

CHAPTER 4

The Neuroscience of Goal Pursuit

BRIDGING GAPS BETWEEN THEORY AND DATA

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Goal pursuit is a multifaceted enterprise that requires coordination among several psychological processes. For example, the goal of finding a job requires a plan to apply and interview, a mechanism to initiate the plan, a set of criteria for offer acceptance, and a way of monitoring progress along the way. An attempt to get a job with only some but not all of these parts would almost surely result in failure, as each element is necessary. Researchers in neuroscience have examined many of these processes, but often in isolation without considering the broader context of a goal-pursuit framework. This chapter links process-level neuroscience evidence to the cognitive-behavioral level of goal-pursuit theories. Utilizing psychological theory to organize neuroscience evidence offers advantages to both sides of the equation. New theoretical insights can be forged through patterns of association and dissociation among the neural networks involved in various goal-pursuit processes. Additionally, gaps in the current neuroscience literature on goal processes are conspicuous once the existing evidence is organized within a theoretical framework, providing avenues for new research. This chapter reviews a common model for goal pursuit in light of recent neuroscience findings, with the hope that it will prove useful to psychologists studying goal pursuit and social neuroscientists.

Overview

We take as our starting point several goal-pursuit models put forth by social and cognitive psychologists, such as the test–operate–test–exit (TOTE) cybernetic model (Carver & Scheier, 1998; Miller, Galanter, & Pribram, 1960), various discrepancy-reduction models (Higgins, Roney, Crowe, & Hymes, 1994; Wicklund & Gollwitzer, 1981), and action planning models (Gollwitzer, 1990; Kuhl, 1984). Rather than focus on any one model to adopt as a framework, we have selected three components common to most models of goal pursuit. We see each of the following steps as places where psychological theory and neuroscience data complement each other and help generate insights for both fields.

The first step in goal pursuit involves simply having a goal to pursue and holding it in memory. “Goal representation” refers to the mental process of maintaining a goal or desired end-state at least during a period of goal pursuit (e.g., be friendly during a brief interview for a job), and possibly much longer (e.g., being a nice person over the course of one’s life). The second step in goal pursuit is the intention to pursue the goal (cf. Bargh and Chartrand, 1999, on automatic activation of goal pursuit). Intention typically serves as the motivating force that comes between holding a goal in memory and initiating goal-pursuit behavior. As such, intention seems to have a cognitive, planning aspect (e.g. “When X happens, I will do Y”) and a motivational aspect (e.g., wanting to pursue the goal, expecting positive outcomes from pursuit). To act upon an intention is to engage in *goal action*, which is characterized in terms of four subcomponents: attention, motor control, response inhibition, and progress monitoring.

Few neuroscience studies explicitly address goal pursuit, but many address components (or subcomponents) of goal pursuit mentioned above. Our review focuses on findings regarding the goal-pursuit components, and particularly on those that seem to be integral to goal pursuit overall. In some cases, the available neuroscience evidence is tangential to the study of goal pursuit in general. For these cases, we identify which aspects of the research might be relevant to goal pursuit and try to point the way toward more pertinent studies. We review each component in turn, first giving a brief discussion of the social psychological research in the area then reviewing the relevant neuroscience findings. In addition, we point out connections to other components of goal pursuit and to related processes that have received attention in neuroscience. Comparing the psychology and neuroscience findings allows us to highlight the gaps in the extant neuroscience research for each component, and also divergences between the social psychology and neuroscience findings.

We conclude with a discussion of several caveats, complications, and further directions in the neuroscience of goal pursuit. First, one broad dif-

ference between the social psychological and neuroscience findings is the distinction between short- and long-term goal pursuits. In general, psychologists are concerned with long-term goal pursuit, lasting weeks, months, or years (such as weight loss, career success, etc.). In contrast, insofar as neuroscientists study goals, they tend to study short-term goals, lasting seconds or minutes (such as success on a laboratory task or on the next trial of a task). We attempt to answer some of the questions that this distinction raises and to capitalize on the commonalities across the literatures. Second, researchers in social psychology (Schneirla, 1959; Miller, 1959; Gray, 1970; Carver & Scheier, 1982; Higgins, 1997; Elliot & Thrash, 2002) and neuroscience (Cunningham, Raye, & Johnson, 2005; Canli et al., 2001) have investigated *approach and avoidance motivation* and its relation to goal pursuit. We believe that this is a crucial construct for goal pursuit and highlight findings that demonstrate the role of this individual difference during goal pursuit. Finally, recent research has begun to examine the possibility of goal pursuit outside of conscious awareness (e.g., Bargh & Chartrand, 1999; Mauss, Evers, Wilhelm, & Gross, 2006). For each component, we highlight what is known about the automatic and controlled parts and point to areas where further understanding is needed.

The Neuroscience of the Goal Pursuit

Goal Representation

From where do we get our goals? Two possible places are from internal sources—from the mental image of who we'd like to be, or our immediate desires such as finding something sweet to eat—and from external sources—the things other people would like us to do, or nonsocial cues from the environment (e.g., being in a library may help motivate studying). Previous empirical and theoretical work by social psychologists has investigated the analogous distinction between intrinsic and extrinsic goals (Sheldon, Ryan, Deci, & Kasser, 2004; Deci & Ryan, 2000). Findings from this area have emphasized the importance of three intrinsic goals or needs—competence, relatedness, and autonomy—for achieving and maintaining well-being. From this perspective, extrinsic goals are evaluated in terms of how well they become internalized to align with intrinsic goals. For example, an employee may be given a task by her boss (an extrinsic goal) but might think about the task differently so that it also fulfills her intrinsic goal of being a competent worker. In this theory, goal representation is an active process that frequently involves re-representing extrinsic goals as intrinsic in a process called “assimilation.”

Research in neuroscience has also uncovered distinctions between internal and external mental representations, although only representation

of extrinsic goals has been considered explicitly. However, findings from extensive neuroscience studies on introspection might apply to representation of intrinsic goals. Extrinsic goals are typically provided for us from the outside. A perhaps trivial (yet relevant) example is that of experimental participants, who accept the instructions from the experimenter as their own goal for the duration of the experiment. Internalization is not typically measured and may not occur in any meaningful way. At least for a few minutes, undergraduates are able to pursue a goal that was given to them from without. A vast body of literature suggests that the orbital and lateral parts of the prefrontal cortex (PFC) are essential for maintaining these *if-then*, rule-based performance goals (see Table 4.1; Miller, 1999; Cohen & Servan-Schreiber, 1992; Wise, Murray, & Gerfen, 1996). The conceptual distinction made by social psychologists between internally and externally generated goals is paralleled by a neural distinction of medial and lateral PFC networks, respectively (Lieberman, 2007).

The paradigmatic externally derived goal in psychology experiments is to succeed on a task such as the color-word Stroop task (Stroop, 1935; Macleod & Mathews, 1991). In this task, participants are presented with color words printed in an incongruent ink color (e.g., “red” written in blue ink). Although the automatic response is to read the word, the externally provided goal is to say the color of the ink. This task requires maintenance of an *if-then* rule in memory and also, on some trials, the top-down inhibition of a prepotent response, making it a popular laboratory approximation of the demands of “real-world” goal pursuit. This type of task typically activates the dorsolateral prefrontal and anterior cingulate cortices. However, it has only recently become clear how these regions each contribute to task performance. An experiment by MacDonald, Cohen, Stenger, and Carter (2000) dissociated the brain regions involved in the two parts of the task (rule maintenance, conflict detection) by inserting a delay between the instructions and the word presentation. In the first phase, participants were instructed to pronounce either the word (“word” trials) or the color (“color” trials) of the upcoming stimulus. After a pause of a few seconds, the stimulus was presented in the second phase. The first part of the task required only the maintenance of the trial-specific goal, and the second part of the task required top-down regulation (in the color trials). Consistent with other evidence regarding rule-based processing (Baker, Frith, Frackowiak, & Dolan, 1996; Fletcher, Shallice, & Dolan, 1998), the dorsolateral PFC was active only during the first portion of the task. Another region, the anterior cingulate cortex (ACC) was active only during the second portion, and within that portion, only active during trials that required inhibition of prepotent responses (e.g., during the color trials). We return to the ACC and its role in goal pursuit in subsequent sections. Critically, the authors conclude that the dorsolateral PFC

TABLE 4.1. Summary of Social-Psychological Findings, Neuroscience Findings, and Unanswered Questions for Goal Pursuit

	Pursuit					
	Representation	Intention	Attention	Motor control	Response inhibition	Progress monitoring
Psychological findings	Intrinsic versus extrinsic goals	Connect a behavior to a situation Translate abstract goals to concrete behavior Affected by approach-avoidance	Attention to goal in context Attention to goal-relevant cues Automatic activation of attention Modulated by approach-avoidance	Stimulus evaluations impact and are pushed-pull Motivation impacts push-pull	Self-control and self-regulation Situational and personality moderators	Discrepancy detection and discrepancy reduction Distinct effects of approach and avoidance goals
Brain regions involved	Intrinsic: medial PFC, medial parietal Extrinsic: lateral PFC, lateral parietal	Readiness potential: SMA, premotor cortex Preparatory set: dorsolateral PFC, SFG	Exogenous: ACC, SMA, FEF, TPJ, superior parietal cortex Endogenous: exogenous and anterior PFC	Primary motor cortex, SMA, premotor cortex Cerebellum and basal ganglia	Dorsolateral and ventral PFC, ACC	Detection: ACC Reduction: PFC
Unanswered questions	Representation of time duration? Representation of abstractness?	Neural correlates of approach-avoidance framing of intention?	For automatic goal pursuit, is attention impacted by awareness?	Separable neural systems for approaching/avoiding?	Further specificity within PFC? Different types of inhibition?	Is conflict detected in the planning or execution of action? Implications for long-term goals?

Note. ACC, anterior cingulate cortex; FEF, frontal eye fields (superior frontal gyrus); PFC, prefrontal cortex; SFG, superior frontal gyrus; SMA, supplementary motor area; TPJ, temporal parietal junction.

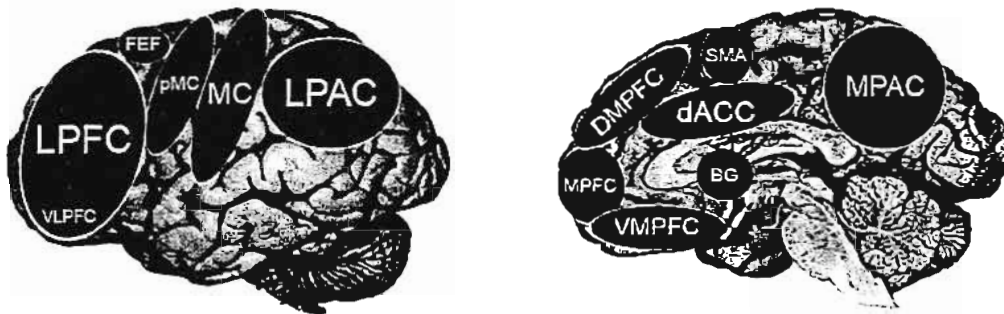


FIGURE 4.1. Key brain regions implicated in the pursuit of goals. BG, basal ganglia; dACC, dorsal anterior cingulate cortex; DMPPFC, dorsomedial prefrontal cortex; FEF, frontal eye fields (superior frontal gyrus); LPAC, lateral parietal cortex; LPFC, lateral prefrontal cortex; MC, primary motor cortex; MPAC, medial parietal cortex; MPFC, medial prefrontal cortex; pMC, premotor cortex; SMA, supplementary motor area; VLPFC, ventrolateral prefrontal cortex; VMPFC, ventromedial prefrontal cortex. Note: The basal ganglia is a subcortical structure presented here on the medial surface for ease of presentation.

is integral in maintaining rules and planning rule-based action as in goal pursuit.

Other recent findings have sharpened these conclusions by separating the brain activations related to maintenance of the task goal from those related to processing the visual stimuli of the task. By employing several versions of the Stroop task across multiple stimulus types (e.g., pictures, words presented visually, words presented aurally), Banich and colleagues (Banich et al., 2000; Herd, Banich, & O'Reilly, 2006) found that regions in dorsolateral PFC and inferior parietal cortex are involved in the Stroop task independent of stimulus modality. Another study reported increased activity in lateral parietal regions during maintenance of rules during a visual response contingency task (Bunge, Kahn, Wallis, Miller, & Wagner, 2003). These studies converge on the finding that the dorsolateral PFC and parietal cortex are involved in representing the rules involved in maintaining extrinsic goals.

Although there have yet to be studies directly investigating the neural correlates of intrinsic goals, there is a growing number of conceptually related studies on introspection of internal states (Kihlstrom & Klein, 1997). Studies that compare internal appraisals about current states (e.g., "Do I like this painting?") or traits (e.g., "Do I possess this trait?") to matched non-self-judgments (e.g., "Is the picture of an indoor or outdoor scene?," "Is this a good or bad trait?") consistently find increased activation in medial PFC and medial parietal cortex (Ochsner et al., 2005; Lieberman, Jarcho, & Satpute, 2004; Gusnard, Akbudak, Shulman, &

Raichle, 2001; Ochsner et al., 2004). Finally, one study reported greater medial prefrontal cortical activation while reflecting upon personal hopes and aspirations than distraction (Johnson et al., 2006). In light of these findings it seems reasonable to speculate that the representation of intrinsic goals might make use of these self-reflective processes and the network of associated neural regions.

Evidence presented in this section leads us toward two observations regarding goal representation. First, the PFC broadly is involved in the generation and maintenance of goal representation. Second, there may be subdivisions within the PFC that make different contributions to goal representation. Insofar as goals are derived from sources internal to the actor such as traits, motives, and desires, those goals might be represented medially. Likewise, insofar as goals are derived from situational cues and maintained by if-then rules that are not internal to an actor, they seem to be represented laterally.

In addition to the distinction between intrinsic and extrinsic goals, psychologists have also discussed two other important dimensions of goal representation: abstractness and temporal duration. For example, on one hand brushing one's teeth and flossing are concrete goals that last only a few moments. On the other, maintaining oral hygiene is a more abstract goal that can endure over years and decades. Psychologists have noted that goals can often be represented hierarchically, with more abstract, longer-term goals at the top, and more concrete, shorter-term goals (sometimes called "plans") at the bottom (Elliot & Church, 1997; Carver & Scheier, 1998; Vallacher & Wegner, 1987). The hierarchy construct is useful because it allows clusters of related goals to be represented simultaneously and within the same framework, with abstract long-term goals (*oral hygiene*) being instantiated behaviorally by concrete short-term goals (*flossing, brushing*). Given that long- and short-term goals can be intrinsic and extrinsic (e.g., wanting to be a good person vs. being told to be a good American by the president; wanting a piece of candy vs. participating in an experiment), temporal duration and goal locus seem to be separate dimensions.

Neuroscientists have yet to examine long-term goals. Although methodological constraints limit our ability to examine the representation of long-term goals in a magnetic resonance imaging (MRI) scanner (e.g., imaging participants while they engage in the task of being a good American), an initial step would be to extend our existing knowledge of short-term goals to slightly broader ones, termed here "medium-term" goals. Medium-term goals would be brief in duration yet still conceptually connected to an individual's abstract, long-term goals, making them ideal for the present purposes. Although it would be difficult to investigate the long-term, abstract goal of physical well-being in a functional MRI (fMRI) scanner, it would be possible to characterize the representation of

that goal by examining successful and unsuccessful episodes of constituent behavioral goals. For example, participants might be led to succeed at one task that requires selectively responding to healthy activities, but be led to fail at another task that requires inhibiting responses to unhealthy foods (or vice versa). Evaluations of goal progress will then differ depending on whether participants are focused on the immediate task or on the abstract goal. This design could clarify several questions regarding the duration of goal pursuit, such as whether a longer-term inhibitory goal recruits similar or different regions than a shorter-term goal, whether the same inhibitory strategies are used for both types of goals, and which brain regions (if any) predict success at the long-term goal. This type of study would begin to build a more sophisticated model of if and how our brains use hierarchies to organize goals and connect long-term abstract objectives with concrete behaviors.

Goal Intention

Regardless of whether the source of a goal is internal or external, once an individual has a goal in mind it must be linked to behavior. Social psychologists have termed the critical link between goal representation and goal pursuit behavior *intention*, and examined it in the context of specific *implementation intentions*, or self-statements in the form of “in situation x , I will engage in behavior y ” (Gollwitzer, 1996; Gollwitzer & Brandstatter, 1997). Implementation intentions serve a dual purpose in the goal-pursuit process. First, they connect a specific behavior to a specific situation, thereby creating a contextual association in memory. Once an implementation intention is formed, the situation itself becomes a cue that, when encountered, increases the likelihood of the action. For instance, Gollwitzer and Brandstatter (1997) found that participants who formed an implementation intention to counterargue a persuasive message at a certain point during the message did so more frequently and closer to the intended time than participants with no implementation intention. Second, implementation intentions provide a bridge from more abstract to more concrete aspects of the goal (Vallacher & Wegner, 1987). Whereas a highly abstract goal may have no obvious behavioral expression (“to be a good person”), creating an implementation intention demands a specific realization of that goal which can actually be implemented (“to help elderly people when I see them having trouble getting on the bus”). This translation from more abstract to less abstract also provides a means of transforming a long-term goal into a more specific and actionable short-term goal (Trope & Liberman, 2003).

A related thread regarding the leap from goal representation to goal-related behavior comes from the motivation literature, which suggests that

intention can arise from personality-level approach and avoidance tendencies (Elliot & Church, 1997; Elliot & Thrash, 2002). In these conceptualizations, goal representations serve as the pathway from broad and abstract approach–avoidance tendencies to specific behavior. As such, internally generated goals reflect an individual’s underlying motivations to approach incentives, avoid punishments, or some combination thereof, providing the why behind the goal intent’s how. This theory has at least two implications for the current discussion. First, the goal representation itself might be modulated by approach–avoidance motivation. In an experimental context, a goal might be represented as “to do well on the task,” or as “to avoid doing poorly on the task,” in approach or avoidance orientations, respectively. Second, how an individual intends to pursue a goal might also be modulated by approach–avoidance motivation. Given the same goal, a relatively approach-oriented person might adopt a strategy designed to maximize rewards whereas a relatively avoidance-oriented person might adopt one that minimizes punishments. Furthermore, these differential strategies can lead to effects on performance (Elliot & Church, 1997; Higgins et al., 1994).

In contrast to the rich theoretical attention goal intention has received in social psychology, relatively few studies have explored the neural mechanisms underlying intention. The studies that have can be divided into two categories. The first category addresses the relation between conscious intention and the neural sources of that intention. Using electroencephalography (EEG) to measure neural activity, Libet and colleagues identified a neural event associated with voluntary movement—the readiness potential (RP)—that occurs 500–1000 milliseconds prior to movement, and even prior to the conscious experience of intending movement (Libet, Gleason, Wright, & Pearl, 1983; Libet, 1985). The RP has subsequently been localized to the supplementary motor area and precentral gyrus (Cheyne, Bakhtazad, & Gaetz, 2006). Converging evidence for this localization comes from a neural stimulation study, which found that stimulation of the supplementary motor area produced an urge to move a particular body part, or the subjective feeling of impending motion (Fried et al., 1991). Although there continues to be debate concerning exactly what the RP represents and its precise role in signaling intent (see Libet, 1999, for discussion), it is at least clear that supplementary motor areas in the frontal cortex precede behavior and are also associated with the experience of intention. Although these experiments did not involve goals per se, the processes involved in transforming action to behavior in general may be similar to those involved in goal pursuit.

The second category of studies that links mental representation of goals to future action examines neural control of visual saccades. Studies in this area have operationalized intent as *preparatory set*, or the set of neu-

ral events that immediately precedes voluntary action (Connolly, Goodale, Menon, & Munoz, 2002; Everling & Munoz, 2000; Funahashi, Chafee, & Goldman-Rakic, 1993; Schlag-Rey, Amador, Sanchez, & Schlag, 1997). In these experiments, participants in the scanner are first shown a central cue (e.g., a colored circle) that indicates later eye movement either toward a target (green) or away from the target (red). Next, after a brief pause, the target appears in the periphery, and the participant is instructed to saccade toward (prosaccade) or away (antisaccade) from the target according to the earlier cue. Although the prepotent orienting response is a prosaccade, participants are given enough onset latency that they can easily antisaccade with only a slightly longer response time. The crucial distinction is that pro- and antisaccade conditions contain rule-based planning for action, but only the antisaccade condition is necessarily “intentional” because it requires something other than the prepotent response. More precisely, the gap period after cue onset but before target onset is thought to reflect an intention to act in the antisaccade condition. By comparing the gap periods of the prosaccade and antisaccade conditions, these studies have isolated the preparatory set for intentional eye movements. Imaging results have shown greater relative activation during intention periods in the frontal eye fields (superior frontal gyrus), dorsolateral PFC, and dorsal premotor activity. Although the frontal eye fields (which are involved in control of eye movement) may be specific to intentional eye movement, the activity in prefrontal and premotor regions might be a reflection of intentional action across goal domains.

Although suggestive, the neuroscience studies thus far only capture the first layer of complexity in intentional goal pursuit. The antisaccade paradigm seems to map onto the structure of implementation intentions (e.g., “when I see a red cue, I will move my eyes away from the target”) but does not capture either the underlying needs or motives within the individual that implementation intentions serve or broader, less context-dependent intentions (e.g., “I intend to study hard for the upcoming exam”) that are unlikely to recruit motor processes. An examination of trait motivation in the context of intention can address these issues and provide a further avenue for neuroscience research. For example, it might well be possible that implementation intentions are flavored by dispositional approach and avoidance motivation, and that individual differences interact with the relative approach or avoidance framing of the goal. These differences have already been shown to affect performance (Elliot & Church, 1997); differences in the framing of the intention (e.g., whether to avoid failure or approach success) seem to be a reasonable place to begin the search for pathways to performance. Employing neuroscience techniques, such as by examining neural pathways for reward and punishment, could further illuminate the approach- and avoidance-related changes in goal intention.

Psychologists have also offered evidence of automatic attention to goal-relevant cues in short-term goal pursuit. Derryberry and Reed (1994) demonstrated that the approach- and avoidance-related personality dimensions of extraversion and neuroticism relate to differential attention to positive and negative cues. Specifically, under voluntary and involuntary orienting conditions, people high in approach but low in avoidance were slower to draw attention away from positive cues, and people low in approach but high in avoidance were slower to draw attention away from negative cues. Other psychologists have studied “goal shielding” (Shah, Friedman, & Kruglanski, 2002) demonstrating that as various factors such as goal commitment and fit between goal type and trait approach–avoidance motivation increase, attention to the primary goal increases and distraction from secondary goals decreases.

Decades of neuroscience studies have investigated voluntary control of visual attention, which consistently corresponds to increased activation in the anterior cingulate, supplementary motor area, the frontal eye fields, and the temporal-parietal junction (TPJ; Posner & Petersen, 1990; Ro, Henik, Machado, & Rafal, 1997; Posner, Walker, Friedrich, & Rafal, 1984). Studies that have attempted to separate neural systems involved in willful (i.e., endogenous) versus cued (i.e., exogenous) shifts in attention have been generally unfruitful, with two notable exceptions (Nobre et al., 1997; Rosen et al., 1999). Both of these studies found similar patterns of activation across endogenous and exogenous attention, except areas in the medial (Nobre et al., 1997) and dorsolateral PFC (Rosen et al., 1999), which were selectively active during endogenous control trials. The authors noted this difference in the PFC and concluded that both types of attention are mediated by a single system involving the frontal eye fields, supplementary motor area, superior parietal cortex, TPJ, and ACC. The tentative conclusion is that although visual attention in general recruits a network of premotor, motor control and visual areas, only willful control of attention recruits anterior parts of the PFC.

Research on attention-deficit/hyperactivity disorder (ADHD) presents another pathway to investigating attentional processes involved in goal pursuit. ADHD is characterized by persistent inattention, impulsivity, and hyperactivity (Barkley, 1997), indicating a lack of components essential to successful goal pursuit. Research has implicated several brain regions in the inattention component of ADHD. Regions that are relatively inactive in adults with ADHD may contribute to attention to goals in normal adults. One positron emission tomography (PET) study found reduced glucose metabolism in premotor and superior prefrontal cortex in adults with ADHD compared to unimpaired adults (Zametkin et al., 1990), and several fMRI studies have documented the role of the ACC in the attentional deficit component of ADHD (Bush et al., 1999; Carter et al., 1998; Bar-

kley, Grodzinsky, & DuPaul, 1992). Patients with ADHD in these studies demonstrate selective ACC hypoactivity during tasks with competition among attentional resources, suggesting the ACC to be involved in modulating attention selection.

In light of social psychological studies on attention to goal cues, the possibility of automatic and nonconscious attention is one notable gap in the existing neuroscience data. Participants in several social psychological studies (e.g., Derryberry & Reed, 1994; Bargh et al., 2001) have been shown to orient toward goal cues and engage in goal pursuit while being completely unaware of both actions. The attentional processes engaged by these participants seems qualitatively different than that in neuroscience studies of exogenous attention shifts because the lack of awareness in the former. It remains an open question as to whether unaware attention is distinct from aware attention (voluntary or involuntary), and whether the two processes recruit distinct or overlapping neural networks. A first step to answering these questions would be to use fMRI to scan participants who were involuntarily attending to different cues, but who are either aware or unaware of their attention. The experiment could be done in an achievement context by flashing the same “achievement” cues for either 500 milliseconds (aware) or 50 milliseconds (unaware) centrally before participants complete a task that measures attention such as the dot-probe task (Tamir & Robinson, 2004). In both cases attention to the achievement-related cues in the dot-probe would be involuntary, but participants in the shorter cue condition would be unaware of the achievement prime. Results could show that some of the same regions that had previously been associated only with voluntary and aware attentional control were also associated with involuntary and unaware attention.

Direct Motor Control

Although a complete review of psychological studies of motor control would be well beyond the scope of this chapter, it is worth noting an interesting set of studies regarding approach–avoidance motivation and motor control. Using a lever push–pull paradigm (Duckworth, Bargh, Garcia, & Chaiken, 2002), several studies have demonstrated that positive stimulus evaluations facilitate level pulling, and negative stimulus evaluations facilitate level pushing (Solarz, 1960; Chen & Bargh, 1999). Several other studies have demonstrated this effect on a trait motivation level, where dispositional approach facilitates pulling and dispositional avoidance facilitates pushing (Neumann & Strack, 2000; Epley & Gilovich, 2001). One study (Fishbach & Shah, 2006) even demonstrated that a brief training to “pull” in response to healthy foods and “push” in response to unhealthy foods increased subsequent interest in healthy foods.

Neuroanatomically, the main regions for motor control relative to goal pursuit are the primary motor cortex (BA4), the supplementary motor area and premotor cortex (BA6), the presupplementary motor area (BA8), and the cerebellum and basal ganglia (Kandel, Schwartz, & Jessell, 1995; Schmahmann & Pandya, 1997). Although there are no direct connections from the PFC to the primary motor cortex, the dorsolateral PFC (BA 46) is connected directly to the supplementary, presupplementary, and premotor areas, as well as to the cerebellum and basal ganglia (Bates & Goldman-Rakic, 1993). Furthermore, the basal ganglia seem to serve as a motor control hub, integrating information from several frontal motor regions and outputting them back to prefrontal, premotor, and motor regions. Their position in the motor network makes them essential to modulating motor control during goal pursuit (Graybiel, Aosaki, Flaherty, & Kimura, 1994).

Response Inhibition

People pursuing goals are faced with an assortment of hurdles along the way such as intrusive thoughts or emotions, attractive yet task-irrelevant behaviors, and prepotent or automatic behavioral responses that run counter to one's goal. For example, given the long-term goal of being healthy, a person might experience a feeling of dread in anticipation of exercise, might want to watch television instead of exercising, or might desire junk food rather than vegetables. A mechanism for response inhibition is crucial to maintaining goal pursuit by inhibiting goal-irrelevant responses—internal thoughts and emotions and external temptations and distractions. A vast body of social psychological research on self-control and self-regulation addresses this problem (Bandura, 1977; Metcalfe & Mischel, 1999; Muraven & Baumeister, 2000; Trope & Fishbach, 2000). Mediators of self-control can take the form of contextual variables such as available resources (Baumeister, Heatherton, & Tice, 1993; Ward & Mann, 2000) and individual difference variables such as self-efficacy (Bandura, 1982), motivation (Carver & Scheier, 1998; Higgins, Shah, & Friedman, 1997), and emotion regulation (Gross, 2002).

Models from neuroscience tend to be broad frameworks of control rather than specific theories like those in social psychology. Several models suggest that the PFC plays a role in response inhibition by biasing attention and behavior toward goals. These models conceptualize response inhibition as a battle between automatic, “bottom-up” behavior on one hand, and controlled, “top-down” goal behavior on the other. Many forces pull us away from or against our goals, and a major role of the PFC is to guide our attention and behavior through this gauntlet in a “top-down” or executive manner, in a process that is known as top-down excitatory

biasing (TEB; Desimone & Duncan, 1995; Miller & Cohen, 2001; Cohen, Dunbar, & McClelland, 1990; Herd et al., 2006). Within a goal pursuit context, TEB can be thought of as a form of attentional control that serves to focus our cognitive resources on a goal or goal-relevant behavior to the exclusion of other temptations or distractions. The PFC is involved in top-down regulation of motor (Horn, Dolan, Elliott, Deakin, & Woodruff, 2003) and nonmotor responses such as cognitions and emotions (Lieberman, in press; Ochsner, Bunge, Gross, & Gabrieli, 2002).

Top-down control encompasses more than just response inhibition. Processes such as goal representation, conflict detection, and progress monitoring are all acting in concert, but they might recruit separable divisions within the PFC (Aron, Robbins, & Poldrack, 2004). Using converging evidence across several inhibitory tasks (e.g., task switching, go/no-go, stop signal), Aron and colleagues have suggested that, although dorsolateral PFC, ventral PFC, and ACC are each activated in tasks that involve inhibition, only the right ventral PFC (inferior frontal gyrus) is necessary for inhibition (Aron et al., 2004). This observation is supported by studies showing patients with lesions to right ventral PFC to have selective deficits in inhibition (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron, Monsell, Sahakian, & Robbins, 2004).

Other evidence in support of this view comes from research on impulsiveness. Individual differences in impulsivity (or in the related construct of novelty seeking) have been linked to the ventral regions of the PFC as well as related subcortical regions in the ventral striatum (Horn et al., 2003). In one recent study, self-reported impulsivity was positively correlated with activity in the caudate and anterior cingulate cortex, and negatively correlated with bilateral ventral PFC during an inhibitory go/no-go task (Brown, Manuck, Flory, & Hariri, 2006). Main effects during the go/no-go task show that participants generally activate the ventral PFC, the ACC, and caudate in no-go relative to go trials. One interpretation of these data is that individuals who are impulsive have stronger impulses to regulate and also less regulatory ability. This interpretation is consistent with the "alarm" theory of the ACC (because participants who are impulsive show greater ACC during no-go relative to go trials), and also with TEB models of ventral PFC involvement in response inhibition (because ventral PFC is recruited more during no-go trials in general but less by individuals who are impulsive). Assuming this interpretation is correct, the construct of impulsivity serves as a wedge to illustrate distinctions within PFC during goal pursuit, with conflict detection being associated with ACC activity and conflict resolution being associated with ventral PFC activity.

In light of the converging evidence for the role of the PFC in TEB broadly and ventral PFC in response inhibition, one path for future research could be to investigate further divergences within that region. As

noted above, psychologists have made distinctions between situational and personality moderators of inhibition, and between inhibition of motor and non-motor. Just as we observed differential roles for the medial and lateral parts of the PFC for goal representation, there might there be a comparable split for regulation of internal distractions (e.g., emotions) from external ones (e.g., alternative options), or of situational from personality moderators of response inhibition. Another intriguing question for future research is what neural machinery allows personality moderators such as approach–avoidance motivation to modulate response inhibition during goal pursuit. Clarifying the processes involved in successful response inhibition due to personality factors can further our understanding of those individual differences, and also generate new theories of response inhibition across domains.

Progress Monitoring

To adapt to changing contingencies across time and situations there must be a mechanism to monitor whether or not progress toward the goal is being made. If progress is not being made and is noticed, the relevant adjustment can be made. Progress monitoring is particularly useful for goal pursuit in novel or unexpected situations where previously formed intentions cannot be mapped to all of the contingencies involved in goal pursuit. For example, a smoker who intends to quit might have decided to throw away any cigarettes he might encounter in his desk drawer but still be caught off guard when an acquaintance offers him a cigarette. Ideally, a progress-monitoring mechanism would be active on some level of awareness to spotlight the fact that smoking is not in line with his quitting goal and guide behavior to overcome the habit. Clearly, progress monitoring shares some features of attention (discussed previously), so this review focuses on conceptual distinctions between the two.

Several goal-pursuit theories have incorporated a self-regulatory component in the form of reciprocal *discrepancy detection* and *discrepancy reduction* mechanisms. These mechanisms act in a loop that serves as an alarm when the current state is discrepant from the goal state and also as a guide to point the way toward discrepancy reduction. For example, the hallmark of Carver and Scheier's (1982, 1998) self-regulation model is the "test" phase, which, in a loop with the "operate" phase, guides behavior to reduce discrepancy. In this model, when discrepancies at a higher level of abstractness are detected, attention is drawn toward lower-order goals in the hierarchy. For example, after the holidays someone with the higher-order goal of "being healthy" might notice that his current state is discrepant from this goal and be moved to engage in a lower-order behavior such as exercise. A related theory by Higgins (1997) considers the affec-

tive consequences of goal discrepancies. In this theory, discrepancy from approach-oriented goals (called ideal goals) results in low-arousal negative affect such as sadness and dejection, whereas discrepancy from avoidance-oriented goals (called ought goals) results in high-arousal negative affect such as anxiety and tension. Both models feature a discrepancy gradient where the urgency or affect resulting from discrepancy increases with distance from the goal.

Much of the existing neuroscience research on discrepancies has focused on disentangling the process of discrepancy detection from the process of discrepancy reduction—in TOTE terminology, pulling apart the neural machinery of the “test” from the “operate” steps (Botvinick, Braver, Barch, Carter, & Cohen, 2001; MacDonald et al., 2000). This body of work adopts a view of the brain as a massive parallel-distributed network that engages in many task-relevant processes simultaneously. Engaging any behavioral goal launches several representational processes, some of which might conflict, and only one of which can be expressed behaviorally at any time. In this massive network, the role of the ACC is to sound a neural “alarm” whenever some of these processes produce conflicting responses. The ACC can do this in two ways. First, the ACC might be involved in action initiation by signaling discrepancy between the current state and the desired end-state. Second, the ACC might be involved in coordinating and directing ongoing action by signaling discrepancy among possible response options.

Botvinick and colleagues (2001) used three sources of evidence to support these conclusions. The first piece of evidence is that the ACC is active during tasks that require inhibition of prepotent responses that conflict with the correct response, such as the Stroop task (Bush et al., 1999; Carter, Mintun, & Cohen, 1995). The authors suggested that the ACC is associated with the discrepancy detection component of the Stroop task rather than the behavioral inhibition per se. In further support of this position, MacDonald et al. (2000) dissociated the discrepancy detection phase of the task from the response correction phase and showed that the ACC is uniquely related to the discrepancy detection phase. These results are consistent with the “alarm” theory of the ACC, which seems to respond to the simultaneous representation of the prepotent (but incorrect) and learned (and correct) response options. However, it is unclear whether the ACC activity during the detection phase reflects the detection of possible upcoming conflict or detection of conflict between the selected course of action and the correct response.

Second, underdetermined tasks (i.e., those with multiple correct responses) elicit activity in the ACC relative to those with only one correct response. For example, in the “F-A-S” fluency task participants are asked to generate lists of words beginning with the letters “F,” “A,” and “S,”

and this task produces increased ACC activity relative to simply echoing the cue (Friston, Frith, Liddle, & Frackowiak, 1993) or performing a lexical decision task (Frith, Frison, Liddle, & Frackowiak, 1991). The control tasks present only one correct response option, whereas the experience of completing the FAS task is a barrage of options becoming available after the cue. Again, the view of the ACC as an “alarm” that indicates the need to resolve the problem of conflicting response pathways is consistent with these findings. Other research demonstrating ACC activation even during silent word generation again suggests that the role of the ACC is in the initial conflict detection rather than during subsequent conflict reduction (Warburton et al., 1996; Wise et al., 1991).

Third, researchers using EEG have noted an event-related potential specific to commission of errors on speeded decision tasks (Gehring, Coles, Meyer, & Donchin, 1995; Falkenstein, Hohnsbein, & Hoorman, 1995; Amodio et al., 2004), which has since been localized to the ACC (Carter et al., 1998). These types of tasks often present participants with two response options (e.g., right/left), and in those cases participants will often re-respond with the correct answer shortly after the incorrect answer: They realize they have made an error and attempt to correct it. Gehring and Fencsik (2001) used electromyogram (EMG) to measure muscle movement in both hands during responding, and showed that activity in the ACC (assessed with EEG) corresponded to periods of response overlap between correct and incorrect button presses. This is perhaps the most direct evidence of the ACC's role in conflict between multiple response pathways. However, the ACC was active during behavior, making it unclear whether this activity reflects conflict detection (between the correct and incorrect representations), or conflict reduction (between the correct and incorrect responses).

Taken together, the studies reviewed here suggest that one role of the ACC is to reflect conflict among multiple representations of response options or among actual response behaviors (Botvinick et al., 2001; Carter et al., 2000). However, most of the studies discussed in this context conflate the intention or planning that occurs immediately before behavior (which involves parallel representation of the current state and the end-state, along with many possible plans) and the actual behavior (which involves parallel representation of different possible behaviors), so it is unclear whether the ACC is involved in only one or both.

One reason for this ambiguity is that laboratory tasks rarely differentiate between the planning and maintenance phases of goal pursuit. Tasks such as the Stroop or FAS occur relatively quickly, on a single-trial basis, and with little opportunity to dynamically adjust behavior across time to match task demands. Even during the time-delayed Stroop employed by MacDonald and colleagues (2000), it is unclear whether the ACC dur-

ing the response inhibition trials reflects conflicting responses in planning (immediately before responding) or during execution (during responding). New paradigms involving longer-term goals that require planning and maintenance of behavior over the span of at least several minutes are necessary to untangle these possibilities. Although it seems plausible that the ACC is integral to both phases, more research in goal-pursuit paradigms is necessary to clarify its precise role.

Conclusion

Several conceptual threads ran through this review. First, there is a tension between the level of abstractness and temporal duration of the goals studied by social psychologists and neuroscientists, with psychologists generally concerned with more abstract, longer-term goals and neuroscientists investigating concrete, shorter-term goals. Second, dispositional and state approach-avoidance motivation has been found to be a key construct across multiple components of goal pursuit. Third, whether goal pursuit occurs within or outside of awareness, and whether this dimension significantly affects performance, remains an open question for several goal pursuit components.

Abstract/Concrete or Long-Term/Short-Term?

One recurrent theme in our discussion is the importance of temporal duration and scale in examinations of goal pursuit: Is there a process-level distinction to be made between brief goal-directed behavior (such as that examined on a trial-by-trial basis in the Stroop task) and longer-term goal pursuit (such as that involved in forming and pursuing a New Year's resolution)? Understanding the distinctions and commonalities between the two is an essential step toward translating what is already known about the neuroscience of short-term goals to the relatively unknown neuroscience of long-term goal pursuit that is of equal or greater importance outside the laboratory. Our review presents two related directions for future research that might provide insight into this question.

First, the literature on action identification (Vallacher & Wegner, 1987) bears on the distinction between concrete and abstract representations of goals. In the same way that individuals are capable of viewing the same action with varying levels of abstraction such as "moving my hand up and down," "brushing my teeth," and "maintaining good oral hygiene," so too might they distinguish between different levels of the same goal, as in "pushing the button as fast as possible," "doing well on the task," and "being a good experimental participant." Indeed, a key tenant

of action identification theory is that any given action (such as engaging in goal pursuit) may be represented at multiple levels of abstraction, and that the level of representation has important implications for how the action is attended to, pursued, and monitored. Neuroscientists have also observed distinctions between levels of mental abstraction, such that more abstract representations activate more anterior regions and more concrete representations activate more posterior regions (Amodio & Frith, 2006). A natural extension of these findings would be to import action-identification paradigms into the scanner and attempt to find convergences between these two literatures. For example, one study observed that people who are alcoholics tend to represent drinking at more abstract levels than people who are not alcoholics, and thus have difficulty altering behavior (Wegner, Vallacher, & Dizadji, 1989). It might be the case that people who are alcoholics recruit more anterior regions when thinking about drinking, and that engaging more posterior regions would be associated with behavior change through transformations of abstract into concrete goals. Researchers can capitalize on the convergence between social psychological and neuroscience findings to forge new theories and even interventions for health behavior change.

Second, the construct of temporal construal, which grew out of the action-identification literature (e.g., Trope & Liberman, 2003; Nussbaum, Trope, & Liberman, 2003), could yield valuable insights about the dynamic processes in the relationship between short- and long-term goals. For example, construal level theory (CLT) explicitly connects the level of abstractness and the temporal duration of a goal. As noted above, our brains recruit different regions to represent and attend to goals as they move from being more abstract to more concrete. Taken together, these observations suggest that there might be a parallel gradient of prefrontal cortical representation of temporal duration moving from posterior (shorter-term) to anterior (longer-term). Furthermore, CLT research has made inroads into experimentally modulating the focus between more and less abstract features of goals (e.g., Liberman & Trope, 1998). Importing neuroscience methods into this field is an important next step toward understanding the regulatory mechanisms involved in shifting construals.

Approach–Avoidance Motivation in Goal Pursuit

Social psychologists have made distinctions at each step of the goal-pursuit process between approaching rewards and avoiding punishments. Whether a stimulus is appetitive or aversive has implications for how it is represented (Elliot & Church, 1997) and attended to (Derryberry & Reed, 1994), how it is acted upon (Fishbach & Shah, 2006), the impact of discrepancies (Higgins et al., 1997), and for progress monitoring (Carver & Scheier, 1998). Neuroscientists are only beginning to make these distinctions.

Although existing studies of neural activity have considered reward (e.g., Knutson, Adams, Fong, & Hommer, 2001) and punishment (e.g., Buchel, Morris, Dolan, & Friston, 1998) separately, we know from social psychological research that it is important to consider both processes in tandem. To date, relatively few neural investigations have done so (but see Seymour et al., 2005), even though there are two important reasons to consider both processes together. First, long-term goal pursuit often involves systems that engage appetitive and aversive stimuli. Dieting, for example, might involve avoiding wanted but goal-inconsistent junk food and also approaching unwanted but goal-consistent vegetables. As neuroscience studies of goal pursuit move forward they will begin to more closely examine long-term goal pursuit and will necessarily involve a mixture of approaching incentives and avoiding punishments.

Second, social psychological theories dating back to the beginning of the study of approach and avoidance motivation have included both systems simultaneously (e.g., Schneirla, 1959; Gray, 1970). Empirical findings have also highlighted the importance of examining individual differences in approach and avoidance motivation within the same experimental context. A recent series of studies from our lab involving a novel goal-pursuit task found that the approach system was related to success across trial types, and that the avoidance system was related to success only on trials where inhibition of prepotent responses was necessary. Furthermore, there was an interaction between the two systems such that individuals high on both systems were the most successful group on the task in general (Berkman, Lieberman, & Gable, 2006). Subsequent fMRI analyses revealed that these systems were related to differential activation in regions sensitive to reward, such as the caudate and nucleus accumbens, and conflict detection and reduction, such as the ACC and dorsolateral PFC (Berkman, Burklund, Gable, & Lieberman, 2007). We view these types of studies to be essential in understanding how individual differences in motivation affect goal pursuit, and what are their unique and additive effects.

Levels of Awareness

We noted in several places in this chapter how goal-pursuit processes might operate at some times in a conscious, controlled way, and at others in a nonconscious, automatic way. An example of the dual nature of goal-pursuit processes are implementation intentions, which are formed by a conscious, deliberative process, yet later become active in a goal-relevant context because of an automatic association between goal context and intent (Gollwitzer, 1996). We reviewed other associative models where goal attention, discrepancy, and even pursuit is activated by situational cues, all entirely outside of awareness (Bargh et al., 2001; Mauss et al., 2006).

One important question faced by researchers in this area is how goal pursuit at these different levels is conceptually similar or different. Intuitively, goal pursuit seems like something that might involve deliberative, rule-based, and conscious processes. Indeed, several of the main components reviewed above have been shown to involve prefrontal regions that are traditionally associated with this type of processing (Miller & Cohen, 2001; Lieberman et al., 2004). However, studies on automatic goal pursuit have demonstrated that people can engage in seemingly “controlled” operations such as enduring in the face of obstacles without awareness (Bargh et al., 2001). Although it is possible that conscious awareness is not a prerequisite to prefrontal activity and that automatic goal pursuit recruits the same regions as controlled goal pursuit, it is also possible that automatic goal pursuit recruits entirely different brain systems to engage in the same behavior (Lieberman, 2007). Neuroscience techniques can be used to differentiate these possibilities.

Beyond adding to our understanding of how automatic and controlled goal pursuit works inside the brain, neuroscience can enhance our knowledge of automatic and controlled goal pursuit inside the person. Given what we know about the complex and multiple processes involved in long-term goal pursuit, it is likely that controlled and automatic processes are employed at some point. Each type of processing has advantages at different stages in goal pursuit; automatic processes are necessary to continuously monitor for goal-relevant cues without exhausting our limited cognitive resources, and controlled processes are useful during active goal pursuit for rule-based operations and inhibiting goal-counter responses. Drawing on existing neuroscience models such as “alarm” and top-down excitatory biasing theories, it is now possible to generate a coherent model of long-term goal pursuit combining social psychological insight and neuroscience data.

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