HAPPINESS HELPS, BUT HOW?

DOES INTERHEMISPHERIC COMMUNICATION MEDIATE THE IMPACT OF POSITIVE AFFECT ON COGNITIVE FLEXIBILITY?

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ABSTRACT

Numerous studies have demonstrated that positive affect has beneficial effects on cognition, mainly due to more efficient and flexible processing of information. Yet, the neural mechanism of these effects has not been thoroughly investigated. We compared the performance of subjects on tasks of cognitive flexibility and interhemispheric communication based on a manipulation of either positive or neutral affect. However, the predicted main effect of affect condition was not observed. Multiple regression analysis indicated that, instead of interhemispheric communication mediating the influence of positive affect, positive affect and interhemispheric communication made independent contributions to increasing cognitive flexibility. The implications of these findings are discussed in terms of existing research.

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INTRODUCTION

Converging evidence indicates that positive affect boosts cognitive flexibility, and that this increase may be mediated by heightened interhemispheric communication. Research has linked each of these three areas to one another, but to our knowledge, no attempt has been made to unite all three. The following review of the literature is intended to present to the reader some of the relevant findings and their theoretical implications, as well as to introduce the current research.

A. **Positive affect**

Happiness helps. That is the basic finding of research on positive emotion, whether its effect is on the perception of emotionally valenced stimuli (e.g., Compton *et al*., 2003) or the emotional state of research participants (e.g. Isen *et al*., 1985; Murray, Sujan, Hirt, and Sujan, 1990, Staw *et al*., 1994). Researchers have observed that positive affect improves subjects' performance on both laboratory and naturalistic assessments. A positive affect state induced in subjects by Isen *et al*. (1985) was found to increase the number of unusual first associations to neutral words. Estrada *et al*. (1997) revealed that inducing positive affect in physicians caused them to diagnose disease more efficiently. Other studies have found that a positive affective state fosters the recall of positive words or situations from memory (e.g. Isen, Shalker, Clark, and Karp, 1978), and benefits the assessment of risk (e.g., Johnson and Tversky, 1983). People in a positive mood state also think more flexibly, as evidenced by their greater inclusiveness when making category membership judgments (Isen and Daubman, 1984).

Research into positive affect is just as old as research into negative affect. Until recently, however, positive affect was not the focus of emotion research. A shift toward examining positive emotion in particular arose for two reasons. First, it was only lately appreciated that, in contrast to the predisposition to mental illness associated with negative attitudes, positive attitudes can exert a protective influence and actually promote mental health. Early research had failed to identify this phenomenon because the field was dominated by the idea that rational thought is healthy and proper, while emotion is always detrimental. Eventually, psychologists recognized that positive emotion might not be that harmful, and now a growing body of research is exploring how positive affect in fact influences mental health (e.g., Fredrickson and Levenson, 1998; Isen, 2000; Izard, 1977; Lewis, 1993; Ryan and Deci, 2000; Tomkins, 1962; all cited in Izard, 2002).

Also driving this shift is the recent growth and popularity of positive psychology, a field dedicated to helping all people, not just people with mental illnesses, improve and enjoy their lives (e.g., Seligman, 2002). Wide publicity, relative to other psychological research, has therefore been given to studies of positive emotion as well as to studies of stress, coping styles, Eastern spiritual practices, and other methods of increasing one's daily satisfaction. For example, Nezlek and Plesko (2003) found that subjects with higher trait positive affect were more strongly buffered against the effects of negative day-to-day events. Stress has been linked to immunosuppression (Cohen *et al*., 1998), and at least one article (Franzini, 2001) has reported that laughter can improve clinical outcomes.

Apart from this historical shift, students of emotion investigate positive affect simply to further our understanding of the mind and the brain. More specifically, research on positive emotion expands our knowledge of the neural mechanisms of emotion and their influence on other neurocognitive pathways. Indeed, part of the effect of positive emotion may be based on neural pathways originating in the brainstem that connect to regions involving memory, smell, and attention (Ashby, Isen, and Turken, 1999).

As we mentioned in the beginning of this section, many studies have demonstrated that positive affect influences certain cognitive abilities, such as memory or problem solving (Isen, Shalker, Clark, and Karp, 1978; Isen and Means, 1983; Isen and Daubman, 1984). This influence is known to be distinct from that of negative affect or physiological arousal (e.g., Isen, Daubman, and Nowicki, 1987). But, where does positive emotion come from?

In general, emotion involves many brain regions, both cortical and sub-cortical. Although it is beyond the scope of this paper to discuss the distinct functions of all of the structures involved, a few will be listed here (see Banich, 2004 for such an analysis). Among sub-cortical structures, the amygdala has long been recognized as an emotional center (e.g., Papez, 1937). The cingulate cortex is another area that has been implicated in emotion, and may link some emotional and cognitive processes (Banich, 2004). The cortical regions most important to emotion are the parietal lobe, especially in the right hemisphere, and the prefrontal cortex.

Positive affect in particular may be related to the dopaminergic reward circuits of the brain (Ashby, Isen, and Turken, 1999). These circuits were thoroughly investigated after it was recognized that reward was a key element in behavior conditioning, itself a major focus of American psychology during the 20th century. Also, feelings of positive affect (although not necessarily its perception or expression) are associated with the left hemisphere of the brain, as reported in some studies of brain damaged patients (Gainotti, 1972; cited in Banich, 2004). Other research, though, has implicated the right hemisphere as having the dominant role in emotion overall (see Borod, 1992 for a comparison). While there is strong evidence supporting this view, for our purposes it will suffice to say that in all probability, no emotion is limited to a particular hemisphere.

Before continuing on, the precise meaning of positive emotion should be considered. Often, researchers of positive emotion use the adjective positive as an all-purpose label. However, it is important to note that (for largely practical reasons) most studies of positive emotion specifically examine mild happiness, and exclude hope, elation, love, or other positive emotions. Happiness, rather than other positive emotions, is the most commonly studied positive emotion because it is itself common. In studies of state emotion, it is fairly simple and inexpensive to induce mild happiness or amusement. In contrast, complex positive emotions and the situations that produce them are more difficult to study. And, in research using emotionally valenced human faces, happiness is the only positive emotion that can be effectively studied because it is the only universally recognized expression of positive emotion (Ekman and Friesen, 1971; Ekman *et al.*, 1987). It is encouraging, therefore, to learn that inductions of such a mild positive state have produced significant effects on cognition, both quantitative and qualitative. In this paper, we will continue to view positive affect as a mild level of pleasure that can be elicited in day-to-day situations.

To summarize briefly, then, positive affect is influential in many aspects of cognition. The focus of some researchers has shifted toward positive affect because of a desire to explore factors that are helpful, rather than detrimental, to mental health, as well as to understand better the neural foundations of emotion. In fact, many areas of the brain are known to be involved in emotion, however, positive affect itself is less well understood. Importantly, the reader should be aware that the term positive affect is understood here to denote a mildly pleasant feeling, inducible in common situations and through simple manipulations.

B. **Interhemispheric communication**

In neurologically intact individuals, the two hemispheres of the brain are highly interconnected. Most of the information communicated between the hemispheres travels via the corpus callosum, a midline structure composed of over 200 million nerve fibers. Other information is conveyed by different cortical connections, such as the anterior commissure, or along sub-cortical pathways. Certain types of information, however, can be transferred only through the corpus callosum. For instance, identifying whether two number digits are physically identical is impossible for patients with a severed corpus callosum, but those same people can still determine that the numbers have the same value (Sergent, 1990; cited in Banich, 2003). Thus, logic dictates that the value comparison is carried out through a non-callosal conduit. Other studies have shown that the hemispheres can use sub-cortical pathways to communicate dichotomous information, as well as some emotional and auditory information (see Gazzaniga, 2000, for a review of commissure transfer).

Exploring interhemispheric communication is critical to developing our understanding of the brain. Research on patients with severed interhemispheric connections (often broadly referred to as split-brain patients) has illustrated that, although these individuals retain most cognitive and social abilities, interesting deficits, such as that presented in the previous paragraph, come to light. Researchers using other paradigms have shown that interhemispheric communication is often a more efficient means of processing than processing by either hemisphere alone; this is the case even for mildly complex tasks such as digit summation (Belger and Banich, 1998; see Banich and Brown, 2000 [cited in Banich, 2004] for a discussion of this topic). Furthermore, the existence of functional hemispheric asymmetry (discussed below) necessitates that complex mental abilities, such as maintaining social relationships or engaging in athletic activity, be understood as dependent upon efficient interhemispheric communication.

Conducting research on interhemispheric communication is greatly facilitated by the fact that sensory and motor information is normally transmitted in an almost exclusively contralateral fashion. That is, input from or output to the *left* side of the body is processed by the *right* hemisphere of the brain, and vice versa. In vision, for example, a stimulus briefly presented to the right of a central (foveal) fixation point is initially seen by both eyes, but by only the left hemisphere. Although both eyes do perceive the stimulus, only the nerves on the left half of each eye are excited (Figure 1: red lines).[1] That signal therefore travels only to the left (contralateral) hemisphere of the brain. The left hemisphere then rapidly shares its image of the stimulus with the right hemisphere, but only if that is necessary for the task at hand. Many researchers use the organization of this system to compare the time needed to perform a task when this sharing of

[1] http://www.clarkson.edu/~rcarlson/PY151Syllabus/Brain/

information both is and is not required. The difference between these two times, they infer, is the time needed for interhemispheric communication to occur. In this way, scientists are able to investigate a process that would otherwise be difficult to assess.

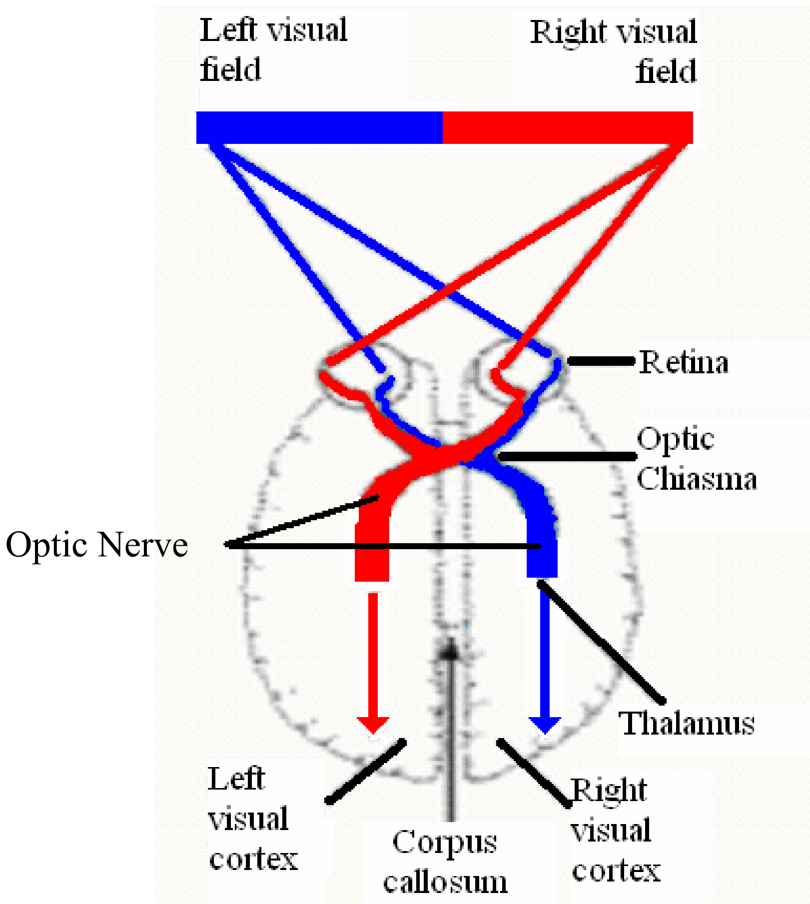


Figure 1. Organization of the brain's visual system.

Early research, especially that of Broca (1861/1960) and Wernicke (1874), strongly supported the theory that the two hemispheres of the brain are functionally distinct (Hellige, 1993). Gazzaniga demonstrated the asymmetry of speech output with visual inputs (1970; cited in Hellige, 1993). When he presented stimuli to the right visual field, and hence to the left hemisphere, subjects with a severed callosum were still able to name them. When stimuli were presented to the left visual field (right hemisphere), however, split-brain patients were tongue-tied. Working with Sperry, Gazzaniga also found that patients who had undergone a similar operation could draw a three-dimensional object on a piece of paper with the left hand, but not with the right (Gazzaniga *et al.*, 1965; cited in Gazzaniga, 2000). This implied that for visuospatial abilities, the right hemisphere is specialized and dominant over the left hemisphere.

Sperry's contribution (Sperry, Zaidel, and Zaidel, 1979; Myers and Sperry, 1985), in fact—working with split-brain patients to elegantly demonstrate the anatomical basis of functional asymmetry—won him the 1981 Nobel Prize in Physiology or Medicine. After their corpus callosum was surgically severed, the patients could verbally name an object if placed in the right hand, but were unable to perform this simple task if the object were placed in the left hand (Myers and Sperry, 1985). Because the left and right hands send sensory information to the contralateral hemispheres of the brain, Myers and Sperry inferred that the left hemisphere has the ability to speak, while the right hemisphere does not. Hence, a split-brain patient can name only an object placed in the right hand. (Interestingly, split-brain patients can say aloud certain attributes of an object placed in the left hand, such as its function, although a full discussion is not within the scope of the present paper.) A vast amount of research has since supported and extended these classic findings (see Hellige, 1993 or Hugdahl and Davidson, 2003, for an extensive review).

Somewhat surprisingly, investigators have also found evidence of hemispheric asymmetry with regard to emotion. Psychologists in the early twentieth century (e.g. Papez, 1937) had thought that emotion was entirely a function of the limbic system, a group of sub-cortical brain structures that includes the amygdala, the hippocampus, and the hypothalamus (Banich, 2004). But while the limbic system does play a role in emotion, an emerging body of evidence indicates that cortical areas in each hemisphere are also important in the expression and perception of emotion.

One of the earliest studies to find a hemispheric disparity in the expression of emotion was conducted by Gainotti (1972; cited in Banich, 2004). When Gainotti looked at individuals with frontal lobe damage in the left versus the right hemisphere, he found that their emotional responses differed. People with damage to the right frontal lobe seemed to give inappropriately positive responses and to be unconcerned with their disability. Those with damage to the left frontal lobe, in contrast, were "emotionally volatile and prone to sad moods and tearfulness" (Banich, 2004: 406). Research in the three decades since Gainotti's influential work has replicated this striking difference using partial brain anesthetization and electroencephalography, leading some to speculate that positive affect is generated by the left hemisphere, while negative affect is generated by the right.

Conflicting evidence was found, however, by researchers studying the perception of emotion. The results of investigations of prosody, facial expressions, and the interpretation of emotional situations seemed to suggest that the right hemisphere is dominant in emotion, regardless of valence. Recent models have focused on integrating these findings by calling attention to the fact that such studies were drawing on different facets of emotional processing (see Borod, 1992; Borod *et al.*, 1998, for a review; see Banich, 2004 for a summary of this debate). Borod (1992) has suggested that the right hemisphere is dominant in emotional perception and in the facial expression of emotion, whereas the two hemispheres may differ in their ability to respond emotionally.

Although much attention has been focused on the neural and hemispheric bases of emotion, few researchers have questioned how emotion (trait, state, or perceived) might itself affect communication between the hemispheres. Within the research that has been done, the most frequent concern has been perceived, rather than internal, emotion. In a series of studies, Compton and her colleagues (Compton, Wilson, and Wolf, 2003a; 2003b; Compton, Feigenson, and Widick, 2003) found differences in the processing of pictured facial expressions. Compton, Feigenson, and Widick (2003) analyzed the accuracy and reaction time of individuals who were asked to match an emotional or neutral stimulus face with one of two target faces. Matching faces appeared in the same visual field in half of the trials (within-field trials), and in opposite visual fields in the other half (across-field trials). This across-field (and hence, across-hemisphere) stimulus placement necessitated interhemispheric communication for a correct response to occur, but a lone hemisphere could generate the correct response for within-field (within-hemisphere) trials. This experiment replicated two prior findings: an advantage of processing by the right hemisphere over the left hemisphere with facial stimuli, and an advantage of interhemispheric communication over single hemisphere processing (as indicated by faster mean reaction times on across-hemisphere trials than on within-hemisphere trials). Additionally, Compton *et al*. (2003) found evidence that this across-hemisphere advantage was greater when subjects matched happy or angry faces compared to neutral faces. This led them to suggest that interhemispheric communication of perceived emotions may be either faster or more redundant than that of non-valenced information.

Using the same stimulus presentation, Compton, Wilson, and Wolf (2003a) looked at both perceived and trait emotion. They investigated whether the perception of emotional faces was impacted by participants' trait emotionality. They administered the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, and Borkovec, 1990) and divided participants into high- and low-worry groups. Their results indicated that the same advantage of interhemispheric processing existed for low-worry subjects, but was absent in those with high levels of worry. This finding was not mediated by emotionality of the face stimuli, meaning that high-worry participants did not process emotional stimuli more proficiently than non-emotional stimuli, nor did the specific emotional tone of the stimuli (happy versus angry) have a bearing on the efficiency of interhemispheric communication.

In a follow-up study, Compton, Wilson, and Wolf (2003b) looked again at the processing of emotional faces in high- and low-worry individuals, but additionally, they manipulated the degree of social evaluation. Half of the participants completed the face-matching task while an experimenter sat quietly in the room; the other half did so in solitude. There was no main effect of the evaluation variable, but an advantage for interhemispheric processing in the evaluation condition was obtained for angry faces. Compton and her colleagues concluded that the perceived evaluation raised the processing load required to match angry faces, thereby promoting interhemispheric communication because it is favored for complex tasks.

These three studies, as well as early research on interhemispheric communication, focused mainly on the effects of negative emotion. They provide an indication that the processing of emotional stimuli is facilitated compared to neutral stimuli, but that trait negative emotion interferes with the efficiency of interhemispheric communication. Neither trait nor state positive emotion, however, has received any attention in this regard. Given that trait negative emotion was detrimental to interhemispheric communication, a logical next step would be to investigate whether trait or state positive emotion bolster the efficiency of interhemispheric communication. Not surprisingly, this is precisely one of the questions that the present research attempted to examine.

In review, recall that lateralization of function was discovered through experiments on split-brain patients, taking advantage of the contralateral organization of the nervous system. Both hemispheres are likely to be involved in emotional processing, although the right hemisphere may exhibit dominance in some regards. While interhemispheric communication plays a role in emotion, so too does emotion influence interhemispheric communication. One of the benefits associated with more efficient interhemispheric communication, in fact, is increased cognitive flexibility, which is discussed below.

C. **Cognitive flexibility**

Cognitive flexibility is an all-purpose ability that, as one might imagine, plays a role in many realms, such as social interaction (e.g., tolerance and group theory; Dovidio *et al.*, 1995; cited in Ashby *et al.*, 1999), consumer behavior (Isen and Means, 1983), and creativity (e.g., novel contrasts or comparisons). Isen has characterized cognitive flexibility as “creative problem solving, remote associations, and integration of diverse material” (75, Stein and Leventhal, 1990). Commenting on Isen’s work, Murray, Sujan, Hirt, and Sujan (1990) broadened the idea of cognitive flexibility to include “actively choosing cognitive strategies that fit individuals’ goals [and] intelligently adapting to one’s environment” (412). Here, we incorporate both propositions to define cognitive flexibility as the *capacity to make remote or novel associations and to adapt to one's situation*. This definition is meant to encompass the concepts of both flexible thinking and creativity, two terms that appear often in the literature on cognitive flexibility.

Popular sentiment holds that creative people are more "right-brained," or in other words, that the right hemisphere of a creative person's brain is dominant over the left. For many people this hypothesis makes sense because the right hemisphere is frequently understood to be the emotional center of the brain, and for thousands of years people have associated creativity and imagination with emotion, rather than with rational thought. That contrast, philosophically stated as a dichotomy between reason and passion, has misled many into interpreting research on emotion as an illustration that induced affect temporarily increases one's creativity simply due to an increase in emotional arousal. Even Sigmund Freud did not escape from the influence of that reason-versus-passion split: he theorized that primary emotional processes in childhood gave way to rational secondary processes as a person matured (D. Davis, personal communication, 2003).

However, research over the last decades has established that inducing emotion does not have a simple, or single, effect. Negative emotion is generally detrimental to cognition, as research on anxiety, stereotype threat, and depression has shown (e.g., Stoeber, 2000; Schmader and Johns, 2003; Beck *et al.*, 2001, respectively). Inductions of negative affect, in the form of worry, anxiety, stress, anger, or sadness, cause subjects in repeated experiments to perform more poorly on tests (e.g., Schmader and Johns, 2003), to consider fewer options, and to think more negatively (e.g., Bower, 1981).

Positive affect, in contrast, has been demonstrated through various lines of research to be associated with more creative, broader, and more efficient thinking (Isen, Daubman, and Nowicki, 1987; Isen and Daubman, 1984; Murray, Sujan, Hirt, and Sujan, 1990; Isen and Means, 1983). These effects are discussed below. As is evident, much of the research in this field has been carried out by Alice Isen, a pioneer in the investigation of positive affect.

Of primary importance, in a 1987 study Isen explicitly differentiated the effects of positive emotion from those of negative emotion and non-specific arousal (Isen, Daubman, and Nowicki, 1987: Experiment 2; see also Greene and Noice, 1988). Subjects in this experiment were assigned to one of five groups—two of positive affect, one of negative affect, one of simple exercise, and no manipulation—and presented with the so-called candle problem, developed by Duncker (1945). In the candle problem, subjects are provided with a candle, a box of tacks, and a book of matches, and asked to attach the candle to a wall so that the candle will not drip wax on the floor. The performance of subjects who exercised for two minutes at the beginning of the session did not differ statistically from that of subjects who received no manipulation. Those who watched a film designed to induce negative affect did not solve the candle task any more or less frequently than neutral film controls, either. The positive film clip, however, did exert an effect: a significantly greater proportion of those who viewed a comedy film clip, as compared to the neutral or negative affect clips, were able to arrive at a solution. Subjects who were given a small candy bar prior to beginning the task did not solve it more frequently than did controls; however, this manipulation has been shown to be effective in other experiments (Estrada, Isen, and Young, 1997; Isen and Daubman, 1984;

Isen, Johnson, Mertz, and Robinson, 1985, pilot data). As a whole, these results suggested to Isen that the observed facilitation of creativity was due to positive affect, and that the induced positive affect was not the same as general arousal.

That work strengthened and extended prior findings by Isen's group, that positive affect influences categorization as well as creativity. Showing that positive affect influences both creativity and categorization illustrates well the comprehensive effect that affect can have on cognition. To study categorization, Isen and Daubman (1984) read exemplars of a category to subjects that were highly, fairly, or only weakly prototypical. Participants in whom a positive affect had been induced by either candy or a comedy film rated low-typicality exemplars as category members to a greater extent than did participants who saw a negative or neutral film, or who received no manipulation. Isen and Daubman concluded from these results that subjects in a positive mood state had a broadened perspective and therefore were able to see both more, and more distant, connections between the category and the given exemplars. In a later study, Isen, Johnson, Mertz, and Robinson (1985) obtained comparable results with a word association task. In that experiment, subjects in the positive affect condition gave first associates that were more unusual than those put forward by control subjects. Isen and co-workers took these results to signify that cognitive organization becomes broader and more positive when positive affect is induced. More generally, they contended that cognitive processes become more flexible during a positive mood state.

Murray, Sujan, Hirt, and Sujan (1990) followed up on that research by investigating whether positive affect allows people to think more flexibly (both inclusively and exclusively) across all hierarchical boundaries, rather than simply being more inclusive as

Isen *et al*. (1985; 1987) had found. In a set of three experiments, subjects categorized television programs after positive or neutral affect was induced. In experiment 1, when asked to focus on differences, subjects in a positive mood state used a greater number of categories, compared to control subjects, but used fewer categories when focusing on similarities. The second experiment used a within-subjects design; in addition to the number of categories used, the types and the creativity of categorization were also assessed. Subjects' performance was similar to that in the first experiment, and they were also found to use more unusual and a greater variety of features in categorization. In the third experiment, Murray and colleagues found that these effects were true for TV shows having both positive and neutral content, and that intrinsic interest correlated highly with the creativity and the number of different types of categories that subjects generated. However, this correlation was significant only for subjects in the positive affect condition, meaning that interest could only be interpreted as a contingent mediator of cognitive flexibility. Murray *et al*. concluded that their research supports the results of Isen and other researchers, and suggested that the mediation by intrinsic interest may provide an explanation for previous conflicting findings.

The two studies discussed next went beyond basic research to examine the practical applications of increased cognitive flexibility. Isen and Means (1983) tested which of six hypothetical cars subjects would buy, based on ratings of nine relevant features for each car (e.g., fuel economy, repair record). Subjects in the positive and neutral affect conditions selected the same cars, but those in a positive affective state took less time to do so while considering fewer of the 9 dimensions and looking at fewer pieces of information repeatedly. Additionally, the dimensions not considered by positive affect subjects were those rated by all subjects as having greater importance. Isen and Means interpreted their results as demonstrating that subjects in a positive affective state processed information more quickly and efficiently than did control subjects.

A second study exploring the practical applications of this research was conducted by Estrada, Isen, and Young (1997), who looked at flexibility of thinking among physicians making a diagnosis. The affect manipulation used in this case was a small bag of candies, and two control conditions (reading "humanistic" statements, and no instructions) were included. Asked to make a diagnosis of a hypothetical patient case, internists who received candy both considered and decided on the correct diagnosis of liver hepatitis in less time than physicians in the control condition. The researchers observed that the cognitive technique of anchoring, defined in their paper as the "distortion or discounting of disconfirming evidence" (127), was significantly less evident in the positive affect group. Moreover, analysis of the physicians' tape-recorded thought processes showed that even after thinking of hepatitis as a possibility, those in the positive affect condition considered more alternative diagnoses, including ones that did not involve the liver, than did doctors in the two control conditions. The authors acknowledged that these results could not be attributed to positive affect with absolute certainty. Nevertheless, they argued that other studies of positive affect, some using the same manipulation and others showing similar effects, provide convergent validation of the affect manipulation used. For example, the results of this study replicated those of a previous study by Isen in which medical school students in a positive affective state correctly diagnosed lung cancer more often than did control participants (1991; cited in Estrada, Isen, and Young, 1997). Estrada *et al*. concluded, based these findings, that the thought process of those physicians was not simply quicker, as some critiques had suggested, but truly more efficient.

So far, this section has considered how positive affect has been found to benefit cognitive flexibility. This effect occurs both in terms of creativity and flexibility of thought. Investigations of positive affect and cognitive flexibility are strengthened by the fact that findings have been compatible across multiple affect inductions, such as candy or positive words, and across multiple dependent measures, including problem-solving, category inclusiveness, and word association. Next we present a theory of how such effects are made possible by the neurochemical pathways of the brain.

In a recent article, Ashby, Isen, and Turken (1999), proposed that the two main dopaminergic pathways of the brain mediate the influence of positive affect on cognitive flexibility. One dopaminergic system is the nigrostriatal pathway, which travels from the substantia nigra to the striatum. The other is the mesocorticolimbic pathway, in which the ventral tegmental area (VTA) of the brainstem connects to the limbic system and the cerebral cortex. This pathway is the brain's reward circuit; high and low dopamine levels in that circuit are respectively correlated with heightened and flattened affect. The neurons of the substantia nigra (SN) affect gross motor activity, which as Ashby *et al.* theorize, decreases in periods of negative affect (e.g., psychomotor retardation in depression) and increases during positive affect.

In support of this theory, Ashby, Isen, and Turken (1999) discuss the empirical evidence relating the areas that receive input from the VTA to cognitive flexibility (Figure 2, following page). The central thrust of this discussion is that the VTA projects to both the prefrontal cortex (PFC), which is generally considered to be important

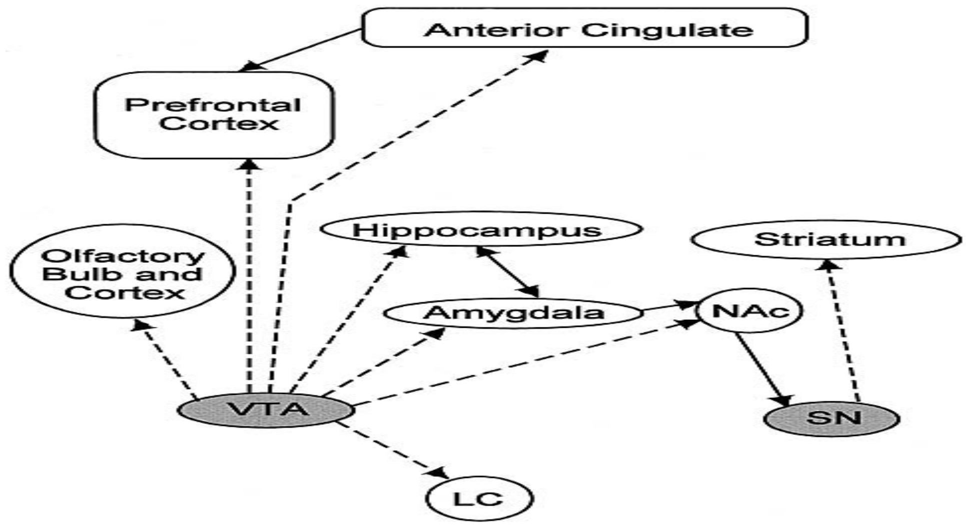


Figure 2. Dopamine projections (dashed lines) in the human brain. NAc = nucleus accumbens, VTA = ventral tegmental area, SN = substantia nigra, LC = locus coeruleus. Adapted from Ashby *et al.*, 1999.

for working memory, and the anterior cingulate cortex, one of the structures involved in executive function. A part of the anterior cingulate is also highly interconnected to the amygdala, a structure vital to emotional processing. The authors report that small increases in PFC dopamine levels seem to improve working memory, and since positive affect causes dopamine release, they surmise that inducing mild positive emotion may similarly facilitate working memory. A parallel explanation is offered for the argument that positive emotion can increase or facilitate control of executive function by the anterior cingulate cortex. Although executive function is a broad label inclusive of many important abilities, Ashby *et al*. highlight the role of the anterior cingulate in selecting among different cognitive perspectives. Facilitation of the anterior cingulate by positive affect would enable a person to perceive a wider variety of perspectives, an ability essential to the current conceptualization of cognitive flexibility. In support of this theory, Ashby and colleagues cite the research by Estrada *et al*. (1997) and Isen *et al*. (1987) described above. These observations, if borne out by further investigation, would go a long way toward explaining how simple manipulations of affect produce such important alterations in cognitive functioning.

The comprehensiveness of their theory seems, at first glance, to rule out any role for interhemispheric communication in cognitive flexibility such as we propose below. However, we offer the following argument against excluding interhemispheric communication from the mechanism of cognitive flexibility. We submit that some of the specific brain regions discussed by Ashby and his colleagues (the anterior cingulate cortex, the prefrontal cortex, the amygdala, and the hippocampus) are bilateral structures, and therefore have projections across the hemispheres, either via the corpus callosum or another commissure (Figure 3A and B).

Figure 3A. Interhemispheric connections of the human brain. Adapted from www.driesen.com/hemispheres_commissures.htm.

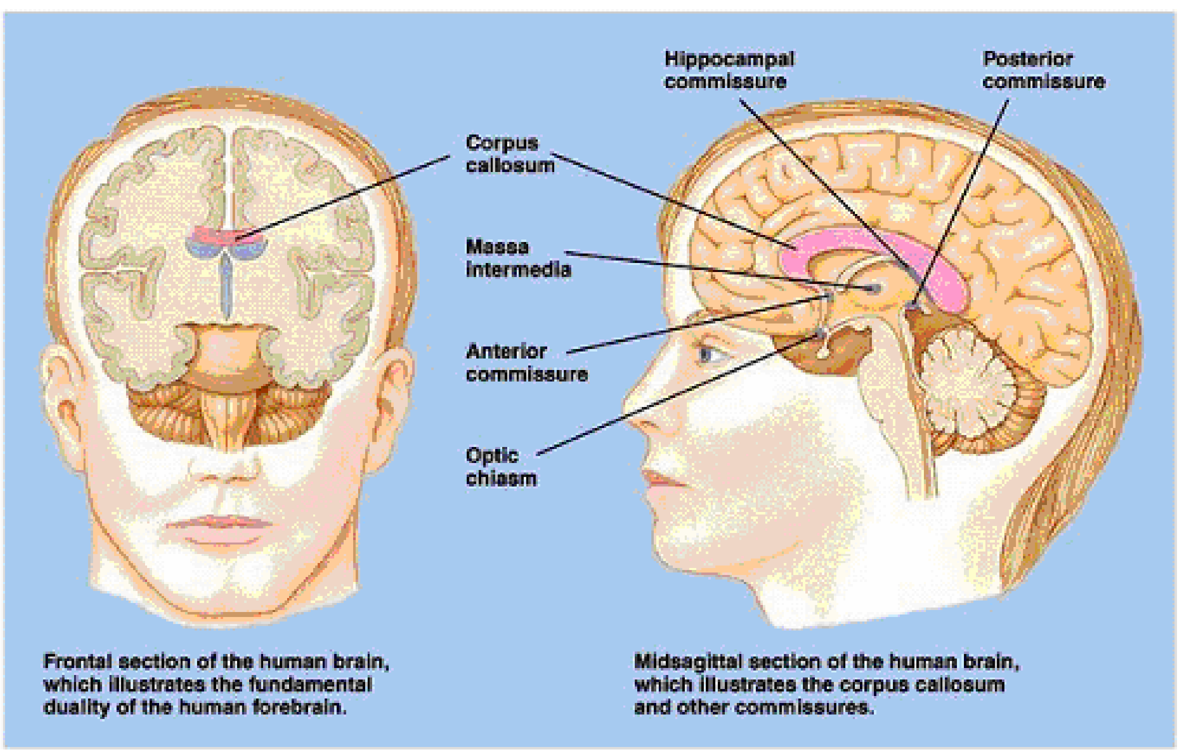
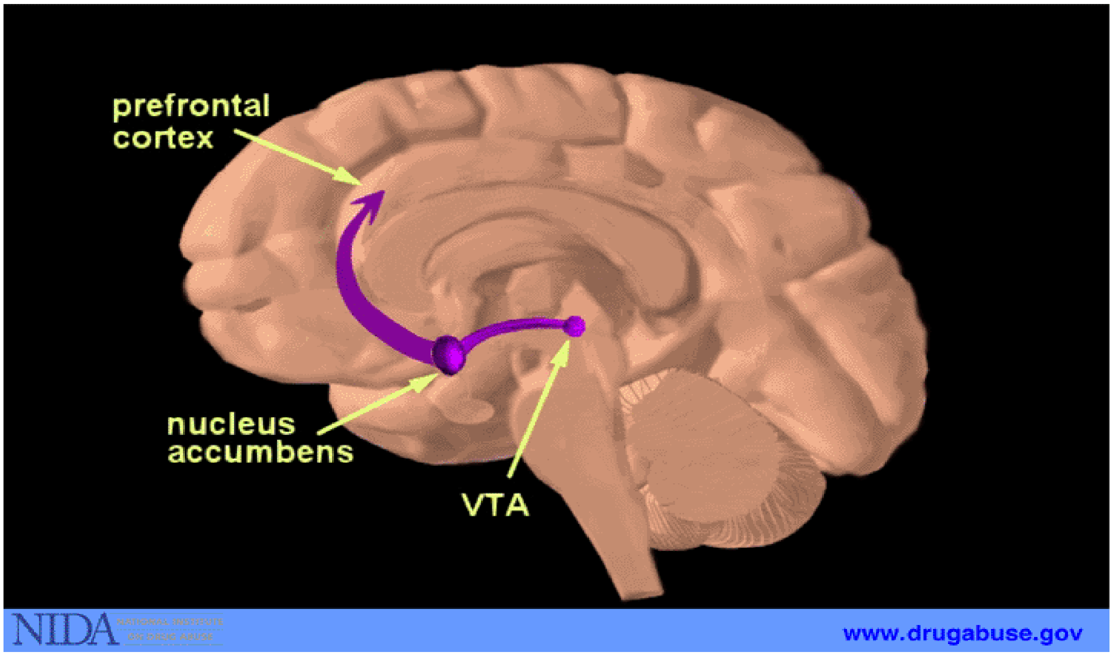


Figure 3B. The mesocortical pathway, one of the main dopaminergic systems of the brain, is involved in working memory and executive functions.



In fact, the callosum contains homotopic connections (connections between the same areas on opposite sides of the brain) to a majority of the cerebral cortex, including the left and right prefrontal cortices (Zaidel and Iacoboni, 2003). That connection is of particular importance to the theory of Ashby and his co-authors because the projections from the VTA to the prefrontal cortex link positive affect directly with cognition. Other commissures—the hippocampal, anterior, and habenular—join brain regions near the VTA and the SN (Zaidel and Iacoboni, 2003). Thus, since the dopaminergic pathways in general do project across the hemispheres, an increase in the efficiency of interhemispheric communication associated with increased cognitive flexibility would reflect activity as much along interhemispheric circuits as in the terminal structures of the pathway themselves.

We began this section by mentioning that a philosophical dichotomy between reason and passion led some people to believe that creativity is the sole province of emotion rather than rational thought. Yet, the evidence presented in this section has shown that positive emotion was beneficial to cognitive flexibility in the forms of both creativity and "rational" decision-making. The theory of Ashby *et al*. (1999) demonstrates that the same neural pathway may mediate both of these effects of positive emotion. In the next section, therefore, we investigate the possibility that cognitive flexibility does not arise from emotion alone, nor from reason alone, but from the interaction of the two.

D. **Linking interhemispheric communication and cognitive flexibility**

Does cognitive flexibility rely upon interhemispheric communication? In attempting to answer this question, we must first inquire whether the anatomy of the brain allows such a hypothesis. The answer, lest the previous pages be written in vain, is that it does. This was suggested as early as the 1960s, by Bogen and Bogen (1969), who investigated the effects of severing interhemispheric connections in cats, monkeys, and humans. Despite decades of research on changes in cognition after callosal section, however, Bogen and Bogen (1988) never directly explored the link between interhemispheric communication and cognitive flexibility. Instead, they concluded only that "creativity in general benefits from interhemispheric collaboration" (298). While these researchers, as well as Hoppe (1988), have speculated that interhemispheric communication is involved in cognitive flexibility, this issue has only begun to be addressed empirically.

In a recent book, Banich (2004) reviewed the relation between interhemispheric communication and task complexity. She explained that, even for comparisons as simple as relative digit value or matching letters of different case (i.e., upper versus lower), the task is sufficiently difficult that communication between the hemispheres produces the correct answer more rapidly than does one hemisphere working alone. In other words, interhemispheric communication is more efficient than within-hemisphere processing for complex tasks. One might infer, then, that interhemispheric communication would be even more helpful in situations requiring an ability as complex as cognitive flexibility.

To that effect, research by Atchley, Keeney, and Burgess (1999) compared two theories of the mechanism of cognitive flexibility. The first theory argues that cognitive flexibility, operationalized as creativity, arises from the interaction of the two hemispheres. The other theory proposes that cognitive flexibility is predominantly a product of the right hemisphere. To assess the validity of these theories, Atchley *et al*. divided subjects in their experiment into low, medium, and high creativity groups. They employed a repeated-trial design, in which 100 prime-target pairs were presented in the same order to both visual fields in sequence. Subjects were primed with a word of ambivalent meaning, and then the target word was presented. The target was either a dominant or a subordinate meaning of the prime word (e.g., with a prime of “bear”, the target could be “furry animal” [dominant] or “to endure” [subordinate]).

In this study the dependent variable was participants’ accuracy in naming the target word, and this was expected to correlate negatively with creativity. That is, more creative participants were actually expected to have lower accuracy than less creative participants. While this might seem counterintuitive, it is a consequence of the timing used in the experiment. A 750-millisecond lapse occurred between the prime and the target words, during which time it was thought that the highly creative hemisphere would be able to generate both the dominant and the subordinate associations to the prime. This would lead to a decrease in accuracy, however, because the simultaneous presence of both words would cause that hemisphere to "stumble" when the target was presented; that is, to be unable to generate that correct target response as precisely as a less creative person would.

If the hemispheric interaction theory were true, then creative participants should exhibit this stumble effect, and the resultant decrease in response accuracy, for both visual fields. If, on the other hand, the right hemisphere were dominant in creativity, the authors speculated that accuracy would decrease only when the target was presented to the left visual field (seen by the right hemisphere). This is because only the right hemisphere would be able to support both the dominant and subordinate meanings simultaneously. Thus, upon target presentation, the right hemisphere would "stumble," and the accuracy of responses to left visual field targets would decrease. The left hemisphere (receiving information from the right visual field), in contrast, would only be able to support one association of the target—dominant or subordinate—after being primed. Thus, when the target was presented, the left hemisphere could either reproduce that word, as it had expected, or release the expected word and generate the other quickly and accurately.

The former is exactly what Atchley and colleagues (1999) obtained. As they phrased it, "That high-creativity subjects have the subordinate meaning available in the left hemisphere, as well as in the right hemisphere, fits well with the notion that both hemispheres contribute to creative processes" (493). The authors do make the caveat that non-verbal forms of creativity such as problem-solving or spatial creativity were not assessed in their research. Nonetheless, this limitation does not weaken their findings; it merely strengthens the need for further investigation. And while this is the only study we found that directly tested theories of the neural basis of cognitive flexibility, Atchley *et al*. note that "little empirical work has been done which supports these notions of hemispheric specialization for creative processing" (482). As a consequence of this research, it seems at the very least possible, if not likely, that cognitive flexibility occurs with the help of interhemispheric communication.

E. **Our research**

The review of literature offered here highlights three distinct lines of research: the effect of positive emotion on cognitive flexibility, the effect of positive emotion on interhemispheric communication, and the interaction between cognitive flexibility and interhemispheric communication. The effect of mild positive emotion, induced in the laboratory or in the field, is to enhance a variety of dimensions of cognitive flexibility (such as problem-solving, categorization, and association). Here, we have inferred that positive emotion also enhances interhemispheric communication based on the findings by Compton *et al*. (2003a; 2003b) that trait negative emotion reduced interhemispheric communication. Interestingly, the two processes that positive emotion has been shown to affect, cognitive flexibility and interhemispheric communication, seem to influence each other as well. Banich (2004) summarized earlier work in stating that interhemispheric communication is favored for complex tasks; tasks requiring cognitive flexibility should be sufficiently complex to do the same. More importantly, collaboration between the two hemispheres of the brain was found to mediate high creativity in research by Atchley *et al*. (1999). While further research is necessary in all of these areas, it struck us that despite these interrelations, no attempt had been made to explicitly connect positive emotion, cognitive flexibility, and interhemispheric communication.

We therefore propose that these three in fact form a pathway, whereby an increase in positive affect will amplify the efficiency of interhemispheric communication, which will in turn improve cognitive flexibility. The present research aims to generate direct support for such a pathway by concurrently testing cognitive flexibility and interhemispheric communication, after a manipulation of affective state.

Many possible methods exist to manipulate affective state. Isen and her colleagues have been able to reliably generate positive affect in the laboratory through a variety of means including candies, film clips, and word association (Isen and Daubman, 1984; Isen, Daubman, and Nowicki, 1987; Isen, Johnson, Mertz, Robinson, 1985). Other researchers have successfully employed positive event recall (Ridgeway and Waters, 1987), posed facial expressions (Fogel and Harris, 2001), and positive statements (Velten, 1968). In the present experiment, positive affect was induced by means of a humorous film clip and a small gift of candy at the beginning of the session. Control subjects saw a neutral film clip, but received candy at the end of the experiment. The film clip and candy manipulations were selected from this multitude of possibilities because they have been the affect inductions used most frequently by Isen. Since the test of cognitive flexibility that we selected was taken from Isen's research, we hoped that by using the affect induction that she employed as well, we would best be able to replicate the improvement in cognitive flexibility that she observed.

A negative affect group was not included in this study for two reasons. The primary reason is that prior research has already elaborated on the cognitive and neurological effects of negative emotion in a consistent manner (Compton and Mintzer, 2001; Compton, Wilson, and Wolf, 2003a; Compton, Wilson, and Wolf, 2003b), making it unnecessary for us to repeat that work here. As noted earlier, Compton, Wilson, and Wolf (2003a; 2003b) found that subjects who scored high on a measure of trait worry did not process emotional faces faster than non-emotional faces, as is commonly found in normal control subjects. Compton and Mintzer (2001) compared the interhemispheric communication of trait worriers with controls under evaluative and non-evaluative conditions. Regardless of evaluation, however, high worriers were again found to have less efficient interhemispheric communication compared to low worriers. Thus, trait negative emotion has reliably been shown to reduce, rather than enhance, interhemispheric communication.

The second reason that we omitted a negative affect group is that the focus of the current research was on the benefits of positive emotion. Previous research (Isen *et al.*, 1987) has already demonstrated that negative affect does not increase cognitive flexibility relative to either a positive affect group or to controls. Additionally, logistical constraints would present an obstacle to data collection if a third, negative affect group had been included.

Cognitive flexibility was evaluated by a lexical task of category inclusiveness. This task assessed one facet of cognitive flexibility, namely the capacity to make remote associations. The inclusiveness task borrowed category names and exemplars of them from a study by Rosch (1975), who used the category names to generate word frequency norms. Subjects rated exemplars listed beneath the category name on a 10-point scale, choosing to what extent items did or did not belong to given category names. This task of cognitive flexibility was selected because, with a limited time in which to conduct our study, ease of task implementation and of analysis were important considerations. Pilot testing was done of the category inclusiveness task to determine its ability to measure cognitive flexibility.

To measure interhemispheric communication, we employed the three-letter paradigm that was developed by Banich (1990), and has subsequently been adopted by many researchers because of its logic and simplicity. (The reader is directed to Banich and Shenker, 1994, for an analysis of methodological concerns in interhemispheric communication research.) Two tasks, a physical-identity match and a name-identity match, have been developed using this stimulus display. In the physical-identity match, subjects are instructed to indicate a match only if two letters are physically identical (e.g., G and G). In the name-identity match, on the other hand, letters are considered to be matching if they have the same name (e.g., G and g). Studies of interhemispheric communication comparing the physical- and name-identity approaches have found that the simplicity of the physical-identity match favors within-hemisphere processing, while the name-identity task favors hemispheric interaction (Belger and Banich, 1998; Weissman and Banich, 2000). Therefore, the name identity match will be used in the present research.

Three hypotheses were tested by the current experiment. First, we expected to replicate prior findings that inducing positive affect improves cognitive flexibility, reflected by an increased ability to make remote associations. More specifically, we expected subjects in the positive affect condition to rate poor category exemplars as having higher typicality, in comparison with control subjects. Our use of the same affect induction technique and measures of cognitive flexibility as those used in prior research lends us confidence in that regard.

Our second hypothesis was that inducing positive affect would also increase the efficiency of participants' interhemispheric communication. In operational terms, we asserted that participants in whom a positive affect was induced would display a greater across-hemisphere advantage on the interhemispheric communication task, relative to participants in a neutral affective state. The name-identity matching task is sufficiently difficult that response time is superior when interhemispheric communication occurs, so an enhanced AHA in the positive affect group, compared to controls, would be indicative of enhanced interhemispheric communication.

Third and most importantly, our central prediction was that the outcome of the interhemispheric communication task would correlate with the outcome of the cognitive flexibility task. In other words, we expected that subjects who demonstrated increased cognitive flexibility would also demonstrate more efficient interhemispheric communication. Together with the distinct lines of research presented above, this result would provide support to our thesis that interhemispheric communication mediates the relation between positive affect and cognitive flexibility.

METHOD

Participants. 73 right-handed undergraduate students at Haverford College (38 female, 35 male) were recruited through e-mail advertisement and personally by this author and his colleagues. Participants were randomly assigned to each experimental condition, and received payment for their participation upon completion of the experiment.

Apparatus. Stimuli for the interhemispheric communication task were presented on an Intel Pentium III PC running E-Prime (Psychology Software Tools).

Procedure. Upon arrival, participants gave their informed consent, and then watched one of two film clips, intended to induce either positive or neutral affect. Next, all participants filled out the 20-item Positive and Negative Affect Schedule (PANAS; Watson, Clark, and Tellegen, 1988). Participants then completed the cognitive flexibility task, as well as the interhemispheric communication task. Order of these was counterbalanced; participants in the CF-IHC order completed the cognitive flexibility task first, and participants in the IHC-CF order completed the cognitive flexibility task second. Finally, all participants filled out a measure of handedness, received payment, and were debriefed.

Materials and Measures. The affect manipulation had two components: a film clip, and a gift of candy. Two film clips were used, each of five minutes duration. Subjects in the positive affect condition watched two short scenes from “Monster’s, Inc.” (Buena Vista Home Entertainment, 2002). Subjects in the neutral affect condition saw a clip from the film “Painting with Light” (Pacific Arts Video, 1988). Pilot testing ascertained that these were equally valid materials with which to manipulate affect, as compared to films used in prior research. In the positive affect condition, participants were offered two small candy bars before the movie was played, as a token of the experimenter's appreciation for their participation. These participants were told that they were free to eat the candy at any time during or after the experiment. In the neutral affect condition, participants received the same offer of candy only at the conclusion of the experimental session.

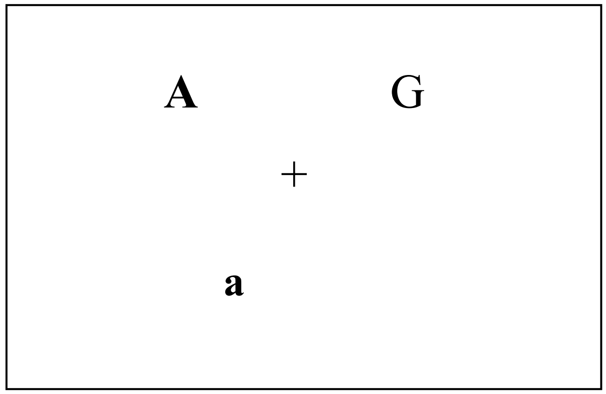
The effectiveness of the affect manipulation was assessed by the Positive and Negative Affect Schedule (PANAS; Watson, Clark, and Tellegen, 1988). The PANAS has been shown to be both a valid and reliable measure of emotion in adults (Wilson, Gullone, and Moss, 1998) and in children (Heubner and Dew, 1995). On the PANAS, participants rated the degree to which they currently felt 20 emotion words on a scale from 1 ("very slightly or not at all") to 5 ("extremely"). Ten of these words comprise the positive affect measure, and the other 10 comprise the negative affect measure. To take into account individual differences in the willingness to endorse these emotion items, however, we used an overall mood score (the *mood difference score*) instead of the positive affect score alone. The mood difference score was calculated by subtracting the sum total of ratings on the negative affect items from that on the positive affect items (i.e., Positive affect – Negative affect = Mood difference). Thus, someone who felt more positive than negative would have a mood difference score above zero, while someone who felt more negative than positive would have a mood difference score below zero, and someone who felt equally positive and negative would have a mood difference score of exactly zero. Given that we investigated the effects of a transient induction of positive affect, participants were asked specifically to rate how they felt at that moment, as opposed to on that day or in general.[2]

Cognitive flexibility was assessed by a measure of the degree of inclusion of items in a category. The inclusiveness task procedure was adapted from that developed by Isen and Daubman (1984, Studies 1 and 2). For each of four categories (*clothing*, *vegetable, furniture, and vehicle*), subjects rated nine exemplars of that category, deciding to what extent the exemplars did or did not belong to the given category. The particular categories selected were chosen because pilot data indicated that typicality norms derived by Rosch (1975) still applied to the exemplars of those categories. Three of the nine exemplars were highly typical of the category (e.g., “car”; from here on referred to as *excellent exemplars*), three were fairly typical (e.g., “tank”; *medium exemplars*), and three were atypical (e.g., “wheelchair”; *poor exemplars*), based on the same typicality ratings (Rosch, 1975). Although atypical, all poor exemplars could be thought of at least loosely as belonging to the category. The first item of each list was an excellent exemplar, but the remaining eight items were in random order. For consistency, the rating scale used was also adapted from Isen and Daubman (1984). The 10-point scale was divided into two parts. Participants were instructed to give a rating from 1 to 5 if they judged that an exemplar did *not* belong to a category, where a higher rating indicated a higher degree of similarity to the category presented. A rating between 6 and 10 was used for an exemplar that *was* judged to belong to a given category, where a higher rating

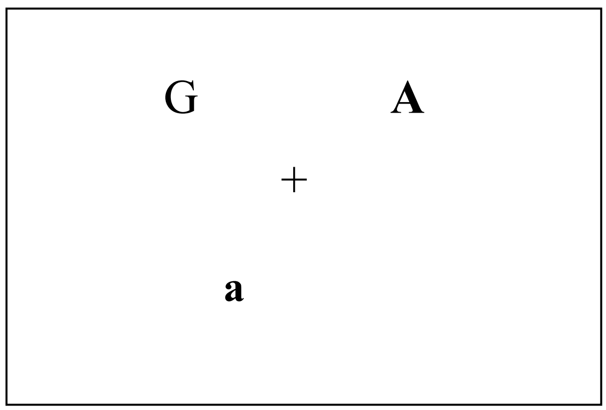
[2] It should be noted that even the researchers who created the PANAS concede that “even momentary moods are, to a certain extent, reflections of one’s general affective level” (1065, Watson, Clark, and Tellegen, 1988). Thus, in one sense, affective trait levels did contribute to the outcomes of our dependent measures. As always, however, random assignment ensures that people who are generally happy or generally sad were distributed across both affect conditions, thereby minimizing the interference of stable personality characteristics.

indicated a greater degree of typicality. In the category of *clothing*, for example, giving a rating of 5 to the item *purse* would reflect a judgment that a purse is not an article of clothing, but is very similar to one in some respects. A rating of 6 for the same item would indicate that a purse is an article of clothing, but is a poor example of one. An increase in flexible thinking would be evident from a higher numerical rating in participants' inclusiveness judgments.

The measure of interhemispheric communication used was the name-identity task, a frequently used stimulus-matching task (Banich and Shenker, 1994). The task consists of three stimuli presented on a computer screen around a fixation point. The stimuli were physically non-identical letters of upper and lower case, arrayed in an inverted "V" formation. The two top letters were uppercase and always differed from one another. They appeared opposite each other, 2.8˚ from the vertical midline and 1.4˚ above the fixation point. The third, bottom letter was lowercase and appeared 1.4˚ below the fixation point, displaced 1.4˚ to either the right of the left of the vertical midline (see Figure 4 on the following page for an example). Each letter subtended approximately 0.6˚ vertically and 0.4˚ horizontally. The letters used were G, E, H, A, T, R, B, and their lowercase equivalents; these letters are commonly used because the uppercase form looks quite different from the lowercase form. One trial consisted first of the fixation point, presented alone for 1000 milliseconds (ms), after which the stimulus array appeared for 200 ms. A 2000 ms inter-trial interval began at the offset point of the stimulus array, and responses (presses of the "h" key) were recorded during this time. Participants were centered in front of the monitor in a table-mounted chinrest with a viewing distance



Within-hemisphere trial



Across-hemisphere trial

Figure 4. Example stimuli for a match trial of the name-identity task.

of approximately 60 cm. Participants completed one practice block of 28 trials, followed by 4 experimental blocks of 56 trials each. All participants switched hands after each trial block, and the hand used to begin the task (left or right) was counterbalanced across participants.

The objective for all trials was to indicate whether a match was present. In match trials, the lower letter (the *probe*) matched one of the upper letters in name identity, but not in case (e.g., *A* and *a*). Half of the trials were match trials, and half were mismatch trials. Trial blocks were further subdivided according to whether the probe was located in the left visual field (LVF) or the right visual field (RVF), and whether the upper matching letter was in the same visual field as the probe (within-hemisphere trials) or the opposite visual field (across-hemisphere trials). The dependent variable was the speed of the key press (i.e., reaction time), but accuracy was also monitored. To test our hypotheses, data were analyzed in terms of both reaction time and the across-hemisphere advantage (AHA). The AHA was calculated by subtracting reaction times on across-hemisphere trials from reaction times on within-hemisphere trials; this yielded the mean amount of time by which the response was faster (or slower) on trials requiring interhemispheric communication. For example, a subject whose mean within-hemisphere reaction time was 550 ms and whose mean across-hemisphere reaction time was 500 ms would have an AHA of 50 ms. Data from one subject was discarded due to below-chance accuracy on the interhemispheric communication task; this left 72 subjects remaining in the data analysis.

The measure of handedness assessed participants' dominant hand for a number of common activities, and was used to verify that participants were right-handed. Excluding left-handed people is standard practice in research on interhemispheric communication because the pattern of brain asymmetry in left-handed people is both different from that of right-handers, as well as inconsistent between left-handers themselves. Thus, it is difficult to accurately interpret the data of this population.

Analysis. Condition and task order were the between-subjects variables in the present experiment. Within-subjects variables for the cognitive flexibility task were category and typicality, and for the interhemispheric communication task they were visual field and trial type. Three main analyses were conducted. The first was a 2 (Condition: positive or neutral affect) X 2 (Order: IHC-CF or CF-IHC) X 4 (Category: clothing, vegetable, furniture, or vehicle) X 3 (Typicality: excellent, medium, or poor) analysis of variance (ANOVA). The second analysis was a 2 (Condition) X 2 (Order) X 2 (Visual Field: left or right) X 2 (Trial Type: within- or across-hemisphere) ANOVA. The third main analysis was a correlation between the ratings of category exemplars and the AHA. In all analyses, an alpha value of .05 was used as the criterion for statistical significance.

RESULTS

Preliminary Analyses. Preliminary analyses found no main effect of subjects' sex, or of the time of day in which the experiment was completed (morning, afternoon, or evening) on any outcomes. Accordingly, subsequent analyses were collapsed across these two variables. The PANAS scales (Watson, Clark, and Tellegen, 1988) served as a manipulation check of the affect induction. Planned one-tailed analysis revealed a significant effect of group on the mood difference score, $t_{(71)} = 1.74$, $p < .04$. Subjects in the positive affect condition had a higher mean mood difference score (mean ± standard deviation, 14.5 ± 8.3) than subjects in the neutral condition (10.6 ± 9.7). This indicated that, as expected, subjects who saw a humorous film clip were in a more positive mood afterwards than subjects who saw a neutral film clip.

Main Hypotheses. The present research investigated three main hypotheses. Our first hypothesis was that inducing positive affect would generate greater cognitive flexibility, leading positive affect subjects to rate poor exemplars as having higher typicality, compared to control subjects. But, the two groups were not expected to differ in their ratings of excellent exemplars (due to a ceiling effect), so we anticipated a Condition X Typicality interaction rather than a main effect of condition. A main effect of typicality was expected to show that subjects gave higher ratings to exemplars of higher typicality. A 2 (Condition) X 2 (Order) X 4 (Category) X 3 (Typicality) ANOVA revealed no main effect of condition, as expected. Neither, however, was there a Condition X Typicality interaction. Counter to our hypothesis, the average ratings of poor exemplars (± SE) were similar among positive affect subjects (3.88 ± 0.18) and control subjects (3.81 ± 0.18). The mood difference scores of positive affect subjects and control subjects did differ significantly, but this difference was apparently not sufficient to produce differences in the cognitive flexibility of each group.

These data were re-analyzed in an unplanned comparison, using subjects' individual mood difference scores as the independent variable, rather than the affect condition. This assessed whether any subjects who were happier gave higher typicality ratings, regardless of their assignment to one or the other affect group. While a correlation between the mood difference score and typicality ratings of poor exemplars did indeed tend toward significance (Pearson's $r[72] = .21$, $p < .08$), it was the correlation with medium exemplars, unexpectedly, that was highly significant (Pearson's $r[72] = .31$, $p < .01$). As Figure 5 depicts, subjects who were in a more positive affective state rated medium exemplars as having higher typicality. Thus, even though an interaction of condition and typicality was not found, the data on individual variability in affect still conformed to Isen's (1984) theory that positive affect increases cognitive flexibility.

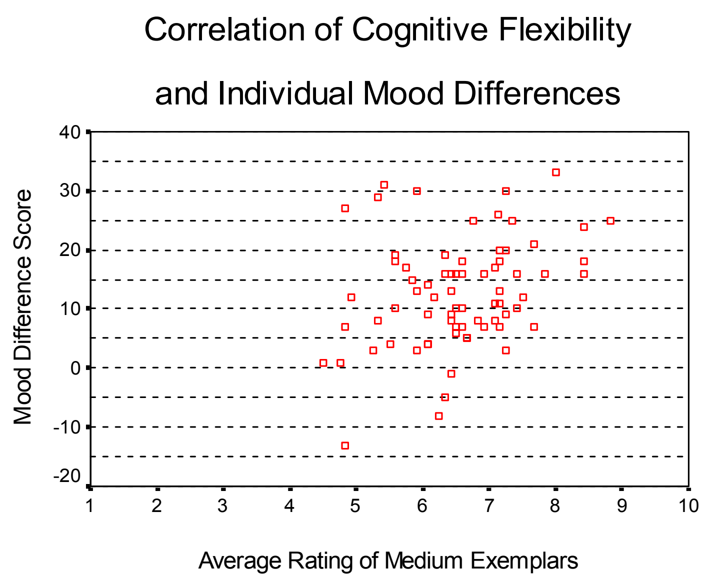


Figure 5. Participants with higher mood difference scores rated medium exemplars higher, indicating greater cognitive flexibility, Pearson's r(72) = .31, p < .01. Boxes represent individual participants' data.

As expected, ratings of excellent, medium, and poor exemplars differed significantly. This ANOVA revealed a main effect of typicality, $F_{(2, 136)} = 1{,}399$, $p < .0001$. Mean ratings (± standard error [SE]) for items on the 10-point typicality scale were 9.4 (0.05) for excellent exemplars, 6.6 (0.11) for medium exemplars, and 3.8 (0.13) for poor exemplars. Post-hoc analysis indicated that excellent, medium, and poor exemplars were all significantly different from one another (Tukey's HSD, p's < .0001). This demonstrates that subjects accurately perceived that excellent exemplars were most typical of a category, that medium exemplars were somewhat typical, and that poor exemplars were least typical. No further significant effects were expected, or found, involving the excellent exemplars.

Unexpectedly, this analysis also revealed a main effect of category, $F_{(3, 204)} = 22.6$, $p < .0001$, such that overall typicality ratings (that is, the average of the ratings of all nine items in a category) of each of the four categories differed significantly from each other. The means for each category are presented in Table 1. Post-hoc analysis revealed that mean ratings of all of the categories differed significantly from one another (Tukey's HSD, p's < .03), except clothing and furniture ($p > .3$). This main effect indicates that the typicality of the items was not perfectly matched across categories.

Category:	Vegetable	Furniture	Clothing	Vehicle
Mean Rating (±SE):	7.1 (.12)	6.7 (.13)	6.5 (.09)	6.1 (.09)

Table 1. Mean rating of all nine items for each category on the cognitive flexibility task.

A significant interaction of category with typicality level was also found, $F_{(6, 408)} = 34.3$, $p < .0001$. Medium and poor exemplars were rated more highly in the Vegetable category than in other categories. Despite this significant interaction, the ratings in each category had very similar trends (data not shown). Neither the main effect of Category nor the Category X Typicality interaction impacted the interpretation of the data in a meaningful way.

Our second prediction was that subjects in the positive affect condition would have more efficient interhemispheric communication than those in the neutral affect condition. But, that interhemispheric communication was only favored on across-hemisphere trials, so a Condition X Trial Type interaction was expected. A main effect of trial type on participants' reaction times was also anticipated, since previous research has shown that reaction times for across-hemisphere trials are faster than for within-hemisphere trials (e.g., Compton, Feigenson, and Widick, 2003). A 2 (Visual Field) X 2 (Trial Type) X

2 (Condition) X 2 (Order) ANOVA found said main effect to be significant, $F_{(1, 68)} = 39.6$, $p < .0001$. Reaction times (± SE) were faster on across-hemisphere trials (473 ± 12 ms) than on within-hemisphere trials (502 ± 12 ms). However, no Condition X Trial Type interaction was found. Positive affect participants were not significantly faster on across-hemisphere trials (mean ± SE, 457 ± 16 ms) than control participants (489 ± 16 ms). Given that individual differences in affect had been associated with categorization, an exploratory comparison tested the correlation between the mood difference score and the AHA. This correlation did not reach significance, either (Pearson's r[72] = 0.14, $p > .2$). Thus, even when affect condition was ignored, subjects who were in a more positive affective state did not exhibit a greater AHA. A main effect of visual field also reached significance in this analysis, $F_{(1, 68)} = 52.5$, $p < .0001$. Mean reaction times (± SE) when the matching probe appeared in the left visual field (464 ± 11 ms) were faster than reaction times when the probe appeared in the right visual field (511 ± 12 ms). While seemingly unusual, this effect has been found by other researchers and is not relevant to the current research (Weissman and Banich, 2000; Weissman, Banich, and Puente, 2000). Finally, although all effects significant for reaction times were also found for accuracy, for simplicity the results are interpreted only in terms of reaction time.

Thirdly, since we proposed that positive emotion would increase both the ratings of poor exemplar and the AHA, we predicted that the correlation between the typicality ratings of poor exemplars in the inclusiveness task, and the degree of AHA on the interhemispheric communication task, would also be significant. Correlational analyses for both relevant levels of typicality demonstrated that this relation did not reach significance for either poor or medium exemplars, although in both cases there was a trend toward significance (poor exemplars: Pearson's r[72] = .18, p < .13; medium exemplars: Pearson's r[72] = .22, p = .06; see Figure 6). In other words, subjects who displayed more efficient interhemispheric communication did have somewhat more cognitive flexibility.

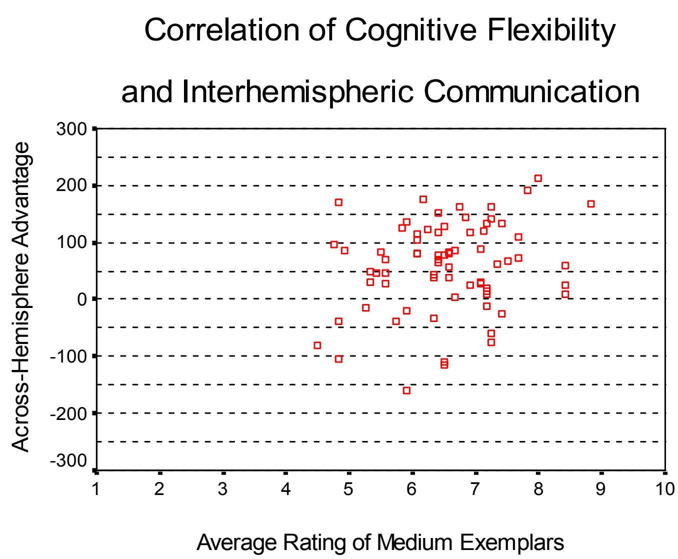


Figure 6. Participants with a higher across-hemisphere advantage had higher ratings of medium exemplars, indicating greater cognitive flexibility as the efficiency of interhemispheric communication increased (Pearson's r[72] = .22, p = .06). Boxes represent individual participants' data.

In sum, albeit by correlation only, two of our three hypotheses were supported. First, positive affect was associated with greater cognitive flexibility. Second, more efficient interhemispheric communication, operationalized as the AHA, was also associated with greater cognitive flexibility. However, positive affect was not correlated with more efficient interhemispheric communication. It would seem, then, that positive affect, cognitive flexibility, and interhemispheric communication are not tied together in the way that we proposed. Figure 7 presents this summary graphically.

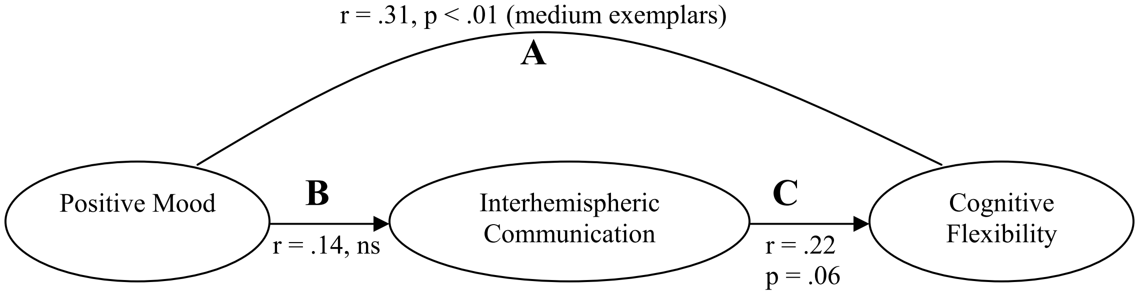


Figure 7. Graphical representation of the three main hypotheses and the results obtained. ns = not significant. Note: all n's = 72.

Unanticipated Findings. While conducting planned analyses, we came across one finding that complicated matters slightly: an interaction of experimental order with the correlation between the AHA and the typicality ratings of medium exemplars (**C**, in Figure 7). This result was particularly surprising because experimental order had been counterbalanced simply as a potentially confounding variable, and it was not expected to have any effect. Recall that the correlation between the AHA and the typicality ratings for medium exemplars was nearly significant using data from all subjects (Pearson's $r[72] = .22, p = .06$). Two distinct groups emerged when order was added to that equation. In the IHC-CF group, the correlation was doubled, Pearson's $r(35) = .44$, $p < .01$. For the CF-IHC group, on the other hand, the correlation was practically zero, Pearson's $r(37) = .02, p > .9$. This effect was echoed for the poor exemplar ratings, which had not correlated significantly with the AHA when all the subjects' data were analyzed. The correlation was again highly significant for the IHC-CF group, (Pearson's $r[35] = .29, p < .01$), but not so for the CF-IHC group (Pearson's $r[37] = .10, p > .5$). Hence, for participants who performed the interhemispheric communication task first, their AHA correlated significantly with their ratings of poor and medium exemplars (Figure 8). In contrast, for participants who performed the cognitive flexibility task first, their AHA did not correlate with their ratings of poor or medium exemplars. A multiple regression analysis demonstrated that the contribution of task order to increasing cognitive flexibility was separate from the contribution of positive affect. The mood difference score and the across-hemisphere advantage were predictor variables in this analysis. The overall model was significant, R = .55, $F_{(2, 33)} = 7.1$, $p < .005$. Both affect ($t = 2.3$, $p < .04$) and interhemispheric communication ($t = 2.6$, $p < .02$) were significant predictors of typicality ratings, even after accounting for the variance of each other. Being in a positive mood and having more efficient interhemispheric communication, therefore, both caused participants to give higher typicality ratings, but each by different means.

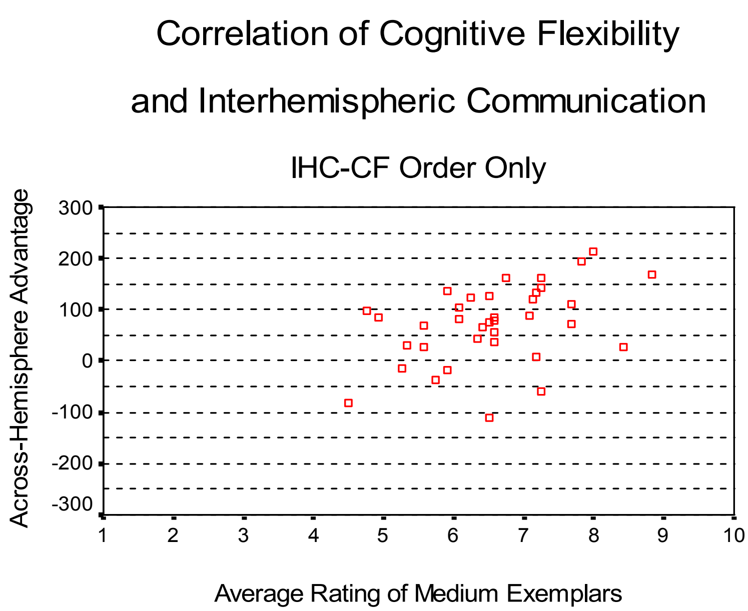


Figure 8. Participants who completed the interhemispheric communication task first, but not those who completed it second, had a significant correlation between their across-hemisphere advantage and their ratings of medium exemplars (Pearson's r[35] = .44, p < .01). For comparison see Figure 6 on page 41. Boxes represent individual participants' data.

CONCLUSION

The present experiment investigated the possibility that interhemispheric communication mediates the increase in cognitive flexibility that is produced by generating positive affect. This theory was formulated by examining three major lines of research. First, a number of studies, particularly those by Isen *et al*. (1978; 1983; 1984; 1985; 1987; 1991) strongly supported the idea that inducing mild positive affect boosts various dimensions of cognitive flexibility. Next, some researchers had already posited that it was interhemispheric communication that gives rise to creativity, a key component of cognitive flexibility (Bogen and Bogen, 1988; Atchley, Keeney, and Burgess, 1999). This was supported by the theory of Ashby, Isen, and Turken (1999), who proposed that dopaminergic pathways mediate the cognitive effects of positive affect. Interhemispheric communication, via the corpus callosum or another connection, almost certainly plays a role in the activity of those pathways. Lastly, recent research demonstrated the detrimental effects of negative affect on interhemispheric communication; we inferred that positive affect, therefore, would enhance it. In light of these links between positive affect and cognitive flexibility, between cognitive flexibility and interhemispheric communication, and between positive affect and interhemispheric communication, and given the dearth of research synthesizing such findings, we sought to understand whether an underlying functional pathway existed.

Thus, this study contained three main hypotheses. First, we expected subjects in whom positive affect was induced to display increased cognitive flexibility. Second, we expected that those subjects would also display an increase in the efficiency of interhemispheric communication. Third, we expected the cognitive flexibility of all subjects to correlate with the efficiency of their interhemispheric communication. That is, subjects with high cognitive flexibility would show more efficient interhemispheric communication, and subjects with low cognitive flexibility would show less efficient interhemispheric communication.

Two of these hypotheses were borne out by the data. First, positive affect was associated with greater cognitive flexibility. We found that positive affect had the greatest association with the ratings of medium, rather than poor, category exemplars, a result contrary to the results of previous researchers who used the same measure of cognitive flexibility (Isen and Daubman, 1984). Isen *et al*. (1984) had found that the ratings of poor exemplars were those most likely to be influenced by a manipulation of affect. However, this difference is likely due to the particular items selected. There appeared to be a floor effect on the poor exemplars in the present experiment, such that all participants consistently rated those as not belonging to the category and as dissimilar to it. Medium exemplars were more often seen as having borderline status, opening the possibility for participants' affect to influence their ratings.

Despite a significant difference between the mood scores of participants in the two conditions, differences in cognitive flexibility were not found based on participants' affect condition, but rather in a correlational analysis. This suggests that the affect manipulation did not cause the differences in cognitive flexibility that were found, as we had expected. Rather, greater cognitive flexibility was present in subjects who were in a more positive affective state, regardless of assignment to the positive or neutral affect manipulation. Our inability to replicate the effect of induced positive emotion on cognitive flexibility was disappointing, considering that we made every effort to match the materials and procedures successfully used by Isen's group. Informal information from study participants, however, indicated that the film clip that we intended to be neutral might have aroused emotion in some people. In addition, the positive affect film clip may not have been as humorous as we had thought to participants who had never seen the movie from which the clip was taken. In this regard, more extensive pilot testing of the film clips or access to the particular films that Isen's group used might have been helpful. Nevertheless, while we cannot say that greater cognitive flexibility was induced by way of the affect manipulation, the results are consistent with previous findings (e.g., Isen and Daubman, 1984) that people in a more positive affective state have greater cognitive flexibility.

The second of our three hypotheses was also confirmed, in that higher cognitive flexibility did correlate with more efficient interhemispheric communication. Specifically, the greater their across-hemisphere advantage, the more likely participants were to rate poor and medium category exemplars more inclusively. Interestingly, this correlation was highly significant for subjects who completed the interhemispheric communication task before the cognitive flexibility task, and not significant for the reverse order.

Many explanations of this order effect are plausible. Interest in the experiment, for one, may have differed depending on which task was begun first. Empirical evidence has suggested that intrinsic task interest is a mediator of the effect of positive emotion on cognitive flexibility (Murray, Sujan, Hirt, and Sujan, 1990). Thus, if the interhemispheric communication task (repeatedly pushing one key for 15-20 minutes) was perceived as boring or interesting (or neither) and that task was completed first, ratings on the subsequent measure of cognitive flexibility might vary based on those reactions. By the same token, for subjects who completed the cognitive flexibility task first, their reactions to the interhemispheric communication task would not influence their inclusiveness ratings, and therefore no relation would be found between the outcomes of the two tasks. Analysis of available data relevant to this hypothesis did not serve to explain the effect of order. That is, on the PANAS scales that participants filled out before these tasks, two of the items rated were interest and alertness. It might have been expected that these ratings of participants' interest would provide insight into the order effect. However, this was not the case (data not shown), and further reflection made it apparent that ratings on the PANAS scales were not a direct enough measure. That information was gathered before participants began either task and, therefore, could ostensibly assess only the intrinsic interest of the experiment or of the film clip, rather than intrinsic interest of the interhemispheric communication task specifically. In favor of the intrinsic interest explanation, on the other hand, was evidence that the order effect on the interhemispheric communication-cognitive flexibility correlation was further modified by condition. Of subjects who completed the interhemispheric communication task first, the correlation with the cognitive flexibility task only reached significance for those in a positive affective state, Pearson's $r(18) = .48$, $p < .05$. Control subjects who completed the tasks in this order did not show a significant correlation ($p > .1$), nor did any subjects who completed the tasks in the reverse order ($p > .7$ for each affect condition). The hypothesis that levels of interest mediated the results could be tested more rigorously by assessing subjects' self-reported interest or engagement in the experiment after each of the two tasks.

Another explanation of the order effect might be that performing the interhemispheric task, in and of itself, had an effect on participants' levels of cognitive flexibility separate from the effect of the mood manipulation. This could happen in many ways. One possibility, assuming that there is some truth to our theory, is that perhaps the task activated cognitive flexibility because participants were utilizing interhemispheric communication. Accordingly, the more efficient a participant's interhemispheric communication was, the greater would be the activation of cognitive flexibility. That activation would dictate the inclusiveness ratings on the cognitive flexibility task, in the IHC-CF group, leading to a high correlation between the across-hemisphere advantage and the exemplar ratings. This effect would be not been seen for participants who completed the cognitive flexibility task first because that ability would only be activated at the end of the experimental session. Thus, no correlation would be expected in the CF-IHC group. If this hypothesis is correct, the order effect should be replicable with different tasks of interhemispheric communication and cognitive flexibility.

A third possible account of the order effect supposes that different heuristics could potentially be applied to completing the cognitive flexibility task. Performing the interhemispheric communication task first, though, may have activated certain heuristics for certain participants. An availability heuristic, for example, would direct participants to rate each item merely by estimating how often in recent memory they have heard, seen, read, *etc*. that item as a category member. This would lead poor exemplars to be given consistently low ratings because base their ratings on the frequency of belonging. This approach might be activated in participants with less efficient interhemispheric communication because it requires little cognitive effort. Poor exemplars might be given higher ratings if a more dynamic heuristic were employed, in which subjects rated the items only after imagining ways that each item could be construed as a member of the given category. This strategy would more likely be activated in participants with more efficient interhemispheric communication because more distant associations could be made with equal effort, compared to simple associations. As a consequence of differential heuristic activation, a high correlation would be seen between the across-hemisphere advantage and the ratings of category exemplars, and only when the cognitive flexibility task was done second. When the cognitive flexibility task was completed first, however, no particular strategy would be active and no correlation would be found with the outcome of the interhemispheric communication task. This hypothesis could be investigated in a number of ways. The simplest might be to record participants' thought process during the cognitive flexibility task. Or, participants could be directed to use a particular approach on a measure of cognitive flexibility. Would the same result be found, for instance, if participants had been told to complete the task quickly and rate the typicality of each item only with the information that came most readily to their minds? Or, would the explicit instruction have overridden the influence of the interhemispheric communication task, causing no order effect to be found? If this order effect were replicated, it would be imperative to understand the mechanism of the apparent activation of cognitive flexibility—whether that be through intrinsic interest, positive feedback in flexibility circuits, or heuristics—so that different modulators of this fundamental ability could be explored. Whatever the explanation, the order effect certainly qualifies, but does not weaken, the evidence found for a link between cognitive flexibility and interhemispheric communication.

Our third main hypothesis, that positive affect would be associated with more efficient interhemispheric communication, was not supported. The across-hemisphere advantage, a measure of interhemispheric communication efficiency, was not significantly higher in positive affect subjects, nor was there a significant relation between affect and interhemispheric communication when individual differences in affect were examined. The expected effect might have been seen with a more robust affect manipulation. However, our inference that positive affect would increase the advantage of interhemispheric communication was based on studies of trait, not state, affect (Compton, Wilson, and Wolf, 2003a). Additionally, positive and negative affect may not always have opposite effects (Reich, Zautra, and Potter, 2001). For differences in affective state to impact upon a process as basic as interhemispheric communication, their magnitude might need to be quite large. For trait affect, on the other hand, such an impact could be observed if trait emotionality were to have consequences for neurological development. A mild positive emotional state, therefore, may not be of sufficient power so as to augment the already-present advantage of interhemispheric communication on the name-identity task used here.

To summarize, our theory was that affect, interhemispheric communication, and cognitive flexibility formed a pathway whereby the association of positive affect with more flexible thinking was due to an increase in the efficiency of interhemispheric communication. This theory was not fully supported, since participants who showed greater positive affect did have greater cognitive flexibility, but they did not have more efficient interhemispheric communication. Participants with more efficient interhemispheric communication, though, also had greater cognitive flexibility. Indeed, multiple regression analysis of the observed order effect confirmed that the affect manipulation and the interhemispheric communication task each made independent contributions to the increase in participants' cognitive flexibility.

Although the present research may have only brought into focus, rather than narrowed, the range of possible neural mechanisms of increased cognitive flexibility, it was never intended as more than a first step in that direction. Further research is clearly warranted to disentangle the complex interactions seen in our introductory exploration of how positive emotion leads to increased cognitive flexibility. Our research would have been improved by a more robust affect manipulation. Care should be taken so that the control manipulation does not alter positive or negative affect. Likewise, participants' affective state should be assessed not only following the affect manipulation but also at the conclusion of the experimental session. The purpose of this would not be to test the duration of the manipulation, but rather to corroborate the involvement of affect, should any mechanistic connection of a purported mediator of cognitive flexibility be observed. Also, as mentioned above, the separate contribution of more efficient interhemispheric communication to increased cognitive flexibility merits examination.

Given our uncertain finding with regard to interhemispheric communication, future work should examine other possibilities for a mediator of the increase in cognitive flexibility, including a rigorous test of the model laid out by Ashby, Isen, and Turken (1999). To carry out such a test, positron emission tomography (PET) could be used, ideally, to determine if dopaminergic pathways become active during inductions of positive, but not neutral or negative, affect. And while the brain regions that receive dopaminergic input (that is, the prefrontal cortices, the nucleus accumbens, and the anterior cingulate cortex) are almost certainly involved in cognitive flexibility to some extent, dopamine may not be the sole neurotransmitter involved.

On a more speculative front, it would be of some interest if research on emotion and creativity could eventually provide insight into the phenomenon of the "tortured artist." The research discussed here found that inducing negative affect was detrimental to experimental measures of cognitive flexibility, which is essential to creativity (Isen, Daubman, and Nowicki, 1987). Yet, artists such as Picasso painted as well while in a deep depression as at any other time. Some believe that great artists produce magnificent work because they suffer greatly; is that the case, or could it be that they do so because they are great artists, in spite of their suffering? In either case, how does this phenomenon connect with the research on cognitive flexibility to date?

This study has some important limitations. First, the neutrality of the neutral affect film clip was not fully established. After the experimental session, some participants reported reactions of interest in or aversion to both the substance and the style of the scenes they viewed (the film was nearly 20 years old). If affect were in fact induced in control subjects, this could certainly have confounded our findings somewhat, especially if different control subjects had different emotional reactions to the neutral movie. Given that participants in the positive and neutral affect conditions did, however, differ significantly on the PANAS, it is evident that many participants reacted to each movie as we predicted they would. A second limitation is that the link made between cognitive flexibility and interhemispheric communication was correlational in nature. In fact, the independent effects of affect and interhemispheric communication on cognitive flexibility were substantiated by multiple regression analysis. Therefore, not having manipulated directly the degree of either cognitive flexibility or interhemispheric communication limits our ability to draw causal inferences from the data. In addition, the independent effect of interhemispheric communication remains to be investigated. Third, some participants were recruited through their acquaintance with this author and his colleagues. This may have introduced a sampling bias. Finally, due to the fact that this author and his colleagues all led experimental sessions after only moderate procedural standardization, study participants' interaction with the experimenter was not uniform. This is especially relevant given that the use of candy as an affect manipulation required a precise description of the candy's purpose to all participants. If participants understood differently the reason that candy was given, or suspected its true purpose as a psychological manipulation, that may have contributed to the lack of strength of the affect manipulation.

Taking these limitations into consideration, the present research should be seen as providing positive, yet inconclusive, support for a relation between interhemispheric communication and cognitive flexibility, a connection that had not previously been investigated. The efficiency of interhemispheric communication was not influenced by a manipulation of affective state, and future research on that question might be better served to utilize manipulations of trait positive affect. Regardless of how they are interpreted, the results of this study are strengthened by the methodological precautions that were taken, by the use of previously validated measures and tasks, and by an adequate sample size.

APPENDIX A – POSITIVE AND NEGATIVE AFFECT SCHEDULE (PANAS)

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent you feel this way right now, that is, at the present moment. Use the following scale to record your answers:

1	2	3	4	5
very slightly or not at all	a little	moderately	quite a bit	extremely

_____interested	_____guilty
_____irritable	_____determined
_____distressed	_____scared
_____alert	_____attentive
_____excited	_____hostile
_____ashamed	_____jittery
_____upset	_____enthusiastic
_____inspired	_____active
_____strong	_____proud
_____nervous	_____afraid

APPENDIX B – COGNITIVE FLEXIBILITY TASK

Subject Number: _______

Instructions: At the top of the following four (4) pages appears the name of a category. When people see or hear such category names, they often think of examples of them. Upon hearing the word *bird*, for example, people may think of a robin or an eagle but are less likely to think of an ostrich or a pheasant. Listed under each category name are nine (9) words. Using the scale given, please rate the degree to which each of the nine words belongs in that category.

A rating between one (1) and five (5) should be used if you believe an item <u>does not</u> belong to the category. The higher the rating, the more an item is *similar* to the category, even though you decide that it is not actually *in* the category. **For instance, given the category of *Sports*, horseshoes might be rated as a 4 or 5 because most people do not really think of horseshoes as a sport, although it is similar to sports in some ways.**

A rating between six (6) and ten (10) should be used if you believe an item <u>does</u> belong to the category. The higher the rating, the more you judge an item to be a *good example* of the category. **For instance, given the category of *Sports*, sailing might be rated as an 6 or 7 because it is a sport, at least to some, but sailing is not what most people envision when they hear the word *Sports*. On the other hand, baseball might be rated a 9 or 10 because it is very typical of what people think of when they hear the word *sport*s.**

Please give only one rating (from 1 to 10) for each item.

Clothing

	Item **is not** in category					Item **is** in category				
	Not very similar		Somewhat similar		Very similar	Not very typical		Somewhat typical		Very typical
1. pants	1	2	3	4	5	6	7	8	9	10
2. apron	1	2	3	4	5	6	7	8	9	10
3. vest	1	2	3	4	5	6	7	8	9	10
4. purse	1	2	3	4	5	6	7	8	9	10
5. shirt	1	2	3	4	5	6	7	8	9	10
6. pajamas	1	2	3	4	5	6	7	8	9	10
7. cane	1	2	3	4	5	6	7	8	9	10
8. jacket	1	2	3	4	5	6	7	8	9	10
9. sandals	1	2	3	4	5	6	7	8	9	10

Vegetable

	Item **is not** in category					Item **is** in category				
	Not very similar		Somewhat similar	Very similar		Not very typical		Somewhat typical		Very typical
1. broccoli	1	2	3	4	5	6	7	8	9	10
2. pumpkin	1	2	3	4	5	6	7	8	9	10
3. peas	1	2	3	4	5	6	7	8	9	10
4. radish	1	2	3	4	5	6	7	8	9	10
5. pickle	1	2	3	4	5	6	7	8	9	10
6. mushroom	1	2	3	4	5	6	7	8	9	10
7. onion	1	2	3	4	5	6	7	8	9	10
8. corn	1	2	3	4	5	6	7	8	9	10
9. peanut	1	2	3	4	5	6	7	8	9	10

Furniture

	Item **is not** in category					Item **is** in category				
	Not very similar		Somewhat similar		Very similar	Not very typical		Somewhat typical		Very typical
1. chair	1	2	3	4	5	6	7	8	9	10
2. bookcase	1	2	3	4	5	6	7	8	9	10
3. piano	1	2	3	4	5	6	7	8	9	10
4. clock	1	2	3	4	5	6	7	8	9	10
5. dresser	1	2	3	4	5	6	7	8	9	10
6. lamp	1	2	3	4	5	6	7	8	9	10
7. rug	1	2	3	4	5	6	7	8	9	10
8. closet	1	2	3	4	5	6	7	8	9	10
9. table	1	2	3	4	5	6	7	8	9	10

Vehicle

	Item **is not** in category					Item **is** in category				
	Not very similar		Somewhat similar		Very similar	Not very typical		Somewhat typical		Very typical
1. bus	1	2	3	4	5	6	7	8	9	10
2. wheelchair	1	2	3	4	5	6	7	8	9	10
3. skis	1	2	3	4	5	6	7	8	9	10
4. car	1	2	3	4	5	6	7	8	9	10
5. surfboard	1	2	3	4	5	6	7	8	9	10
6. tank	1	2	3	4	5	6	7	8	9	10
7. wheelbarrow	1	2	3	4	5	6	7	8	9	10
8. truck	1	2	3	4	5	6	7	8	9	10
9. yacht	1	2	3	4	5	6	7	8	9	10

REFERENCES

Anderson, A. K., and Phelps, E. A. (2001). Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature, 411*, 305-9.

Ashby, F. G., Isen, A. M., and Turken, A. U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106(3)*, 529-550.

Atchley, R. A., Keeney, M, and Burgess, C. (1999). Cerebral hemispheric mechanisms linking ambiguous word meaning retrieval and creativity. *Brain and Cognition, 40,* 479-499.

Banich, M. T. (2003). Interaction between the hemispheres and its implications for the processing capacity of the brain. In K. Hugdahl and R. Davidson (Eds.), *The Asymmetrical Brain*. Cambridge: A Bradford Book.

Banich, M. T. (2004). *Cognitive neuroscience and neuropsychology*. New York: Houghton Mifflin.

Banich, M. T., and Brown, W. S. (2000). A life-span perspective on interaction between the cerebral hemispheres. *Developmental Neuropsychology, 18(1)*, 1-10.

Banich, M. T., and Shenker, J. I. (1994). Investigations of interhemispheric processing: methodological considerations. *Neuropsychology, 8(2)*, 263-277.

Beck, R., Perkins, T. S., Holder, R., Robbins, M., Gray, M., Allison, S. H. (2001). The cognitive and emotional phenomenology of depression and anxiety: Are worry and hopelessness the cognitive correlates of NA and PA? *Cognitive Therapy and Research, 25(6)*, 829-838.

Belger, A., and Banich, M. T. (1998). Costs and benefits of integrating information between the cerebral hemispheres: A computational perspective. *Neuropsychology, 12(3)*, 380-398.

Bogen, J. E. (2000). Split-brain basics: relevance for the concept of one's other mind. *Journal of the American Academy of Psychoanalysis, 28(2)*, 341-369.

Bogen, J. E., and Bogen, G. M. (1969). The other side of the brain: III. The corpus callosum and creativity. *Bulletin of the Los Angeles Neurological Society, 34(4)*, 191-220.

Bogen, J. E., and Bogen, G. M. (1988). Creativity and the corpus callosum. *Psychiatric Clinics of North America, 11(3)*, 293-301.

Borod, J. (1992). Interhemispheric and intrahemispheric control of emotion: a focus on unilateral brain damage. *Journal of Consulting and Clinical Psychology, 60(3)*, 339-348.

Borod, J. C., Cicero, B. A., Obler, L. K., Welkowitz, J., Erhan, H. M., Santschi, C. Grunwald, I. S., Agosti, R. M., and Whalen, J. R. (1998). Right hemisphere emotional perception: Evidence across multiple channels. *Neuropsychology, 12*, 446-458.

Borod, J. C., and Koff, E. (1989). The neuropsychology of emotion: Evidence from normal, neurological, and psychiatric populations. In E. Perecman (Ed.), *Cognitive processing in the right hemisphere* (pp.83-110). New York: Academic Press.

Bower, G. H. (1981). Mood and memory. *American Psychologist, 36(2)*, 129-148.

Broca, P. (1861/1960). [Remarks on the seat of the faculty of articulate language, followed by an observation of aphemia]. In Bonin, G. von (Ed.), *Some Papers on the Cerebral Cortex*. Springfield, IL: Charles C. Thomas.

Burgess, C. and Simpson, G. B. (1988a). Cerebral hemispheric mechanisms in the retrieval of ambiguous word meanings. *Brain and Language, 33*, 86-103.

Burgess, C. and Simpson, G. B. (1988b). Neuropsychology of lexical ambiguity resolution: The contribution of divided visual field studies. In S. L. Small, G. W. Cottrell, and M. K. Tanenhaus (Eds.), *Lexical ambiguity resolution: Perspectives from psycholinguistics, neuropsychology, and artificial intelligence* (pp. 411-430). San Mateo, CA: Morgan Kaufman.

Cohen, S., Frank, E., Doyle, W. J., Skoner, D. P., Rabin, B. S., and Gwaltney, J. M. Jr. (1998). Types of stressors that increase susceptibility to the common cold in healthy adults. *Health Psychology, 17(3)*, 214-223.

Compton, R. J., Feigenson, K., and Widick, P. (2003). Take it to the bridge: an interhemispheric processing advantage for emotional faces. Manuscript under review.

Compton, R. J., and Mintzer, D. A. (2001). Effects of worry and evaluation stress on interhemispheric interaction. *Neuropsychology, 15(4)*, 427-433.

Compton, R. J., Wilson, K., and Wolf, K. (2003a). When two hemispheres are not better than one: effects of worry on interhemispheric processing. *Brain and Cognition, 51*, 213-5.

Compton, R. J., Wilson, K., and Wolf, K. (2003b). Mind the gap: interhemispheric communication about emotional faces. *Emotion, in press*.

Conrad, M., and Hammen, C. (1993). Protective and resource factors in high- and low-risk children: A comparison of children with unipolar, bipolar, medically ill, and normal mothers. *Development and Psychopathology, 5(4)*, 593-607.

Cornelius, R. R. (1996). *The science of emotion*. Upper Saddle River, NJ: Prentice Hall.

Dovidio, J. F., Gaertner, S. L., Isen, A. M., and Lowrance, R. (1995). Group representations and intergroup bias: Positive affect, similarity, and group size. *Personality and Social Psychology Bulletin, 21(8)*, 856-865.

Duncker, K. (1945). On problem solving. *Psychological Monographs, 58(5, no. 270)*.

Eisenberger, R. and Cameron, J. (1998). Reward, intrinsic interest, and creativity: New findings. *American Psychologist, 53(6)*, 676-9.

Ekman, P., and Friesen, W. V. (1971). Constants across cultures in the face and emotion. *Journal of Personality and Social Psychology, 17*, 124-129.

Ekman, P., Friesen, W. V., O'Sullivan, M., Chan, A., Diacoyanni-Tarlatzis, I., Heider, K., Krause, R., LeCompte, W. A., Pitcairn, T., Ricci-Bitti, P. E., Scherer, K. R., Tomita, M., and Tzavaras, A. (1987). Universals and cultural differences in the judgments of facial expressions of emotion. *Journal of Personality and Social Psychology, 53(4)*, 712-717.

Estrada, C. A., Isen, A. M., and Young, M. J. (1997). Positive affect facilitates integration of information and decreases anchoring in reasoning among physicians. *Organizational Behavior and Human Decision Processes, 72(1)*, 117-135.

Fogel, T. G., and Harris, L. J. (2001). Do unilateral right and left face contractions induce positive and negative emotions? A further test of Schiff and Lamon's (1989) hypothesis. *Brain and Cognition, 47(3)*, 513-524.

Fredrickson, B. L., and Levenson, R. W. (1998). Positive emotions speed recovery from the cardiovascular sequelae of negative emotions. *Cognition and Emotion, 12*, 191–220.

Gainotti, G. (1972). Emotional behavior and hemispheric side of the lesion. *Cortex, 8(1)*, 41-55.

Gazzaniga, M. S. (1970). *The bisected brain*. New York: Appleton-Century-Crofts.

Gazzaniga, M. S. (2000). Cerebral specialization and interhemispheric communication: does the corpus callosum enable the human condition. *Brain, 123*, 1293-1326.

Gazzaniga, M. S., Bogen, J. E., and Sperry, R. W. (1965). Observations on visual perception after disconnexion of the cerebral hemispheres in man. *Brain, 88*, 221-36.

George, M. S., Ketter, T. A., Parekh, P. I., Horwitz, B., Herscovitch, P., and Post, R. M. (1995). Brain activity during transient sadness and happiness in healthy women. *American Journal of Psychiatry*, *152(3)*, 341–351 [Abstract only].

Greene, T. R., and Noice, H. (1988). Influence of positive affect upon creative thinking and problem solving in children. *Psychological Reports*, *63*, 895–898.

Heller, W. (2004). Emotion. In M. T. Banich (Ed.), *Cognitive neuroscience and neuropsychology*. New York: Houghton Mifflin.

Heller, W., Schmidtke, J. I., Nitschke, J. B., Koven, N. S., and Miller, G. A. (2002). States, traits, and symptoms: Investigating the neural correlates of emotion, personality, and psychopathology. In D. Cervone and W. Mischel (Eds.), *Advances in personality science*. New York: Guilford Press.

Hellige, J. B. (1993). *Hemispheric asymmetry: What's right and what's left*. Cambridge: Harvard University Press.

Hoppe, K. D. (1988). Hemispheric specialization and creativity. *Psychiatric Clinics of North America, 11(3)*, 303-315.

Hoptman, M. J., and Davidson, R. J. (1994). How and why do the two cerebral hemispheres interact? *Psychological Bulletin, 116(2)*, 195-219.

Huebner, E. S., and Dew, T. (1995). Preliminary validation of the positive and negative affect schedule with adolescents. *Journal of Psychoeducational Assessment, 13(3)*, 286-293.

Hugdahl, K., and Davidson, R. J. (2003). *The Asymmetrical Brain*. Cambridge, MA: A Bradford Book.

Isen, A. M. (1990). The influence of positive and negative affect on cognitive organization: Some implications for development. In N. L. Stein and B. Leventhal (Eds.), *Psychological and biological approaches to emotion* (pp. 75-94). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Isen, A. M. (2000). Some perspectives on positive affect and self-regulation. *Psychological Inquiry, 11*, 184–187.

Isen, A. M., and Daubman, K. A. (1984). The influence of affect on categorization. *Journal of Personality and Social Psychology, 47(6)*, 1206-1217.

Isen, A.M., Daubman, K. A., and Nowicki. G. P. (1987). Positive affect facilitates creative problem solving. *Journal of Personality and Social Psychology, 52(6)*, 1122-1131.

Isen, A. M., Johnson, M. M. S., Mertz, E., and Robinson, G. F. (1985). The influence of positive affect on the unusualness of word associations. *Journal of Personality and Social Psychology, 48(6)*, 1412-1426.

Isen, A. M., and Means, B. (1983). The influence of positive affect on decision-making strategy. *Social Cognition, 2(1)*, 18-31.

Isen, A. M., Rosenzweig, A. S., Young, M. J. (1991). The influence of positive affect on clinical problem solving. *Medical Decision Making, 11*, 221-227.

Isen, A. M., Shalker, T. E., Clark, M. S., and Karp, L. (1978). Positive affect, accessibility of material in memory, and behavior: A cognitive loop? *Journal of Personality and Social Psychology, 36*, 1-12.

Izard, C. E. (1977). *Human emotions*. New York: Plenum Press.

Izard, C. E. (2002). Translating emotion theory and research into preventive interventions. *Psychological Bulletin, 128(5)*, 796-824.

Johnson, E. J., and Tversky, A. (1983). Affect, generalization, and the perception of risk. *Journal of Personality and Social Psychology, 45(1)*, 20-31.

LeDoux, J. E., Wilson, D. H., Gazzaniga, M. S. (1977). Manipulo-spatial aspects of cerebral lateralization: Cues to the origin of lateralization. *Neuropsychologia, 15(6)*, 743-750.

Leibenluft, E., Charney, D. S., and Pine, D. S. (2003). Researching the pathophysiology of pediatric bipolar disorder. *Biological Psychiatry, 53*, 1009-1020.

Lewis, M. (1993). The emergence of human emotions. In M. Lewis and J. M. Haviland (Eds.), *Handbook of emotions*. New York: Guilford Press.

Meyer, T. J., Miller, M. L., Metzger, R. L., Borkovec T. D., et al. (1990). Development and validation of the Penn State worry questionnaire. *Behavioral Research and Therapy, 8*, 487-495.

Murray, N., Sujan, H., Hirt, E. R., and Sujan, M. (1990). The influence of mood on categorization: A cognitive flexibility interpretation. *Journal of Personality and Social Psychology, 59(3)*, 411-425.

Myers, J. J. and Sperry, R. W. (1985). Interhemispheric communication after section of the forebrain commissures. *Cortex, 21*, 249-260.

Nezlek, J. B., and Plesko, R. M. (2003). Affect- and self-based models of relationships between daily events and daily well-being. *Personality and Social Psychology Bulletin, 29(5)*, 584-596.

Papez, J. W. (1937). A proposed mechanism of emotion. *Archives of Neurology and Psychiatry, 38*, 725-743.

Reich, J. W., Zautra, A. J. and Potter, P. T. (2001). Cognitive structure and the independence of positive and negative affect. *Journal of Social and Clinical Psychology. 20(1)*, 99-115.

Ridgeway, D. and Waters, E. (1987). Induced mood and preschoolers' behavior: Isolating the effects of hedonic tone and degree of arousal. *Journal of Personality and Social Psychology, 52(3)*, 620-625.

Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General, 104(3)*, 192-233.
Ryan, R., and Deci, E. (2000). The darker and brighter sides of human existence: Basic psychological needs as a unifying concept. *Psychological Inquiry*, *11*, 319–338.

Seligman, M. E. P. (2002). *Authentic Happiness: Using the New Positive Psychology to Realize Your Potential for Lasting Fulfillment*. New York: Free Press/Simon and Schuster.

Sergent, J. (1990). Furtive incursions into bicameral minds. *Brain, 113(2)*, 537-568 [Abstract only].

Sperry R. W., Zaidel E., and Zaidel D. (1979). Self recognition and social awareness in the deconnected minor hemisphere. *Neuropsychologia, 17(2)*, 153-166.

Staw, B. M., Sutton, R. I., and Pelled, L. H. (1994). Employee positive emotion and favorable outcomes at the workplace. *Organizational Science*, *5*, 51–71.

Tomkins, S. S. (1962). *Affect, imagery, consciousness*. Volume I: *The positive affects*. New York: Springer.

Velten, E. Jr. (1968). A laboratory task for induction of mood states. *Behaviour Research and Therapy, 6(4)*, 473-482.

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology, 54(6)*, 1063-1070.

Weissman, D. H. and Banich, M. T. (2000). The cerebral hemispheres cooperate to perform complex but not simple tasks. *Neuropsychology, 14(1)*, 41-59.

Weissman, D. H., Banich, M. T., and Puente, E. I. (2000). An unbalanced distribution of inputs across the hemispheres facilitates interhemispheric interaction. *Journal of the International Neuropsychological Society, 6*, 313-321.

Wernicke, C. (1874). [The Aphasia Symptom-Complex: A Psychological Study on an Anatomical Basis].

Wilson, K. G., and Eleonora Moss, S. (1998). The youth version of the Positive and Negative Affect Schedule: A psychometric validation. *Behaviour Change, 15(3)*, 187-193.

Zaidel, E., and Iacoboni, M. (2003). *The parallel brain: The cognitive neuroscience of the corpus callosum*. Cambridge, MA: A Bradford Book.

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