Abstract
The goal of the present chapter is to show the relevance of neuroscience research to human motivation researchers. The first part of the chapter discusses the current status of the possible integration of motivational psychology and neuroscience into the new emerging field of motivational neuroscience. The second part identifies 15 brain structures and 5 neural pathways that underlie most of the neural basis of human motivational states. The third part examines how recent findings in neuroscience have advanced the understanding of 14 widely studied motivational concepts, including those automatically activated by environmental stimuli (hunger, thirst), those learned from the rewarding properties of environmental stimuli (incentives, rewards, expectancy, value), and those proactively generated by the individual (agency, volition, self-regulation, goals, curiosity, intrinsic motivation, psychological needs, and autonomous self-regulation). The chapter concludes with suggestions for future research.

Keywords: motivation, neuroscience, striatum, reward, dopamine, prefrontal cortex

We organized this chapter into three sections. First, we provide a contemporary update on the status of the newly emerging field of motivational neuroscience. Second, we identify this new field's subject matter, which revolves around the brain structures and neural networks that underlie human motivational states. Third, we provide a neuroscience perspective on a wide range of motivational states that are highly studied by motivational psychologists.

Motivational Neuroscience: Current Status of the Field
Motivational neuroscience is the empirical study of all the brain-based processes that energize, direct, and sustain behavior. Brain-based processes include brain structures (e.g., striatum), pathways of interconnected neural structures (e.g., mesocortical pathway), and the neurotransmitters that organize these pathways (e.g., dopamine). The field also includes measures of bodily based processes, such as hormones and psychophysiological states, but the endocrine system (hormones) and autonomic nervous system (psychophysiology) are regulated by these brain-based processes. So, typically, the subject matter and dependent measures emphasized in motivational neuroscience investigations are the activation of specific brain structures, networks, and neurotransmitters.

Motivational neuroscientists are a loosely connected group of scholars who focus their attention on the aforementioned brain-based processes to help them better understand motivation and motivated behavior. Their research is often *top-down* because it typically begins with a well-studied motivational phenomenon (e.g., self-regulation, intrinsic motivation) and then proceeds to investigate the phenomenon from the new, fresh perspective of neuroscience. That is, neuroscience is typically used to supplement and extend what has previously been discovered about that motivational phenomenon, and researchers do this by incorporating neuroscientific methods...
and findings into their programs of research. An example of this approach can be seen in the application of neuroscience methods and dependent measures to better understand the undermining effect that extrinsic rewards sometimes have on intrinsic motivation (Murayama, Matsumoto, Izuma, & Matsumoto, 2010).

Another group of scholars are neuroscientists who are interested in incorporating motivational phenomena (e.g., reward, value, self-control) into their programs of research. This research is often bottom-up because it typically begins with a deep understanding of specific brain mechanisms and then proceeds to investigate their motivational implications. An example of this approach can be seen in the brain-centric approach to understanding reward-motivated approach behavior (Berridge & Kringelbach, 2008).

Currently, human motivation study and neuroscience are for the most part two different and separate fields. To understand the implications of having two independent working groups focused on motivation study, it is instructive to examine the relation between neuroscience and a different field of study—namely, educational psychology. This is so because, 2 decades ago, Richard Mayer (1998) characterized the relationship between neuroscience and educational psychology through the imagery of dead-end, one-way, and two-way streets. He characterized (and lamented) the relation between neuroscience and his field as an intellectual landscape characterized by dead-end streets in which the two fields of study had little in common and each contributed little to the enrichment of the other. He also observed (and again lamented) an intellectual landscape of one-way streets in which neuroscience research was unidirectionally applied to educational psychology. For instance, neuroscientists identified the limits of hippocampal-based short-term memory (e.g., cognitive overload), and educational psychologists revised their theories of learning and their recommendations for the design of instruction accordingly (e.g., Paas, Tuovinen, Tabbers & van Gerven, 2003). He could find very few one-way streets from educational psychology to neuroscience.

The metaphor Mayer offered to enrich interdisciplinary activity was that of a two-way street. In this scenario, neuroscientific study influences, informs, and enriches educational psychology, while educational psychology study influences, informs, and enriches neuroscience. It has been 20 years since the publication of that paper, and it seems that these two-way streets never materialized. Most streets remain dead-end streets because educators have simply been unable to utilize or apply the progress being made in neuroscience (or vice versa). Attempts to construct a few one-way streets have been made. For instance, educators are hopeful that off-the-shelf, commercially available headsets (e.g., portable electroencephalography headsets) can be utilized to monitor students’ attention, motivation, and learning as they are exposed to learning materials, much in the same way that movie studios are hopeful of utilizing facial recognition software with artificial intelligence to learn how movie-goers respond emotionally to their film content. But there are no two-way streets, and there are no one-way streets that start in the land of educational psychology and end in the land of neuroscience. Overall, the two fields continue to be largely independent domains of scholarship.

Some fields have fared better in building interdisciplinary (two-way) streets with neuroscience, including cognitive neuroscience (Gazzaniga, Ivry, & Mangun, 2014), affective neuroscience (Davidson & Sutton, 1995; Panksepp, 1998), social neuroscience (Decety & Cacioppo, 2011; Harmon-Jones & Inzlicht, 2016), and neuroeconomics (Loewenstein, Rick, & Cohen, 2008). With regard to motivational neuroscience, there is some, but only a little, overlap between motivational science and neuroscience.

Unfortunately, the methods, equipment, data analytic techniques, and research methodologies of neuroscience often prove too overwhelming for motivational psychologists to integrate into their programs of research, at least not without collaborations with neuroscientists. Further, the knowledge base, research methodologies, data analytic techniques, and data-collecting machinery in neuroscience are developing at an incredibly rapid pace. This state of affairs makes it clear that a motivational psychologist cannot be a part-time neuroscientist. For now, motivational psychologists necessarily partner with full-time neuroscientists to get their work done and their questions answered. So, there are some meaningful barriers that are keeping motivational psychologists from becoming full-fledged motivational neuroscientists.

Similarly, neuroscientists have a difficult time bringing motivational psychology into their programs of research. What motivational psychologists have to offer are motivation theories (and applied problems to solve). Neuroscientists tend to stay intellectually close to basic motivational processes, such as reward, value, and conflict, and resist subjectively experienced motivational phenomena. There is little deductively
Guided theory in neuroscience because the field is instead largely inferential as it takes neuroscientific findings (not theory) as its starting point. For instance, it is more common in neuroscience to start a program of research by asking, "What is the function of this particular brain structure?" than it is to start with a guiding theory about how motivational processes work. Motivation theories often specify motivational antecedents and consequences (i.e., the origins and outcomes of the motivational state), but neuroscientists are more interested in basic processes than in antecedents, mediators and moderators, consequences, etc. So, just as there are meaningful barriers keeping motivational psychologists from becoming full-fledged motivational neuroscientists, there too are meaningful barriers keeping neuroscientists from becoming full-fledged motivational neuroscientists—namely, the lack of a perceived need for guiding theory.

Looking toward the future, one can see the blueprints on the drawing board for how to build this new city (motivational neuroscience) populated with highly trafficked two-way streets. Neuroscience can share its subject matter (brain behavior) and research methodologies, and motivation psychology can share its subject matter (motivation theories) and real-world applications. But this has not yet happened, at least not at a critical mass. It is telling, for instance, that there is no existing Motivational Neuroscience journal. What is needed for a flourishing new field of motivational neuroscience is what has been successfully achieved in other fields (cognitive neuroscience, social neuroscience, and neuroeconomics), which is for large-scale motivation-centric laboratories in major universities and institutions to develop specialized working groups of professors, graduate students, and postdoctoral fellows who are trained in and stay committed in equal measure to both fields of study—they are not simply motivational psychologists or neuroscientists but, rather, truly both. Perhaps this chapter can offer some of the engineering work needed to build the two-way streets first envisioned 2 decades ago by Richard Mayer.

**Key Brain Structures and Pathways in Human Motivation**

Figure 20.1 shows the anatomic location of 14 key brain structures identified by neuroscience research as motivationally relevant. Three structures make up

![Figure 20.1 Anatomic location of 17 key motivation- and movement-relevant brain structures.](image_url)

*Note:* (A) A medial sagittal section of the brain. The dashed line represents the primary coronal section of the brain. (B) A lateral sagittal section of the brain.

*Figure 20.1 A coronal section of the brain.*
the prefrontal cortex—the ventromedial prefrontal cortex, dorsolateral prefrontal cortex, and orbitofrontal cortex—while the anterior cingulate cortex is part of the frontal lobe. Five structures reside within the basal ganglia: the dorsal striatum (dorsal parts of the caudate nucleus and putamen), ventral striatum (primarily the nucleus accumbens but also the ventral parts of the caudate nucleus and putamen), globus pallidus, ventral pallidum, and substantia nigra. One structure overlaps (lies between) the neocortex and basal ganglia—the insular cortex. Two structures reside within the limbic system: the amygdala and hypothalamus. One lies within the midbrain—the ventral tegmental area. Figure 20.1 further shows three motor-related structures, the motor cortex, the presupplementary motor cortex, and the supplemental motor cortex, because motivation is mostly about action and how psychological states invigorate and restrain action. These structures interconnect to form communication pathways, including the mesocortical pathway, the mesolimbic pathway, the orbitofrontal-striatal circuit, the ventromedial prefrontal—amygdala pathway, and the anterior insula—anterior cingulate cortex. These pathways do not appear in Figure 20.1, but they will be described in the text. Collectively, these brain structures and communication highways constitute (most of) the neural bases of human motivation.

Prefrontal Cortex

The prefrontal cortex lies immediately behind the forehead and consists of the dorsolateral, ventromedial, and orbitofrontal regions. The anterior cingulate cortex is part of the frontal lobe, but not necessarily the prefrontal cortex, because it lies posterior to the prefrontal lobe and wraps around the anterior part of the corpus callosum in its distinctive C shape. One lobe is on the right side of the brain (right prefrontal cortex) while the other is on the left side (left prefrontal cortex). Rather than reference the general prefrontal cortex, neuroscientific studies refer to the specific dorsolateral, ventromedial, and orbitofrontal regions, because each part of the prefrontal cortex sometimes functions differently or independently. Hence, that is what we, too, will do in this chapter.

Dorsolateral Prefrontal Cortex

The dorsolateral prefrontal cortex is the upper ("dorsal") region of the prefrontal cortex. It is involved in top-down information processing, goal representation, and attentional control. For instance, the dorsolateral prefrontal cortex is involved in the effort to resist temptation during the pursuit of long-term goals (especially the right dorsolateral prefrontal cortex; Knock & Frist, 2007). It contributes inhibitory, self-control-based input during decision-making to resist a sensory-based urge, temptation, or reward that arises from either the striatum (McClure, Laibson, Loewenstein, & Cohen, 2004) or the ventromedial prefrontal cortex (Haze, Camerer, & Rangel, 2009). In addition, it evaluates the learned emotional value of environmental events and possible courses of action, though this function is more associated with the ventromedial prefrontal cortex and orbitofrontal cortex, as discussed next. That said, people have a great deal of learned emotional value and meaning for the objects and events around them, and these emotional memories are largely stored in the dorsolateral prefrontal cortex and accessed to make an emotionally informed action decision.

Ventromedial Prefrontal Cortex

The ventromedial prefrontal cortex and orbitofrontal cortex tend to be hard to distinguish anatomically. Basically, the ventromedial prefrontal cortex is relatively the more ventral (lower) and medial (inner or central) region than is the orbitofrontal cortex (Davidson & Irwin, 1999; Volk & von Cramon, 2009). It evaluates the emotional value of basic sensory (unlearned or natural) rewards, such as taste, and also affective-based information from social cues, such as a smiling face (Roy, Shohamy, & Wagner, 2012). It plays an important function in risk assessment, decision-making, social judgments, and self-control. It plays this role by performing a cognitive valuing and revaluing of emotional inputs that lead to effective decision-making (Davidson & Irwin, 1999; Ochsner & Gross, 2005).

Orbitofrontal Cortex

The orbitofrontal cortex is the anatomical floor of the prefrontal cortex; it lies beneath the prefrontal cortex, just above the eyes. It stores and processes reward-related information about environmental objects that helps people formulate preferences and choose between options (Dickinson & Balleine, 2002; O’Doherty, 2004). The orbitofrontal cortex also inhibits inappropriate actions, because it is involved in the delay of gratification, as will be discussed in the orbitofrontal-striatal circuit section below.

Anterior Cingulate Cortex

The anterior cingulate cortex features dorsal and ventral regions. The dorsal anterior cingulate cortex
is associated with cognition and is connected with the prefrontal cortex and motor areas, while the ventral anterior cingulate cortex is associated with emotion and is connected with the amygdala, striatum (nucleus accumbens), hypothalamus, and anterior insula. There is a lot of conflict in the brain, as occurs in adjusting to new situations and in solving difficult problems. The anterior cingulate cortex is involved in detecting conflict, prioritizing attention, making choices and decisions, predicting the consequences of actions, and alerting and recruiting other cortical areas to help resolve conflict and exert greater cognitive control. It utilizes this cortical input mostly to select appropriate action, but it also uses emotional information gained from subcortical areas to guide this same decision-making and action selection (Bush et al., 2002; Matsumoto, Suzuki, & Tanaka, 2003). The anterior cingulate cortex also evaluates the extent of mental effort required on a task, especially difficult tasks (Walton, Bannerman, Altecrescu, & Rushworth, 2003), and it calculates a cost-benefit analysis as to whether a possible course of action has enough reward value associated with it to warrant an investment of effort (Hayden, Pearson, & Platt, 2009).

Motor Areas

The primary motor cortex is on the top of the head (where you might put a child), but it also has a strip structure that runs down both sides of the head. The motor cortex sends “go” signals to the body's muscles to produce movement. But before such movement occurs, the presupplemental and supplemental motor areas first plan, excite, inhibit, and enact these motor commands. The presupplemental and supplemental motor areas are anatomically located between the prefrontal cortex and the primary motor cortex (the motor cortex lies posterior to the frontal lobes). The presupplemental motor cortex lies next to the frontal lobes and receives massive input from the frontal lobes. The supplemental motor area receives input from the presupplemental motor area but not from the frontal lobes. It is somatotopically organized in a way that corresponds to the somatotopical organization of the motor cortex. These interconnections are important because they are the presupplemental motor area that receives decision-making and action-planning information from the prefrontal cortex as well as motivationally and emotionally biased input from the striatum and basal ganglia. It is in the presupplemental motor area that all this information is integrated in terms of preferred courses of action (Nachev, Wydell, O’Neill, Husain, & Kennard, 2007). This information is then communicated to the supplemental motor area, which then sends the integrated motor instructions to the premotor and motor cortex. The supplemental motor area, premotor cortex, and motor cortex are therefore more related to movement and action than they are to motivation and emotion per se. It is information from the prefrontal cortex and basal ganglia that is sent to and processed by the presupplemental motor area that collectively provide the motivational and emotional punch to volitional movement and action as well as to the achievement and execution of a smooth and coordinated (rather than conflicted) action plan (Kuehn & Brass, 2009; Nachev, Kennard, & Husain, 2008).

Basal Ganglia

The basal in basal ganglia refers to “at the base of the cortex,” while ganglia refer to “a group of nerve cells.” As the prefrontal cortex is composed of various cortical regions, the basal ganglia are similarly composed of various subcortical regions. The largest of these structures is the striatum (dorsal, ventral), and additional structures include the globus pallidum, ventral pallidum, and substantia nigra. Overall, the basal ganglia are involved in selecting between different possible courses of action and in performing voluntary behavior smoothly. They do this by exerting inhibitory control over the motor areas, and it is the release of basal ganglia input that allows for smooth action. The globus pallidum receives input from the striatum and sends inhibitory output to several motor areas. Its function is to motivationally and emotionally prepare action, as it makes a planned action more or less potent (more or less energized or invigorated). The ventral pallidum is a core part of the reward system, because it receives input from the dopamine-generating ventral tegmental area and contains one of the brain's hedonic hot spots, or pleasure centers. The substantia nigra supplies the striatum with dopamine. The substantia nigra plays a key role in reward-seeking, learning, motor planning, and addiction, but it does so through its input to the striatum, so this chapter will focus on the striatum. All basal ganglia—substantia nigra, globus pallidum, ventral pallidum, substantia nigra, and striatum—are closely connected to and receive information from the cortical areas of the brain (to receive action plans) and to the motor, premotor, supplemental, and presupplemental motor areas (to execute and carry out those action plans). The collective role of the basal ganglia is sometimes
to energize (invigorate) and other times to inhibit (restrain) those action plans (Pessiglione et al., 2007).

**Striatum (Dorsal and Ventral)**
The striatum consists of the nucleus accumbens, caudate nucleus, and putamen, and it consists of both a ventral and a dorsal region (Lijleveland & O'Doherty, 2012). The dorsal (upper part) region includes the large dorsal parts of the caudate nucleus and putamen, and it is heavily interconnected with prefrontal lobe regions. These connections allow the dorsal striatum to play an important role in goal-directed action, including the selection of behavior based on the value of goals. Through its connections with the prefrontal cortex, the dorsal striatum exercises an executive function over action. The ventral (lower part) region includes the nucleus accumbens as well as the ventral parts of the caudate nucleus and putamen. The activation of the ventral striatum is involved in the “hedonic evaluation of stimuli” (i.e., reward). Through the activation of the ventral striatum (nucleus accumbens), people learn what environmental objects and events to like, to value, to prefer, and to want (Smith, Tindell, Aldridge, & Berridge, 2009).

**Ventral Tegmental Area**
The ventral tegmental area is the manufacturing site for brain dopamine, so it is the starting point in the brain’s dopamine-based reward center. Dopamine is a neurotransmitter that is densely represented in the subcortical brain that is involved in incentive motivation (Berridge, 2007), motor function (Volkow et al., 1998), and the facilitation and actual initiation of voluntary action (Watanabe & Munoz, 2010). When excited, the ventral tegmental area communicates with the nucleus accumbens (ventral striatum) to release dopamine. What excites the ventral tegmental area is reward anticipation, rather than reward receipt (i.e., motivation rather than reinforcement). Dopamine release is therefore greatest when rewarding events occur in ways that are unpredictable or underpredicted (Mirenowicz & Schultz, 1994). Together, the connections between the ventral tegmental area and the nucleus accumbens form the mesolimbic circuit, discussed in the mesolimbic pathway section below.

**Insula**
The insula (insular cortex) lies above the basal ganglia and just beneath the cortex; it is covered by parts of the frontal, parietal, and temporal lobes. Though there are several parts to the insula, it is generally divided into two parts—anterior and posterior. The posterior insula (which is aligned more with the subcortical brain, thalamus, and brainstem) receives, monitors, and becomes aware of changes in interoceptive (visceral, homeostatic) bodily states and relays this information to the anterior insula (which is aligned more with the cortical brain) to construct a consciously aware representation of how one feels (Craig, 2002, 2009; Wicker et al., 2003). That is, the anterior insula deals with relatively more subjective, abstract, and complex awareness/feeling processes than does the posterior insula (Craig, 2002, 2009; Wicker et al., 2003). Insula activity is involved in a wide range of feelings, which consist of mostly “gut-felt” or intuitive feelings, such as disgust, trust, empathy, uncertainty, disgust, unfairness, and so forth (Craig, 2009). In the anterior insula, people consolidate this bodily based feeling-state information with social-contextual information about the task they are involved in and the people around them to form a conscious experience (subjective awareness) of emotion or affect (Craig, 2002, 2008), such as making a social judgment such as trust or anxiety (Paulus & Stein, 2006) or empathy (Gu, Liu, van Dam, Hof, & Fan, 2012). The insula also processes and learns about risk and uncertainty (Huaert, Stowe, Gordon, Warner, & Platt, 2006; Kuhnen & Knutson, 2005) to produce a global feeling state that guides decision-making (Singer, Critchley, & Petershoff, 2009).

**Amygdala**
The amygdala is a pair of small, almond-shaped structures composed of many separately functioning nuclei that are collectively located adjacent to the hippocampus and deep within the temporal lobes. These nuclei connect bilaterally to different brain structures, ranging from receiving sensory input from the thalamus to sending emotion-laden information to prefrontal structures. The right amygdala is closely associated with negative emotions and self-preservation (e.g., fear, anger, anxiety), because it automatically and instantaneously detects, learns about (remembers), and responds to emotionally significant and aversive events (Cardinal, Parkinson, Hall, & Everitt, 2002; Gallagher & Chiba, 1996). The left amygdala is closely associated with positive emotions and reward, because it automatically and instantaneously detects, responds to, and learns about (forms stimulus-emotion associations) rewarding and beneficial properties of
various environmental objects and events (e.g., its presence, value, predictability, and potential costs; Baxter & Murray, 2002; Berridge & Kringelbach, 2008; Whalen, 1999, 2007).

**Hypothalamus**

The hypothalamus is a diamond-shaped collection of numerous fiber tracts and nuclei located below the thalamus and above the pituitary gland. Through the stimulation of its 20 neighboring but separate nuclei, the hypothalamus regulates a range of important biological functions, including eating, drinking, and body temperature (via the motivations for hunger, satiety, and thirst). The hypothalamus is responsive to natural rewards (e.g., food). It further regulates both the endocrine system (by exerting control over the pituitary gland) and the autonomic nervous system (the hypothalamus is the starting point of the autonomic nervous system).

**Mesolimbic Pathway**

The mesolimbic pathway consists of the dopamine-based neural fibers between the ventral tegmental area and the nucleus accumbens (ventral striatum). The meso- in the title refers to the midbrain, in which the ventral tegmental area is located. Together, this pathway communicates the dopamine release information that is the biology of reward.

**Mesocortical Pathway**

The ventral tegmental area projects fibers into the ventral striatum to form the mesolimbic pathway, but the ventral tegmental area also projects other fibers that extend into prefrontal regions, including the orbitofrontal cortex in particular, to form the mesocortical pathway. This pathway delivers dopamine reward-related information to the prefrontal cortex, thereby allowing the orbitofrontal cortex region to know (to remember) that a particular environmental object has produced rewarding consequences in the past. More specifically, people learn the reward value of any object or event first through stimulus appraisal (amygdala, ventral striatum) and then through extent of dopamine release information that is transmitted to the prefrontal cortex region for storage via the mesolimbic and mesocortical pathways (Lamport & O'Doherty, 2007; McClure, York, & Montague, 2004; O'Doherty, 2004).

**Orbitofrontal–Striatal Circuit**

The orbitofrontal cortex has a direct connection with the subcortical brain's reward center (the orbitofrontal–striatal circuit) that allows it to receive reward-related information from the striatum and, once received, allows people to remember the reward value associated with the objects, events, and options they encounter and reencounter. The orbitofrontal cortex also inhibits inappropriate actions to exert self-control over these subcortically generated urges and impulses for immediate action and to exercise the delay of gratification (i.e., quieting the urge for an immediate reward to favor a larger delayed reward). It does this through its dense neural connections into the ventral striatum. That said, the orbitofrontal–striatum communication system, being reciprocal, allows urges and emotions to be considered and potentially take precedence over conscious planning.

**Ventralmedial Prefrontal–Amygdala Pathway**

The amygdala generates negative emotionality, such as that related to fear, anger, anxiety, and depression. In the ventromedial prefrontal cortex–amygdala pathway, the ventromedial prefrontal cortex sends neural connections to the amygdala to exert an inhibiting or dampening effect on amygdala activity. Without this cortical constraint, heightened or unchecked amygdala activity would generate potentially overwhelming negative emotionality, as occurs in mood and anxiety disorders (Mortkin, Philipp, Wolf, Baskaya, & Koening, 2015). Communication is bidirectional, so this pathway not only allows for the cognitive modulation of negative emotion, but also allows negative emotion to inform beliefs, judgments, and decisions, as when people experience a gut-feel negative emotionality that signals risk or that something is wrong or untrue (Cunningham & Zelazo, 2007).

**Anterior Insula–Anterior Cingulate Cortex Circuit**

The von Economo neurons, showing much bigger size and faster processing speed than other neurons, are observed only in the anterior insular cortex and anterior cingulate cortex (Allman et al., 2010). This means that these two anatomically far-off regions have fast information highways. In many situations (including survival), people must be aware of and feel both environmental conditions and their internal (bodily) reactions to these external conditions (anterior insula). People are then able to use this information when they decide how to respond to the situation at hand (e.g., implementation and
regulation of actions via the anterior cingulate cortex (Craig, 2009). Though the anterior insulanteor cingulate cortex circuit must be further investigated, this circuit can be a key candidate in explaining the unique human capacity of self-awareness and feeling processes.

Neural Basis of Key Motivations
By understanding the function of the aforementioned brain structures and circuits, we gain greater potential to understand key motivational states. Here we review the neural basis of 14 different motivations, starting with motivations that are mostly automatically activated by environmental stimuli (thirst) and moving to those that are proactively generated and psychologically complex (self-regulation).

Automatically-Activated Motivational States: Hunger, Thirst
Neuroscientific approaches to motivation do a particularly good job of explaining relatively automatic and highly reliable homeostatic motivational processes that are driven by ingestibles (or consumables). Ingested substances are natural rewards (e.g., food, water) that play a key role in energizing consummatory behaviors that then lead to changes in homeostatic and hedonic motivational states. These motivational states (e.g., appetite, satiety) are closely monitored and regulated by subcortical limbic structures, including the hypothalamus and mesolimbic-based mesolimbic pathway (Saper, Chou, & Elmquist, 2002) to motivate relatively automatic consummatory behavior.

Thirst is a brain-generated motivational state that arises when people physiologically need to ingest water to maintain adequate fluid balance throughout the body. Reduced water generates thirst—the hypothalamically based urge to ingest water. That said, the majority of human beverage consumption is determined by the reward aspects of the ingested fluid, including those related to taste, odor, temperature, alcohol, caffeine, and social consequences (Booth, 1991). Thus, brain structures such as the orbitofrontal cortex and amygdala respond to the rewarding properties of fluid intake (Rolls, 2000), and these brain structures then feed this reward-related information into the striatum that underlies the dopamine reward system that energizes fluid intake (Wise, 2002). Recognizing the important motivational role of the rewarding properties of ingestibles (e.g., sweet taste) expands drinking motivation from hypothalamic-centric homeostatic motivational states to include stimulus-driven, dopamine-centric motivational states (i.e., incentive motivation).

Learned Motivational States
Incentives
Environmental incentives are those environmental objects we learn to return to after experiencing their rewarding properties. Incentives have rewarding properties and promote approach-oriented behavior because they send information through the five senses that reach the mesolimbic dopamine-based reward circuitry (Wise, 2002). The learning (remembering, conditioning) of the incentive value of environmental events takes place in several brain areas. The amygdala evaluates a stimulus as associated with either reward or punishment, signals that it is potentially important (or not), and evaluates the stimulus as unpredicted or not (Whalen, 1999, 2007). In this way, amygdala activity builds associative knowledge about an incentive's motivational and emotional significance (Baxter & Murray, 2002; Baxter, Parker, Lindner, Izquierdo, & Murray, 2000; Schoenbaum, Chiba, & Gallagher, 1999). This information is mainly stored in the hippocampus and insular cortex, though it is also stored in cortical regions, including the orbitofrontal cortex. The more automatic or simple the incentive-based information is, the more likely it is that it will be stored subcortically in the limbic system, and the more learned or conditioned the incentive-based information is, the more likely it is that it will be stored cortically in the orbitofrontal cortex. When instrumental behaviors are needed, these various brain regions deliver their stored incentive value information to the mesolimbic dopamine system, which then energizes consummatory motivated action whenever intense enough to exceed a threshold of response.

Reward
Reward is fundamental to motivation-related effort, learning, well-being, and survival (Schulz, 2000). The stimulus characteristics of an environmental object are first processed in the amygdala and ventral striatum, and the experience of rewarding and pleasurable feelings (e.g., pleasant taste, social acceptance) occurs in the ventral striatum (nucleus accumbens) (Berridge & Kringelbach, 2008; Berridge & Robinson, 2003; Pecina & Berridge, 2005; Sabatinelli, Bradley, Lang, Costa, & Versace, 2007; Wise, 2002). Once activated by the release of dopamine, the ventral striatum translates the experience of reward into motivational force, approach
behavior, and the exertion of physical effort (Pessiglione et al., 2007).

Repeated experiences with objects and events allow people to form mental representations in which these environmental stimuli come to signal reward information in a predictive fashion. In this way, past reward-related information helps establish an anticipatory motivational value of objects and events. This learned reward-related information serves as the basis of future goals, values, and preferences.

Figure 20.2 outlines the neural substrates of this dopaminergic family of reward-based motivational states. The neural core of goal-directed motivated action is the pathway from the motivation-generating dopamine system through movement preparation (substantia nigra, globus pallidus) to the behavior-generating motor system (see the right side of Figure 20.2). Feeding into this basic reward-processing core of the dopamine system are a number of brain areas that process reward information, such as responsiveness to natural rewards (hypothalamus), the reward characteristics of objects (amygdala), gut-feelings and core affect (insular cortex) as well as responsiveness to the values (and relative values) of various rewards (orbitofrontal cortex), the mental representation of reward as a goal object (dorsolateral prefrontal cortex), and executive control over goal-directed action (anterior cingulate cortex). In addition, as depicted by the boldface double-sided arrows on the left side of Figure 20.2, reciprocal relations connect the subcortical, insula, and prefrontal cortex regions with feed-forward (bottom-up) and feedback (top-down) projections. Last, as depicted by the six double-sided arrows in the left center of Figure 20.2, reciprocal relations connect the dopamine system with the subcortical, insular, and prefrontal cortex structures.

EXPECTANCY

Expectancy is a central concept in the contemporary study of human motivation; it serves as the core explanatory construct underlying motivations such as personal control beliefs, mastery motivation, self-efficacy, and learned helplessness, among others (Skinner, 1995, 1996). These expectancy-based constructs involve the interrelations among person, behavior, and outcome such that people have expectancies of being able to generate effective coping behavior (efficacy expectations) and they have expectancies of whether their coping behavior, once enacted, will produce the outcome they seek (outcome expectations).

In neuroscientific investigations, however, expectancy is largely investigated as how expected a reward is. This research, which takes place under the umbrella term of reward prediction error (Schultz, 1998), shows that dopamine neurons are responsive when a reward is received unexpectedly. When that same reward is expected, based on prior experience, the neurons respond not to reward receipt but to the informative nature of the predictive cue. Thus,
dopamine neurons are responsive to reward-related novelty (Schott et al., 2004), the anticipation of cues and reward (Schott et al., 2008), and the difference between expected reward and actual reward, which is the reward prediction error (Schultz, 1998). Overall, dopamine neurons throughout the basal ganglia report ongoing reward prediction errors, and they do so by providing anticipatory, unexpected, and actual signals of motivational relevance (i.e., reward cues). This information is then passed on to target brain regions, including the prefrontal cortex and anterior cingulate cortex, to coordinate reward-based learning and the motivation to learn about goals, guide goal setting and goal prioritizing, and resolve cost-benefit and approach-avoidance decisional conflicts.

The neuroscientific study of reward prediction errors is similar to the outcome expectancy concept in the human motivation literature. Reward prediction errors mostly serve the function of learning (not of motivation per se), as dopamine neurons activate with unexpected reward experiences to produce new learning. However, these same dopamine-based responses can be used to influence future choice behavior (Schultz, Dayan, & Montague, 1997). That is, as people navigate their surroundings, they evaluate various courses of action that have differential predictions of reward associated with them. These predictions of future rewards (outcomes) are influenced by past expected reward learning. Hence, dopamine responses provide information to enact the most basic expectancy-based motivational principle—namely, approach and engage in action correlated with increased dopamine activity and avoid action correlated with decreased dopamine activity.

VALUE

Value is a central concept in motivation studies because it serves as a core construct underlying the expectancy-value family of motivation theories (Wigfield & Eccles, 2002). In these theories, value is a multidimensional construct composed of four divergent sources: intrinsic interest, utility value, attainable value, and cost. High values on each of these components of value (cost must be reversed scored) generally correlate with choice behavior and persistence (Wigfield & Eccles, 2002). This psychological conceptualization of value, however, is noticeably different from the neuroscience conceptualization of value, which is the automatic and learned reward-related information of an object or event (Dickinson & Balleine, 2002). Though it is difficult to make functional distinctions between the ventromedial prefrontal cortex and the orbitofrontal cortex, natural reward value is generally processed in the former, while learned reward value is generally processed in the latter (Arana et al., 2003; Rushworth, Behrens, Rudebeck, & Walton, 2007).

Whereas expectancy-value theorists emphasize divergent sources of valuing, neuroscientists generally do not place emphasis on the converging sources of valuing. The orbitofrontal—striatal circuit is viewed as a valuation system in which this circuit continually computes valuation (how rewarding, how punishing) of all environmental objects (Montague & Berns, 2002). It does so by utilizing a common dopamine-based valuation scale, which is somewhat like the neutral equivalent of monetary currency in a nation’s economic system. Rewards vary in their type, magnitude, salience, and immediacy, and the orbitofrontal—striatal circuit (and the striatum in particular) converts and integrates these diverse sources of reward-based information into a common currency and, by doing so, values all rewards on a common scale. Once diverse environmental incentives can be compared and contrasted via a common currency, people can compare disparate environmental objects (a beverage vs. a video game vs. social interaction) to plan action.

Somewhat in agreement with expectancy-value theorists, neuroscientists now add cost as a second key factor in action selection. While the orbitofrontal—striatal circuit computes unidimensional value, the anterior cingulate cortex predicts the amount of control and effort that must be invested to achieve a valued outcome and it uses this information to determine the cost of the required cognitive effort (Shenhav, Botvinick, & Cohen, 2013). Both dopamine informed expected value and the anticipated cost from mental exertion are therefore central to decision-making and action selection.

A second perspective on value in the human motivation literature conceptualizes it as an internalization process in which socially recommended prescriptions ("do this, believe that") and proscriptions ("don't do this, don't believe that") are accepted as one's own (Ryan & Deci, 2017). The internalization process of valuing is not so much an emotional associative process (as studied in neuroscience) as it is a process in which a particular way of thinking, feeling, or behaving is accepted as personally beneficial for self-functioning (similar to the utility value in expectancy-value theories). It is a proactive and intentional process that is based not on reward but on self-development and personal adjustment. This
second perspective on valuing will be discussed in the final section on autonomous self-regulation.

**Person-Generated Motivational States**

**AGENCY**

In the motivation literature, agency is action taken to produce an intentional, desired, and optimizing effect on the environment in which one lives (Bandura, 2006; Reeve, 2013). That is, when agentic, people proactively affect intentional change on their environments, as they strive to contribute to, manipulate, influence, transform, improve, select, or create their surrounding environment.

Neuroscientists study agency more narrowly, because they contrast an experience of self as cause versus other as cause of an action (Engbert, Wohlschlager, & Haggard, 2008; Farrer & Frith, 2002; Spengler, von Cramon, & Brass, 2009). In these investigations, the person performs a simple action (e.g., move a joystick) that causes an event to happen (e.g., make an image appear on the screen), and the causal source of that action is manipulated experimentally with a computer program such that what happens is directly linked to the person's own intentions and behaviors or is unrelated to them.

Results show that an experience of agency is closely linked to and dependent on the activities of the supplementary and presupplementary motor areas.

That is, agency arises from a prerequisite self-initiated instruction to generate movement and a tight correspondence between that self-generated motor instruction and the action taken. If the person enacts the same behavior without self-instruction to do so (e.g., an outside agent causes the person's behavior), little agency is experienced. Further, the greater the length of time that elapses between one's action and the effect it produces, the less the resulting sense of agency will be, because the sense of "I did that" (self as cause) is put into doubt by the rival belief that "maybe something or someone else did it" (other as cause) (Spengler et al., 2009).

Such agency ("I intentionally caused the action") is associated with insula activation, while such nonagency ("the action was not caused by me") is associated with inferior parietal cortex activation (Farrer et al., 2003; Farrer & Frith, 2002; Lec & Reeve, 2013). Pressing a button while lying in a functional magnetic resonance imaging machine is a long way from improving one's working conditions or changing one's career path, but the premise is the same—"unless people believe they can produce desired effects by their actions, they have little incentive to act" (Bandura, 2006, p. 170). Endowed with agency, people willingly act on their environmental surroundings to change things for the better. Lacking this intuitive sense, such action seems rather pointless.

**VOLITION**

Motivation concerns all those processes that initially energize and direct action, while volition concerns the ongoing effort to sustain that motivated action, especially in the face of difficulty or obstacles (Gollwitzer & Bayer, 1999; Kuhl, 1984, 1987).

In the neuroscience literature, volition is studied as mental control over action (Haggard, 2008). In this research, neuroscientists use experimental tasks that give participants freedom in whether to perform actions, when to perform actions, or how many times to perform actions, and they then search for related neural activities (Haggard, 2008; Libet, Gleason, Wright, & Pearl, 1983; Nachev, 2006; Nachev, Recs, Pratou, Kennard, & Husain, 2005). The results consistently indicate that (a) voluntary mental control activates motor-related brain regions, such as the supplementary and presupplementary motor areas, and (b) conflict monitoring during this voluntary control activates the (dorsal) anterior cingulate cortex to exert the mental control and problem-solving effort that can be conceptualized as volitional action (i.e., conflict monitoring that is supplemented and aided by diverse cognitive, emotional, and motivational control over action; Haggard, 2008; Nachev, 2006; Nachev et al., 2005).

**SELF-REGULATION AND GOALS**

In the motivation literature, self-regulation is an ongoing, cyclical process that involves forethought, action, and reflection (Zimmerman, 2000). Forethought involves goal setting and strategic planning, while reflection involves assessment and making adjustments to produce more informed forethought prior to the next performance opportunity. What is regulated during self-regulation are the person's goals (and, to a lesser extent, the means to these goals, such as plans, strategies, emotions, and environments).

From a neuroscience point of view, several brain structures exercise executive control and inhibition over action (Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). The prefrontal cortex contributes top-down control that guides behavior by activating internal representations of action such as goals and intentions by sending information to other areas of the brain to promote goal-relevant actions. While the prefrontal cortex generates goals and intentions, executive control over action seems to be carried out in many additional prefrontal...
cortex regions, including the dorsolateral prefrontal cortex, the anterior cingulate cortex, and the ventral medial prefrontal cortex; each is involved in a high-level regulation of action, including self-control and the self-regulation of action such as planning, organizing, and changing action (Damasio, 1994, 2003; Ochsner & Gross, 2005; Rueda, Posner, & Rothbart, 2004). As a case in point, the dorsolateral prefrontal cortex activations occur when one pursues a long-term reward in favor of a shorter term, striatum-based reward (McClure et al., 2004).

In addition, the anterior cingulate cortex plays a high-level role in the regulation of action because it not only receives information about sensory events, monitors conflict, and integrates emotional information (Botvinick, Cohen, & Carter, 2004; Craig, 2008), but also is further active during any decision to change one’s course of action (Devinsky, Morrell, & Vogt, 1995) and is involved in adjusting past learning about environmental contingencies when their reliability changes over time (Behrens, Woolrich, Walton, & Rushworth, 2007).

In understanding the cognitive control over decision-making and action, one recognizes the massive neural connections, feedback, and feed-forward that occur throughout the brain. For instance, the amygdala not only processes the emotional significance of sensory information and sends that information to the prefrontal cortex (feed-forward), but also receives feedback information from the prefrontal cortex (Frege & Amaral, 2005). Similar (and massive) feedback flows of information occur throughout cortical and subcortical brain regions (as depicted by the double-sided arrows on the left side of Figure 20.2). This prefrontal cortex flow of feedback information adds information about the environmental context and conscious intentions into the neural core depicted on the right side of Figure 20.2. Further, this prefrontal lobe information comes in cycles of continuous information and, according to some estimates, these top-down feedback projections likely exceed the number of bottom-up feed-forward projections, at least with adults (Salin & Bullier, 1995). The result is an integrated feed-forward and feedback system in which basic sensory information feeds forward rather automatically and rapidly, while top-down deliberative feedback information (intentions, goals), which is affected and biased by the aforementioned feed-forward information, contributes regulatory and intentional processing (Cunningham & Zelazo, 2007; Miller & Cohen, 2001).

**INTRINSIC MOTIVATION AND EXTRINSIC MOTIVATION**

In the motivation literature, intrinsic motivation is the inherent tendency to seek out novelty and challenge, to explore and investigate, and to stretch and extend one’s capacities (Ryan & Deci, 2017). When intrinsically motivated, people act out of interest and because they find the task at hand to be inherently enjoyable, producing satisfactions such as “It’s fun” and “It’s interesting.” This behavior occurs spontaneously and is not enacted for any instrumental (extrinsic) reason, such as a contingent environmental consequence (e.g., “I go to work for money, not for the job-task per se”).

In the neuroscience literature, the anterior insula is the key brain structure involved in intrinsic motivation (Lee & Reeve, 2013, 2017). Intrinsic motivation arises from intrinsic rewards, such as subjective feelings of interest and enjoyment (Lee, 2017). These intrinsic rewards are the spontaneous satisfactions one feels while engaged in a task (e.g., satisfaction from a job well done), and it is this sense of task-generated satisfaction that allows the activity to be experienced as interesting and enjoyable. These intrinsic satisfactions are generated by the anterior insula. What this means is that when a person engages in a task “because it is interesting,” the task is generating a sense of satisfaction and the extent of this felt satisfaction is represented by extent of activation in the anterior insular cortex (Lee & Reeve, 2013).

The opposite of intrinsic motivation is extrinsic motivation, which is the seeking and consuming of environmental incentives and rewards (e.g., food, money, tokens, social approval). In the neuroscience literature, extrinsic motivation is synonymous with incentive motivation. Incentive (extrinsic) motivation is well explained by the striatum-based reward center and by the orbitofrontal–striatal circuitry. As people experience extrinsic motivation toward a task, they show greater orbitofrontal cortex activity as they weigh the value of the incentive being offered and greater anterior cingulate cortex as they go through a pros versus cons decision-making process as to whether engagement in the activity will bring enough benefit to justify the effort expenditure (Lee, Reeve, Xue, & Xiong, 2012). In the human motivation literature, however, extrinsic motivation is a complex construct in which types of extrinsic motivation exist, including external regulation (the prototype of extrinsic motivation, which is incentive motivation), introjected regulation
(the person—rather than the environment per se—self-administer rewards and punishments, as in feeling contingent pride or contingent shame), and identified regulation (discussed in the previous section as the internalized process of valuing). Identified regulation has been studied as value (utility value) in the neuroscience literature, but little neuroscience research has been conducted on introjected regulation.

Intrinsic motivation and incentive (extrinsic) motivation interact with one another, and the tendency of highly salient extrinsic rewards to decrease intrinsic motivation represents the undermining effect in the human motivation literature (Deci, Koestner, & Ryan, 1999). To investigate this social psychological process within a neuroscience perspective, one group of researchers asked participants to engage themselves in an interesting task either with the promise of a contingent extrinsic reward (money) or simply to experience the sheer challenge embedded within the task itself (Murayama et al., 2010). Engaging in the challenging task generated meaningful striatal and lateral prefrontal cortical activity, activations that confirmed that the challenging task was inherently rewarding (i.e., intrinsically motivating) and cognitively engaging. When the same task was paired with the promise of a contingent monetary reward, striatal and lateral prefrontal cortical activity increased significantly, suggesting that the extrinsic reward added to the task-inherent intrinsic motivation. In the crucial second phase of the study, the extrinsic reward was removed. The researchers then examined how much striatal and lateral prefrontal cortical activity the task itself could generate. For participants in the no-reward condition, striatal and lateral prefrontal cortical activity were essentially the same the second time around—the task was just as rewarding and engaging as before. For participants in the reward condition, however, striatal and lateral prefrontal cortical activity disappeared—the capacity of the once interesting and challenging task to generate pleasure (striatum) and cognitive engagement (lateral prefrontal cortex) had been undermined by the previously contingent extrinsic reward. This program of research nicely shows how a complex human motivational concept (intrinsic motivation) can be better understood within a neuroscientific program of research.

PSYCHOLOGICAL NEEDS
A psychological need is an inherent nutrient within all people whose satisfaction is necessary for the person to experience positive functioning, personal growth, and well-being. There are three psychological needs—autonomy, competence, and relatedness (Ryan & Deci, 2017). Autonomy satisfaction is experiencing a sense of volition and personal endorsement of one's behavior; competence satisfaction is experiencing a sense of effectance in one's environmental interactions; and relatedness is experiencing a sense of connection with the important people in one's life. For need satisfaction to occur, the individual generally interacts with environmental activities (plays a game, takes a trip with a friend), and when that activity engagement allows the person to feel volition, effectance, and connection, then it produces need-satisfying spontaneous satisfactions. These satisfactions are associated with anterior insular activations (Lee & Reeve, 2017; Reeve & Lee, 2019).

For example, in an event-related within-subjects research design, participants (in a scanner) were presented with and tried to solve challengeless anagrams (e.g., WITTED) or challenging anagrams (e.g., CRPEI). Anterior insular activations occurred while participants worked on the competence-enabling challenging anagrams to a greater degree than when participants worked on the competence-neutral challengeless anagrams.

The neuroscience of psychological need satisfaction and intrinsic motivation are similar, and this is because intrinsic motivation arises from the satisfaction of the three psychological needs (Ryan & Deci, 2017). When need satisfaction energizes intrinsically motivated behavior, the neural system of intrinsic motivation involves not only anterior insular activity, but also striatum activity and, further, anterior insula–striatum functional interactions (Lee & Reeve, 2017). This suggests that subjective feelings of intrinsic satisfaction (associated with anterior insular cortex activations), reward processing (associated with striatum activations), and their interactions all underlie the actual experience of intrinsic motivation and the enactment of intrinsically motivated behavior. These neural findings are consistent with the conceptualization of intrinsic motivation as the pursuit and satisfaction of subjective feelings (interest and enjoyment) as intrinsic rewards.

Autonomous Self-Regulation
Intrinsic motivation is highly volitional, but many nonintrinsically motivated behaviors are also undertaken with a strong sense of autonomy. Activities that are not inherently interesting or enjoyable but are personally meaningful and important to the
person (e.g., brushing your teeth, practicing a needed skill) are undertaken volitionally. Because the person "identifies" with the value and worth of the activity, the motivation to engage in the uninteresting but personally important task is referred to as identified regulation (Ryan & Deci, 2007).

Internally guided, volitional decision-making and action recruit self-referential cognitive processes (Nisbett & Wilson, 2000), which in turn recruit ventromedial prefrontal cortex activations that are involved in using such self-referential knowledge to resolve conflicts toward a direction of personal decision-making. Such ventromedial prefrontal neural activity is especially helpful during action selection (Di Domenico, Fournier, Ayaz, & Ruocco, 2013), partly because it biases decision-making toward autonomously motivated considerations but also partly because it calms (resolves) anterior cingulate cortex activations (Di Domenico, Le, Liu, Ayaz, & Fournier, 2016), which suggests decision-making characterized by high volition and choice and low anxiety and conflict. More than just making decisions, however, autonomous self-regulation involves regulating one's lifestyle (goals, values, priorities, personal preferences) in ways that reflect the self (Di Domenico et al., 2016). When people make personal choices, ventromedial prefrontal cortical activity occurs; and when people use self-referential information to resolve conflicts (i.e., reduce cognitive dissonance during choice making). Anterior cingulate cortex activity is lessened (Matsuzaka et al., 2015). In contrast, decision-making and action selection can certainly take place in the absence of such self-referential input ("My boss told me to call this client"), but such activity would lack a sense of autonomous "want to" self-regulation and therefore reflect controlled "have to" non-self-regulation.

Conclusion
Motivational neuroscience is young. The emerging field now has a solid foundation, as represented by the knowledge base of how the neural structures and pathways shown in Figure 20.1 underlie and support the many motivational states highlighted in the second half of the chapter. This knowledge and these findings have laid the groundwork for motivational neuroscience to now flourish as an important science of the future.

Future Directions
1. Will the relation between neuroscience and human motivation become more reciprocal and bidirectional in the future, or will it remain largely a landscape of one-way—and even dead-end—streets? Movement toward a truly integrated field worthy of the name motivational neuroscience will depend on the emergence of exceptionally well-trained scholars who are highly and equally committed to both motivation study and neuroscience.

2. Can motivation theory be integrated with neuroscientific methods and findings? Neuroscientific methods and findings serve the new field of motivational neuroscience well when the focus is on relatively automatic motivations (hunger, thirst) and perhaps on stimulus-driven and environmentally acquired motivations (incentive) as well. But neuroscientific methods and findings come up short for all those motivations that are self-generated. The neuroscientific understanding of such motivations as agency, volition, intrinsic motivation, and autonomous self-regulation comes across as incomplete (or only partial) explanations, and this is because they lack the rich motivation theory developed by motivational psychologists. How motivation theory is integrated into a neuroscience analysis will be an important macrotheme in the future direction of motivational neuroscience.

3. How well can the dependent measures used in neuroscience (e.g., reaction times, neural activations) align with the dependent measures used in human motivation study (e.g., effort, phenomenology)? It is not yet clear how intercorrelated these measures are, and it is not yet clear whether these different measures tell the same story or two different stories. This future direction will likely be determined by the extent to which neural dependent measures align (correlate) with behavioral and self-report measures of motivation.

4. How integrated is brain activity during motivational processes? The past decade of motivational neuroscience has largely sought to identify the neural bases of specific individual motivational states (e.g., the amygdala is involved in this, the anterior cingulate cortex is involved in that). But the hallmark of the human brain is its massive interconnectivity. This chapter highlighted five important neural circuits (e.g., mesolimbic pathway), but future research will likely reveal a much richer picture of integrated functioning during motivation.

5. Can the brain generate motivation of its own? Or is brain-based motivation always an adaptive response to environmental events? Neuroscientific
investigations of motivation have revealed much about environmental sources of thirst, reward, and even curiosity. It is still an open question, however, as to how much this paradigm might reveal about intrinsic sources of motivation.

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References


