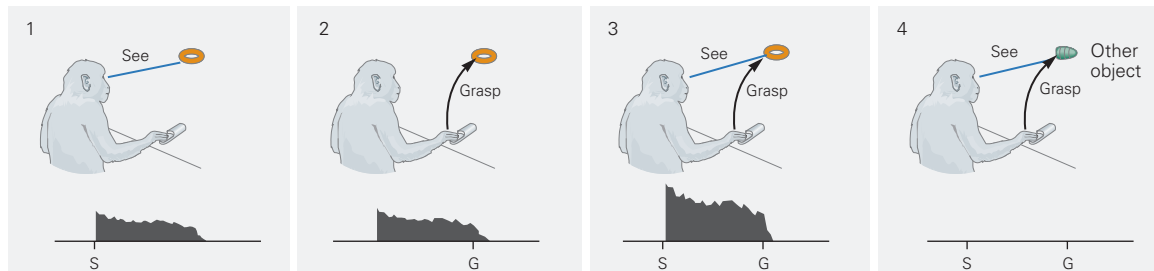
A Lateral intraparietal area



B Medial intraparietal area



C Anterior intraparietal area



expectations derived from sources such as personal experience, books, friends, and spreadsheets. Some are based on internal (subjective) valuation or preference. Many involve reasoning from sources of evidence that may differ in reliability and that must be weighed against costs and benefits. To what extent do the neural mechanisms of perceptual decision-making apply to these other types of decisions?

Imagine the following scenario. As you leave your home in the morning, you realize that you will be outdoors from 4 to 5 pm and must decide whether to carry an umbrella. To make this interesting, assume this occurred before the age of the internet and accurate satellite weather prediction. You must decide based on yesterday's forecast of "possible chance of rain", the clear appearance of the sky at 7:00 am, a small drop in the barometric pressure compared to 1 hour before, and the observation that among a dozen pedestrians visible from your window only one seems to be carrying an umbrella. Let us assume further that you have experience with such decisions and have some sense of how reliable these indicators are. Finally, the cumbersomeness of carrying the umbrella is such that your decision boils down to a reasoned assessment of whether rain is more likely than not.

The right way to make this decision is to consider each of the indicators and ask how likely they would be if rain does or does not occur in the afternoon. These likelihoods are learned estimates of conditional

probabilities, the probability of observing the indicator when it rains in the afternoon, and the probability of the same observation when it does not rain. For example, suppose through experience you have learned that the forecast, chance of rain, implies a 1 in 4 chance of rain. Then, the conditional probabilities are 1 in 4 and 3 in 4 that it will or will not rain, respectively, given the weather report. The ratio of these two probabilities is termed the likelihood ratio (LR), which is 1 in 3 in this case. If the LR is greater than 1, it favors rain, and if the LR is less than 1, it favors no rain. There is an LR for each of the four indicators. If the product of the four LRs is greater than 1, then you should carry the umbrella.

For reasons that will be clear in a moment, it is useful take logarithms of LRs, termed the log-likelihood ratio (logLR). This provides a more natural scale for belief, and it allows us to replace multiplication with addition [recall that  $\log(xy) = \log(x) + \log(y)$ ]. To appreciate the scale, assume that the one passerby with an umbrella would be equally likely to carry the umbrella whether or not rain is a prospect. Both probabilities are 1 in 2. The LR is therefore 1, and the  $\log(1) = 0$ , which corresponds to the intuition that this observation is uninformative. LRs greater than 1 have positive logarithms, and LRs less than 1 have negative logarithms, consistent with the way they bear on the prediction of rain.

Monkeys can be trained to perform a version of this weather prediction task. In the experiment depicted in

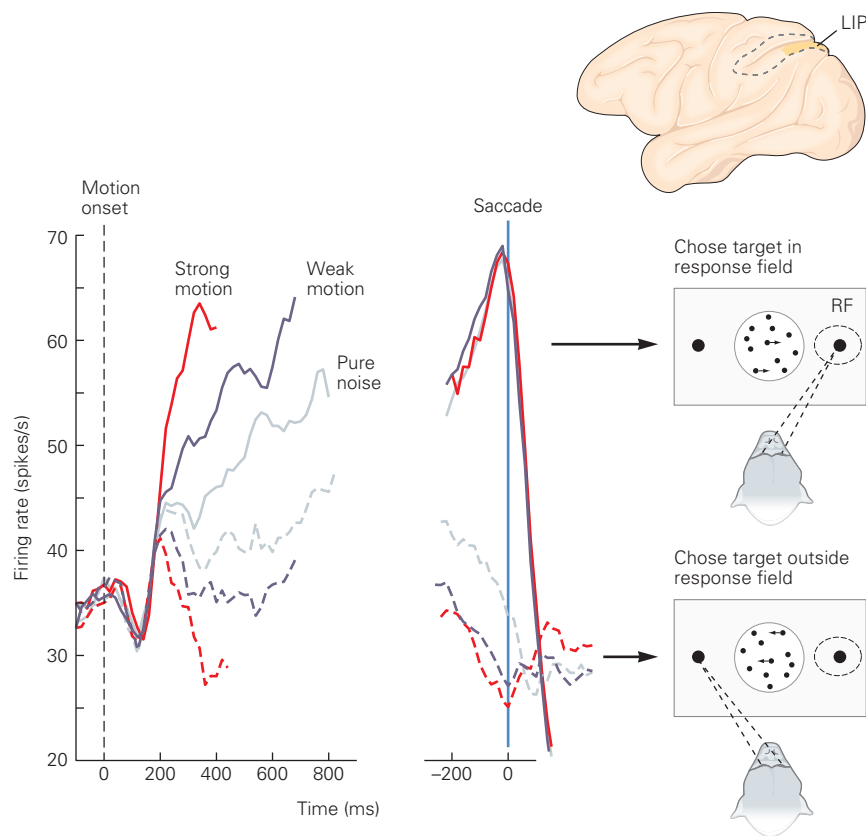
**Figure 56–7 (Opposite) Persistent neural activity maintains working memory, attention, and plans of action.** The monkey is asked to view a scene and respond to a visual stimulus (S) by either moving its eyes (E) or reaching (R) or grasping (G) with its hand. Each histogram represents the firing rate of a representative neuron as a function of time following presentation of the visual stimulus. The **dashed circles** show the *response fields*. This term is preferable to receptive and movement field because these neurons are neither purely sensory nor purely motor. The **blue line** shows where on the screen the monkey is asked to initially fixate its gaze.

**A.** Neurons in the lateral intraparietal area (LIP) fire when a monkey is preparing to make an eye movement to an object or when the monkey directs attention to the object's location. Most LIP neurons are not selective for object features such as shape and color. This neuron fires when the object is presented in the neuron's response field, which lies in the circled area to the right of where the monkey is looking (1). The neuron's firing is enhanced if the object is presented while the monkey's attention is directed to this location or if the monkey is asked to plan an eye movement to the location (2). The firing can persist for several seconds after the stimulus has been removed (2), thereby providing a potential mechanism for maintaining a short-term or working memory of its location. The neuron does

not fire if an object is presented outside the neuron's response field (eg, to the left) (3) even if the monkey is asked to attend to the location of the neuron's response field (4). An object must appear there even if only briefly (2).

**B.** In the medial intraparietal area (MIP), neurons fire when the monkey is preparing to reach for a visual target. This neuron starts firing shortly after the appearance of a target in the response field of the neuron, in this case, a fixed angle to the right of where the monkey is looking, whether its gaze is on the left edge (2) or the center (3) of the screen, and it continues to fire as the monkey waits to reach. The neuron does not fire when the monkey reaches for a target at the center of its gaze (1) or when the monkey plans to shift its gaze to a target in the response field, without reaching (4). The physical direction of the reach is not a factor in the neuron's firing: It is the same in 1 and 2, and yet the neuron fires only in 2.

**C.** In the anterior intraparietal area (AIP), neurons fire when the monkey is looking at or preparing to grasp an object and are selective for objects of particular shapes. This neuron fires when the monkey is viewing a ring (1) or making a memory-guided reach to it in the dark (2). It fires especially strongly when the monkey is grasping the ring under visual guidance (3). It does not fire during viewing or grasping of other objects (4).



**Figure 56-8** Neurons in the lateral intraparietal area (LIP) represent the accumulation of noisy evidence. These neural recordings were obtained while a monkey performed the reaction time version of the motion task. The traces are average firing rates from 55 neurons. The neurons were of the same type shown in Figure 56-7A.

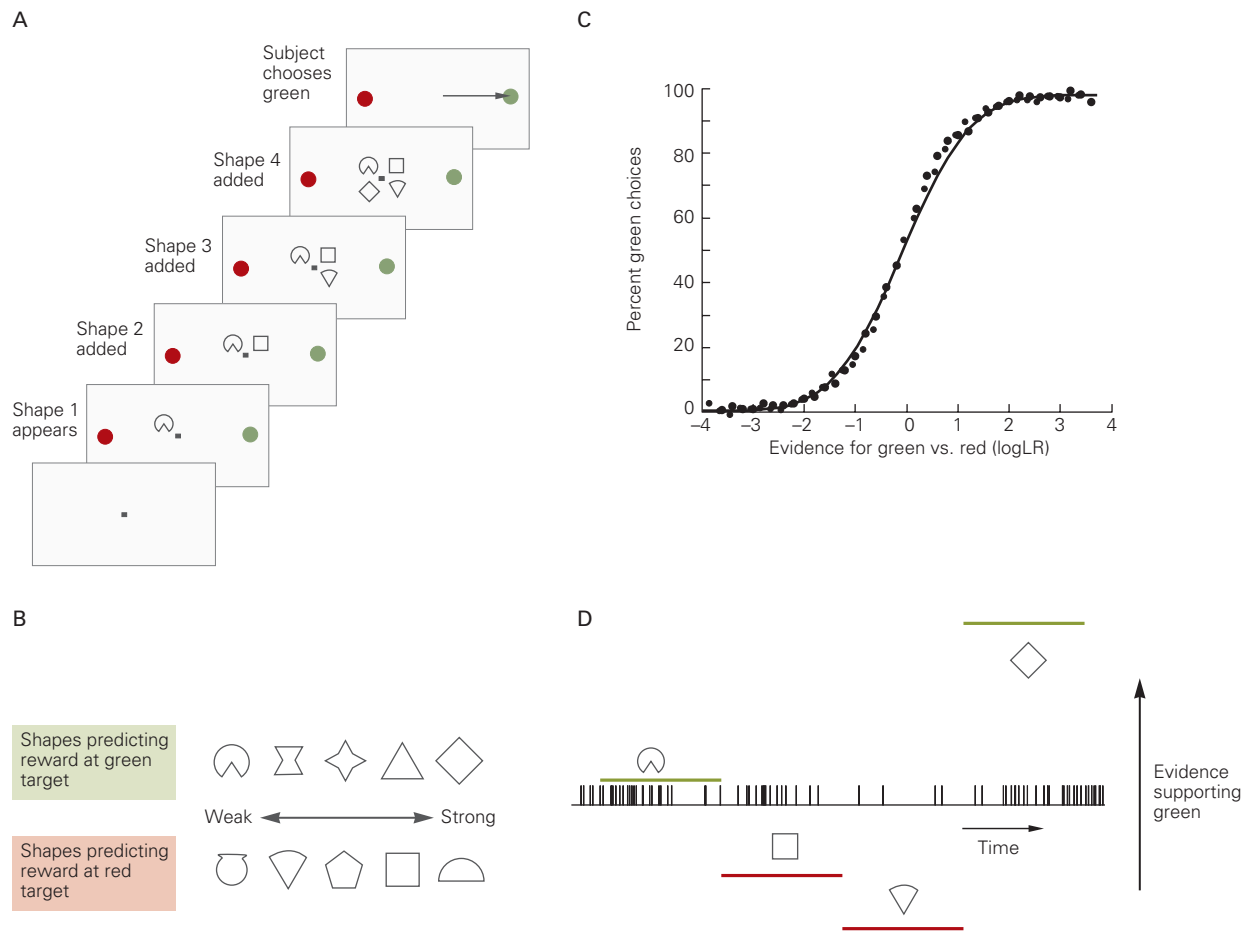
The traces show average responses to three motion strengths: strong (red), weak (purple), and zero (pure noise, gray). The **solid traces** are from trials in which the monkey chose the target in the neuron's response field (RF; right choice). The **dashed traces** are from trials in which the monkey chose the target outside the neuron's response field (left choice). For the nonzero strengths, the direction of random dot motion was the direction the monkey chose (ie, only correct choices are shown). The responses in the plot on the left, which are aligned to the start of random dot motion, exhibit a

gradual buildup of activity, leading to rightward choices, and a gradual decline in activity, leading to leftward choices. The rate of this buildup and decline reflects the strength and direction of motion. The responses on the right are to the same dot motion but are now aligned to the moment the monkey makes its eye movement (**saccade**) to indicate its choice and reveal its reaction time. The responses reach a common level just before the monkey makes its choice, consistent with the idea that a threshold applied to the firing rate establishes the termination of these trials. The responses do not reach a common level before leftward choices because these decisions were terminated when a separate population of neurons, with the left choice target in their response fields, reached a threshold firing rate. (Adapted, with permission, from Roitman and Shadlen 2002. Copyright © 2002 Society for Neuroscience.)

Figure 56-9, a monkey had to decide whether to look at a red or a green target, only one of which would lead to a reward. Before committing to red or green, the monkey was shown four shapes. Each served as an indicator about the location of the reward. The monkey had learned to associate predictive value with a total of 10 shapes, half of which favored reward at red, the other half at green. The shapes also differed in the reliability with which they predicted the reward location. The monkey learned to rely on these shapes rationally,

making its decisions by combining evidence from each shape and by giving the more informative shapes more leverage on the choices.

While the monkeys made their decisions, neural activity was recorded from the same parietal area studied in the motion task. As before, the neurons responded in a way that revealed the formation of the decision for or against the choice target in their response field. When the red target was in the response field, the neuron assigned positive values



**Figure 56-9** Evidence accumulation underlies probabilistic reasoning from evidentiary symbols.

**A.** A monkey was trained to make decisions based on a sequence of four shapes, drawn randomly with replacement from a set of 10. The shapes were added to the display sequentially every one-half second.

**B.** Each shape provides a different amount of evidence that a reward is associated with a red or green choice target. Some, like the diamond and semicircle, are highly reliable predictors that a reward will occur if the choice is for green or red, respectively. Others are less reliable predictors. The degree of reliability is quantified by the likelihood ratio or its logarithm. A good decision-maker should base the decision on the product of the likelihood ratios or the sum of their logarithms (**logLR**).

**C.** The monkey's decisions were guided by the probabilistic evidence from the four shapes. On trials in which the sum of the logLR from the four shapes strongly favored green, the monkey almost always chose green. When the sum was closer to 0, the monkey had to base its decision on weak evidence and chose less consistently. The pattern of choices demonstrates that the monkey assigned greater weight to the shapes that were more reliable (strong versus weak).

**D.** The same types of parietal neurons studied in the perceptual decision-making task represent the running sum of evidence bearing on the choice target in its response field. The spikes are shown from a single decision when the green target was in the neuron's response field. The **horizontal black line** below the spikes marks the neutral level of evidence for green versus red, such that the two choice targets are equally likely to be rewarded. The vertical position of the green or red lines associated with each successive presentation of an indicated shape show the cumulative evidence conferred by the shapes that the reward was at the green target. The first shape was weak evidence for green. The second and third shapes supplied mounting evidence against green (for red). Note the reduction in firing rate. The final shape provided strong evidence for green, such that the cumulative evidence from all the shapes favored green. Note the increase in firing rate. It is an example of a single neuron in the association cortex using persistent activity to compute quantities useful for decision-making. Based on the firing rates from many trials, it was shown that neurons encode the cumulative sum of the logarithm of the probability ratios—the logLR that a reward is associated with the choice target in the neuron's response field. (Adapted, with permission, from Yang and Shadlen 2007.)

to the red-favoring shapes and negative values to the green-favoring shapes. When the green target was in the response field, the signs were reversed. As shown in the example, the response changed discretely when each of the four shapes was presented, and it did so by an amount commensurate with the degree of reliability. In fact, the increment (or decrement) was proportional to the logLR assigned by the experimenter to the shape! The brain simply adds these logLRs to form a decision. And if the monkey is allowed to view as many shapes as it wants, it will typically stop when the accumulated evidence (in units of logLR) reaches a criterion level. The LIP neurons do the same thing they did in the motion decision. They produce firing rates that represent the cumulative sum of noisy increments and decrements.

By adding in units of logLR, the brain achieves reasoning from probabilistic cues in the way a statistician or actuary combines evidence from multiple sources. The experiment demonstrates that the mechanism used for perceptual decision-making is also at play in more complicated decisions that involve reasoning from more abstract sources of evidence. It speaks to the broader theme of this chapter: The study of decision-making offers insight into how the brain achieves a variety of cognitive functions.

### Decisions About Preference Use Evidence About Value

Many, if not most, decisions made by humans and animals are expressions of preference, based on an assignment of value. In some instances, the value is innate. For example, most animals experience sweet as positive and bitter as negative (Chapter 29). In the vast majority of instances, however, value is learned through experience, or it is derived from reasoning based on other preferences. Unlike a decision about the direction of motion, a medical diagnosis, or the weather, a decision about which of a pair of items one prefers is not objectively right or wrong. It can only be said to be consistent or inconsistent with one's expression of value. In fact, our knowledge of a subject's valuation of an object may only be revealed to us by observing her choices.

Yet despite the qualitative difference between subjective and objective evidence, there are parallels between the neural mechanisms that support perceptual and value-based decisions. Decision-makers take more time to choose between items of similar value than items that differ substantially in value, and their choices are less consistent. In a typical experiment, the

participant is asked to indicate the value of each item that they will later make choices about. For example, they might be asked how much they are willing to pay or they are asked to indicate a rating from highly undesirable through neutral to highly desirable. This procedure is typically repeated to provide a subjective value for each item to be used in the experiment.

The participant is then asked to decide between pairs of items. The difference in the subjective values communicated before the experiment provides an index of the difficulty of the decision between the items. It is analogous to motion coherence. A similar approach works with animals. For example, a monkey might demonstrate a preference for grape juice over apple juice, and then be asked to choose between a small volume of grape juice versus a large volume of apple juice. The decision is rendered more difficult by titrating the ratio of volumes to values that lead the monkey to choose either juice with equal tendency.

Two types of neurons associated with this type of value encoding have been identified. The first, typically located in the striatum, encodes the value associated with an action. The second, primarily in the orbitofrontal and cingulate cortex, appears to encode the value associated with specific items. Decisions about preference seem to arise from the same strategy that governs perceptual decisions. Just as a decision between left and right motion is guided by the difference in firing rates of left- and right-preferring sensory neurons, a decision between two items is based on the difference in activity of neurons encoding the values of each item. These neural representations are noisy, and this feature might explain why a decision-maker may make choices that are inconsistent with their values. It might also explain why decisions between items of similar value tend to take more time—a speed-consistency trade-off similar to the speed-accuracy trade-off discussed above.

The analogy to perceptual decision-making is appealing, but it misses the more interesting aspects of value-based decisions. As mentioned above, the value of most items is not given by biology but instead is learned. Further, there is no reason to assume that such value is monovalent. One may value an item differently, based on different qualities and considerations, and one or more of those qualities may dominate under different circumstances. Accordingly, the value of an item could appear to change simply by the occasion of its comparison to another item, which might invite emphasis on a more or less desirable aspect. Novelty, familiarity, and the value of exploration itself might also play a role in modifying a subjective valuation.

These considerations might contribute to the “noisy” representation of value that is thought to



explain inconsistencies and long decision times in preference choices. This type of noise belies processes that are far more complex than variability in random dot displays and the noisy spike rates of neurons. Such evaluative processes are likely to involve prospection and memory retrieval, which are only beginning to be understood at the neural level (Chapter 52). In the end, these processes must furnish samples of evidence bearing on the relative value of the items, and this evidence is either accumulated or evaluated individually against a criterion to halt the process with a decision.

### Decision-Making Offers a Framework for Understanding Thought Processes, States of Knowing, and States of Awareness

States of knowledge have persistence. Even if they concern information derived from the senses, the knowledge of sensation generally outlasts the sensory activity itself. In this way, the state of knowledge resembles a perceptual decision—a commitment to a proposition about the object, based on sensory evidence. As we have seen, these states are often tied to possible behaviors rather than to the features of the sensory information. This is a position argued by many philosophers and the psychologist James J. Gibson.

This simple point can be made on empirical grounds. Persistent neural activity is not present in sensory areas of the brain unless a stimulus is unchanging and then only if the neurons do not adapt. Naturally, sensory neurons must change their response when the environment changes or the observer moves in the environment, whereas knowledge states persist through sensory changes and without a continuous stream of input. Indeed, persistent activity is apparent in areas of the brain that associate sources of information—from the senses and from memory—with circuits that organize behavior.

In the prefrontal cortex, persistent states represent plans of action, abstract rules, and strategies. In the parietal and temporal lobes, neural representations have the dual character of knowledge and the behavior that knowledge bears upon, such as making an eye movement or reaching, eating, or avoiding. The responses can resemble a spatial representation, as they do in area LIP, if the target of the projection is the eye movement system, but that is only because there is correspondence between space and action. A useful guide is to consider the source and target of the association. If the source is the visual cortex and the targets are premotor areas that control hand posture (eg, grip), as they do in the anterior intraparietal

area (Figure 56–7C), the association area might convey knowledge about curvature, distance, convexity, and texture. One might be inclined to use terms borrowed from geometry to catalogue such knowledge, but it may be simpler to think about the repertory of hand shapes available to the organism. Importantly, the neurons in association cortex do not command an immediate action. They represent the possibility of acting in a certain way—an intention or provisional affordance (Box 56–1).

Let us defer for the moment the aspect of the knowledge state that includes conscious awareness and consider the simpler sense of knowledge as a state of possible utilization. Such preconscious ideation is probably the dominant state in which an animal interacts with the environment. It is arguably also the lion's share of human experience, although because we are not conscious of it, we underestimate its dominance. Two important insights emerge from this perspective. The first is that the correspondence between knowledge and neuronal activity lies at a level of brain organization between sensation and behavior. Although the flow of information from sensory epithelia (eg, the retina) through the primary cortical sensory areas is essential for perception, knowledge resulting from activity in higher brain regions has temporal flexibility and persistence not seen in lower brain regions—what the philosopher Maurice Merleau-Ponty termed the *temporal thickness of the present*.

The second insight is that the computation leading to a knowledge state has the structure of a decision—a provisional commitment to something approximating a possible selection from a submenu of the behavioral repertory. We might say that the parietal association neurons interrogate the sensory areas for evidence bearing on the possibility of a behavior: look there, reach there, posture the hand this way to grasp. Of course, neurons do not ask questions. Nevertheless, we can think of the circuits as if they scan the world looking for evidence bearing on a possible behavior. The type of information they can access is limited by functional and anatomical connectivity. The type of question is framed by the target of the projection, such as regions that control gaze, reaching, and grasping.

Sir Arthur Conan Doyle endowed Sherlock Holmes with the insight that the key to discovery was knowing where to look and what to look for. We acquire knowledge by controlling the brain's interrogation system. Some interrogations are automatic, whereas others are learned. An example of the former is a sudden change of brightness of an object in the visual field; it provides evidence bearing on the possibility of orienting the eyes or body toward it. An example

### Box 56–1 Affordances, Perception, and Knowledge

James J. Gibson, known for his ecological theory of perception, referred to *affordances* as properties of objects and the environment. The term comes from the verb *afford*. An object affords possible behaviors, such as lifting, grabbing, filling, hiding in, drawing/writing upon (eg, parchment) or with (eg, a brush), or walking upon. The affordance refers to the potential behaviors of the animal. The same object, say a stone, could afford grasping, dropping, breaking (ie, used as a tool), throwing (as a missile weapon), or pinning (as a paperweight).

Gibson was widely criticized for claiming that perceptual processes picked up these affordances directly from the optical array, what he termed “direct perception.” The term is commonly misunderstood as antithetical to computational accounts of information processing. By “direct perception,” Gibson did not mean that there were no computations on the data received through the senses. He promoted the mathematical understanding of these operations. He meant that we do not perceive the intermediates.

We do perceive the parts of objects that are accidentally occluded by something in our line of sight, and we perceive the back of an opaque object that is occluded by its front. We do not perceive the outlines, the line art, and many other details, but that is not to say that they do not register on the retina and the visual cortex. Gibson held that representation of visual information is not a sufficient condition for perception. From the perspective of the neuroscience of decision-making, one might place emphasis on the representation of potential behavior—something like a provisional commitment to a plan.

Affordance still refers to a category of actions, but it is about the organization of the action (eg, throwing) or strategy, and also—but not necessarily—a quality of the object. The modifier, “provisional,” emphasizes that the action may not actually ensue now or ever. This modifier would have been superfluous in Gibson’s use of the term *affordance*, because an affordance was a property of the object (in his ecological framework) and therefore had a permanence independent of the perceiver.

of the latter draws on learning and foraging; we learn, through play and social interaction (eg, school), how to look for hidden items and how to explore in a goal-directed way.

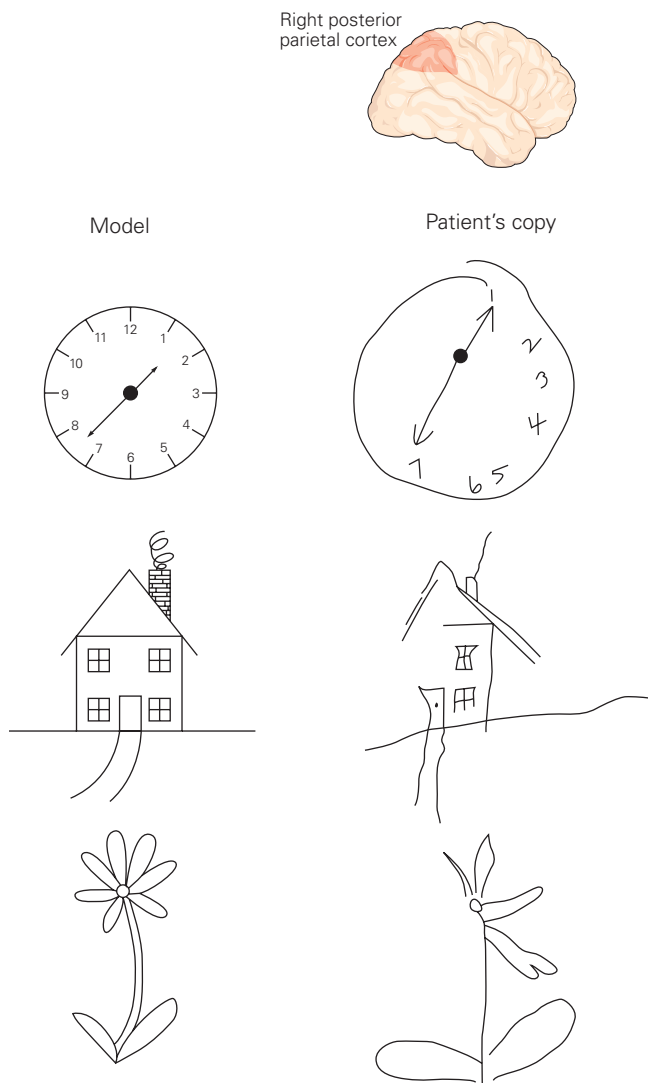
The beautiful thing about this construction is that an answer to the question confers a kind of meaning. Even for such a mundane question like “Might I look there?,” an affirmative answer—a decision to (possibly) look at an as yet undefined object in the periphery of one’s visual field—confers a spatial knowledge about the item. Before we have looked directly at it to identify what it is, we know about its *thereness*. From the perspective of decision-making, the location of an object is not perceived because there is a neural activity in a map of the visual field. Rather, the location is perceived because some aspect of the visual field—a fleck of contrast, change in brightness, appearance or disappearance—answered the question above in the affirmative.

This way of thinking helps us understand the disease states known by the term *agnosia*, from the Greek word meaning “absence of knowledge.” The classic example is visual hemineglect, which is caused by damage to the parietal lobe (Chapter 59). A patient with a right parietal lesion will ignore the left side of the visual field and also the left side of objects even when the entire object is in the right visual field (Figure 56–10; see

also Figure 59–1). Unlike the left side blindness, called homonymous hemianopsia (or hemiblink), which accompanies damage to the right visual cortex (homonymous because it is the same regardless of which eye is used), the patient with a parietal lesion does not complain of an inability to see. She is unaware of the deficit, so much so that crossing a street is a major hazard.

A hemiblink patient with damage to the right visual cortex still expects to interrogate and receive information from the left visual field. When that patient receives no visual information, he knows to turn to face parallel to the street, thereby placing its contents in the intact right hemifield. In contrast, the patient with hemineglect does not interrogate the left hemifield in the first place. She does not perceive a lack of visual information because the apparatus to conduct the interrogation is not working. Like most deficits, there is enough redundancy in the brain (or the damage partial) that some visual capacities are present. In fact, when confronted with a single spot of light on a dark background, the same patient may report its presence accurately even in the affected hemifield.

There are other versions of hemineglect that involve an absence of knowledge of the body. For example, a patient with a right parietal injury may deny that her left arm is hers. She may recognize it as



**Figure 56-10** Damage to the parietal or temporal cortices results in agnosia, or deficits in knowing. After damage to the right parietal lobe, many patients are unaware of the left side of space or the left part of objects. The drawings on the right were made by patients with unilateral visual neglect following lesion of the right posterior parietal cortex. Agnosias can also be induced in healthy individuals by diverting attention (see Figure 25-8). (Reproduced, with permission, from Bloom F, Lazerson A. 1988. *Brain, Mind and Behavior*, 2nd ed., p. 300. New York: Freeman.)

an arm but deny that it is hers. When asked whose arm it is, she may express ignorance bordering on disinterest (personal experience). The syndrome is usually associated with some visual neglect as well and some weakness on the same side of the body suggestive of a more rostral and superior localization. Consider that the body's position is known to us partly through the somatosensory system, partly through the predicted

consequences of our motor command, and partly through vision. The arm in particular is a common feature of our lower visual field. Indeed, we are accustomed to ignoring it.

These examples are the most common of the agnosias (which are thankfully rare). Other well-known examples involve problems in face recognition (prosopagnosia) and the perception of color (achromatopsia), both associated with lesions of the temporal lobe. The different types of agnosia have loose correspondence to the anatomical specializations we learned about in Chapter 24. In particular, the ventral extension of the central visual pathways into the temporal lobe is referred to as the “what” pathway, which contains circuits that are specialized for processing faces, objects, color, and semantic memory. The dorsal extension, which has been termed the “where” or “how” pathway, seems concerned with representations supporting localization.

An alternative formulation would characterize these streams in terms of associations with behaviorally relevant targets. For the dorsal stream, those are parietal areas with projections to motor systems that reach, look, or grasp. For the ventral stream, those are temporal lobe areas with projections to structures that guide foraging decisions to eat, avoid, hide, approach, mate, and communicate. The last few behaviors are social affordances conferred by color and facial identity/expression. With a small stretch of imagination, the organization of social affordances links to other functions of the temporal lobe (and temporal parietal junction) in humans. For example, these regions are associated with language comprehension and inference about what someone else is thinking. The former is associated with a devastating agnosia, known as Wernicke aphasia (Chapters 1 and 55); the latter is known as theory of mind and will be discussed below.

From the perspective of decision-making, perceiving, believing, and thinking have the character of a provisional commitment to a proposition. Brain states that correspond to a sense of knowing, be it perceiving or believing, share two important aspects with decision-making: an extended temporal profile that withstands changes in the sensory and motor streams (ie, a freedom from immediacy) and a propositional character captured by the term “affordance.” Knowing is not solely about the information but is like the outcome of a decision to embrace a proposition: Might I do something, enact something, approach someone, or retain the possibility of trying the option I am not choosing now?

Two caveats deserve mention. This framework does not replace a computational account of



information processing, nor does it explain the neural mechanisms that support these computations. It mainly tells us about the level of brain organization that carries out these operations. For example, consider the search for the neurons that achieve knowledge about the color red, despite changes in the spectral content of the morning and evening light—a phenomenon known as *color constancy*. Instead of searching in sensory areas for neurons that respond selectively to red in this invariant way, one might look for neurons that guide the choice of ripe fruit. This does not obviate the computations required to recover the surface reflectance properties of the fruit's skin, despite variation in the spectral content of the illuminating light. The raw data for such computations are supplied by sensory neurons that lack color constancy and maintain temporal fidelity with changes in the environment. The knowledge state "red," however, is invariant to the illuminant and likely persistent. In animals that lack language, the knowledge state may not be dissociable from "ripe vegetation."

The second caveat is that we have not distinguished knowledge states that we are consciously aware of from those that we experience unconsciously. For example, as I make my way through the forest trying to find the creek that I hear burbling, my brain might consider locations of objects I pass that are graspable, attached to vegetation, and with color suggesting ripeness. I may be unaware of this consciously. Yet that evening in my search for food, I may return to this part of the forest, guided by these unconscious encounters. I may do this without knowing why, or the memory might pierce consciousness. All that has been said up to now could apply to conscious and nonconscious experience. We are now prepared to elucidate the difference.

### Consciousness Can be Understood Through the Lens of Decision Making

Clearly, we are unaware of most of the operations that transpire in our brains, and this is true even for the processes that ultimately pierce consciousness. This is why Freud famously quipped that consciousness is overrated. Every thought that enters our awareness began as neural computation preceding the conscious awareness of that thought. Indeed, the sophistication of nonconscious mental processes, including those leading to "I've got it!" moments and the activities we perform while occupied by a phone call, involves decisions that transpire without conscious awareness.

It is difficult to study nonconscious processing because people deny experience of the process. Indeed, the term nonconscious experience seems like an oxymoron. The experimenter must find a way to prove that information processing has occurred despite the fact that the subject is unaware of it. In recent years, it has become possible to establish conditions whereby information is provided to a human subject that has a high likelihood of going unnoticed but is nonetheless able to influence behavior, thereby permitting scientific characterization of nonconscious mental processing (Chapter 59). This has encouraged neuroscientists to ask what it is about the neural activity that gives rise to the thoughts, perceptions, and movements that do reach conscious awareness. We will not review this vast topic here but instead share a pertinent insight: Viewed through the lens of decision-making, the problem of consciousness may be simpler than imagined.

Broadly speaking, two sets of phenomena fall under the heading consciousness. The first concerns levels of arousal. One is not conscious when one is asleep, under general anesthesia, comatose, or having a generalized seizure. One is fully conscious when awake, and there are levels of consciousness between these extremes. These states are associated with terms such as confusion, dissociation, stupor, and obtundation. Some alterations of consciousness are normal (eg, sleep), whereas others are induced by toxins (eg, alcohol), metabolic disturbances (eg, hypoglycemia), low oxygen, trauma (eg, concussion), or fever (eg, delirium).

The neuroscience underlying these states—and the transitions between them—is immensely important to medicine. We might classify this group of phenomena as neurology-consciousness. However, these topics are not what most people mean when they speak of the mystery of consciousness. This is partly because they are less mysterious but also because their characterization is more objective and the phenomena can be studied in animals. That said, there is much to be learned about the mechanisms responsible for sleep, awakening, anesthesia, and so forth. Much of the neuroscience is unfolding at a rapid pace (Chapter 44).

We will not say more about neurology-consciousness here, except to seed one useful insight. Imagine a mother and father sleeping comfortably in their bedroom as a storm ensues outdoors. There are also traffic sounds and even the occasional thunder. This scene goes on for some time, until the cry of a baby awakens the parents. This common occurrence tells us that the nonconscious brain is capable of processing sounds and deciding to become conscious. It decides, nonconsciously, that some sounds afford an opportunity for more sleep while others sound a call to nurture. This