CHAPTER 21

Neuroscience and Human Motivation

Johnmarshall Reeve and Woogul Lee

Abstract

Recognizing the potential for interdisciplinary research in motivational neuroscience, the goal of the present chapter is to show the relevance of neuroscience research to human motivation researchers and to suggest ways to expand their programs of research, methodological options, and theoretical conceptualizations of the motivational constructs with which they work. To illustrate the neural bases of human motivation, we highlight 15 key motivation-relevant brain structures, identify the neural core of reward-based motivated action, and discuss a range of brain-generated motivational states that extend from those that are relatively automatic and stimulus dependent (e.g., pleasure from taste) to those that are relatively intentional and context sensitive (e.g., goals). We then examine the following 10 well-researched concepts from the human motivation literature to suggest how each might be enriched through neuroscientific investigation: agency, volition, value, intrinsic motivation, extrinsic motivation, flow, expectancy, self-efficacy, self-regulation, and goals. We conclude with suggestions for future research.

Key Words: motivation, neuroscience, striatum, reward, dopamine, prefrontal cortex

Introduction

The "and" in the chapter title is important, as it reflects the contemporary view that human motivation study and neuroscience are two different fields. That is, the people who study human motivation, the journals they publish in, and the empirical methods they rely on are not generally populated by a neuroscience focus, though these same researchers (and journals) recognize the potential contribution of neuroscience to human motivation study. Neuroscientists often study the same content-the same motivational constructs, though they routinely conceptualize these motivational constructs more narrowly. Neuroscientists also tend to study basic, stimulus-driven motivations, such as hunger, thirst, pleasure and reward, though more complex motivations (e.g., volition, self-regulation) are also investigated. Overall, equal measures of optimism and skepticism are in the air when human motivation researchers sit down at the table with neuroscientists to discuss collaborations and points of integration.

A decade ago, Richard Mayer (1998) characterized the relationship between neuroscience and his field—educational psychology—through the imagery of dead-end, one-way, and two-way streets. He characterized (and lamented) the then-present 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 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).

The metaphor Mayer offered to enrich interdisciplinary activity was that of a two-way street. In this scenario, neuroscience study influences motivation research, while motivation study influences neuroscience research. Such a two-way relationship is only possible with the emergence and contributions of interdisciplinary researchers. Interdisciplinary researchers are those who feel free and able to traverse not only the landscape of their home field of study but also the landscape of the allied field. Several examples of such successful interdisciplinary research have emerged, including cognitive neuroscience (Gazzaniga, Ivry, & Mangun, 2008), affective neuroscience (Davidson & Sutton, 1995), social neuroscience (Decety & Cacioppo, 2010), and neuroeconomics (Loewenstein, Rick, & Cohen, 2008).

The goal of the present chapter is to embrace this two-way street imagery and, in doing so, embrace the potential value in interdisciplinary motivational neuroscience. If interdisciplinary motivational neuroscientists are to become a critical mass of scholars, researchers in both fields will need to consider the merits of reengineering these otherwise one-way and dead-end streets into two-way streets of information, methodology, and theory development. To facilitate such progress in the present chapter, we first overview the neuroscience research that is broadly relevant to probably all contemporary human motivation study as we illuminate the biological substrates of human motivation. We then address conceptual points of convergence and divergence between neuroscience and human motivation study across the following 10 frequently studied motivational constructs: agency, volition, value, intrinsic motivation, extrinsic motivation, flow, expectancy, self-efficacy, self-regulation, and goals.

Any new field of study (e.g., motivational neuroscience) necessarily begins with description and taxonomy. In that spirit, Figure 21.1 lists 15 key brain structures identified by neuroscience research as motivation relevant and illustrates the anatomic location for each. Five structures reside within the neocortex: prefrontal cortex, ventromedial prefrontal cortex, dorsolateral



Fig. 21.1. Anatomic location of 15 key motivation-relevant brain-structures. (A) A medial sagittal section of the brain. The dotted line represents the point that a coronal section of the brain (C) is acquired. (B) A lateral sagittal section of the brain.

prefrontal cortex, orbitofrontal cortex, and anterior cingulate cortex. Six structures reside with the basal ganglia: dorsal striatum—caudate nucleus and putamen, ventral striatum—nucleus accumbens, globus pallidus, ventral tegmental area, substantia nigra, and ventral palladium. And four structures reside within the limbic system: amygdala, hypothalamus, hippocampus, and insular cortex. It is with these 15 brain structures that we will illustrate the neural bases of human motivation.

When defined in the context of behavioral science, motivation concerns the study of all those processes that give behavior its energy and direction (Reeve, 2009). In neuroscience, motivation is generally conceptualized as energy for behaviors related to obtaining rewarding stimuli or situations (Mogenson, Jones, & Yim, 1980; Robbins & Everitt, 1996). That which energizes behavior is subscribed to a rather narrow set of neural processes, such as those in the mesolimbic dopamine system. While these basic neural processes energize behavior, the sources that activate these basic neural processes are many (e.g., natural rewards, social rewards; Berridge, 2004; Berridge & Robinson, 2003; Wise, 2004). In the next section, we summarize the basic subcortical neural core that energizes reward-related action. Once done, we overview the more specific types of motivation that activate these basic subcortical neural processes.

Neural Core of Reward-Based Motivated Action

From a biological perspective, the role of reward in motivation is fundamental. It is fundamental to survival, to learning, to well-being, and to the generation of goal-directed effort (Schultz, 2000). The energization or generation of goal-directed effort (motivated action) follows from and is dependent on first extracting reward-related information from environmental objects, events, and circumstances, and this reward-related information consists largely of the release of the neurotransmitter dopamine (Berridge & Kringelbach, 2008).1 The rewardrelated information that people extract from their surroundings includes the presence and availability of reward, the value of the available reward, the predictability of the reward, and the costs associated with trying to obtain that reward.

In addition, 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. Reward receipt and reward expectation both involve neural activations that typically give rise to pleasant feelings and a good mood and, hence, to the subjective experiences of pleasure and positive affect (at least in humans). This same reward-related information also serves as the basis of future goals, which are mental representations of sought-after (reward-related) environmental events. In addition, when the reward values of multiple environmental events are compared, people show preferences (in terms of choice and the amount of effort expended) for different objects and events. Hence, biologically experienced reward serves as the basis not only for reward but for the additional motivational constructs of value, expectancy, pleasure/affect, goal, and preference.

The neural substrates of this dopaminergic family of reward-based motivational states appear in Figure 21.2. The neural core of goal-directed motivated action is the pathway from the motivation-generating dopamine system to the movement-preparation and behavior-generating supplementary motor area and premotor cortex (see right side of Fig. 21.2). Within the phrase "motivated action," the Dopamine system box represents the fundamental core of "motivated" while the Substantia nigra, globus pallidus box represents the fundamental core of "action." Feeding into this basic reward processing core are a number of brain areas that process reward information by releasing dopamine, such as responsiveness to natural rewards (hypothalamus), the particular characteristics of any one particular reward in the limbic regions (e.g., amygdala), and the interoceptive information of rewards in the limbic-related regions (e.g., 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 in the boldface double-sided arrow on the left-hand side of the figure, reciprocal relations connect the limbic regions with the prefrontal cortex as limbic regions generally feed-forward projections into the prefrontal cortex while prefrontal regions generally feed-back projections to the various limbic regions. Lastly, as depicted in the six double-sided arrows in the center of the figure, reciprocal relations connect the dopamine system with the limbic regions and prefrontal cortex.



Fig. 21.2. Neural core of reward-based motivated action.

Sources of Reward-Based Motivation

It is important to understand the nature of various biological sources of motivation (depicted on the left-hand side of Fig. 21.2) because different sources of motivation lead to different types of motivation. For instance, some sources of motivation are implicit and objective (e.g., thirst, hunger), while other sources are more conscious and cognitive (e.g., ultimate goals). As we will see, the types of motivation induced by relatively implicit and objective sources tend to generate rather automatic motivational states, whereas the types of motivation induced by more conscious and cognitive sources tend to be rather rational motivational states. Accordingly, to classify and to understand the different types of biologically generated motivational states, we need to think carefully about (1) what the sources of the motivational state are, (2) how much the source of the motivational state is implicit and objective (versus explicit and cognitive), and (3) how much the various sources of motivation conflict when sources of motivation are divergent. Based on these considerations, we present four sections to illustrate a range of brain-generated motivational states that extend from those that are largely subcortical, relatively automatic, and stimulus dependent (e.g., pleasure from taste) to those that are largely cortical, intentional, and context sensitive (e.g., personal strivings).

Relatively Automatic Motivational States

Neuroscientific approaches to motivation do a particularly good job of explaining relatively automatic homeostatic motivational processes that are driven by ingestibles (or consumables), such as food and water. Ingested substances are natural rewards (e.g., food, water) that play a key role in energizing consumatory behaviors that then lead to changes in homeostatic and hedonic motivational states. These motivational states are closely monitored and regulated by subcortical limbic structures (Saper, Chou, & Elmquist, 2002), as the hypothalamus plays an important role in relatively automatic consumatory behavior while the dopamine-based mesolimbic system plays an important role in learned instrumental behaviors. Homeostatic motivational states such as hunger (appetite) and satiety arise rather automatically (and reliably) from cooperative networks distributed throughout the body, including those in the brain (hypothalamus, mesolimbic system) but also those in the endocrine/hormonal and autonomic systems (Powley, 2009).

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 urge to ingest water, and the body's remarkable constancy of intracellular and extracellular water is regulated by neural, hormonal/endocrine, and behavioral mechanisms (McKinley, 2009). Though

hypothalamic-based thirst contributes to water intake (drinking) and to the involuntary regulation of water conservation (e.g., hormone release, kidney function), most 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 rewardrelated information into the striatum that underlies the dopamine reward system that energizes fluid intake (Wise, 2002), as depicted in Figure 21.2. Recognizing the important motivational role of the rewarding properties of ingestibles (e.g., sweet taste) expands the neural bases of motivation from hypothalamic-centric homeostatic motivational states to include stimulus-driven, dopamine-centric motivational states (i.e., incentive motivation).

Motivational States Based on Associative Learning (Close to Automatic)

Environmental incentives are those we tend to approach and 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 to (1) activate those reward pathways (e.g., Fig. 21.2), (2) activate those reward pathways powerfully (above threshold), (3) activate those reward pathways with little delay in reinforcement (so to yield a high degree of reward effectiveness), and (4) produce rewarding effects that decay rapidly (half-second after onset) (Wise, 2002). Some incentive values are universal or objective, such as a sweet taste or a toxic smell. Other incentive values (e.g., color preference) are learned subjectively or circumstantially. The more an incentive value is universal or objective, the more it will be associated with motivational states that are automatic.

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 a stimulus's motivational and emotional significance (Baxter et al., 2000; Baxter & Murray, 2002; Schoenbaum, Chiba, & Gallagher, 1999). This information is

mainly stored in the hippocampus and insular .cortex, though it is also stored in cortical regions as well, 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 or in the limbic-related regions (e.g., insular cortex); the more cognitive and less automated 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 consumatory motivated action (when intense enough to exceed a threshold of response). In addition, the nucleus accumbens (within the ventral striatum) is active in the experience of rewarding and pleasurable feelings, as the presentation of pleasant images, pleasant tastes, and many addictive drugs (e.g., opiates, cocaine, amphetamine) are dopamine releasers in the nucleus accumbens (Sabatinelli et al., 2007; Wise, 2002).

To explain how associative learning processes occur, some researchers parse reward information into three psychological components-learning, affect (emotion), and motivation (Berridge, 2004; Berridge & Robinson, 2003). Learning has two forms-associative and cognitive. Associative learning refers to the relatively automatic forms of incentive learning, while cognitive refers to the relatively more complex and less automatic learning related to activities in the cortex (e.g., orbitofrontal cortex). Affect also has two forms: liking and conscious pleasure. Liking is one's implicit (nonconscious), hedonic reaction to an objective environmental stimulus (e.g., sweet taste) that arises from nondopamine mesolimbic activity (e.g., opioid neurotransmission). Conscious pleasure is a more general form of liking that involves awareness and arises from cortical activity. Motivation too has two forms-wanting which is implicit (nonconscious) and objective, and wanting that is cognitive, conscious, and goal directed.

The affective distinction between implicit liking and explicit pleasure and the motivational distinction between implicit desire and explicit goal striving is important for several reasons. First, affect and motivation can diverge. Liking and wanting typically converge in natural situations (i.e., we want and like the same thing), but they can diverge, as when a medicine smells or tastes disgusting (no liking) yet is wanted for health reasons (cognitive wanting) or when one craves an addictive drug (implicit wanting) that brings little or no pleasure (conscious liking). Second, these two forms of liking and these two forms of wanting mean that incentive values will sometimes be conflicting in naturally occurring behavior (e.g., should I watch the television show I like or should I go to a social event to meet potential new friends?). In these situations, people need to resolve these motivational conflicts using higher order cognitive, emotional, and motivational processes (Litman, 2005).

Implicit Motivational States Involved in Decision Making and Action

Subcortical (limbic system) processing of environmental events plays an important role in decision making and action. In daily life, few situations involve only a single stimulus, as decision making in the face of diverging and conflicting incentive values is the norm (two restaurants, two social events, 30 different chapters in this Handbook). When people make decisions, they rely on a great deal on both cognitive processes and emotional processes, even to the point that it is difficult to separate out cognitive activity from emotional activity, as the two are so neurally intertwined that it makes little sense to treat them as separate entities during decision making. In this section, we review how nonconscious processing creates feelings (e.g., affect, intuition) that bias what memory content emerges into conscious awareness that is then acted on in terms of decision making and action. Such affectively based decision making can be demonstrated through the dopamine hypothesis of positive affect, priming, and the somatic marker hypothesis.

DOPAMINE HYPOTHESIS OF POSITIVE AFFECT

Positive affect influences decision making and problem solving such that people who feel good, compared to people in a neutral mood, are more likely to recall positive material from memory, and this accessibility has been shown to promote flexibility in thinking, creative problem solving, efficiency and thoroughness in decision making, improved thinking on complex tasks, variety seeking, enhanced intrinsic motivation, and a greater willingness to help (Isen, 1987, 2003). The dopamine hypothesis of positive affect (Ashby, Isen, & Turken, 1999) proposes that the presence of mild positive feelings systemically affects cognitive processes and that it is increased dopamine in certain brain regions that produces the mild positive feelings and facilitating . effects on cognition. For instance, the receipt of a small unexpected positive event (unexpected gift,

humor, task success) activates dopamine neurons in the ventral tegmental area, which sends dopamine projections into many cortical areas, including (a) the prefrontal cortex, which enriches working memory, openness to information, willingness to explore, creative problem solving, and the integration of ideas; and (b) the anterior cingulate cortex, which increases attention, flexible thinking, switching easily among alternative objects or action plans, and the sort of enhanced perspective taking that leads to prosocial behaviors such as cooperativeness, generosity, social responsibility, and improved negotiating skills (Ashby et al., 1999).

Crucially, the dopamine hypothesis of positive affect proposes that it is only mild, everyday positive feelings-the type of positive affect that remains outside of conscious attention-that produces these facilitating effects on decision making, problem solving, creativity, and prosocial behavior (Isen, 2003). If the dopamine increase is relatively large or if the person is made aware of the positive affect state (e.g., "My, aren't we in a good mood today?"), then research shows that the facilitating effect is lost (Isen, 1987). The dopamine hypothesis, however, seems to contradict the wanting versus liking distinction introduced in the previous section, as liking is not dopamine based. The difference between the two hypotheses might suggest that the positive affect (liking) is epiphenomenal and that it is only the dopamine increase (not the positive affect experience per se) that facilitates cognitive processes and prosocial behavior.

PRIMING

Priming is the procedure that evokes an implicit response from an individual upon exposure to a stimulus that is outside his or her conscious awareness. While priming occurs outside of the person's conscious awareness, the prime itself can be delivered unconsciously or consciously. An example of an unconsciously delivered prime might be a word that is flashed so briefly on a computer screen (e.g., 30 msec) that it is not recognized, though it still produces an implicit effect. An example of a consciously delivered prime might occur as the person is asked to judge if a dot appears above or below a word, a word whose content induces an implicit effect (e.g., the words "good" or "pleasant" might produce implicit positive feelings).

Primes that activate a mental representation of a behavior (outside the person's awareness) prepare people to enact behaviors consistent with that mental representation. For instance, the smell of a cleaning solution, the site of a briefcase, and viewing a library painting lead people to engage in cleaning behavior, competitive behavior, and hushed conversation, compared to the absence of these primes, though participants report being unaware of the aroma, briefcase, or painting (Aarts & Dijksterhuis, 2003; Holland, Hendriks, & Aarts, 2005; Kay, Wheeler, Bargh, & Ross, 2004). These findings show that nonconscious primes prepare (i.e., motivate) action.

Primes also influence a wide range of motivations. Primes have been shown to activate implicit motives such as power and affiliation (Schultheiss, 2008), outcome expectancies (Custers, Aarts, Oikawa, & Elliot, 2009), autonomous motivations (Hodgins, Yacko, & Gottlieb, 2006), and so forth. For instance, students who were asked to solve language puzzles populated by achievementrelated words ("win") outperformed and outpersisted students who were asked to solve the same language puzzles populated by neutral words when both groups worked on a second task unrelated to the language-puzzle task (Bargh et al., 2001). This means that the nonconscious activation of the motivational state promotes behavioral activation if the motivational state itself is associated with positive valence (Aarts, Custers, & Marien, 2008; Custers & Aarts, 2005). That is, primes facilitate motivated action by activating mental representations of action (i.e., the subliminal presentation of the words "exert" and "vigorous"), implicit motivational states, and positive affect; furthermore, these effects occur even though participants are unaware of the presentation of the primes.

SOMATIC MARKER HYPOTHESIS

Another hypothesis about the role of feelings in decision making is the somatic marker hypothesis (Bechara & Damasio, 2005; Bechara, Damasio, & Damasio, 2000). In this hypothesis, the key brain structure is the insular cortex (Singer, Critchley, & Preuschoff, 2009). The insula (insular cortex) processes interoceptive (visceral, homeostatic) information about the state of one's body and allows the person to construct a consciously aware representation of how he or she feels (Craig, 2009; Wicker et al., 2003). Furthermore, insula activity seems to be involved in practically all subjective feelings (Craig, 2009). In the anterior insula, people consolidate this feeling-state information with social-contextual information about the task they are involved in and the people around them to form a basis of the conscious experience (subjective awareness) of emotion or affect (Craig, 2002, 2008). The insular also

processes and learns about risk and uncertainty. This is important because the role of the insula seems to be to integrate current feeling, a risk prediction forecast (that has a degree of uncertainty) that arises from the anticipation or consideration of the future outcomes of one's actions, and contextual information to produce a global feeling state that guides decision making (Singer et al., 2009).

The somatic marker hypothesis was originally based on observations that patients with ventromedial prefrontal cortex lesions commonly showed emotional impairments and made destructive social decisions, even though their cognitive capacities were unaffected. Based on these clinical observations, researchers proposed that emotional processes (bodily states and feelings in this case) played an important and constructive role in the decisionmaking process (Damasio, 1994, 1996). The body's primary inducer of bodily states is the amygdala, and the ventromedial prefrontal cortex works as a secondary inducer of bodily states (e.g., pain, heartbeat awareness, rhythm, affiliation) (Baxter & Murray, 2002; Baxter et al., 2000; Schoenbaum et al., 1999). As incentive-related events (those associated with motivational and emotional significance for the person) change the body, the insula integrates these changes into a conscious, subjective emotional experience (much in the spirit of the James-Lange theory of emotion; James, 1894).

Neural Bases of Rational Motivational States in Decision Making and Action

Several regions in the prefrontal cortex exert executive or cognitive control over decision making and action. For instance, the medial prefrontal cortex (both dorsal and ventral), inferior frontal cortex, dorsal section of the anterior cingulate cortex, and the dorsolateral prefrontal cortex all work for cognitive control of decision making and action (Davidson & Irwin, 1999; Ochsner & Gross, 2005; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 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, Laibson, Loewenstein, & Cohen, 2004).

In understanding the cognitive control over decision making and action, one needs to recognize the massive cortical feedback that occurs 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 the amygdala

also receives information from the prefrontal cortex (Freese & Amaral, 2005). Similar (and massive) feedback flows of information occur throughout cortical and subcortical brain regions (as depicted by the large double-sided arrow between them in Fig. 21.2). This prefrontal cortex flow of feedback information adds information about the environmental context and conscious intentions into the neural core depicted on the right-hand side of Figure 21.2. Furthermore, this prefrontal lobe information comes in cycles of continuous information and, according to some estimates, these topdown 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 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).

Motivationally relevant brain structures are clearly reactive and responsive to environmental events. In this sense, motivation "happens" to the person as an adaptive reaction to these environmental events. It is also true, however, that brain activity is proactive in that people regularly anticipate the future (Bar, 2007). According to Bar, people are not so much passively waiting to be activated by environmental events as they are continuously busy generating predictions about the future. These predictions have motivational and emotional implications and therefore focus attention on the neural bases of proactive and purposive motivational states.

At one extreme, the brain is involved in proximal predictions, such as expecting to receive a shot upon walking in the doctor's office. But, at another extreme, the brain is involved in distal predictions, as the person anticipates experiences, plans far ahead, and uses memory-guided simulations to mentally travel into the future (Szpunar, Watson, & McDermott, 2007; Addis, Wong, & Schacter, 2007). The important point is that people plan, imagine, and project themselves into the future in a way that allows them to better prepare for that future, and these activities are subserved by brain processes specific for complex executive forecasts and predictions. Necessarily, these future-oriented forecasts, intentions, decisions, and plans take place under conditions of uncertainty (Cohen & Aston-Jones, 2005; Daw, O'Doherty, Dayan, Seymour, & Dolan,

2006). It is this set of complex executive predictions and forecasts that dominate current thinking about human motivation (e.g., goals, plans, expectations, future time perspective, possible selves), the topic to which we now turn.

Key Motivational Constructs in Human Motivation Study

To this point in the chapter, the conversation has been rather one sided, as we have presented and summarized the neuroscientific perspective on motivation. In the present section, we focus on several central motivational constructs that are richly studied in the human motivation research literature that occurs outside of a neuroscience focus. In doing so, we will compare and contrast the human motivation understanding of these complex motivational states with the neuroscientific understanding of these same phenomena. In particular, we discuss agency, volition, value, intrinsic motivation, extrinsic motivation, flow, expectancy, self-efficacy, selfregulation, and goals.

Agency

Agency is the sense that "I did that," and it lies at the center of intentional, voluntary, and purposedriven action. Human motivation researchers tend to study agency broadly, defining it, for instance, as self-generated motivation to act on the environment-the proactive desire to create, manipulate, influence, and transform the environment that one is in so to improve it in some way (Bandura, 2006). Neuroscientists study agency more narrowly, as they contrast an experience of self-as-cause versus otheras-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 such that what happens is directly linked to the person's own intentions and behaviors or is unrelated to them, because a computer program or the experimenter causes the action such that anything done by the participant is superfluous. Results show that an experience of agency is closely linked to and dependent on the activities of motor-related brain regions, such as the supplemental motor area and the presupplemental motor area, which plan and enact an efferent motor command-that is, agency arises from a tight relation between action and effect as the person must self-generate the motor instruction to perform

an action to feel a true sense of personal agency. If the person enacts the same behavior without selfinstruction to do so (e.g., an outside agent actually causes the person's behavior), little agency is experienced. Furthermore, 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, as the sense of "I did that" is put into doubt by the rival belief that "maybe something or someone else did it" (Spengler et al., 2009). Such agency is associated with activation in the insula, while such nonagency is associated with activation in the inferior parietal cortex (Farrer et al., 2003; Farrer & Frith, 2002). Pressing a button while lying in an fMRI 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).

Volition

Some neuroscientists study mental control over action as volition, rather than as agency (Haggard, 2008). In this research, neuroscientists use experimental tasks that give participants freedom 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, Rees, Praton, Kennard, & Husain, 2005). The results consistently indicate that (1) voluntary control activates motor-related brain regions, such as the supplementary motor area and the presupplementary motor area, and (2) conflict monitoring during this voluntary control activates the dorsal anterior cingulate cortex, as the individual attempts to cope with the cognitive conflicts that arise. In the human motivation research literature, Heinz Heckhausen distinguished what was termed agency in the preceding paragraph from volition by defining agency (motivation) as that which initiates action (e.g., need, goal), whereas volition involved the persistent striving of that motivated action over time and in the face of obstacles (Heckhausen, 1977). In other words, human motivation researchers view volition as the cognitive, emotional, and motivational control that occurs over time to carry out (not to initiate) goal-directed behavior (Gollwitzer, 1996). As such, volition encompasses diverse cognitive, emotional, and motivational processes (e.g., conflict monitoring). To expand the study of volition beyond that of agency, it would seem that interdisciplinary motivational neuroscience researchers need to examine the neural circuits of various aspects of cognitive, emotional, and motivational control over action, and some neuroscientist have begun to do this (Haggard, 2008; Nachev, 2006; Nachev et al., 2005).

Value

Value is a central concept in contemporary motivation study, as it serves as the core construct underlying the expectancy X value family of motivation theories (Wigfield & Eccles, 2002). In expectancy X value theories, value is a multidimensional construct composed of four divergent sources: intrinsic interest, utility value, attainment value, and cost. High values on each of these components of value (cost needs to be reversed scored) generally correlate with choice behavior and persistence (Wigfield & Eccles, 2002). This conceptualization of value is noticeably different from the neuroscience conceptualization of value, which is the incentivebased, reward-related information of an object or event, and that reward value is sometimes natural (e.g., water, orange juice) but often learned or conditioned (Dickinson & Balleine, 2002). When the learned reward-based information is subjective or circumstantial (rather than universal or objective), orbitofrontal cortex information is active and, once the incentive value of various environmental objects and events is learned, activity in the orbitofrontal cortex helps people make choices between options, consider their options, remember the incentive value associated with each of those options, and make their selection among the differently valued objects to pursue (Arana et al., 2003; Rushworth, Behrens, Rudebeck, & Walton, 2007).

While expectancy X value theorists emphasize divergent sources of valuing, neuroscientists generally do the opposite and emphasize 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) across a broad range of stimuli and environmental events (Montague & Berns, 2002). It does so by valuing all these potential stimuli and events on a common dopamine-based scale, which is sort of like the neural equivalent of monetary currency in a nation's economic system. Rewards vary on their type, magnitude, salience, and immediacy, and the orbitofrontal-striatal circuit (and the striatum in particular) convert and integrate these diverse sources of reward-based information into a common currency and, by doing so, value all rewards on a common scale. Once diverse

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environmental incentives can be compared and contrasted via a common currency, people can compare disparate stimuli (which would you rather do—drink a glass of orange juice, go for a walk in the park, or play a videogame?) so to assign their attention and plan their action. Perhaps some similar process allows people to integrate the various sources of value within expectancy X value theory (intrinsic value, utility value, and attainment value) on a common scale to compare the value of an interesting but not useful event (play) with an uninteresting but useful event (work).

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 & Connell, 1989). The internalization process of valuing is not so much an emotionally associative process (as valuing is 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 X value theories). It is an active and intentional process that is based not on reward but in self-development and adjustment (Ryan, 1993). In both the expectancy X value literature and in the internalization literature, value (like volition in the previous section) is conceptualized more broadly than it is in the neuroscience literature.

Intrinsic Motivation and Extrinsic Motivation

Intrinsic motivation is the inherent propensity to engage one's interests and to exercise one's capacities and, in doing so, to seek out and master optimal challenges (Deci & Ryan, 1985). When people are intrinsically motivated, they act out of interest and because they find the task at hand to be inherently enjoyable-producing spontaneous satisfactions such as "It's fun" and "Its interesting" during activity engagement. This behavior occurs spontaneously and is not enacted for any instrumental (extrinsic) reasons. Intrinsic motivation is a concept that neuroscientists have not been able to explain (or understand). What is known, however, is that during greater insular cortical activity people become aware of how the task they are engaged in is affecting their subjective feelings and they consolidate this feelingstate information with social-contextual information about their task engagement (e.g., is there a deadline involved?) to form a global conscious experience of "my feelings about that thing" (Craig, 2009, p. 65). As one example, people experience greater insular activity as they enjoy (experience spontaneous satisfactions from the experience) music (Koelsch, Fritz, Cramon, Muller, & Friederici, 2006).

In the neuroscience literature, extrinsic motivation is synonymous with incentive motivation, which we reviewed under the heading of "Motivational States Based on Associative Learning." In the human motivation literature, extrinsic motivation arises from environmental incentives and consequences (e.g., food, money, tokens, extra credit points) in which approach motivation is based not on the characteristics of the task itself but on the conditioned incentive value of the separate environmental event/consequence. 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 decision-making process as to whether engagement in the activity will bring enough benefit to justify the effort expenditure (Plassmann, O'Doherty, & Rangel, 2007). 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-selfadministers 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). This differentiated view of extrinsic motivation has not been explored in the neuroscientific research literature. Furthermore, almost no research exists to date on the neuroscientific study of intrinsic motivation.

Intrinsic motivation and 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 inherently interesting sense of challenge within the task itself (Murayama, Matsumoto, Izuma, & Matsumoto, 2010). By itself, the interesting, challenging task generated meaningful striatal and lateral prefrontal cortical activity, activations that confirmed that the challenging task

was inherently rewarding 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 a 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 on the second encounter with the activity-the task was just as rewarding and engaging as before. For participants in the reward condition, however, striatal and lateral prefrontal cortical activity practically 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 by a neuroscience emphasis, and it therefore provides an exemplary model for how future researchers might integrate neuroscientific methods and perspectives within human motivation study.

Flow

Flow is a state of concentration that involves a holistic absorption and deep involvement in an activity (Csikszentmihalyi, 1990). It is a highly pleasurable feeling that involves a sense of optimal challenge and perceived competence, and it is characterized by a loss of time perspective in which time passes relatively slowly. The anterior insular cortex integrates feelings generated by homeostatic, environmental, hedonic, motivational, social, and cognitive inputs to produce a "global emotional moment," which represents conscious awareness of one's feelings at one (present) moment in time (Craig, 2008, 2009). Under conditions of strong emotion (joy, or flow from achieving competent functioning during a challenging task), the anterior insular cortex produces a dilation of time in which many global emotional moments occur rapidly (Tse, Intriligator, Rivest, & Cavanagh, 2004). Hence, subjective time dilates, as the actor subjectively feels that little time has passed even when engagement has continued for an objectively long(er) period of time. Like the study of the undermining effect of rewards on intrinsic motivation, the human motivation and neuroscientific studies of flow represent

a second case of rather high convergence between . these two literatures.

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-ofcontrol" constructs involve the interrelations among person, behavior, and outcome such that people have expectancies of being able to generate effective coping behavior (e.g., efficacy expectations) and they have expectancies of whether their coping behavior, once enacted, will produce the outcome they seek (outcome expectations). In neuroscientific investigations of reward learning, 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 cued 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 gangliadorsal striatum, ventral striatum, ventral tegmental area, and substantia nigra-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. For instance, once this information is passed on to the anterior cingulate cortex, approach versus avoidance decisional conflicts can be resolved based on expected probabilities of reward, payoff, and costs, just as this same information can be passed on to the prefrontal cortex to guide goal setting and prioritizing.

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.

Dopamine-based learning plays a key role in reward expectation and receipt, which are closely related to outcome expectancies. But it also facilitates episodic memory formation that is used for future adaptive behavior. That is, dopamine information during learning helps build and enable the forging of memory from one's past experience that then becomes the basis for future adaptive behavior (Shohamy & Adcock, 2010). It is this "adaptive memory" that then forms the basis of the second major type of expectancy motivation studied in the human motivation literature—namely, self-efficacy.

Self-Efficacy

Efficacy expectations are rooted in questions such as "Can I cope well with the task at hand?" and "If things start to go wrong during my performance, do I have the personal resources within me to cope well and turn things around for the better?" Self-efficacy is the generative capacity in which the individual (the "self" in self-efficacy) organizes and orchestrates his or her skills in the pursuit of goal-directed action to cope with the demands and circumstances he or she faces. Formally defined, self-efficacy is one's judgment of how well (or poorly) one will cope with a situation, given the skills one possesses and the circumstances one faces (Bandura, 1997). The precuneus (embedded within the parietal lobe) is involved in many of these processes, including self-related imagery, episodic memory retrieval, preparing future action, and the experience of agency (Cavanna & Trimble, 2006; den Ouden, Frith, Frith, & Blakemore, 2005).

The primary determinant of self-efficacy expectations is one's history of episodic memory-based mastery enactments, which might be conceptualized by neuroscientists as perceived skill in that domain. Studies of motor skill acquisition (Poldrack et al., 2005) and cognitive skill acquisition (Fincham & Anderson, 2006) show that trained individuals come to direct their attention not to intermediate goal-directed steps but to the larger aim (as automation of skill occurs). Automation of procedural skills allows one to focus attention to environmental demands and challenges, retrieve relevant episodic memories, and predict and plan effective future courses of action, while it further lessens cognitive confusion and anxiety (Bandura, 1988). The hippocampus is important to automation of procedural knowledge, and the downregulation of competent self-representations has been shown to lessen negative affect, affect intensity, and cortisol reactivity during coping (Sapolsky, 1992).

Perhaps the most productive way that human motivation research on self-efficacy can contribute to interdisciplinary motivational neuroscience research is to stress the point that neural systems that focus attention, mentally represent value, detect the causal structure of the world, and integrate this information into effective decision making and action is only one part of the adaptive story (Bandura, 2001). The other part of the adaptive story is self-efficacy-fueled agency in which people proactively devise ways to adapt flexibly to a wide range of physical and social environments to redesign them to their liking and controllability. Such a perspective places lesser influence on environmentally responsive and adaptive brain processes and relatively greater influence on proactive and agentic brain processes in the exercise of personal control over environments to be encountered in the future.

Self-Regulation and Goals

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). In the human motivation literature, goals are future-focused cognitive representations that guide behavior to an end state that the individual is committed to either approach or avoid (Hulleman, Schrager, Bodmann, & Harackiewicz, 2010). It is the prefrontal cortex that houses a person's conscious goals (Miller & Cohen, 2001), and this information is used in goal-directed action in the top-down flow of information depicted in Figure 21.2.

From a neuroscience point of view, several brain structures exercise executive control and inhibition over action. The prefrontal cortex contributes topdown 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 ventral medial prefrontal cortex, the anterior cingulate cortex, and the dorsolateral prefrontal cortex, as 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; Oschsner & Gross, 2005; Rueda et al., 2004). The anterior cingulate cortex, for example, plays a high-level role in the regulation of action, as it not only receives information about sensory events, monitors conflict, and integrates emotional information (Botvinick et al., 2004; Craig, 2008), it is 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). These research findings suggest a possible convergence between human motivation researchers and neuroscientists, as neuroscientists have done an especially impressive job in explaining the neural bases of forethought, decision making, and reflective action.

Conclusion

The intellectual landscape that connects human motivation study and neuroscience is not currently populated by ever-present two-way information highways in which the methodologies, findings, and theoretical developments in one field flow into the other and return back in a more informed and sophisticated way. It is clear, however, that human motivation researchers have a lot to gain from such interconnectivity. To date, the most obvious benefit for human motivation research has been that neuroscientific investigations have brought to light the neural meditational processes that underlie the how and the why of the basic motivation mediation model: environment \rightarrow motivation \rightarrow adaptive action. That is, neuroscientific investigations have enriched the understanding of both the generation of motivational states (i.e., environment \rightarrow neural activations → motivation) and their adaptive functions (motivation \rightarrow neural activations \rightarrow adaptive functioning).

It is equally clear that neuroscience researchers have gained from greater motivation-neuroscience interconnectivity. The most obvious benefit for neuroscience research has been to gain a greater

theoretical depth and complexity for the motivational constructs it studies. Motivational concepts such as volition, agency, value, intrinsic motivation, self-efficacy, and self-regulation can be understood more richly when neuroscientific analyses are supplemented and informed by behavioral and psychological findings, methodologies, and especially theories. Once understood in their theoretical richness, these motivational constructs can be studied in ways that increasingly map onto and reflect what is known about them from traditional human motivation study. Such integration, if it is to occur, will likely be carried out by a generation of interdisciplinary motivation neuroscience researchersscholars whose interests, professional training, and intellectual home is as much in neuroscience as it is in human motivation study, and vice versa.

Future Directions

1. Will the relationship 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 deadend—streets? This trend will depend on human motivation researchers' openness to neuroscience and to their willingness to form collaborations and learn the methods and knowledge base of neuroscience.

2. Is neuroscience relevant to only some classes or facets of motivation—for example, homeostasis and reward—or is it more generally relevant to more complex motivations such as intrinsic motivation and self-efficacy? This is a question of whether the motivation-neuroscience collaboration will be a narrow or a broad one.

3. What are the benefits of maintaining the existing distinction between the two different levels of analyses (neurological versus behavioral and self-report) embraced by neuroscience on the one hand and human motivation study on the other? 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)? 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. 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 motivation and reward. It is still an open question, however, as to how much this paradigm might reveal about intrinsic sources of motivation.

5. Lastly, the past decade of motivational neuroscience has largely sought to identify the neural bases of various motivational states. This has been and continues to be a productive enterprise. As the neural bases of various motivational states become well understood, motivational neuroscience will need to ask new questions and take on a new sense of purpose. It is interesting to speculate what this future direction will be, but it will like be one that transcends description (e.g., the amygdala is involved in this, the anterior cingulate cortex is involved in that) to address explanation.

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Note

1. While dopamine is the key neurotransmitter involved in the processing of reward, other neurotransmitters also contribute to the processing of reward, including choline, GABA, glutamate, opiod, and serotonin (Knapp & Kornetsky, 2009).

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