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Positive affect versus reward: emotional and motivational influences on cognitive control

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It is becoming increasingly appreciated that affective influences can contribute strongly to goal-oriented cognition and behavior. However, much work is still needed to properly characterize these influences and the mechanisms by which they contribute to cognitive processing. An important question concerns the nature of emotional manipulations (i.e., direct induction of affectively valenced subjective experience) versus motivational manipulations (e.g., delivery of performance-contingent rewards and punishments) and their impact on cognitive control. Empirical evidence suggests that both kinds of manipulations can influence cognitive control in a systematic fashion, but investigations of both have largely been conducted independently of one another. Likewise, some theoretical accounts suggest that emotion and motivation may modulate cognitive control via common neural mechanisms, while others suggest the possibility of dissociable influences. Here, we provide an analysis and synthesis of these various accounts, suggesting potentially fruitful new research directions to test competing hypotheses.

Keywords: emotion, motivation, cognitive control, reward, dopamine

INTRODUCTION

Human nature is uniquely characterized by the flexibility, complexity, and sophistication with which thought and behavior can be deployed in the service of a goal. This ability is thought to depend on *cognitive control*, a collection of mechanisms, including perceptual selection, response biasing, and online maintenance of contextual or goal information, by which the human cognitive system adaptively configures itself to optimally perform specific tasks (Miller and Cohen, 2001; Braver et al., 2002). Most of the goals pursued in daily life are emotionally or motivationally meaningful – i.e., to obtain outcomes that are pleasurable or important for survival, and avoid outcomes that are not. It has long been understood that such affective significance is central to determining the goals around which human behavior is organized; indeed, impairments in affectively driven goal-pursuit may be a critical component of a number of psychiatric disorders, such as depression and schizophrenia (Pessoa, 2008). Consequently, the psychological and neurobiological mechanisms by which affective influences modulate cognitive control have become of major interest in recent years and continue to be an important emerging topic of study.

Much of the experimental research examining how affect modulates cognitive control has involved one of two types of manipulations: emotional manipulations, in which affectively valenced subjective experience is directly induced (e.g., through mood inductions or exposure to emotional stimuli), or motivational manipulations, where motivational state is altered through the introduction of rewarding or punishing incentives. Both types of manipulations are thought to carry affective significance, and both have been hypothesized to impact goal-pursuit and/or cognitive control. However, for the most part, these bodies of research have been carried out independently of one another. In a recent

review, Pessoa aimed to ameliorate this situation by considering examples of both an emotional manipulation (threat) and a motivational manipulation (reward) on cognition within a common conceptual framework (Pessoa, 2009). His review suggests that both threat and reward operate in highly similar ways, impacting cognitive performance at both perceptual and executive stages of information processing. However, Pessoa acknowledges that emotion and motivation are broad constructs, the impacts of which may not be comprehensively characterized by the phenomena of threat and reward alone. In contrast, and as described further below, other theories of emotion and motivation suggest the possibility of dissociations between the two constructs (e.g., “liking” versus “wanting”; Berridge, 1996) but this remains an understudied issue. Thus, the goal of the present paper is to discuss more explicitly existing theoretical accounts regarding the relationship of emotion and motivation to cognitive control, examine how they may relate to one another, and speculate on commonalities and differences in the mechanisms by which they operate. We also suggest future research directions that could be pursued to clarify ambiguity regarding the emotion versus motivation distinction.

EMOTION AND MOTIVATION: TERMINOLOGY AND CONCEPTUALIZATION

Emotion and motivation are highly related constructs within the domain of affect (Rolls, 2000; Lang and Bradley, 2008), but their influences on cognition generally have not been explicitly considered in relation to one another. When examining the literature regarding the impact of each on cognitive performance, it is important to provide working definitions of relevant terms, so as to begin more carefully examining how these constructs may relate to one another.

One review suggests that emotions are best functionally defined as “psychological or physiological states that index occurrences of value” (Dolan, 2002). As this description suggests, emotion is generally conceptualized as a construct that can be decomposed into multiple subcomponents defining the relation between individual and environment. Davidson et al. (1990) suggest that emotions are comprised of three elements: autonomic reactions, cognitions, and behaviors. More recently, Roseman (2008) asserts that emotion can be thought of as a syndrome of *phenomenology* (thought and feeling qualities), *physiology* (neural, chemical, and other physical responses in the brain and body), *expressions* (signs of emotion state), *behaviors* (action tendencies or readinesses), and *emotivations* (characteristic goals that people want to attain when the emotion is experienced). Gendron and Barrett (2009) similarly claim that emotions are comprised of subprocesses, including an affective and cognitive (e.g., situational construal) component, and are highly contextualized in nature. Common to all of these definitions is the idea that emotions are an affective experience that can be characterized by physiological changes and defined by a cognitive construal of some kind. As states indexing occurrences of value, emotions have been proposed to carry functional value in physiologically preparing the body for action, permitting flexibility of behavioral responses to reinforcing stimuli, facilitating communication and social bonding, and influencing cognitive processes including evaluation, memory encoding, and memory recall (Rolls, 2000).

Motivations are similar to emotions in that they also serve to define the relation between the individual and the environment (Roseman, 2008), but differ from emotions in being more tightly linked to action and explicit goal associations; motivated action can be thought of as behavior that is at least partly determined by a desired and hedonically laden end-state (i.e., it is goal-directed). Pessoa (2009) suggests that motivation can be commonly defined as what makes one work to obtain reward or to avoid punishment. Similarly, Roseman (2008) proposes that a motivation is an internal state producing behavior which moves the individual toward desirable reference values or away from undesirable reference values.

Carver suggests a useful distinction between the two constructs as they relate to goals: while motivation may be the drive toward goal fulfillment, emotion may be emergent from one’s sensed *rate of progress* toward goals; the difference between one’s present status and one’s goal state is experienced as affect and may lead to goal reprioritization in order to maximize goal fulfillment (Carver, 2006). Similarly, Rolls (2000) suggests that emotions are states elicited by rewarding and punishing reinforcers of behavior. Likewise, Lang and Bradley (2008) claim appetitive and defense-related brain circuits have evolved to cope with motivationally significant stimuli in the environment; positive and negative emotion, respectively, are associated with the experience of these brain circuits being activated. Thus, according to this general view, emotion can be considered an emergent property of motivationally driven neural activity. However, the Lang and Bradley view also suggests that emotion is highly characterized by hedonic experience, which accordingly is also tied to the activation of motivational neural circuitry. They postulate that “...evaluative reports of *pleasure/displeasure* roughly index which motivational system is

activated by a stimulus event (i.e., appetitive or defensive)” (Lang and Bradley, 2008). Buck (2000) and Laming (2000), commenting on Rolls’ (2000) review of emotion and motivation, argue that emotion and motivation cannot be considered separately of one another: Laming (2000) argues that emotion is the subjective experience of being motivated, thus there is no separation between the two; Buck argues that motivation and emotion cannot be distinguished from one another if emotion is, as he describes, the “manifestation or ‘read-out’ of motivated potential” (Buck, 2000).

A contrasting perspective can be drawn from the work of Kent Berridge, which has highlighted the potential dissociation between activation of motivational circuitry and the neural systems that code for hedonic experience (Berridge, 1996, 2003; Berridge and Robinson, 1998, 2003; Berridge et al., 2009). He proposes that the hedonic (i.e., subjective experiences of pleasure/displeasure) and motivational (i.e., attribution of incentive salience) facets of reward, shorthanded as “liking” and “wanting” respectively, are neurobiologically dissociable: evidence from rodents indicates that hedonic activation may depend on opioid-related circuitry while attribution of incentive salience may depend on the mesolimbic and neostriatal dopamine (DA) systems. This work suggests that the constructs of emotion and motivation might involve separable neural mechanisms, and as such may have distinct influences on cognitive processing.

Psychological accounts postulating theoretical distinctions between emotion and motivation have been less common. However, Roseman (2008) has recently suggested key differences: while both may lead to goal-directed action, he proposes several differences between emotion and motivation. Roseman argues that motivations are specific, relatively deliberate, and associated with a specific goal. In contrast, emotions are produced by multiple contingencies, are somewhat more impulsive, and are not tightly linked to a particular goal. Additionally, he suggests that emotions typically take precedence over motivations: specifically, by engendering *emotivations*, emotion-specific motivations, that take precedence over non-emotional motivations. These *emotivations* could potentially be understood (in terms of Carver’s conceptualization of emotion) as a manifestation of goal reprioritization resulting from emotion as an indicator of motivational status.

From these working definitions and theoretical accounts of the relationship between emotion and motivation, we suggest that an emotion may be presently considered a construct of multiple processes that together serve to provide an index of value associated with an internal or externally experienced state. While a motivation may be similarly comprised of multiple components, a motivation should be considered a state that produces behavior specifically oriented to carry out a goal that has hedonic value. Thus, whereas an emotion may emerge from one’s status relative to motivational goals, it may not necessarily be directly relevant to a particular goal.

Examining the influences of emotion and motivation on cognitive performance may be fundamental to clarifying the relation between these constructs; currently, however, these investigations have been conducted largely in parallel. The goal of this paper is to integrate these literatures by highlighting some key theoretical accounts of emotional and motivational influences on cognition, and illustrating where empirical evidence suggests these influences

may diverge. To facilitate comparison between the emotional and motivational literatures, we have chosen to restrict the focus to studies involving positive emotions and reward incentives. It is, of course, also crucial to explore the relationship between negative emotions and punishment/avoidance-based motivational states, but as positive and negative emotion may be independent of one another (Watson et al., 1988), the extent to which they share the same mechanisms on cognition remains unclear.

POSITIVE AFFECT AND COGNITIVE CONTROL

Gray and Braver (2002) postulate that investigations of emotional influences on cognitive control should fulfill two global aims. The first is to determine whether emotional influences can and do have a selective influence on cognitive control: this must be established first and independently of the nature of these influences. The second aim is to elucidate the mechanisms by which such influences operate. In the present section, we discuss psychological theories regarding the adaptive value of positive emotion on cognition as well as theories regarding the specific mechanisms by which positive emotion takes its effect.

It has been suggested that positive emotion might be an adaptive signal indicating safety and security in the environment, giving the organism the freedom to explore and engage in new opportunities (Fredrickson, 2004). Building on this postulation, several psychological theories have suggested that positive affect serves to broaden cognition, promote creative problem-solving, and improve cognitive flexibility. Foundational work in this area was conducted by Isen and Daubman (1984), who observed that positive affect induction led to broader categorization and facilitated creative problem-solving (Isen et al., 1987). Relatedly, Fredrickson (2004) proposed the *broaden-and-build theory of positive emotions*, which posits that positive emotions broaden one's repertoire of thought and action, promoting building of intellectual, social, and psychological resources. In the cognitive domain, empirical support for the broaden-and-build theory has come from visual processing and semantic association tasks suggesting a broader scope of attention (Fredrickson and Branigan, 2005). Dovetailing nicely with this work is Carver's (2003) "coasting hypothesis," which suggests that the security of positive affect might emerge from one's sensed rate of progress toward goals, and result from goal completion at a faster rate than anticipated. Under such circumstances, one is free to "coast" on the goal in question and consider new ideas and/or the pursuit of other goals (leading to changes in goal prioritization).

The neural mechanisms underlying positive emotion's effects on cognition remain unclear. Different theories have been posited to explain these effects. One influential theory, the *dopaminergic theory of positive affect* (Ashby et al., 1999) was developed to address findings that positive emotion is linked to broadened cognition. Ashby and colleagues extrapolated from the literature on the neural substrates of reward processing to propose that the psychological effects of positive emotion are specifically linked to increased dopamine (DA) release (via the substantia nigra and ventral tegmental area) in these states. The particular cognitive effects of increased DA release during positive affect were postulated to occur through mesocorticolimbic system projections to the anterior cingulate cortex (ACC) and substantia nigra

projections to striatum, with increased DA facilitating the ability of ACC and striatum to initiate a switch among active task sets, rules, or goal representations maintained in lateral prefrontal cortex (PFC). This facilitation of switching among task-set representations under positive affect enables unusual or non-dominant sets to become active with a greater probability than under neutral affect conditions, which then facilitates creative problem-solving. In connectionist simulations, the account was tested and exhibited an ability to account for certain behavioral performance patterns observed by Isen and colleagues under positive affect manipulations (i.e., improved performance on creative problem-solving and semantic association tasks; Ashby et al., 1999, 2002).

Dreisbach and Goschke (2004), Dreisbach (2006), and Muller et al. (2007) developed a related theoretical framework, which emphasizes that the cognitive flexibility associated with positive affect may have systematic costs *in addition to* the benefits posited by broadening theories. Specifically, Dreisbach proposed that changes in dopamine activity triggered by positive affect lead to a shift in the balance between cognitive stability and cognitive flexibility, by increasing the tendency to update to new task goal representations and decreasing the tendency to perseverate in maintaining old ones. Empirical evidence from performance in set-shifting and context maintenance paradigms was consistent with this hypothesis, demonstrating positive affect induced facilitation of performance under conditions that depended on flexibility, but impairment under conditions stressing maintenance (Dreisbach and Goschke, 2004; Dreisbach, 2006).

A separate theoretical account, put forward by Gray (2001) and Gray and Braver (2002), argued for a hemispherically specialized basis of interactions between positive affect and cognitive control. In this account, an important congruence is noted between prior affective research associating positive emotions with increased activity in the left frontal cortex (Davidson et al., 1990; Davidson, 1992; Davidson and Irwin, 1999; Canli et al., 2001), and cognitive research linking the left frontal cortex to the active maintenance of verbal information in working memory (D'Esposito et al., 1998; Smith and Jonides, 1998). The primary theoretical claim of the account is that different affective states (positive versus negative) should trigger associated behavioral goals in working memory, and that it is adaptive for these goals to be hemispherically segregated such that they can be selectively prioritized by the appropriate affective state. Thus, the theory postulates that positive affect states should selectively facilitate verbal working memory – a hypothesis that was confirmed experimentally (Gray, 2001). Nevertheless, this account is agnostic about why positive and negative affect would be selectively linked with particular stimulus modalities in working memory.

In summary, theoretical accounts of the effect of positive emotion on cognition have tended to emphasize influences on cognitive flexibility, potentially by enhancing updating of goal information in working memory. Although most work has emphasized the adaptive value of such influences, it has also been suggested to come at a cost to goal maintenance. At the level of neural mechanisms, the focus has been on the dopamine system and PFC, which, as is discussed next, has strong parallels to theoretical accounts regarding how motivation might modulate cognitive control.

REWARD MOTIVATION AND COGNITIVE CONTROL

Theoretical accounts of motivation suggest a strong linkage to cognitive control (Simon, 1967; Carver and Scheier, 1998; Kruglanski et al., 2002). Although early motivational theories suggested a general drive or energization function for motivation (Miller, 1951; Hull, 1952; Duffy, 1962), information processing accounts of higher-level cognition have instead emphasized that motivational signals may play a more focused role in the prioritization, updating, and termination of goal representations that provide hierarchical control of behavior (Simon, 1967). Over the last 20 years, the intrinsic relationship between motivation and goals has been a central focus of researchers primarily working within the social and individual differences tradition, based on the central claim that motivations are expressed primarily as the activation and representation of specific cognitive and behavioral goals over others (Kruglanski et al., 2002). More recent work has been geared toward demonstrating that goal-directed behavior can be primed and biased by implicit and/or subliminal motivational cues, suggesting a relatively direct route for motivation–cognition interactions (Bargh et al., 2001; Custers and Aarts, 2010). In particular, Aarts et al. (2008b) have suggested an affective/motivational account of goal-pursuit in which positive motivational signals strengthen goal activation and maintenance, even when this occurs outside of conscious awareness. More recently, psychological theories postulating the role of motivation in activating goals and guiding behavior have begun to be bridged with neuroscience-based studies to more clearly specify the mechanisms by which motivation might influence cognitive control.

A primary focus of neuroscience studies on motivation and cognitive control has been to demonstrate that these two processes are integrated within specific brain regions, such as the lateral PFC. Early work involving single-unit recording in primates demonstrated that task-related neuronal activity in PFC was modulated by the expected reward value associated with performance (Watanabe, 1996; Leon and Shadlen, 1999; Watanabe et al., 2002). In one compelling demonstration, it was found that reward value directly enhanced the fidelity of active maintenance in working memory (Leon and Shadlen, 1999). More recent fMRI studies carried out in humans have used designs that orthogonally manipulate cognitive control demand and motivational value across a range of task domains, including working memory (Pochon et al., 2002; Taylor et al., 2004), context processing (Locke and Braver, 2008; Kouneiher et al., 2009), task-switching (Savine and Braver, 2010), and selective attention (Padmala and Pessoa, 2011). These studies have confirmed the presence of specific regions within lateral PFC (along with effects in other associated regions, such as the ACC) that are sensitive to the interaction of the two factors, consistent with a specific role in integrating motivational and cognitive control functions.

The DA system also plays a central role in accounts of both motivation and cognitive control. Dopamine has long been thought to be a critical component of motivation and reward processing (Wise and Rompre, 1989; Mirenowicz and Schultz, 1996; Robbins and Everitt, 1996; Schultz, 1998). More recent accounts have suggested that DA shows phasic, cue-triggered responses to specific events that indicate reward availability (Montague et al., 1996; Schultz et al., 1997) and/or high motivational salience

(Berridge, 2007). This signal, particularly when a reward is different from anticipated (i.e., prediction error), may serve as a mechanism for reward-based associative learning (Schultz et al., 1997; Schultz, 2002; Arias-Carrion and Poppel, 2007). While the role of dopamine as a learning versus salience signal in reward has been debated (Berridge, 2007), both kinds of accounts are compatible with the idea of phasic DA involvement in processing motivational incentives and thus consistent with our account. Additionally, a separate theoretical account has emphasized that the motivational utility of the current environmental context might be reflected in tonic, rather than phasic, DA activation (Niv et al., 2007). Together, these accounts suggest DA activity will be increased both by transient cues and sustained contexts that indicate high reward or motivational value.

It is worth noting a completely separate literature focused on the influence of DA release within PFC, which suggests that the DA system provides modulatory role on cognitive control functions. Neurophysiological studies in primates show that application of DA into PFC sharpens actively maintained stimulus representations (Sawaguchi et al., 1988; Sawaguchi and Goldman-Rakic, 1991; Arnsten et al., 1994). In contrast, DA antagonists reduce both active maintenance related PFC activity, and also cause behavioral impairments in working memory and cognitive control tasks (Sawaguchi et al., 1990; Sawaguchi and Goldman-Rakic, 1994; Williams and Goldman-Rakic, 1995). Similar effects have been observed in human pharmacological and fMRI studies, with DA agonists (administered systemically) being associated with improvements in working memory and cognitive control, and leading to associated modulations of PFC activity (Kimberg et al., 1997; Gibbs and D'Esposito, 2006). It is striking that the effects of pharmacological manipulations of DA in PFC are so similar to the effects that have been observed from motivational manipulations (Leon and Shadlen, 1999; Watanabe et al., 2002).

These linkages between the role of DA and PFC in motivation, and the effects of DA modulation on PFC-mediated cognitive control functions have prompted the development of theories that explicitly link these two mechanisms. The gating model account, put forward by Braver and Cohen (2000), emphasized the importance of phasic DA activity within PFC for the updating and active maintenance of goal representations. Specifically, this account suggests that the phasic DA responses to cues signaling reward prediction could also be exploited as a means of learning which task-related information should be actively maintained in PFC, and when to update such information. Simulation studies demonstrated that a system could in fact learn appropriate updating and maintenance of task context or goal information based on reward prediction cues. Thus, this account suggests the possibility of a linkage between the reward/motivational and cognitive control functions mediated by DA–PFC interactions. This point was made even more explicitly in the recent Dual Mechanisms of Control framework (Braver et al., 2007), which specifically suggests that signals of reward motivation will bias cognitive control toward a “proactive” mode, in which task cues trigger sustained goal activation and maintenance in the service of preparation for anticipated control demands, via the aforementioned DA–PFC interaction. Proactive control is distinguished from reactive control, in which the same task cues only trigger transient control related processes,

rather than sustained active maintenance, under conditions of low DA activity, such as when the environmental context is perceived to have reduced motivational value. This account has been supported by recent experimental evidence from an fMRI study of motivational influences on task-switching (Savine and Braver, 2010). Task trials that had high reward value were associated with increased activity in both lateral PFC and the midbrain DA system. Moreover, the increased cue-related PFC activation on high reward trials was associated with behavioral measures of improved task preparation, supporting the idea of a reward-related shift toward proactive control.

In summary, investigations of motivation and cognitive control have primarily focused on the role of goal representations in psychological models, and on interactions of the DA system in PFC in neuroscience studies. One mechanistic account suggests that DA activity triggered by reward cues can serve as an updating and prioritization signal, that modulates active maintenance of goal information within PFC. The potential similarity of the proposed mechanisms underlying both positive affect and reward motivation influences on cognitive control, according to the Ashby model (i.e., cognitive changes due to increased dopamine release to cortical areas such as the PFC and ACC), is striking, but has not yet been directly confirmed by experimental studies. This issue is discussed next, followed by suggestions for promising future research directions.

EMOTION VERSUS MOTIVATION: COMMON OR DISSOCIABLE INFLUENCES?

Emotion and motivation are closely related constructs, but it is still not clear how to relate their influences on cognitive control. Some theories do not clearly distinguish between the two, while others more explicitly state that emotion and motivation, while highly related, remain distinct constructs. Given the state of current evidence, this is still a question calling for clarification. Hints of dissociation between the two serve as starting points for future research.

Most proposals regarding affective influences on cognitive control have not drawn a clean distinction between emotion and motivation. This includes Gray's (2001) hemispheric specialization hypothesis, which explicitly does not distinguish between positive/negative emotion and approach/avoidance motivation, and Ashby et al.'s (1999) dopaminergic theory of positive affect, which posits a relation between DA and positive emotion *because* of DA's involvement in reward processing. Aarts et al. (2008b) go even further, by explicitly suggesting an equivalence between positive emotion and reward motivation in terms of their effects on goal-pursuit and executive control. In their model, positive affective signals occurring in temporal proximity to activation of a cognitive goal should strengthen the maintenance, accessibility, and pursuit of that goal, regardless of whether those affective signals relate to goal attainment (i.e., whether or not they serve as direct reward motivation cues).

Despite these claims, the relationship between positive affect, approach motivation, and DA system activity is somewhat tenuous. Experimental studies have shown that affective valence (positive/negative) and motivational direction (approach/avoidance) can be dissociated (Harmon-Jones, 2003; Harmon-Jones and

Gable, 2009). Likewise, in Carver's (2006) theoretical model, positive and negative affect emerge from detection of the rate of progress toward fulfilling *either* approach or avoidance-related goals: positive emotions result from above-anticipated goal progress; negative emotions result from below-anticipated goal progress. Thus, positive affect could potentially arise while pursuing avoidance-motivational goals. Finally, in Berridge's neuroscience-based account, dopamine is only critical for the transfer of motivational salience, or stimulus-triggered "wanting" to new cues or events, and does not generate hedonic experience, or "liking" (which is thought to be represented in the ventral pallidum via neurochemicals such as opiates and endocannabinoids; Berridge, 2007; Berridge et al., 2009). Thus, without supportive direct evidence, links between positive affect, approach motivation, and DA system activity should not be assumed.

Deconfounding emotional and motivational influences from one another is a challenge for exploring and clarifying these relationships. We argue that, as a starting point, emotional and motivational manipulations need to be operationalized (i.e., with exposure to emotional stimuli during or just prior to the task, or motivational performance-contingent incentives, respectively) and examined with performance-independent measures. Examining psychophysiological signatures of these influences [e.g., startle reflex, facial electromyography (EMG)] that have been linked to valence but not motivational orientation of affective experiences (Cacioppo et al., 1986; Lang et al., 1990) may be useful in dissociating these influences from one another.

Although these influences have yet to be directly disentangled, independent empirical work from the emotion and motivation literatures indirectly hints that these are dissociable influences. While several theories have proposed that positive emotion can lead to cognitive broadening and flexibility (Isen et al., 1987; Ashby et al., 1999; Fredrickson, 2004; Rowe et al., 2007) and exploration of alternate goals (Carver, 2003), growing evidence suggests that reward incentives enhance goal maintenance/representation and influence proactive cognitive control (Savine and Braver, 2010; Padmala and Pessoa, 2011). Empirical evidence is mixed, suggesting that positive emotion and reward may have similar effects on some cognitive processes, such as task-switching (reducing switch costs; Yan-Mei and De-Jun, 2008; Savine et al., 2010), opposite effects on other processes, such as selective attention (Rowe et al., 2007; Padmala and Pessoa, 2011) and mixed results on yet other processes such as goal maintenance (Dreisbach and Goschke, 2004; Dreisbach, 2006; Aarts et al., 2008b; Locke and Braver, 2008). How these diverging effects relate has yet to be systematically clarified, since positive affect and reward motivation have not yet been directly examined and compared.

Nevertheless, there is at least one example from the literature in which the same experimental paradigm – the AX continuous performance task (AX-CPT; Cohen and Servan-Schreiber, 1992; Servan-Schreiber et al., 1996; Braver et al., 2001) – has been utilized (in separate studies) to explore the effects of positive affect and reward motivation on cognitive control. The AX-CPT is a potentially advantageous paradigm for this purpose, because it permits selective examination of goal maintenance capability and proactive control. However, surprisingly, the results of the positive affect and reward motivation studies appear to be somewhat different. Under

positive affect induction via valenced pictures displayed prior to each trial, participants showed evidence of reduced maintenance capability relative to neutral affect (Dreisbach, 2006). Conversely, under manipulations of reward motivation, participants showed evidence of enhanced maintenance capability relative to baseline (Locke and Braver, 2008). In both studies, the results were interpreted as arising from modulation of DA activity in PFC, but it is not clear if the two different manipulations actually led to similar or distinct effects within these brain systems. Thus, direct comparisons are clearly needed, with monitoring of neural activity, to determine whether there is a potential dissociation between positive affect and reward motivation effects on goal maintenance.

One possibility that is worth considering is that DA activity in PFC underlies both positive affect-related reduction in maintenance capability and reward-related increases in maintenance capability, but that the two effects reflect dissociable temporal dynamics of DA influence. In particular, it is well-accepted that DA activity should be considered in terms of both tonic and phasic components, which can interact with each other (Grace, 1991). Further, prior research has more strongly linked facilitation of goal maintenance with tonic DA activation in PFC, primarily via D1 receptors; in contrast, phasic DA activity in PFC may promote updating and cognitive flexibility, potentially via D2 receptors (Cohen et al., 2002; O'Reilly and Frank, 2006; Durstewitz and Seamans, 2008). Thus, distinctions between reward motivation and positive affect may reflect a distinction in the balance between tonic versus phasic DA activation and/or a D1 versus D2 dominated state. However, the relationship between emotional and motivational processes and differential temporal dynamics of DA activity has not been directly shown and has yet to be investigated.

DIRECTIONS FOR FUTURE RESEARCH

The constructs of emotion and motivation are closely interrelated, and typically their influences on cognition have not been explicitly separated from one another (e.g., Pessoa, 2009). However, in the light of accumulating evidence suggesting they may be dissociable, their influences on cognition must be clarified. As alluded to above, there are unresolved questions in this domain that provide promising routes for future investigation. Here we discuss some of these in greater detail.

A first, straightforward suggestion is for studies to be conducted that directly test and compare the effects of positive affect manipulations with those involving reward motivation within a single sample, and using closely matched experimental designs. Of course, this suggestion does beg the question of what exactly differentiates a positive affect manipulation from one involving reward motivation, especially since some studies advertised as examining positive affect have actually used manipulations involving delivery of rewards (Isen et al., 1987; van Steenbergen et al., 2009). Although this question is one that may involve a deeper discussion that is outside of the scope of this article, we want to highlight that this issue has not really been adequately considered by researchers working in this area. Nevertheless, it is at least possible to operationalize a distinction in which positive affect is manipulated by influences such as mood inductions or strongly valenced stimuli, whereas reward motivation is manipulated by varying the incentives provided for task-performance.

With such an approach, it would be possible to directly test the hypothesis that positive emotion promotes cognitive flexibility while reward incentives promote greater goal maintenance. As mentioned previously, cognitive paradigms that specifically probe active maintenance and proactive control, such as the AX-CPT, could be used with emotional and motivational experimental manipulations to probe the possibility of dissociable versus common behavioral effects and/or their associated physiological bases. Other paradigms should also be examined, such as the remote associates and global/local paradigms, that have been frequently and fruitfully examined to demonstrate increased cognitive flexibility under positive affect (Isen and Daubman, 1984; Fredrickson and Branigan, 2005; Rowe et al., 2007), but have not previously been studied with respect to reward motivation. Finally, the use of a common paradigm would be useful for exploring other hypotheses relating to positive affect and/or reward motivation such as Carver's coasting model. Unfortunately, this model has not previously been studied within cognitive experimental paradigms, so further work in how to operationalize maintained goal-pursuit versus goal-switching would need to occur (e.g., via exploration of potentially approach paradigms such as volitional task-switching).

A second promising direction for future research is a more direct examination of the role of neurotransmitter systems in mediating affective and motivational influences on cognitive control. This is especially important with regards to the effects of positive emotion on cognition, since theories such as Ashby's posit a neurotransmitter mechanism without direct evidence for its involvement. Study of the role of neurotransmitter systems in positive affect is somewhat challenging, since detecting positive affect in animal models is difficult (although potentially not impossible, e.g., Berridge, 2000), as is direct monitoring of neurotransmitter activity in humans. However, studies that examine state-related changes in neurotransmitter receptor binding (e.g., using PET radioligand-labeling methods and dynamic imaging approaches) do provide a promising avenue for this research, especially for the monitoring of DA system activation (Egerton et al., 2009). In particular, receptor binding studies may provide a powerful means of directly testing whether increases in positive affect are associated with increases in DA system activity. Pharmacological manipulations provide another method by which to examine the link between neurotransmitter activity and cognitive change. Pharmacological challenge studies involving agents that influence DA activity have been used fruitfully in a range of domains to understand the role of this system in cognitive functions such as working memory (e.g., Cools et al., 2007), as well as in mediating basic aspects of reward processing (e.g., Pessiglione et al., 2006). Thus, targeted studies are needed that directly investigate how pharmacological manipulation of this system impacts motivational versus affective effects on cognitive control.

Although dopamine has received much attention for its involvement in reward and cognitive control processes, other neurotransmitters such as norepinephrine (NE) may also play crucial roles. NE activity, historically linked to physiological arousal (Foote et al., 1980), is becoming increasingly appreciated as a complex and specific mediator in the control of behavior as well (Aston-Jones and Cohen, 2005). The locus coeruleus (LC)-NE system may play a critical role in the regulation of exploitation (i.e., optimizing current

task-performance) and exploration (i.e., disengagement in search of alternative behaviors) tendencies during task-oriented behavior – phasic and tonic NE activity may respectively reflect these control tendencies; Aston-Jones and Cohen, 2005). It may be that exploration is highly analogous to Carver's (2003) idea of "coasting" or that the exploitation–exploration balance is analogous to the maintenance–flexibility balance discussed with regard to dopamine and control (Dreisbach and Goschke, 2004; Muller et al., 2007), but connections between these bodies of work have yet to be made. In particular, it is still not well understood what the relative roles of dopamine and norepinephrine are in emotional and motivational interactions with cognition. Exciting new evidence suggests that pupil dilation can be used as a non-invasive marker of LC-NE activity in humans, with pupil dilation changes indexing shifts in the exploitation–exploration balance during performance of cognitive control tasks (Gilzenrat et al., 2010). Thus, pupillometric methods might be one promising avenue for exploring the role of the LC-NE system in affective versus motivational influences in cognitive control, along with the psychopharmacological and neurotransmitter imaging methods described above.

More generally, the use of psychophysiological measures may provide another approach by which possible dissociations between emotional and motivational influences on cognition can be investigated. Pupil dilation has been well-established to index fairly specific changes in cognitive demand and effort (Beatty, 1982; Granholm et al., 1996; Beatty and Lucero-Wagoner, 2000) and thus may provide a measure of cognitive control, independent from behavior, that can finely index changes in temporal control dynamics. For example, pupil dilation has been successfully utilized to examine the temporal dynamics of goal maintenance and proactive versus reactive control within the AX-CPT paradigm (related to developmental changes; e.g., Chatham et al., 2009). Additionally, pupil dilation is sensitive to emotional variables as well, and may reflect emotional arousal (Bradley et al., 2008). Thus, pupillometric methods might be exceptionally well-suited for examining interactions of affective/motivational systems and cognitive control, although such interactions have almost never been explored (e.g., Satterthwaite et al., 2007). Other psychophysiological indices might be promising as well in this regard – skin conductance (SCR), startle probes, and EMG are all well-established autonomic indicators of affective state (Bradley et al., 2001). Thus, comparison of the effects of affective versus motivational manipulations on these indicators might help to reveal potential dissimilarities in autonomic profile, as well as whether some indicators serve as better predictors of the cognitive control effects of such manipulations.

Another means by which to probe for distinctions between emotion and motivation might be to more clearly assess the role of subjective experience. Subjective experience is thought to be a core ingredient to the construct of emotion (Barrett et al., 2007), but it remains unclear whether it should be considered key to the construct of motivation as well. Recent evidence suggests that subliminally presented reward cues can lead to similar effects on behavior and cognitive control as stimuli that are consciously perceived (Aarts et al., 2008a; Bijleveld et al., 2010; Zedelius et al., 2010), suggesting that subjective awareness of motivational value is not critical. In the emotion realm, subliminal information has

been shown to influence affective preference (Zajonc, 1980), and non-emotional facial changes (i.e., to a smile-like position) have been associated with changes in emotional response (Strack et al., 1988). However, subliminal presentation of positively valenced stimuli seems to only impact motivated behaviors such as the amount consumed and willingness-to-pay for rewards, but not subjectively experienced affective responses such as positive mood or reward liking (Winkielman et al., 2005). Thus, it is not clear whether subliminal manipulations of positive affect would impact cognitive control in the same manner as manipulations that are subjectively experienced.

As a final consideration, the relationship between emotion and motivation could be explored by examining the effect these manipulations have on *each other*. Some evidence suggests that reward incentives promote positive mood (Meloy et al., 2006), but such research is relatively sparse and, to our knowledge, effects of emotion on the effectiveness of a motivational manipulation remains unknown.

SUMMARY AND CONCLUSION

While emotion and motivation have been assumed to be related, they have largely been investigated independently with relation to cognitive control. Research in both areas may benefit from greater theoretical and empirical integration. Current theories suggest that the influences of positive emotion and reward incentives may depend on a common neuroanatomy: both may increase mid-brain dopaminergic activity (i.e., ventral tegmental area), which projects to control-associated areas, such as the PFC and the ACC. The PFC in particular has received attention as a potential integration site for task and affective information in both emotional and motivational lines of research.

Despite these parallels, many research questions remain to be addressed. Perhaps most fundamentally, the neurobiological mechanism, independent of reward, by which positive emotion influences cognition remain unclear. Specifically, there is as of yet no direct evidence that supports a model in which positive emotion, independent of other components of reward, is associated with dopamine activity. Clarifying this mechanism will be key to establishing whether positive emotion and reward motivation influences on cognitive control are common or distinct. Second, further exploration of differential contributions of tonic and phasic activity in both the DA system and other relevant neurotransmitter systems, such as LC-NE, could help characterize both emotional and motivational influences on cognition, especially in probing further the hypothesis that positive affect and reward might be associated with more reactive and proactive (and/or exploratory versus exploitative) modes of cognitive processing, respectively. Third, inclusion of both psychophysiological measures and assessment/manipulation of subjective experience may be beneficial in theoretically distinguishing constructs of emotion from motivation and improving understanding of how they impact cognition. Fourth, effects of emotion and motivation on one another should be probed to help clarify their relationship.

Emotions may be characterized as emergent from one's current status relative to one's optimal goal status (Carver, 2006; Lang and Bradley, 2008). Thus, while emotion and motivation are closely related, emotions as an evaluator of goal status serve a slightly

different functional purpose than motivations, and consequently may be more fluid in relation to any given goal. Accordingly, they may have a more variable influence on cognitive control relative to motivational influences, which serve to optimize goal-relevant processing directly. Clarifying these constructs will help unite

disparate lines of research within a common theoretical framework, and provide a more nuanced picture of these interactions and their complexities. By doing so, this research effort may help to significantly advance the emerging field of affect–cognition interactions.

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- that could be construed as a potential conflict of interest.

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