

## A Neuropsychological Theory of Positive Affect and Its Influence on Cognition

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Positive affect systematically influences performance on many cognitive tasks. A new neuropsychological theory is proposed that accounts for many of these effects by assuming that positive affect is associated with increased brain dopamine levels. The theory predicts or accounts for influences of positive affect on olfaction, the consolidation of long-term (i.e., episodic) memories, working memory, and creative problem solving. For example, the theory assumes that creative problem solving is improved, in part, because increased dopamine release in the anterior cingulate improves cognitive flexibility and facilitates the selection of cognitive perspective.

Feelings permeate people's daily lives. For example, many cognitive processes are performed in the presence of some affective or emotional state. Somewhat surprisingly, a large amount of research has shown convincingly that even moderate fluctuations in positive feelings can systematically affect cognitive processing (for reviews, see Isen, 1993, 1999). For example, Isen and others have shown that mild positive affect, of the sort that most people can experience every day, improves creative problem solving (e.g., Estrada, Young, & Isen, 1994; Greene & Noice, 1988; Isen, Daubman, & Nowicki, 1987; Isen, Johnson, Mertz, & Robinson, 1985), facilitates recall of neutral and positive material (Isen, Shalker, Clark, & Karp, 1978; Nasby & Yando, 1982; Teasdale & Fogarty, 1979), and systematically changes strategies used in decision-making tasks (Carnevale & Isen, 1986; Estrada, Isen, & Young, 1997; Isen & Geva, 1987; Isen & Means, 1983; Isen, Nygren, & Ashby, 1988; Isen, Rosenzweig, & Young, 1991). Despite these pervasive and well-documented effects, there are few theories of how positive affect influences cognition. There is almost no mention of positive affect in the neuroscience literature,

and with few exceptions, cognitive psychologists have ignored positive affect in their own theories of human cognition.

Although there is little mention of positive affect in the neuroscience literature, there is considerable mention of a number of topics that seem closely related to positive affect. For example, there is a huge literature on the neurobiology of reward (for reviews, see Beninger, 1983; Lieberman & Cooper, 1989; Wise, 1982; Wise & Rompré, 1989). In humans, reward often induces positive affect. In fact, one of the most common methods for inducing positive affect is to administer a noncontingent reward to experimental participants (i.e., by giving an unanticipated gift). Thus, it is possible that many of the behavioral influences of positive affect are mediated by the same neural mechanisms that mediate reward. The neuroscience literature on reward has focused on the neurotransmitter dopamine. For example, it has been shown that rewards, and events that signal reward, elicit release of dopamine from several brain stem sites (for reviews, see, e.g., Beninger, 1991; Bozarth, 1991; Phillips, Blaha, Pfaus, & Blackburn, 1992; Phillips, Pfaus, & Blaha, 1991), and it is well known that dopamine antagonists (i.e., neuroleptics) disrupt reward signals and render reinforcement ineffective (e.g., Wise, 1982).

This article describes a theory that was developed from the initial hypothesis that many of the behavioral and cognitive effects of positive affect are mediated by the dopamine system. More particularly, when developing the theory, we began with the following two assumptions. First, we assumed that positive affect is associated with increased brain dopamine levels, although we did not assume that dopamine causes the pleasant feelings associated with positive affect. Second, we assumed that at least some changes in cognitive processing that have been observed in positive affect conditions are due to the increased brain dopamine levels associated with positive affect. For example, we present evidence that creative problem solving is improved because conditions of positive affect are associated with increased dopamine

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levels in frontal cortical areas (i.e., prefrontal cortex and anterior cingulate).

A number of researchers have proposed hypotheses related to the theory developed here. For example, Depue and his colleagues have argued that the genetically determined sensitivity of the brain to dopamine is positively correlated with the personality trait of extroversion or positive affectivity (Depue & Iacono, 1989; Depue, Luciana, Arbisi, Collins, & Leon, 1994). Others have discussed the neural mechanisms of moods and emotions (e.g., Derryberry & Tucker, 1992) and their possible neurochemical correlates (e.g., Panksepp, 1986, 1993), and there even have been occasional proposals that positive affect is associated with dopamine release (e.g., Phillips, 1984; Phillips et al., 1992). However, to our knowledge, we are the first researchers to propose that the resulting increased dopamine release could mediate the effects of positive feelings on cognition. Moreover, the theory we propose addresses the impact of mild, induced positive affect, allowing that the dopamine effects we consider need not be genetic.

The theory developed in this article describes some of the neural pathways and structures (and neurotransmitter systems) that we believe are most heavily responsible for mediating the neural effects of positive affect and its influence on cognition. The resulting theory has a number of advantages over current theoretical approaches to the study of positive affect. First, of course, it provides a neuropsychological account of a number of well-documented positive affect phenomena. Second, it predicts influences of positive affect on tasks that previously have not been investigated in the positive affect literature (e.g., working memory and odor perception tasks). Third, it describes a variety of tasks in which positive affect is predicted not to affect performance (e.g., visual perception tasks). Fourth, it ties results from the positive affect literature to previously unrelated neuropsychological literatures. For example, the theory contrasts cognitive processing in healthy people under positive affect conditions with cognitive processing in a variety of neuropsychological patient groups (e.g., Parkinson's disease, schizophrenia, major depression). Thus, in addition to providing a coherent account of current data on the influences of positive affect on cognition, the new theory suggests many new avenues of research.

The next section of this article briefly reviews the literature on the influences of positive affect on cognitive organization and creative problem solving. The third section contrasts the effects of positive affect with those of arousal and negative affect. The fourth section introduces the dopaminergic theory of positive affect and reviews the evidence bearing on the central postulate of that theory, namely, that dopamine and positive affect are closely related. The fifth section elaborates the theory and examines predictions and preliminary tests from a variety of cognitive tasks. The sixth section considers some documented influences of positive affect that are beyond the scope of this article, and the seventh section considers some of the neuropsychological implications of the theory. Finally, we close with some brief conclusions.

### Positive Affect and Creative Problem Solving

It is now well recognized that positive affect leads to greater cognitive flexibility and facilitates creative problem solving across a broad range of settings. These effects have been noted not only with college student samples but also in organizational settings, in

consumer contexts, in negotiation situations, in a sample of practicing physicians asked to solve a diagnostic problem, with adolescents, and in the literature on coping and stress, just to name a few (e.g., Aspinwall & Taylor, 1997; Carnevale & Isen, 1986; Estrada et al., 1994, 1997; Fiske & Taylor, 1991; J. M. George & Brief, 1996; Greene & Noice, 1988; Hirt, Melton, McDonald, & Harackiewicz, 1996; Isen, 1984, 1987, 1993, 1999; Isen & Baron, 1991; Isen & Daubman, 1984; Isen et al., 1985, 1987; Kahn & Isen, 1993; Mano, 1997; Showers & Cantor, 1985; Staw & Barsade, 1993; Staw, Sutton, & Pelled, 1994; Taylor & Aspinwall, 1996). This research suggests that positive affect increases a person's ability to organize ideas in multiple ways and to access alternative cognitive perspectives. In some of these studies, naturally occurring positive affect or optimism was examined, but in dozens of experiments supporting these conclusions, participants were assigned randomly to either a neutral or a positive affect condition, and positive affect was induced in a variety of simple ways. The agreement of the results obtained in these different settings, using diverse methods and measures, adds to the strength of the findings.

The most common methods for inducing positive affect in neutral affect participants are to give them a small unanticipated gift (less than \$1 in value) or to have them watch a comedic film, read funny cartoons, or experience success on an ambiguous task. The simple nature of these methods indicates that the effects can be prompted readily, by small things in people's lives. Thus, by positive affect, we mean a seemingly mild increase in positive feelings brought about by commonplace, everyday events.

A more detailed examination of this literature indicates that positive affect has predictable consequences in different types of tasks. First, in word association, people in a positive affect group have been shown to respond to neutral words (but not to negative words) with a broader range of first associates than do neutral affect controls (Isen et al., 1985). Similarly, in a study with adolescents, positive affect increased verbal fluency, and adolescents in the positive affect condition gave more category words and more unusual examples of the category than did adolescents in the neutral affect control condition (Greene & Noice, 1988). A similar finding, with adults, was obtained by Hirt et al. (1996).

Second, people in positive affect conditions are able to classify material more flexibly and are better able to see ways in which nontypical members of categories can fit or be viewed as members of those categories (e.g., Isen & Daubman, 1984; Isen, Niedenthal, & Cantor, 1992; Kahn & Isen, 1993). This effect has been found for items in natural categories, such as those used by Rosch (1975; Isen & Daubman, 1984); for products in a mildly pleasant class of snack foods (Kahn & Isen, 1993); for person types in positive but not in negative person categories (Isen et al., 1992); and for the perception and classification of human social groups (enabling a socially distinct "out-group" to be integrated and perceived as part of a superordinate, mutual "in-group"; Dovidio, Gaertner, Isen, & Lowrance, 1995). Thus, positive affect has been shown to enable people to see more similarities among items or people during the categorization process. Positive affect also can result in more perceived differences if people are asked specifically to focus on differences and to find ways in which items differ from one another (Isen, 1987, p. 234; Murray, Sujana, Hirt, & Sujana, 1990). This is probably because positive affect fosters cognitive elaboration (e.g., Isen et al., 1985), which has been found to influence

perceived similarity and difference as a function of contextual factors, such as the question posed (Tversky & Gati, 1978).

Third, people in positive affect conditions have been shown to perceive an interesting assigned task, but not a dull one, as richer and more varied than do control participants (Kraiger, Billings, & Isen, 1989). In the organizational behavior literature, task richness is closely related to the complexity, variety, diversity, and interestingness of the task. The influence of positive affect on perceived task richness can be seen as reflecting an ability on the part of the positive affect participants, again, to see additional associations and aspects of interesting things.

Fourth, positive affect increases the likelihood that people will pursue a problem-solving approach that leads to improved outcomes for both parties in an integrative bargaining task (Carnevale & Isen, 1986). To reach the optimal agreement in such a task, people must make tradeoffs of differing values, see new possibilities, think innovatively, and reason flexibly about how these tradeoffs might be made. Obvious compromises or simple yielding will not result in satisfactory outcomes (for greater detail, see, e.g., Pruitt, 1983).

Fifth, positive affect has been found to increase variety seeking among safe, enjoyable products but not among risky or dangerous alternatives.<sup>1</sup> Specifically, Kahn and Isen (1993) reported that people in a positive affect group showed more switching among alternative choices in a food category (e.g., soup or snacks) than did controls and included a broader range of items in their choice sets, as long as the circumstances did not make potentially unpleasant or negative features of the items salient. Thus, there is evidence that positive affect promotes enjoyment of variety and of a wider range of possibilities, but only when the situation does not prompt people to think of unpleasant outcomes.

Finally, positive affect has been shown to improve performance on several tasks that typically are used as indicators of creativity or innovative problem solving (Isen et al., 1987). In one of these tasks, the so-called candle problem (Duncker, 1945), a person is given a candle, a box of tacks, and a book of matches and is asked to attach the candle to the wall so that it will burn without dripping wax on the table or the floor. To solve the problem, the person can empty the box of tacks, tack the box to the wall, and then use the box as a platform for the candle. Thus, the person must use one of the items (the box) in an unaccustomed way. In three studies from two different laboratories, using both college students and adolescents (eighth graders), positive affect participants performed significantly better than controls on this task (Greene & Noyce, 1988; Isen et al., 1987). Such responding can be seen as involving cognitive flexibility, or the ability to put ideas together in new but useful ways—a classic definition of *creativity* (e.g., Koestler, 1964). It also has been referred to as “breaking set” or overcoming “functional fixedness” (Duncker, 1945; Wertheimer, 1945).

A second task that has been used to study the influence of positive affect on cognitive flexibility or creativity is based on the Remote Associates Test (M. T. Mednick, Mednick, & Mednick, 1964), which was designed in accord with S. A. Mednick’s (1962) theory of creativity. In this test, which in its full form was designed to measure individual differences in creativity, participants are presented with three words and a blank line and are asked to respond with a word that relates to each of the three words given in the problem. An example is the following:

mower atomic foreign \_\_\_\_\_.

(The correct answer is *power*.) Seven items of moderate difficulty from the Remote Associates Test have been used in the research on the influence of affect. Several studies have found that positive affect improves accuracy in this test, not only in college students but also in a sample of practicing physicians (Estrada et al., 1994; Isen et al., 1987).

To summarize the research described so far, more than 25 experiments, from at least 10 different topic areas, using varied affect inductions and diverse measures of cognitive flexibility, have indicated that randomly assigned positive affect enhances people’s ability to see alternative cognitive perspectives. In addition, several studies investigating naturally occurring positive affect in applied settings (or positive affectivity) have reported compatible results, namely, that this variable is associated with creative problem solving (e.g., J. M. George & Brief, 1996; Staw & Barsade, 1993; Staw et al., 1994) and promotes flexible and effective coping skills (e.g., Aspinwall & Taylor, 1997; Taylor & Aspinwall, 1996). Thus, in both laboratory and field studies using a diverse set of measures and assessing a wide variety of contexts, positive feelings have been shown to lead to cognitive elaboration and flexibility, giving rise to more thoughts, more nontypical thoughts, and innovative solutions to problems. In positive affect, thinking is flexible so that both usual and unusual aspects and senses of concepts may be accessible.

As indicated in our review, a number of studies investigating the impact of induced affect have reported significant interactions between positive affect and the task materials or conditions. In many studies, positive affect has been found to increase cognitive flexibility only when the situation is neutral or positive in emotional content, or at least minimally engaging or involving. Thus, positive affect does not improve performance on all tasks, so the effects that have been reported do not simply reflect an increased global motivation or activation on the part of people in the positive affect conditions nor some general increase in nonsystematic processing, because such effects would tend to equally affect all stimuli or situations. Rather, they suggest that positive affect enables flexible thinking about topics that people want or have to think about. Typically, these would include topics people expect to enjoy, but there also is evidence that people in positive affect want to think about a wide range of serious tasks and not just about games or fun. These tasks include diagnostic problems in the case of physicians and medical students (e.g., Estrada et al., 1994; Isen et al., 1991), and problem-solving, negotiations that are otherwise acrimonious, and product choice and categorization in the case of college students (e.g., Carnevale & Isen, 1986; Isen et al., 1985, 1987; Kahn & Isen, 1993).

There also is evidence that positive affect can promote attempts to cope with negative events or information, and studies have shown that under conditions of positive affect, people are less defensive and can better focus on needed negative information (Aspinwall, 1998; Isen & Geva, 1987; Trope & Neter, 1994; Trope & Pomerantz, 1998). Such coping cannot be assessed in studies in

<sup>1</sup> As we discuss later, positive affect also has been found to have adaptive effects when situations are unpleasant or negative and to foster attention to negative material when that would be useful. However, these effects are different from variety seeking, which occurs only in safe, enjoyable contexts.

which there is no need or benefit to elaborating on negative information. Unless the negative information is useful or important, people in positive affect will most likely not engage it carefully, which may play a role in producing the observed statistical interactions between affect and valence of the material. However, accumulating evidence indicates that when the information is useful or important, positive affect facilitates careful processing of negative as well as positive information.

### Positive Affect Versus Arousal and Negative Affect

Some studies showing an impact of positive affect on cognitive flexibility also indicate that positive affect is distinct from negative affect and affectless "arousal" in its ability to facilitate flexible responding (e.g., Isen et al., 1987). It is important to note, at least briefly, the evidence that positive affect and arousal do not appear to have identical effects, because at one time, affect and arousal were thought to be synonymous (e.g., Duffy, 1934, 1941), and even now, there is some confusion regarding this point. There are two common ideas about how to manipulate arousal. One is through exercise (e.g., Zillmann, 1979), and the other is through the induction of an emotional state (e.g., LeDoux, 1996). Typically, this emotional state would involve negative affect such as fear or anger, but according to some views, arousal increases with either positive or negative affect. Thus, if the increase in cognitive flexibility observed with positive affect is simply an arousal effect, then induced negative affect also should facilitate cognitive flexibility.

Some studies have included conditions or measures intended to address this question. For example, in two sets of experiments, positive affect participants reported more positive affect, but not more arousal or alertness, than neutral affect control participants on a manipulation-check questionnaire that followed the affect induction (Isen & Daubman, 1984; Isen & Gorgoglione, 1983). In addition, the behavioral results of these experiments correlated better with the affect-induction treatments than with the reported levels of arousal. In another series of studies, Isen et al. (1987) asked four groups of participants to solve the candle problem and to complete a subset of items taken from the Remote Associates Test. One group served as neutral affect controls. Positive affect was induced in a second group. In a third, exercise group, participants stepped up and down on a cinder block for 2 min before the test, which increased their heart rates by about 60%. Finally, a fourth group, a negative affect group, viewed a few minutes of the film *Night and Fog*, a French documentary of the World War II German death camps. As expected, the positive affect participants performed better than the control participants on both the candle task and the Remote Associates Test items. Equally important, people in the exercise and negative affect groups performed no better than the control participants on either test. Thus, again, Isen et al. found evidence that, unlike positive affect, arousal does not improve creative problem solving.

There is other evidence against the hypothesis that the effects of positive affect on cognitive flexibility are due to arousal. First, current theories do not predict that arousal increases creativity because arousal is thought to increase the likelihood of a dominant response, rather than an innovative response (Berlyne, 1967; Eastbrook, 1959). Second, reconceptualizations of the "arousal" concept suggest that it may not be a unitary construct and may need to

be investigated differently from the way it has been addressed in the past (e.g., Dienstbier, 1989; Lacey, 1967, 1975; Neiss, 1990; Venables, 1984). Third, a recent trend in the affect literature has attempted to disentangle arousal and pleasantness by conceptualizing affect as having two orthogonal dimensions—pleasantness and arousal (e.g., Lewinsohn & Mano, 1993; Mano, 1997). This work investigated effects of pleasantness and arousal separately, for example, by comparing the influences of pleasant-arousing, pleasant-nonarousing, unpleasant-arousing, and unpleasant-nonarousing conditions or affects. On the other hand, even though they may be logically independent, pleasantness and arousal may be empirically correlated. Indeed, research has indicated that, especially up to a point, arousal can have a pleasant and facilitating effect on task performance (e.g., Berlyne, 1967; Yerkes & Dodson, 1908). However, there is considerable evidence that arousal is associated with increased activity in neurotransmitter systems other than dopamine (e.g., norepinephrine and acetylcholine). And, as noted, the empirical effects of arousal or negative affect are different from those of positive affect. Thus, in sum, there is substantial reason to believe that affect and arousal are not synonymous, as was once proposed (e.g., Duffy, 1934, 1941), and that the increases in cognitive flexibility and creative problem solving reported in so many articles are indeed due to positive affect, not simply to increases in arousal.

The last section reviewed many studies that examined the influence of positive affect on cognition. There is also a large literature on negative affect, which indicates that the impact of negative affect is more complex and difficult to predict than is the case for positive affect (for reviews, see, e.g., Isen, 1987, 1990). Even so, referring to these different emotional states as "negative affect" and "positive affect" suggests they might represent two ends of the same continuum. If this were true, then performance under negative affect conditions could be predicted from the theory developed in this article by simply assuming that in negative affect conditions, people have lower brain dopamine levels than in neutral affect control conditions. Unfortunately, this naive hypothesis is surely wrong. Negative affect is not simply the opposite of positive affect in either its behavioral or cognitive effects, and happiness and sadness apparently are also mediated by independent neural pathways (e.g., M. S. George et al., 1995). Some researchers have suggested that negative and positive affect may even be localized in different cerebral hemispheres (e.g., Davidson, 1992; Henriques & Davidson, 1991). In support of this hypothesis, for example, there is evidence for hemispheric asymmetry in the dopaminergic pathways (with the left hemisphere favored over the right hemisphere; Tucker & Williamson, 1984). Thus, the evidence that positive and negative affect are not polar opposites in process and function is strong, and we believe that there is no way to use the theory developed in this article to make predictions about the influence of negative affect on cognition. Instead, for that purpose, a new theory would be required that focuses specifically on negative affect. Such a theory is beyond the scope of this article. The remainder of this section briefly describes a few of the problems associated with the assumption that negative and positive affect are related in any simple manner.

First, if negative and positive affect were opposites and if the theory developed here is correct, then reducing brain dopamine levels below normal resting levels should induce negative affect. However, the best evidence is that reductions in dopamine levels

are associated with anhedonia (flattened affect or loss of pleasure) rather than negative affect. For example, dopamine antagonists (i.e., neuroleptics), which block the effects of dopamine, flatten affect. Neuroleptics (e.g., haloperidol) are commonly prescribed drugs because of their antipsychotic properties (e.g., Hyman & Nestler, 1993). For this reason, they are included in the routine treatment for senile dementia and schizophrenia. Their effect on mood is well known. For example, *Physicians' Desk Reference* (Huff, 1988) prominently lists "flattened affect" as a common side effect associated with use of the popular neuroleptic haloperidol.<sup>2</sup> Anhedonia is a prominent diagnostic criterion of major depression (American Psychiatric Association, 1994), but it is not typically associated with a brief episode of mild negative affect.

Second, stressful or anxiety-provoking events, which presumably would produce a negative affective state in humans, actually appear to increase dopamine levels in certain brain regions. In particular, animal studies indicate that stressful events (e.g., foot-shock, tailpinch) cause increased dopamine release from some dopamine-producing areas (i.e., the ventral tegmental area [VTA]) but have little or no effect on dopamine release from other areas (i.e., the substantia nigra; Abercrombie, Keefe, DiFrischia, & Zigmond, 1989; Cenci, Kalén, Mandel, & Björklund, 1992; Imperato, Puglisi-Allegra, Casolini, & Angelucci, 1991; Sorg & Kalivas, 1993; Zacharko & Anisman, 1991). Thus, there is no evidence that brain dopamine levels are decreased following exposure to stressful or anxiety-provoking events.

### Dopamine and Positive Affect

Two separate, but interacting, dopamine systems are especially relevant to this article. The *nigrostriatal system* consists of dopamine-producing cells in the substantia nigra pars compacta that project into the striatum (i.e., the input region of the basal ganglia that consists of the caudate nucleus and the putamen). This system is primarily associated with motor activity, although recently it has been implicated in certain cognitive tasks (e.g., Ashby, Alfonso-Reese, Turken, & Waldron, 1998). The *mesocorticolimbic system* consists of dopamine-producing cells in the VTA that project to a number of limbic and cortical areas. This system is primarily associated with reward and motivation. Some of the more important projections are shown in Figure 1.

There is a good deal of evidence that the dopamine pathways shown in Figure 1 are active during periods of positive affect and that dopamine may mediate some of the effects positive affect has on cognition. First, of course, is the already mentioned fact that dopamine is released after presentation of rewarding stimuli, and reward is closely associated with positive affect, at least in humans. Second, drugs that mimic the effects of dopamine (i.e., dopamine agonists) or that enhance dopaminergic activity elevate feelings (e.g., Beatty, 1995). These drugs include morphine and apomorphine (agonists), cocaine (which blocks reuptake), and amphetamines (which increase dopamine release). Similar effects occur with naturally produced endorphins, because endorphin release stimulates the dopamine system and improves affect (e.g., Beatty, 1995; Harte, Eifert, & Smith, 1995). Third, as mentioned in the previous section, dopamine antagonists (i.e., neuroleptics) are thought to flatten affect.

Fourth, both dopamine release and positive affect are associated with increased motor activity. The well-documented increase in

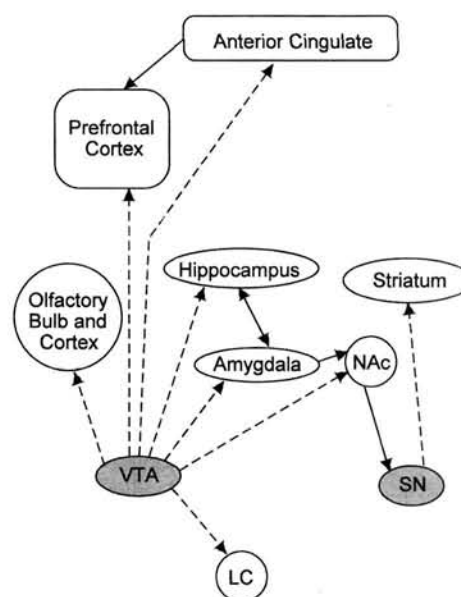


Figure 1. Some dopamine projections in the human brain. Dopamine-producing areas are shaded in gray, and dopamine projections are illustrated by the dashed lines. NAc = nucleus accumbens; VTA = ventral tegmental area; SN = substantia nigra; LC = locus ceruleus.

motor activity that occurs when brain dopamine levels increase (e.g., Kelly, Sevier, & Iversen, 1975; Protais, Bonnet, & Costentin, 1983) is associated primarily with the nigrostriatal system. Therefore, as one might expect, damage to the nigrostriatal system tends to decrease motor activity. The most widely known example of this damage occurs in Parkinson's disease, in which there is a progressive death of dopamine-producing cells in the substantia nigra (e.g., Strange, 1992). The classical symptoms of the disease include akinesia (dramatic reduction in motor activity) and bradykinesia (difficulty in initiating movement and a slowness of movement, once initiated). These symptoms are alleviated by the drug L-dopa, a precursor to dopamine. Although positive affect has been shown to increase motor activity in laboratory conditions (e.g., Hale & Strickland, 1976; Strickland, Hale, & Anderson, 1975), much of the evidence that positive affect increases motor activity is anecdotal, as represented by colloquial expressions such as "dancing" or "jumping" with joy. There also is substantial evidence that flattened affect and depression are associated with reduced motor activity. For example, the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; American Psychiatric Association, 1994) lists decreased energy and psychomotor retardation (e.g., slowed body movements, speech that is slowed and decreased in volume) as symptoms that commonly co-occur with

<sup>2</sup> However, it is difficult to rule out the possibility that the flattened affect commonly ascribed to neuroleptic therapy is not due, at least partially, to a reduced range of facial expression caused by extrapyramidal side effects of these drugs. In this case, there would be the appearance of an affect reduction but little or no true change in affective state (J. D. Cohen, personal communication, January 15, 1998).

a major depressive episode.<sup>3</sup> The dopaminergic theory of positive affect argues that increased motor activity occurs with positive affect because the events precipitating the elevation in mood lead to stimulation of the VTA, which in turn stimulates the substantia nigra (probably through intermediate stimulation of the nucleus accumbens; see Figure 1). This stimulation causes the substantia nigra to increase dopamine release into the striatum, which leads to increases in motor activity.

We propose that dopamine mediates the cognitive effects (or some of the cognitive effects) of pleasant feelings. An interesting and important question is whether dopamine also mediates the pleasant feelings that are associated with positive affect. Until recently, for the following reasons, it appeared that such feelings were associated with the mesolimbic projection from the VTA into the nucleus accumbens. First, severing these fibers or injecting dopamine antagonists into the nucleus accumbens blocks the rewarding properties of food, water, and other reinforcers (e.g., Lyness, Friedle, & Moore, 1979). Second, injecting dopamine agonists directly into the nucleus accumbens is rewarding (e.g., Monaco, Hernandez, & Hoebel, 1980). More specifically, there is growing evidence of increased dopamine release in the nucleus accumbens whenever an animal anticipates or prepares for a reward (for a review, see, e.g., Robbins & Everitt, 1996), actions that, in humans, are likely to elicit positive affect. In addition, the nucleus accumbens communicates directly with brain areas known to be closely associated with emotion. In particular, the (basolateral) amygdala and the anterior cingulate cortex project directly to the nucleus accumbens. The nucleus accumbens, in turn, can affect activity in the anterior cingulate by way of a known loop through the pallidum and the thalamus (Alexander, DeLong, & Strick, 1986). The cingulate played a key role in Papez's (1937) original circuit for emotions, and more recent work confirmed the association between emotion and anterior cingulate activation (e.g., Vogt, Finch, & Olson, 1992). The importance of the amygdala in emotional response is well known (e.g., Shepherd, 1994). In particular, there is a large literature showing that the amygdala is vital for learning to associate primary rewards with previously neutral stimuli (e.g., Robbins & Everitt, 1992; Rolls, 1995).

In the past few years, however, evidence has accumulated that the story is not so simple. First, it was discovered that the dopamine cells in the VTA that project to the nucleus accumbens respond most strongly to unanticipated reward (Mirenowicz & Schultz, 1994; Schultz, 1992). After a reward has become routine or expected, VTA dopamine cell firing is substantially reduced. Thus, if the firing of dopamine cells in the VTA is correlated with positive affect, then positive affect should follow the same rules. Evidence from the positive affect literature is compatible with this prediction, in that many of the positive affect inductions involve unexpected events (e.g., an unexpected gift, humor, or report of success on an ambiguous task). In addition, at least one influential theoretical account (Mandler, 1975, 1984), which proposes that emotion results from interruption, is also compatible with this prediction. Although there has not been a direct comparison of expected and unexpected gifts, it seems likely that giving a small gift will induce positive affect much more effectively when it is unexpected.

Second, there is a time-course problem. Dopamine cells in the VTA fire in the presence of unanticipated reward for only a few seconds (Mirenowicz & Schultz, 1994; Schultz, 1992), whereas

the change in affect that is caused by giving an unexpected gift can last for 30 min or longer. Recent neurophysiological results suggest a possible resolution to this apparent paradox. Floresco, Yang, Phillips, and Blaha (1998) electrically stimulated the basolateral amygdala of rats and measured dopamine release in the nucleus accumbens. As indicated in Figure 1, there is a direct (glutamate) projection from the amygdala to the nucleus accumbens, and a number of studies have found that these projections may directly modulate dopamine release from dopamine cells in the VTA that project to the nucleus accumbens (e.g., Gracy & Pickel, 1996; Imperato, Scrocco, Bacchi, & Angelucci, 1990; L. R. Johnson, Aylward, Hussain, & Totterdell, 1994). Floresco et al. found that stimulation of the basolateral amygdala for 10 s increased dopamine release in the nucleus accumbens for about 30 min, even under conditions in which the VTA cells were unable to fire (i.e., following microinjections of lidocaine directly into the VTA). Thus, dopamine release occurs long after dopamine cells have stopped firing, and the time course for dopamine release reported by Floresco et al. is remarkably similar to the time course for standard affect-induction techniques.

Third, dopamine cells in the VTA of cats have been shown to fire to loud clicks and bright flashes of light that have never been paired with a reward (Horvitz, Stewart, & Jacobs, 1997). Although it seems possible that cats confined to laboratory cages might find such stimulation rewarding, such results also raise the possibility that VTA dopamine cells fire not only to stimuli that signal reward but to any novel or startling stimulus (e.g., Wickelgren, 1997).

Fourth, as mentioned earlier, stressful or anxiety-provoking events, which presumably would produce a negative affective state in humans, actually appear to increase dopamine levels in certain brain regions (i.e., prefrontal cortex). In particular, animal studies indicate that mildly stressful events (e.g., footshock, tailpinch) cause increased dopamine release from dopamine cells in the VTA that project to the prefrontal cortex but have little or no effect on dopamine levels in the nucleus accumbens or on dopamine release from the substantia nigra (Abercrombie et al., 1989; Cenci et al., 1992; Imperato et al., 1991; Sorg & Kalivas, 1993; Zacharko & Anisman, 1991). However, it is not completely clear that the increased dopamine release from parts of the VTA is associated with negative affect. Because dopamine cells in the VTA are known to respond in anticipation of reward, one possibility, which cannot be ruled out at the present time, is that dopamine cells in the VTA respond to stressful events in anticipation of the relief that occurs with the termination of the event (e.g., through the animal's escape; e.g., Wilkinson, 1997). Of course, even if this were true, the dopamine release would occur in anticipation of pleasure; therefore, it could not mediate the pleasure *per se*.

Finally, many researchers have argued that a primary function of dopamine is to serve as the reward signal in reward-mediated learning (e.g., Beninger, 1983; Miller, 1981; Montague, Dayan, & Sejnowski, 1996; White, 1989; Wickens, 1993). Thus, one possibility is that at least some of the results that purportedly link

<sup>3</sup> Psychomotor agitation also is possible (e.g., inability to sit still, pacing, hand-wringing), and major depression is commonly thought to involve a variety of neurotransmitter systems (e.g., norepinephrine and serotonin, as well as dopamine; see, e.g., Hyman & Nestler, 1993). Consequently, results from patients with major depression must be interpreted with caution.



dopamine and reward are actually due to a failure of learning. For example, when animals are administered neuroleptics (i.e., dopamine antagonists), the animals behave as if primary rewards, such as food, have lost their rewarding properties (e.g., Wise, 1982). However, it is also possible that such rewards still do elicit the same hedonic response under neuroleptics but that the animals have failed to learn the association between the reward and the predictive stimulus.

Although these results do not disconfirm the hypothesis that dopamine release occurs during periods of positive affect, they do argue against the stronger hypothesis that dopamine release is responsible for initiating the pleasant feelings associated with positive affect. Berridge (1996) argued that reward is associated with functionally separate motivational and feeling components (which he called "wanting" and "liking"). He argued that dopamine mediates the motivational component of reward and that the pleasant feelings induced by consuming the reward are mediated by forebrain opioid circuits. Endogenous opioid peptides are a promising candidate because there is a large literature associating opiates and reward (for reviews, see, e.g., Feldman, Meyer, & Quenzer, 1997; Wise, 1989). In addition, there also are reports that opioid antagonists decrease the pleasantness ratings of foods (Drewnowski, Krahn, Demitrack, Nairn, & Gosnell, 1992; Fantino, Hosotte, & Apfelbaum, 1986; but see Hetherington, Verbaet, Blass, & Rolls, 1991). This interesting hypothesis deserves further study. However, for the purposes of this article, in which we propose that dopamine mediates the cognitive effects of positive affect, it is important that dopamine release or uptake increases during conditions of positive affect but not that dopamine causes the pleasant feelings associated with positive affect.

In closing this section, it is important to note that in addition to dopamine, other neurotransmitters and neuromodulators are known to influence mood and emotion. For example, theories of depression have long focused on norepinephrine and serotonin (e.g., Schildkraut, 1965). As a result, a complete theory of mood, and probably also a complete theory of positive affect, must consider many neurochemicals. Even so, we believe that to account for the influences of positive affect on cognition, the most important place to begin is with dopamine.

### Dopaminergic Projections and Preliminary Tests of the Theory

If positive affect is associated with increased dopamine release from the VTA, then the VTA projections illustrated in Figure 1 provide strong clues about the types of behaviors that should and should not be influenced by positive affect. Specifically, two separate hypotheses seem reasonable. First, positive affect may alter processing in any structure that receives a direct projection from the VTA. Therefore, we should look for influences of positive affect on any behavior mediated by such structures. Second, changes due to positive affect are less likely in behaviors mediated by structures that do not receive a direct projection from the VTA.

#### *Locus Ceruleus*

The VTA (and to a lesser extent the substantia nigra) projects to the locus ceruleus (Feldman et al., 1997; McRae-Deguerce & Milton, 1983; Simon & Le Moal, 1977)—a brain stem site (i.e., in

the pons) that is the largest producer of norepinephrine in the brain (e.g., Heimer, 1995). Although little is known about the function of dopamine in the locus ceruleus, the VTA–locus-ceruleus projection is potentially quite important because norepinephrine is the neurotransmitter most important for arousal. In fact, a prominent theory is that arousal is largely mediated by norepinephrine release from the locus ceruleus (other monoaminergic and cholinergic systems are thought to also contribute; e.g., Robbins & Everitt, 1995). Although earlier we reviewed extensive evidence that positive affect and arousal are mediated by separate systems, we also noted that they are nevertheless empirically correlated, in the sense that positive affect is often associated with increases in arousal. The dopaminergic theory of positive affect predicts that a possible mediator of this empirical correlation is the VTA–locus-ceruleus projection.

#### *Olfactory Cortex*

Figure 1 illustrates a direct projection from the VTA into primary olfactory areas. Actually, these are reciprocal connections because there also are direct projections from the primary olfactory cortex (i.e., olfactory tubercle) into the VTA (Oades & Halliday, 1987) and the nucleus accumbens (Newman & Winans, 1983). There also is evidence that these projections have important behavioral effects. First, patients with Parkinson's disease are impaired in olfactory same–different matching tasks, even when the two odors are presented only a few seconds apart (Zucco, Zaglis, & Wambsganss, 1991). Although the most widely known effect of Parkinson's disease is damage to the nigrostriatal system, there also is concomitant damage to the mesocorticolimbic system. In particular, dopamine production in the VTA is substantially diminished as the disease progresses (Javoy-Agid & Agid, 1980; Scatton, Rouquier, Javoy-Agid, & Agid, 1982). Second, presenting odors to anesthetized rats changes firing rates of cells in the nucleus accumbens, and these rates are altered after electrical stimulation of the VTA (West & Michael, 1990). Similarly, dopamine levels in the nucleus accumbens increase after male rats are exposed to air that was passed through the bedding of estrus female rats (Mitchell & Gratton, 1992).<sup>4</sup>

These results suggest a possible association between odor and positive affect. The VTA does not project to any other primary sensory areas (at least not to any substantial degree), which suggests that of all the senses, odor may be most closely linked to affect (for a review of the literature on olfaction and emotion, see Ehrlichman & Bastone, 1992). Thus, the dopaminergic theory of positive affect makes several strong predictions. First, positive affect could directly influence odor perception. Second, the absence of a significant projection from the VTA into visual or auditory areas suggests that, in contrast, positive affect might be unlikely to directly affect visual or auditory perception. Third, of all stimuli, odors might elicit the most direct and immediate affective response. To our knowledge, Prediction 1 is untested. We know of no data that address this question. As with any null hypothesis, Prediction 2 is difficult to affirm. Nevertheless, there

<sup>4</sup> Mitchell and Gratton (1992) attributed this increase primarily to activity in the accessory olfactory system, which responds to pheromones, rather than to activity in the olfactory system, which responds to odors.

are no data indicating that positive affect directly changes visual or auditory perception (e.g., see Niedenthal & Kitayama, 1994). Indeed, the existing data indicate that even the interpretations of clear visual stimuli are not altered by positive affect, although those of ambiguous stimuli are (e.g., Isen & Shalke, 1982; Schiffenbauer, 1977a, 1977b). Although these data do not directly address the question of the impact of positive affect on perceptions themselves, they do suggest that the perceptions are not directly influenced.

The third prediction is the most difficult to test because it does not state that odors are the only stimuli that are able to elicit an affective response, but only that they will tend to elicit a more immediate affective response than visual or auditory stimuli. Nevertheless, there is a wealth of data showing that odors do elicit immediate affective responses. For example, much of the variance in multidimensional-scaling solutions of odors is accounted for by the participant's affective response (e.g., Wright & Michaels, 1964; Yoshida, 1979). In contrast, multidimensional-scaling solutions of visual stimuli rarely load on an affective dimension. Even so, noticing that an odor is pleasant does not necessarily induce positive affect. Therefore, it is also important that there are preliminary data showing that certain odors may induce positive affect. For example, Baron and his colleagues (Baron, 1990; Baron & Bronfen, 1994; Baron & Thomley, 1994) found that pleasant odors increased helping behaviors and improved performance on an anagrams task, in much the same way as other methods for inducing positive affect (e.g., giving a small unexpected gift). Of course, visual and auditory stimuli are also sometimes used to induce positive affect, so the fact that odors can induce positive affect is necessary, but not sufficient, to verify Prediction 3.

### *Hippocampus and Amygdala*

Figure 1 indicates a dopamine projection into the hippocampus (mostly into sector CA1; e.g., Gloor, 1997), a medial temporal lobe structure that is thought to be necessary for the consolidation of episodic memories (e.g., Gluck & Myers, 1997; McClelland, McNoughton, & O'Reilly, 1995; Polster, Nadel, & Schacter, 1991; Squire & Alvarez, 1995). Normal functioning in the hippocampus depends critically on the neurotransmitter acetylcholine because reductions in hippocampal cholinergic activity produce spatial memory deficits in rats (Kim & Levin, 1996). Dopamine has been shown to increase acetylcholine release in the hippocampus (Imperato, Obinu, & Gessa, 1993) and to improve memory consolidation in a brightness discrimination task (Grecksch & Matthies, 1981). Thus, it is plausible that positive affect could improve episodic memory. In fact, there is substantial evidence that positive affect facilitates the recall of neutral and positive material (Isen et al., 1978; Nasby & Yando, 1982; Teasdale & Fogarty, 1979). The fact that this type of memory facilitation is often asymmetrical, favoring positive affect and positive material, may simply reflect the fact that people typically organize material for memory storage in terms of positive but not negative feelings. This does not mean that material is never organized in terms of a negative affective tone, especially in cases of extreme affect, but rather that under normal circumstances, most people do not use negative feelings for memory organization and storage.

Another structure that could play an important role in the relation between memory and affect is the amygdala, which also

receives a dopamine projection from the VTA<sup>5</sup> (see Figure 1). The amygdala is reciprocally connected to the hippocampus, and as mentioned above, it plays a key role in learning to associate stimuli with either primary reward or punishment (e.g., see Rolls, 1995). For example, animals with bilateral removal of the anterior temporal lobes (which include the amygdala; the so-called Klüver-Bucy syndrome; Klüver & Bucy, 1939) show deficits in learning to associate neutral stimuli with primary reinforcement (either reward or punishment) but not with secondary reinforcement (e.g., Gaffan, 1992). Even so, the amygdala appears to respond differently during happiness and sadness. M. S. George et al. (1995) found substantially more activation in the amygdala during transient sadness than during transient happiness.

There is also convincing evidence that the amygdala is a key component in the memory system for emotional events and stimuli (e.g., see Cahill & McGaugh, 1998; LeDoux, 1993). For example, there is a well-known recall advantage for emotionally salient material relative to neutral affect control material (e.g., see Blaney, 1986, for a review). Patients with a rare hereditary disorder that causes bilateral damage to the amygdala (i.e., Urbach-Wiethe disease) lose this recall advantage (Cahill, Babinsky, Markowitsch, & McGaugh, 1995). One possibility is that during memory consolidation, the amygdala plays an important role in associating an affective state with a memory trace. This association could involve automatic processes, attentive processes, or both. This is essentially a special case of Damasio's (1994; Damasio, Tranel, & Damasio, 1991) somatic marker hypothesis, with the additional provision of a possible attentive process that operates either during recall or when material is organized for memory storage (or at both times). Such tagging or marking could affect memory in two ways. First, traces associated with extreme affective states might be easier to recall, and second, the person's current affective state might serve as a cue that facilitates the recall of material tagged with that state. Although research indicates that positive affect more effectively cues the recall of positive material than negative affect cues the recall of negative material (e.g., see Isen, 1987, 1999, for reviews), this may be more true when the negative affect is sadness rather than other negative states such as anger (see Isen, 1990, for a discussion).

### *Prefrontal Cortex*

The projections from the VTA into the prefrontal cortex and the anterior cingulate are especially important because they provide a direct mechanism through which positive affect can influence cognition. There is evidence that these two projections might influence separate cognitive functions. In particular, there is evidence that the dopamine projection into the prefrontal cortex facilitates working memory, whereas the projection into the anterior cingulate facilitates executive attention and the selection of cognitive perspective.

There is growing consensus that the prefrontal cortex is the key cortical substrate of working memory (a review is beyond the scope of this article; see, e.g., Fuster, 1989; Goldman-Rakic, 1987, 1995). There also is strong evidence that dopamine is necessary for

<sup>5</sup> The densest dopamine projections are into the central nucleus, but the basal nucleus also receives a prominent projection (e.g., Gloor, 1997).



the normal functioning of this memory system. First, loss of dopamine input to the prefrontal cortex causes working memory deficits in monkeys (Brozoski, Brown, Rosvold, & Goldman, 1979; Roberts et al., 1994; Sawaguchi & Goldman-Rakic, 1991, 1994). Second, patients with Parkinson's disease, who have reduced dopamine levels in the prefrontal cortex, show working memory deficits (e.g., Gotham, Brown, & Marsden, 1988; Levin, Labre, & Weiner, 1989). Third, in vivo (iontophoretic) application of dopamine agonists and antagonists systematically affects firing rates of cells that are thought to subserve working memory in the prefrontal cortex of monkeys (Williams & Goldman-Rakic, 1995).

Thus, the evidence suggests that reductions in dopamine levels in the prefrontal cortex cause working memory deficits. There is less data, however, that allow us to predict the effects on working memory of increases in dopamine levels. Some evidence suggests an overall facilitation. First, when patients with Parkinson's disease are given L-dopa (a precursor to dopamine that increases brain dopamine levels), their working memory is improved (Lange et al., 1992). Second, several studies have reported improvements in the working memory of healthy humans who were given a dopamine agonist (Luciano, Depue, Arbisi, & Leon, 1992; Müller, von Cramon, & Pollmann, 1998). In contrast, Williams and Goldman-Rakic (1995) found that high levels of a dopamine antagonist disrupted the memory properties of cells in the prefrontal cortex of monkeys but that very low levels of the same antagonist were facilitative. On the basis of this evidence, they concluded that working memory performance is optimized at some intermediate dopamine level.<sup>6</sup> If positive affect is associated with increased dopamine release, then working memory may be affected in a similar manner when positive feelings are induced. A plausible hypothesis, and one supported by the behavioral and neuroscience data, is that moderate levels of positive affect may improve working memory but extreme levels may disrupt it (e.g., Isen, 1999). This suggestion is compatible with the findings in the affect literature, which has typically used mild, rather than strong, affect inductions, but thus far, there have been no rigorous tests of this prediction.

### *Anterior Cingulate and Selection of Cognitive Perspective*

As mentioned in the previous section, there is a prominent dopamine projection from the VTA into the anterior cingulate. Although it has been the subject of much recent investigation, the function of the anterior cingulate is still in question. In addition to the classical view of the cingulate cortex as part of the Papez (1937) emotional circuit, many recent results also implicate the anterior cingulate in a variety of cognitive functions. It could be that many of these views are correct, with different areas of the anterior cingulate having different functions.

There is substantial evidence that rostral areas of the anterior cingulate (i.e., the pregenual portions) play a direct role in mediating a number of affective processes, including the regulation of autonomic and endocrine function, conditioned emotional learning, assessment of motivational content, assignment of emotional valence to internal and external stimuli, and social interaction (for a review, see Devinsky, Morrell, & Vogt, 1995). First, this region is densely interconnected with the amygdala, the nucleus accumbens, and the orbitofrontal cortex, structures that are crucial for affective processes. Second, electrical stimulation of various sites

in the rostral anterior cingulate elicits emotional responses such as fear, sadness, anguish, and euphoria (Meyer, McElhaney, Martin, & McGraw, 1973; Talairach et al., 1973). Third, tumors in the anterior cingulate are often associated with a variety of emotional changes (e.g., see Devinsky et al., 1995). Fourth, neuroimaging studies indicate increased activation in the anterior cingulate in healthy women during transient periods of happiness or sadness (M. S. George et al., 1995). Similarly, Drevets and Raichle (1995) reported high levels of activation in the dorsal and rostral anterior cingulate in participants who were asked to think sad thoughts. In contrast, when participants were required to generate a verb semantically related to a stimulus noun, high levels of activation were observed only in the dorsal anterior cingulate. Thus, a complete theory of positive affect is likely to assign an important role to rostral regions of the anterior cingulate.

The regions of the anterior cingulate implicated in cognitive processing are dorsal and posterior to the affective region. Different researchers have attributed a number of different cognitive functions to these regions, including executive attention (Posner & Petersen, 1990), selection among alternative motor programs (Paus, Petrides, Evans, & Meyer, 1993), error monitoring (Dehaene, Posner, & Tucker, 1994; Gehring, Goss, Coles, Meyer, & Donchin, 1993), anticipatory and preparatory processing (Murtha, Chertkow, Beauregard, Dixon, & Evans, 1996), and the general monitoring of internal events (Frith, 1992). Although each of these functions could dramatically affect cognitive performance, perhaps the most profound effects on cognition would be due to manipulations of executive attention.

Posner and Petersen (1990; see also Posner & Raichle, 1994) proposed that there are a number of separate but interacting attention systems in the human brain. For our purposes, two of these systems are especially important. Roughly speaking, the posterior system mediates perceptual attention, whereas the anterior system mediates cognitive or executive attention. The anterior cingulate cortex is assumed to be a key structural component of the anterior attentional system. Posner and his colleagues (Posner & Petersen, 1990; Posner & Raichle, 1994) hypothesized that the (dorsal) anterior cingulate is involved in the selection of cognitive perspective and in the conscious directing of executive attention. Their arguments were based partly on neuroimaging studies, which indicated that the anterior cingulate is activated in tasks in which a person must select or switch among various interpretations or aspects of the stimulus. In conditions in which such selection or switching is not required, the cingulate is not activated. For example, Corbetta, Miezin, Dobmeyer, Shulman, and Petersen (1991) found cingulate activation in a same-different task in which two visual stimuli could differ in any one of three components but not when the stimuli could differ in only one component.

<sup>6</sup> There are two classes of dopamine receptors. The D<sub>1</sub> class includes the D<sub>1</sub> and D<sub>5</sub> receptors, and the D<sub>2</sub> class includes the D<sub>2</sub>, D<sub>3</sub>, and D<sub>4</sub> receptors (e.g., Seeman & Van Tol, 1994; Sibley, Monsma, & Shen, 1993). Of these, the D<sub>1</sub> and D<sub>2</sub> receptors are, by far, the most common, and in the prefrontal cortex and the anterior cingulate, there are approximately 10 times as many D<sub>1</sub> receptors as there are D<sub>2</sub> receptors (Lidow, Goldman-Rakic, Gallagher, & Rakic, 1991). As one might expect from this numerical discrepancy, most studies reporting an effect of dopamine on working memory have used either general dopamine agonists or antagonists, or drugs that act selectively on D<sub>1</sub> receptors.

The former condition requires selection of the appropriate dimension, whereas the latter condition does not. Similarly, the cingulate is not activated when people are simply required to read a stimulus word, but it is activated when they are required to name a verb related to the stimulus word (Petersen, Fox, Posner, Mintun, & Raichle, 1988) or when the word is a color name printed in the ink of a different color (i.e., the classic Stroop task; Bench et al., 1993). Reading a word does not require people to select a meaning, but naming a related verb does, and Stroop tasks require people to select between conflicting semantic and perceptual cues.

One difficulty with interpreting neuroimaging results such as these is that, because of massive reciprocal innervation, the dorsolateral prefrontal cortex tends also to be activated when there is anterior cingulate activation.<sup>7</sup> Thus, neuroimaging results alone make it difficult to decide whether the selection of cognitive perspective and the directing of executive attention are mediated by the anterior cingulate or by the dorsolateral prefrontal cortex. However, Turken and Swick (1998) recently reported results from a patient with a lesion restricted to the right anterior cingulate who participated in a task similar to the same-different task used by Corbetta et al. (1991). As predicted by the hypothesis that the anterior cingulate is an important executive-attention structure, the patient showed deficits in performing the task, especially in the divided-attention condition (i.e., on trials in which the stimuli could differ in any one of several components).

Oades (1985) argued that dopamine facilitates switching among a broad variety of signals in the central nervous system. We propose, more specifically, that dopamine and also positive affect facilitate the selection of, or the switching among, alternative cognitive perspectives.<sup>8</sup> In fact, there is considerable behavioral evidence that dopamine enhances this ability. First, dopamine antagonists impair cognitive set shifting (Berger et al., 1989). Berger et al. administered haloperidol, a common dopamine antagonist, to patients with idiopathic spasmodic torticollis—a disorder without known neuropsychological dysfunction in which the symptoms are sometimes alleviated by treatments with either dopamine agonists or antagonists. Before haloperidol administration, the group with torticollis performed as well as a control group on a simplified version of the Wisconsin Card Sorting Test. In this task, participants sort cards according to some perceptual attribute (e.g., color). After reaching a criterion level of accuracy, the relevant attribute is changed without warning (e.g., from color to shape). After the group with torticollis was administered haloperidol, however, they made significantly more perseverative errors than the control group. Similarly, several studies have found that administering a dopamine antagonist (i.e., chlorpromazine) to healthy adults impairs their ability to see alternative interpretations of ambiguous (i.e., reversible) figures (Harris & Phillipson, 1981; Phillipson & Harris, 1984).

Second, patients with Parkinson's disease, which reduces brain dopamine levels, are impaired in performing tasks that require selection or set shifting. For example, these patients show more perseverative errors than age-matched controls on the Wisconsin Card Sorting Test (e.g., Brown & Marsden, 1988; Cools, van den Bercken, Horstink, van Spaendonck, & Berger, 1984).

Following Posner and Petersen (1990), we hypothesized that the structure most important for the selection of cognitive perspective is the (dorsal) anterior cingulate. The results reviewed in this section support this hypothesis. However, it is important to realize

Table 1

*The Logical Structure of the Two Tasks Designed by Owen et al. (1993)*

Condition	Perseveration task		Selection task	
	Relevant component	Irrelevant component	Relevant component	Irrelevant component
Training	A	B	A	B
Transfer	C	A	B	C

that many patients with neuropsychological disorders besides those with Parkinson's disease perseverate on the Wisconsin Card Sorting Test, including several populations with no known cingulate dysfunction. For example, patients with lesions of the prefrontal cortex perseverate on this task. In fact, the Wisconsin Card Sorting Test is used primarily as an instrument for detecting frontal dysfunction (e.g., Kolb & Whishaw, 1990).

Owen et al. (1993) argued that perseverative errors on the Wisconsin Card Sorting Test could occur for two different reasons. One is a failure to select the appropriate stimulus aspect, and the second is a failure to switch attention from an inappropriate to an appropriate aspect. To test this hypothesis, Owen et al. designed two new tasks in which the different errors would be observable. Let A, B, and C represent different aspects, components, or dimensions of the stimulus display. For example, A might represent rectangles that vary in shape, B might represent circles that vary in size, and C might represent lines that vary in orientation. Next, let AB, for example, represent an experimental condition in which the stimuli vary in aspects A and B, and aspect C is not present, and in which participants must learn to sort the stimuli according to the value of each stimulus on aspect A. Thus, the first aspect listed is critical, and the second aspect is irrelevant. In our earlier example, the stimulus displays in the AB condition would contain a rectangle and a circle, and the participants' task would be to sort the stimuli according to the shape of the rectangle.

Owen et al. (1993) created two different tasks with the logical structure illustrated in Table 1. The perseveration task consists of condition AB followed by condition CA. A perseverative error occurs if the participant continues to respond on the basis of aspect A in the transfer condition. In contrast, the selection task consists of condition AB followed by condition BC. Here, an error in the transfer condition cannot be attributed to perseveration because aspect A is not present on transfer trials. Thus, attention must naturally switch from A to something else. An error occurs in the transfer condition of the selection task if the participants select the

<sup>7</sup> The projections into the prefrontal cortex tend to originate from regions of the cingulate that are more anterior than the cingulate regions that receive projections from the prefrontal cortex. This allows the possibility that anterior and dorsal regions of the anterior cingulate participate in Posner and Petersen's (1990) anterior attentional system, whereas more posterior regions of the anterior cingulate mediate the selection of alternative responses (Paus et al., 1993).

<sup>8</sup> There are obvious adaptive benefits of such facilitation. When an animal receives an unexpected reward, an increased cognitive flexibility should improve the animal's ability to explore and exploit the environment in which the reward was received.

wrong aspect for switching. Using this clever design, Owen et al. found that patients with frontal damage were impaired on the perseveration task but not on the selection task, whereas (unmedicated) patients with Parkinson's disease were impaired on both tasks. These results support the hypothesis that the anterior cingulate mediates the selection operation and that the prefrontal cortex participates in the switching operation. This is because (a) there are dopamine projections from the VTA into both the prefrontal cortex and the anterior cingulate, (b) Parkinson's disease causes the death of dopamine-producing cells in the VTA (as well as in the substantia nigra), and (c) people with frontal impairment have prefrontal cortex lesions but not anterior cingulate lesions.

Although the evidence is strong that the prefrontal cortex participates in the switching operation, the hypothesis that it plays the main role is controversial (e.g., Curran, 1995). Another possibility is that the basal ganglia perform the switching. There are known loops from the prefrontal cortex that project into the striatum, then to the globus pallidus, then to the thalamus, and finally, back to the prefrontal cortex (Alexander et al., 1986). Separate loops could be established for each of the critical alternatives, which would allow the basal ganglia to perform the switching. There are several lines of evidence supporting this hypothesis. We mention two. First, injection of a glutamate agonist directly into the striatum increases the frequency with which cats switch from one motor activity to another in a task in which food rewards are delivered for such switching behaviors<sup>9</sup> (Jaspers, De Vries, & Cools, 1990a, 1990b). Second, lesioning the dopamine fibers that project from the VTA into the prefrontal cortex improves the performance of monkeys on an analogue of the Wisconsin Card Sorting Test (Roberts et al., 1994). If switching occurs in the prefrontal cortex, then such lesions should impair switching performance (as seen, e.g., in patients with Parkinson's disease). If the switching occurs in the basal ganglia, then lesioning dopamine fibers in the prefrontal cortex should have no direct effect on switching. How then can one explain that lesioning dopamine fibers in the prefrontal cortex actually improves performance on the Wisconsin Card Sorting Test? An important clue to this apparent paradox comes from reports that such lesions tend to increase dopamine levels in the basal ganglia<sup>10</sup> (Roberts et al., 1994). If the basal ganglia are responsible for switching, if switching is enhanced by dopamine, and if lesioning the dopamine fibers that enter the prefrontal cortex increases dopamine levels in the basal ganglia, then lesioning the dopamine fibers in the prefrontal cortex should improve switching. On the basis of these data, therefore, we hypothesized that switching among cognitive perspectives is mediated primarily by the basal ganglia whereas the selection of cognitive perspective is mediated primarily by the anterior cingulate.

This hypothesis may also explain why people with schizophrenia who have positive symptoms (e.g., delusions, hallucinations; also called Type I schizophrenia) have difficulty maintaining cognitive set (e.g., American Psychiatric Association, 1994), despite good evidence of reduced activity in frontal cortical areas of people with schizophrenia<sup>11</sup> (e.g., Farkas et al., 1984; Ingvar & Franzén, 1974; Weinberger, Berman, & Zec, 1986). If both selection and switching were mediated by frontal structures, then hypofrontality should lead to reduced switching and perseveration, rather than to the frequent and inappropriate switching (e.g., "derailment," "word salad") actually exhibited by people with schizophrenia. In contrast, the hypothesis that selection is mediated by

the anterior cingulate and switching by the basal ganglia predicts that the derailment and word salad of schizophrenia could co-occur with hypofrontality if people with schizophrenia show increased activity in the basal ganglia. In fact, there is substantial evidence of increased dopaminergic activity in the basal ganglia of people with schizophrenia (mediated by D<sub>2</sub> receptors; for reviews, see, e.g., Feldman et al., 1997; Grace, 1991). It is important to note, however, that we are not proposing a connection between positive affect and schizophrenia. The increased dopaminergic activity postulated to occur in the basal ganglia of individuals with schizophrenia should far exceed the relatively modest increases that we hypothesized might occur under normal positive affect. Presumably, this is why the speech of people who are feeling happy does not typically resemble a word salad. People in positive affect are flexible, not psychotic. Also, the hypofrontality thought to occur in schizophrenia differs dramatically from the enhanced frontal functioning that we predicted for positive affect. Clearly, positive affect and schizophrenia are qualitatively different, and we certainly do not expect positive affect to induce symptoms that are even approximately schizophrenia-like. For example, in striking

<sup>9</sup> Alternatively, switching between motor behaviors and switching between cognitive sets may be mediated differently. The striatum consists of two structures: the caudate nucleus and the putamen. Generally speaking, the putamen is more involved in motor activity, and the caudate is more involved in cognitive activity. There are two separate, parallel projections from the putamen to the internal segment of the globus pallidus. One is a direct projection, and the other is an indirect projection through the external segment of the globus pallidus and the subthalamic nucleus (e.g., Heimer, 1995). Berns and Sejnowski (1996) proposed that both these direct and indirect pathways are necessary for selection or switching to occur in the basal ganglia. This hypothesis works well for motor switching but less so for cognitive switching. This is because cortical projections to the subthalamic nucleus are exclusively from motor areas, and the fibers that project from the caudate through the subthalamic nucleus (i.e., through the globus pallidus) are apparently less dense than those projecting from the putamen through the subthalamic nucleus (e.g., Heimer, 1995).

<sup>10</sup> Dopamine levels in the basal ganglia apparently increase because the prefrontal cortex tonically inhibits the VTA. Lesioning the dopamine fibers into the prefrontal cortex releases this inhibition, which effectively stimulates the VTA. There are a number of scenarios in which increased VTA activation could lead to increased dopamine levels in the striatum. Perhaps the most likely is the VTA–nucleus accumbens–substantia nigra–striatum pathway.

<sup>11</sup> In contrast, some researchers have argued that (positive) schizophrenia is associated with elevated cortical dopamine levels (e.g., Crow, 1980, 1982; Swerdlow & Koob, 1987), largely because of the success of dopamine antagonist (neuroleptic) therapy in treating schizophrenia. In support of this assumption, recent evidence suggests that the therapeutic action of neuroleptics is primarily on cortical dopamine D<sub>2</sub> receptors (Lidow, Williams, & Goldman-Rakic, 1998). However, in contrast to this view, neuroleptic treatment is not immediately effective. Partly for this reason, a number of current theories argue that although subcortical dopamine activity is increased in schizophrenia, cortical dopamine activity is actually decreased (Cohen & Servan-Schreiber, 1992; Goldman-Rakic, 1991; Karoum, Karson, Bigelow, Lawson, & Wyatt, 1987; Weinberger, Berman, & Illowsky, 1988). This latter view is supported by recent results indicating that chronic neuroleptic treatment is efficacious because it leads to upregulation of cortical D<sub>2</sub> receptors (although apparently at the cost of downregulation of D<sub>1</sub> receptors; Lidow et al., 1998).

contrast to schizophrenia, we expect positive affect to have a general facilitative effect on cognitive processing and speech.

If positive affect is associated with increased dopamine release from the VTA, and if dopamine facilitates selection in the anterior cingulate, then we would expect positive affect to improve cognitive flexibility and the selection of cognitive perspective. There is preliminary support for this hypothesis. Estrada et al. (1997) reported that positive affect reduced "anchoring" or rigidity in thinking on a medical decision-making task. Specifically, Estrada et al. induced positive affect in a group of physicians and asked them to read a medical chart and make a diagnosis. Compared with a control group of neutral affect physicians, the positive affect physicians were more open to new information, even when it contradicted an early diagnostic hypothesis they were holding.

It is possible that much of the improvement in creative problem solving that is observed under conditions of positive affect is due to the facilitation of executive attention that occurs with increased dopamine release into the anterior cingulate cortex. For example, consider Duncker's (1945) candle problem, in which participants are given a box of tacks, a book of matches, and a candle and are asked to attach the candle to the wall and light it in such a way that no wax drips on the floor. Isen et al. (1987) found that people in the positive affect group were significantly more accurate (58% correct) on the candle problem than were neutral affect controls (13% correct). Success on this task is more likely for participants who overcome the dominant cognitive set (viewing the box as a container) and select a set that is less typical (viewing the box as a platform). If dopamine enhances the ability of the executive-attention system to select more flexibly, then it seems reasonable to expect positive affect to improve performance on the candle task.

Positive affect may facilitate performance on other creative problem-solving tasks in a similar way. For example, consider the word-association and remote-associates tasks discussed earlier. In word association, participants are presented with a stimulus word and then asked to respond with the first word that comes to mind. As described above, Isen et al. (1985) found that people in the positive affect group were more likely to respond with unusual first associates (54% of total responses) compared with neutral affect controls (39% of total responses), where unusualness was defined by Palermo and Jenkins's (1964) word-association norms. In addition, participants in the positive affect condition showed greater diversity in their responses than did those in the control group. It is easy to imagine situations in which the selection of unusual or nondominant cognitive sets would lead to unusual responses in the word-association task. For example, consider a trial in which the stimulus word is *pen*. To respond, participants must select among the various meanings of this word. The dominant interpretation (or set) is of *pen* as a writing implement. In this case, participants are likely to respond with a high-frequency associate, such as *pencil* or *paper*. A more unusual interpretation is of *pen* as a fenced enclosure. Participants who select this interpretation are likely to respond with a low-frequency associate, such as *barn* or *pig*.

In the Remote Associates Test (M. T. Mednick et al., 1964), participants are presented with three cue words and are asked to find a fourth word that is related in some way to each of the three cue words. For example, one set of cue words is *gown*, *club*, and *mare*. In this case, the correct response is *night* (i.e., *nightgown*,

*nightclub*, and *nightmare*). As mentioned previously, Isen et al. (1987) found that people in a positive affect group were significantly more accurate on a subset of moderately difficult items from the Remote Associates Test than were neutral affect controls (71% correct vs. 43% correct, respectively). Note that in this example, to produce the word *night* when presented with the cue words *club*, *gown*, and *mare*, participants must overcome the dominant cognitive set that the correct response is semantically related to the cue words. Instead, participants must consider alternative ways in which the words may be related, such as by being part of a compound word. Thus, it is possible that the effects of positive feelings on the candle, word-association, and remote-associates tasks are all due to a common phenomenon, namely, that positive affect is associated with increased dopamine release into the anterior cingulate, which increases the flexibility of the executive-attention system.

A rough sketch of one possible model that instantiates these ideas is shown in Figure 2, for a trial of the word-association task in which the stimulus word is *pen*. The alternative cognitive sets are represented in the prefrontal cortex (i.e., *pen as a writing implement* and *pen as a fenced enclosure*). On the basis of appropriate context, one of the cognitive sets is activated (*pen as a writing implement* in Figure 2), and the anterior cingulate is involved in this selection. Presumably, this cognitive set is loaded into working memory. If an alternative set is to be noted or selected, then the switching is accomplished in the striatum (i.e., in

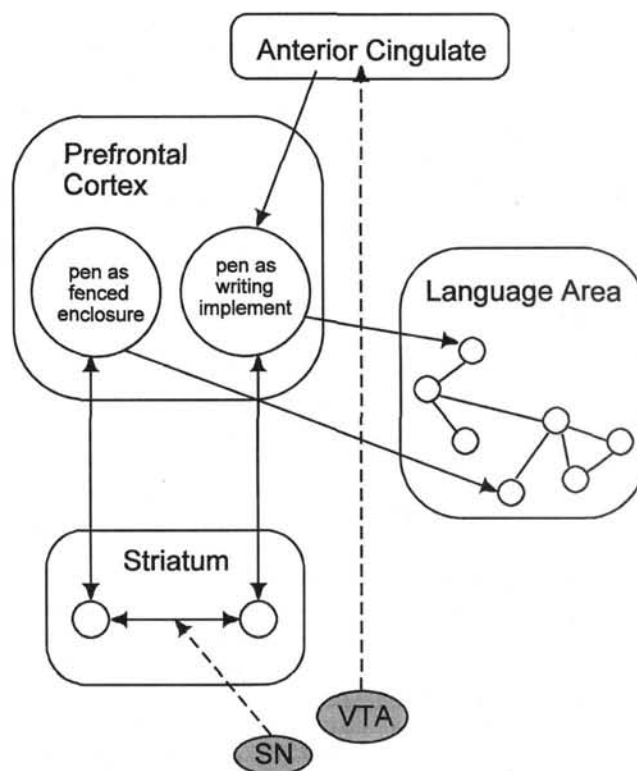


Figure 2. Proposed architecture of a neural network that mediates creative problem solving. Dopamine-producing areas are shaded in gray, and dopamine projections are illustrated by the dashed lines. VTA = ventral tegmental area; SN = substantia nigra.

the caudate nucleus in the case of word association). A simple way this might work is through lateral inhibition. Although competition within the striatum is often thought to be resolved in this manner (e.g., Wickens, 1993), direct recording studies have so far failed to find evidence of strong inhibition within the striatum (e.g., Jaeger, Kita, & Wilson, 1994). For now, we tentatively assume that switching is accomplished through lateral inhibition within the striatum, but we leave open the possibility that the switching is due to some other process within the basal ganglia (e.g., an alternative was proposed by Berns & Sejnowski, 1996; see Footnote 9).

In the model shown in Figure 2, each of the cognitive set units projects back to a different semantic network in some cortical language area (presumably in the temporal lobe). For example, *pen as a writing implement* is shown projecting to a network that might include the words *paper* and *pencil*, and *pen as a fenced enclosure* is shown projecting to a network that might include *barn* and *pig*. For the present purposes, there is no need to make assumptions about the details of these semantic networks. In Duncker's (1945) candle task, we assume the relevant cortico-cortical projections are from the cognitive set units in the prefrontal cortex to specific motor units in the premotor or motor cortex, rather than to temporal language areas, as in Figure 2. In the model shown in Figure 2, the dopamine projection from the VTA into the anterior cingulate facilitates the selection process, and the dopamine projection from the substantia nigra into the striatum facilitates switching.<sup>12</sup> Of course, dopamine is present even in neutral affect conditions, so we assume that the effect of positive mood is to alter existing activation patterns, rather than to initiate any new processing. The model in Figure 2 is greatly oversimplified. In practice, positive affect has also been found to allow more flexible consideration of complex bodies of material, such as goals (e.g., Carnevale & Isen, 1986), and component sets of relevant problem-solving material (e.g., Estrada et al., 1997). In such cases, a much more elaborate conceptualization would be needed.

Neuroimaging data support a general model of this type. For example, Frith, Friston, Liddle, and Frackowiak (1991a) used positron emission tomography scanning to examine cortical activity in normal adults during word fluency and lexical-decision tasks, as well as a number of control tasks. Relative to the control tasks, they found increased activation in the anterior cingulate and the (dorsal lateral) prefrontal cortex in the semantic tasks and either increased or decreased activation in the temporal language areas, depending on the type of semantic task. On the basis of these results, Friston, Frith, Liddle, and Frackowiak (1991) postulated that in semantic tasks involving selection or generation, the prefrontal cortex modulates activity in the temporal language areas through (glutamatergic) cortico-cortical projections. Frith, Friston, Liddle, and Frackowiak (1991b) generalized this hypothesis to nonsemantic tasks. Specifically, they proposed that in many tasks requiring "willed action," the prefrontal cortex modulates activity in remote, but task-relevant, cortical areas.

One way to test a neuropsychological theory is to evaluate the ability of a mathematical model derived from that theory to account for behavioral data. Unfortunately, to derive quantitative predictions from the model in Figure 2, many more assumptions must be made. Following this approach, Ashby, Turken, and Isen (1996) developed a formal connectionist network based on the model in Figure 2. Standard pharmacological techniques were used to derive the theoretical effects of dopamine on the activation

function of units in the portion of the network that corresponds to the anterior cingulate.<sup>13</sup> The network successfully accounted for the effects of amphetamines on two-choice guessing data (Ridley, Baker, Frith, Dowdy, & Crow, 1988; i.e., amphetamines increased the number of alternation responses), and it accounted for the effects of positive feelings on the three creative problem-solving tasks discussed above (Duncker's [1945] candle task, word association, and the Remote Associates Test). Despite these successes, Ashby et al.'s modeling approach is limited because the data on the effects of feelings on cognition do not sufficiently constrain the model. When the creative problem-solving data discussed in this section were collected, there were no theories that made specific quantitative predictions about how positive affect would influence performance on these tasks. Instead, the major interest was on whether there would be effects. It is possible that a number of different models could account for the word-association, remote-associates, and candle task data just as well as the network tested by Ashby et al. Thus, the success of the tested model should be considered more a demonstration of the potential of the dopaminergic theory of positive affect rather than a rigorous test of that theory. Also, because there now is a theory that makes rigorous predictions, future experiments can collect and report data in such a way that allows more rigorous testing.

Another creative problem-solving task in which positive affect might influence performance is word fluency. In this task, participants are asked to produce, within some time limit, as many words as possible that begin (or end) with some specified letter. This task seems closely related to word association, so it is natural to ask whether word fluency is also influenced by affect. There is evidence that word fluency is affected by brain dopamine levels. First, administration of haloperidol, a powerful dopamine antagonist, impairs performance on word fluency tests (Berger et al., 1989), and second, patients with Parkinson's disease are impaired in word fluency compared with age-matched controls (Stuss et al., 1983; Wallesch, Kornhuber, Köllner, Haas, & Hufnagel, 1983). For these reasons, positive affect might improve word fluency, with the improvement largely coming from enhanced flexibility in the selection of cognitive perspective. More specifically, we predicted that positive affect might lead not only to increased word produc-

<sup>12</sup> This model is computationally similar to a model of cognitive processing in individuals with schizophrenia that was proposed by Cohen and Servan-Schreiber (1992). Both models assume that alternative cognitive sets are represented in the prefrontal cortex and that these sets are used to support task-relevant representations in more posterior systems. Both models also assume that dopamine makes it easier to overcome dominant response tendencies. The main difference is that in Cohen and Servan-Schreiber's model, the prefrontal cortex representations are assumed to have equal strength, and selection and switching are performed by posterior components (and Cohen and Servan-Schreiber did not link dopamine release to positive affect).

<sup>13</sup> This model assumed that dopamine, acting through the D<sub>1</sub> receptor, modulates the effects of glutamate. Specifically, it was assumed that dopamine increases the efficacy of glutamate by prolonging the action of the Ca<sup>2+</sup> second messenger that is activated when glutamate binds to the N-methyl-D-aspartate (NMDA) receptor (Hemmings, Walaas, Ouimet, & Greengard, 1987; Pessin et al., 1994; Wickens, 1990, 1993) and that dopamine decreases the affinity of glutamate for non-NMDA receptors (Cepeda, Radisavljevic, Peacock, Levine, & Buchwald, 1992).

tion but also to more words coming from different categories or word types. For example, when producing words that begin with the letter *c*, a person might initially focus on nouns (or some subset of nouns, such as words of a certain category or from a certain context). When the response rate decreases, an effective strategy is to shift attention to some other word group or context (e.g., verbs or nouns in another category). Such shifting should be enhanced by positive affect. Some preliminary data support this prediction. In particular, Greene and Noice (1988) reported that positive affect increased word fluency in adolescents (eighth graders).<sup>14</sup>

In this section, we postulated that, because of increased dopamine release in the anterior cingulate and possibly the striatum, positive affect is likely to facilitate cognitive set switching and selection, and we argued that such facilitation might underlie the well-documented improvements in creative problem solving that occur with positive affect. However, improvements in cognitive set switching and selection could facilitate performance on a wide variety of tasks, besides those traditionally associated with creative problem solving. For example, earlier we presented evidence that success on the Wisconsin Card Sorting Test and on Owen et al.'s (1993) selection task (condition *AB* followed by condition *BC*; see Table 1) is facilitated by flexibility in cognitive set switching and selection. As a consequence, positive affect might improve performance on both of these classification tasks. The predictions for the perseveration task (condition *AB* followed by condition *CA*; see Table 1) are less clear. There is evidence that increased dopamine in the striatum should facilitate performance on this task (Roberts et al., 1994), and as discussed above, behavioral evidence suggests that positive affect is associated with increased dopamine in the striatum (e.g., because of the increased motor activity that occurs under positive affect conditions). Thus, the theory developed in this article predicts that both selection and switching could be facilitated. However, Roberts et al. found that lesioning the dopamine fibers that project into the prefrontal cortex (i.e., from the VTA) increased striatal dopamine levels. We assumed that positive affect increases dopamine levels in the prefrontal cortex, so one might infer from Roberts et al.'s results that positive affect could lead to decreases in striatal dopamine levels. Unfortunately, there is not much data in the current literature that addresses this question. Most tasks that putatively study cognitive switching actually require facility in switching and selection. As such, evidence that positive affect facilitates performance on these tasks does not allow us to determine where the facilitation is in switching alone, selection alone, or both processes. Further research on this question is needed.

A recent neuropsychological theory of category learning suggests that the influence of positive affect on classification might extend considerably beyond the Wisconsin Card Sorting Test. Ashby et al. (1998) proposed that category learning is a competition between separate explicit (i.e., hypothesis or theory testing) and implicit (i.e., procedural learning) categorization systems. Explicit categorization rules were defined operationally as those rules that are easy to describe verbally. The resulting model was called COMpetition between Verbal and Implicit Systems (COVIS). Each system in COVIS is mediated by separate cortical–striatal–pallidal–thalamic loops. The anterior cingulate is assumed to select the type of explicit rule to be used on the coming trial, so COVIS assigns essentially the same functions to the anterior cingulate as we propose in this article. Together, the dopaminergic

theory of positive affect and COVIS predict that positive affect might facilitate learning in any categorization task in which performance is maximized by an explicit rule (e.g., one that is easily verbalized).<sup>15</sup> The facilitation is predicted because the anterior cingulate should be more adept at selecting the correct explicit rule type under positive affect conditions. By this logic, positive affect might improve performance on the Wisconsin Card Sorting Test because all of the classification rules that succeed in this task are explicit (e.g., they all are easily verbalized because category membership is determined by the number of geometric symbols on a card, by the shape of the symbols, or by the color of the symbols). COVIS is helpful, however, in identifying the verbalizability of the correct classification rule as the key feature of the task that renders it susceptible to manipulations of affect. In particular, COVIS predicts that many other surface features of the Wisconsin Card Sorting Test are of relatively little importance to the affect predictions. These include the nature of the stimuli used, whether the stimulus dimensions are continuous- or discrete-valued, whether participants are shown specific category exemplars, and whether the task requires participants to learn a single rule or a series of different rules.

In addition to the tasks discussed in this section, there are many other tasks that seem to involve cognitive or perceptual set switching. It is natural to ask whether positive affect might influence performance on all such tasks. Although it is tempting to adopt a strong position with respect to this question, there are a number of reasons to be cautious. For example, dopamine antagonists impair the ability to see alternative interpretations of ambiguous (i.e., reversible) figures (Harris & Phillipson, 1981; Phillipson & Harris, 1984), so one might hastily conclude that positive affect would improve this spontaneous ability. However, positive affect might not produce this result, because the rather tedious reversible-figures task could destroy the participant's positive affect or lead the participant to prefer engaging in other tasks or thought processes available at the time. Accumulating evidence shows that this would not be likely if the task were presented as being important (e.g., Bodenhausen, Kramer, & Susser, 1994), but it could be a factor if the task is tedious or aversive and is not

<sup>14</sup> In a related study, Baker, Frith, and Dolan (1997) had normal adults perform the verbal fluency task under neutral, negative, and positive affect conditions while undergoing positron emission tomography scanning. No behavioral data were reported, so our main prediction was not tested in their study. However, overall, the verbal fluency task was associated with greater anterior cingulate activation than a control task in both the neutral and positive affect conditions. In the negative affect condition, anterior cingulate activation was attenuated during verbal fluency. In contrast, anterior cingulate activation during verbal fluency was not greater in the positive affect condition than in the neutral condition. Baker et al. required participants to produce only one word every 5 s, so it is possible that this latter null result was due to a ceiling effect.

<sup>15</sup> This is not to say that we predicted no effect in tasks in which the optimal rule is not explicit (i.e., not easily verbalized). According to COVIS, the striatum is a critical structure in such implicit tasks (although the anterior cingulate is not). Because there is a prominent dopamine projection from the substantia nigra into the striatum (see Figure 1), which is thought to facilitate learning (Ashby et al., 1998), there is a possibility that positive affect might also improve performance in implicit category-learning tasks.



perceived as being important or necessary. Staring at the same figure for an extended time might be considered tedious by many people, and if the task is not perceived as being important, then an influence of positive affect might not be apparent.

Finally, it is important to note that some predictions might fail because performance on the task might not steadily improve with increasing dopamine levels. For example, some of the predictions derived in this article are based solely on data showing that performance is impaired when brain dopamine levels are decreased (either because of administration of dopamine antagonists or because of some neurological disorder). It is not necessarily the case that such results imply that increases in dopamine, above normal levels, will enhance performance on this same task. The relation between dopamine level and performance may be an inverted U, so that either increases or decreases in dopamine from some optimal level impair performance (as predicted, e.g., by Lidow et al., 1998). Another possibility is that even if the neutral affect control group performs well below ceiling, increasing dopamine levels above this normal level may have no more effect on performance.

### Other Tasks Influenced by Positive Affect

The theory developed in this article provides an account of the influence of positive affect on creative problem-solving tasks; it predicts potential effects of positive feelings on many cognitive tasks that have not been investigated in the affect literature; and equally important, it specifies some types of tasks in which performance should be unaffected by an elevation in mood (e.g., visual and auditory perception tasks). Even so, positive affect has been found to influence many tasks that we have not yet discussed. These include decision-making and risk-preference tasks (e.g., Carnevale & Isen, 1986; Isen & Means, 1983; Isen et al., 1988, 1991) and some tasks related to social situations, such as stereotyping of members of groups (Bodenhausen et al., 1994) and reactions to persuasive communications (e.g., Bless, Bohner, Schwarz, & Strack, 1990; Mackie & Worth, 1989; Petty, Schumann, Richman, & Strathman, 1993; Smith & Shaffer, 1991). In addition, positive affect is sometimes assumed to lead to a global or nonsystematic style of processing, or to foster the use of "heuristics," in contrast to effortful or systematic processing. In most cases, evidence presented in support of this latter idea came from studies that used certain specific kinds of materials or tasks. More recent findings suggest, in contrast, that when the task is at least either minimally interesting or important, positive affect promotes careful, thorough, open-minded, and systematic processing (e.g., Aspinwall, 1998; Bodenhausen et al., 1994; Estrada et al., 1997; Isen et al., 1991; Mano, 1997; Martin, Ward, Achee, & Wyer, 1993; see also Isen, 1993, 1999, for discussions of this issue).

Although the increased dopamine release that we postulated to co-occur with positive affect may contribute to some of these effects, in general, these phenomena seem more complex than the tasks considered earlier in this article. In particular, many of these tasks involve complex strategies and goals. For example, in the attitude-change paradigms, many goals besides pure processing of the persuasive message may be in operation. In particular, a desire to be accommodating or to go along with the attitude-change attempt may play a role in the findings obtained in those studies,

especially because positive affect is known to promote sociability and helpfulness, among its other effects (see Isen, 1993, for further discussion). As another example, in risk-taking paradigms, positive affect is associated with greater expectation of positive outcomes (E. Johnson & Tversky, 1983). However, in the same context, positive affect is associated with greater disutility of negative outcomes (Isen et al., 1988). Typically, the result of these opposing effects is that people who are feeling happy are less likely to take a real, meaningful risk than are neutral affect controls (Isen & Geva, 1987; Isen & Simmonds, 1978). For the present purposes, however, the important point is that multiple processes and effects are in operation. Therefore, although brain dopamine levels should be increased in these studies, their effects may not be apparent in these tasks, or if other affective states are induced inadvertently along with positive affect (e.g., Mano, 1997), then dopamine may contribute to these effects along with other neurotransmitters and neurological pathways. As such, although the dopaminergic theory of positive affect may provide an alternative way to conceptualize these complex situations, and may eventually help to address an even broader range of findings, at present these tasks are beyond the scope of this article.

### Neuropsychological Implications

The dopaminergic theory of positive affect has a number of practical implications that may be quite important for several neuropsychological patient populations. First, the theory proposed in this article might be used to improve the understanding of some of the cognitive changes that occur with natural aging. During the course of normal aging, dopamine levels in the human brain decrease by 7% or 8% during each decade of life (e.g., Gabrieli, 1995; van Domburg & ten Donkelaar, 1991). As a consequence, the dopaminergic theory of positive affect suggests that a natural question to ask is whether cognitive flexibility and creative problem-solving ability also decrease with age. We are not aware of any studies that specifically have examined the effects of age on performance in word association, the Remote Associates Test, or Duncker's (1945) candle task. Even so, it is generally assumed that people become less flexible and more rigid and set in their ways as they age, and a large literature exists purporting to show that cognitive flexibility does decrease during normal aging (e.g., Collins & Tellier, 1994; Stankov, 1988). It is important to note, however, that life experience and experience with solving frequently encountered problems may often compensate for losses in problem-solving ability caused by natural aging, especially on common tasks. Nevertheless, the theory proposed here appears to be consistent with the available data on the effects of aging on mental flexibility and creative problem solving.

Second, the theory predicts that events and conditions that induce positive affect elevate brain dopamine levels. Therefore, any pathological condition that is associated with reductions in brain dopamine levels might be relieved temporarily by positive affect. For example, in Parkinson's disease, there is reduced dopamine production in the substantia nigra and, to a lesser extent, in the VTA. The most widely known and obvious symptom of Parkinson's disease is motor dysfunction (akinesia and bradykinesia), but as discussed throughout this article, there are also well-documented cognitive deficits. Treatment with L-dopa, a dopamine precursor, alleviates the motor problems (one cannot be treated

with dopamine itself because it does not cross the blood–brain barrier). However, long-term treatment with L-dopa is problematic (e.g., Strange, 1992). An intriguing and potentially very exciting prediction of the theory described in this article is that positive affect might stimulate increased production or release of dopamine, which might contribute to alleviating (temporarily) some of the motor and cognitive dysfunction that characterizes Parkinson's disease. Of course, this requires that the disease is not so progressed that the induction of positive affect is impossible and that the amount of dopamine released during positive affect is not negligible.<sup>16</sup>

Third, the dopaminergic theory of positive affect sharpens the available predictions as to the cognitive effects that might be expected from administering dopamine antagonists. This is important because dopamine antagonists are routinely prescribed for a variety of pathological conditions. The principal known benefit of these drugs is that they reduce hallucinations and other symptoms of psychosis, which is why they are classified as antipsychotics and why they are routinely prescribed as treatment for schizophrenia and senile dementia. As mentioned above, a well-known side effect of antipsychotic medication is flattened affect. The theory proposed here suggests that pronounced cognitive deficits also might occur. In particular, patients taking dopamine antagonists might have reduced olfactory acuity, impaired working memory, reduced cognitive flexibility, and impaired creative problem-solving ability. In some cases, however, reduced cognitive flexibility actually might be an advantage. A good example occurs with (positive) schizophrenia, because a hallmark of this disorder is loose associations, or an inability to maintain set. In many cases, however, dopamine antagonists are routinely prescribed to patients lacking such symptoms (e.g., patients with Alzheimer's disease). It is important that physicians are aware of the cognitive and affective costs of dopamine antagonist therapy when they are considering alternative treatments.

### Conclusion

In this article, we discussed many studies showing that positive affect systematically influences performance on a variety of cognitive tasks. In almost all of these studies, participants were assigned randomly to either a neutral affect control condition or a positive affect condition, and positive affect was induced by using mild and innocuous methods (e.g., by giving a small unanticipated gift; by reporting success on an ambiguous task; or by using mild, nonsexual and nonaggressive humor). Control conditions for arousal, surprise, negative affect, social contact, and a host of other variables were included in many of these studies. Thus, there is a substantial literature showing that mild positive affect, of the sort that people can experience every day, systematically affects cognitive processing.

The dopaminergic theory of positive affect that was proposed and developed in this article assumes that during periods of mild positive affect, there is a concomitant increased dopamine release in the mesocorticolimbic system and perhaps also in the nigrostriatal system. The theory further assumes that the resulting elevated dopamine levels influence performance on a variety of cognitive tasks (e.g., olfactory, episodic memory, working memory, and creative problem solving). It should be stressed, however, that we did not assume that positive affect simply turns dopamine on or

off. Instead, we assumed moderate levels of dopamine are present even under neutral affect conditions. The induction of mild positive affect is assumed to increase only slightly these normal dopamine levels. Similarly, although this article discusses the effects of several drugs and pathological conditions that affect brain dopamine levels and influence cognitive processes in ways compatible with the dopaminergic theory of positive affect, it is important to note that the fluctuations in dopamine associated with these conditions are more extreme than we anticipated for positive affect. Therefore, the pathological conditions discussed in this article should not be interpreted as models for positive affect. We do not suggest that positive affect is equivalent to any pathological or drugged state. The data that show facilitating effects of positive affect on problem solving, improved social interaction, and a host of other tasks argue convincingly on this point.

Posing a neurological mechanism or mediator of processes like creativity, problem solving, and emotional reaction may seem, at first, to suggest that the behavioral, or even experiential or cognitive, level of analysis is unnecessary for understanding these processes. To the contrary, we believe that even if a solid understanding of the neurological mechanisms that mediate positive affect were available, research at the behavioral and experiential levels is still needed to fully understand the form and function of positive affect systems. For example, for a complete theory of positive affect, it is necessary to understand why certain things make people happy, even if it were known that dopamine is released when people are happy, and why dopamine release has the particular consequences it does on cognition. Moreover, purposive and constructive processes in the generation and influence of affect still can play a role in the effects observed. In other words, finding a neurological mechanism associated with affective processes does not rule out the important role that thinking and planning play in these same processes. The many studies reporting effects of variables such as task importance support this conclusion.

Furthermore, it is sometimes assumed that finding a neurological mechanism for such processes means that the processes are genetically based or innate. This is not necessarily the case. Learning is known to alter brain functioning. Moreover, even if some aspects of affective functioning turn out to be genetically based, this would not diminish the importance of experience, learning, and life events in determining the specific effects and processes associated with affect. The data from dozens of studies on the impact of induced affect attest to this point.

Throughout the course of this article, we made many assumptions. In some cases, these assumptions were based on a substantial body of supporting evidence, but a number of assumptions must be considered speculative. As a consequence, at least some details of the theory proposed here are surely wrong. Nevertheless, we believe that the dopaminergic theory of positive affect makes a substantial contribution. First, it provides the first description of the neuropsychological mechanisms that underlie the influence of positive affect on cognition. Second, it provides bridges between a

<sup>16</sup> Another group that might benefit temporarily from positive affect is substance abusers, especially long-term users of heroin or cocaine. This prediction follows because prolonged exposure to these drugs is thought to cause downregulation of dopamine receptors (e.g., Feldman et al., 1997) and cognitive inflexibility (e.g., Beck, Wright, Newman, & Liese, 1993).

number of huge and disparate literatures, including the social psychological literature on positive affect, the cognitive literature on creative problem solving, the emotions literature, the neuroscience literature on reward, and the literature on a variety of neuropsychological patient groups. Third, the theory presented here predicts influences of positive affect on many tasks that previously have not been investigated in the positive affect literature. Fourth, the theory encourages several lines of new research, which we believe can further increase understanding of positive affect and its influence on cognition. This last contribution is the most important that the theory can make, and we hope it will serve this function.

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