NORTHWESTERN UNIVERSITY

# The Behavioral and Neural Basis for the facilitation of Insight Problem-Solving by a Positive Mood

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

DOCTOR OF PHILOSOPHY

FIELD OF NEUROSCIENCE (Northwestern University Interdepartmental Neuroscience Program)

By

Karuna Subramaniam

EVANSTON, ILLINOIS

December 2008

# ABSTRACT

## The Behavioral and Neural Basis for the facilitation of Insight Problem-Solving by a Positive Mood

**Karuna Subramaniam**

Previous research has shown that creative insight problem-solving is distinct from systematic analytical problem-solving. Behaviorally, a positive mood has shown to facilitate insights but without knowing the processes that are fundamental to insight, the mechanisms as to how a positive mood facilitates insights have remained unspecified. Here, we investigate the neural basis of how a positive mood facilitates insight-solving. We assessed mood/personality variables in 79 participants before they tackled word problems that can either be solved with insight or analytically. Participants higher in positive mood solved more problems, and specifically more with insight, compared to participants lower in positive mood. Functional magnetic resonance imaging (fMRI) was performed on 27 of the participants while they solved problems. Positive mood correlated with preparatory brain activity within the anterior cingulate cortex (ACC) that preceded each solved problem. Modulation of this preparatory activity in ACC biased people to solve either with insight or analytically. Analyses examined whether (a) positive mood modulated activity in brain areas showing increased preparatory signal; (b) positive mood modulated activity in areas showing stronger activity for insight solutions than analytical solutions and (c) insight effects occurred in areas that showed a positive mood-related preparatory effect. Across three analyses, ACC showed sensitivity to both mood and insight, demonstrating that positive mood alters preparatory activity in ACC, biasing participants to engage in processing conducive to insight solving. We next manipulated positive and neutral mood states within each participant to draw strong causal inferences as to whether a positive mood induction (MI) would specifically facilitate insights. When participants were in the positive MI, they showed increased preparatory activity in ACC, particularly for preparation leading to insights, and solved more problems overall compared to when they were in the neutral MI. These results from the mood induction study replicate the positive mood-insight facilitatory effect observed in our assessed mood study. Specifically, across both studies, we show that a positive mood enhances insight by modulating attention/cognitive control mechanisms within the ACC to either allow more sensitivity to detect competing solution candidates, to enhance switching and/or to enhance selection processes to converge to the correct solution.

# ACKNOWLEDGEMENTS

I would like to acknowledge my committee, Dr. Jay Gottfried, Dr. Richard Zinbarg, and Dr. Mark Jung-Beeman for your guidance and support throughout this process. Special thanks to my mentor, Dr. Mark Jung-Beeman, for inspiring my research interests and providing me with several years of invaluable training in the neuroimaging field within the cognitive neurosciences. Additional thanks to the Jung-Beeman lab, to NUIN and to Dr. David Schneeweis for your support and encouragement. Finally, I would like to sincerely thank all of the individuals who participated in this study.

# Table of Contents

# Chapter 1: Introduction

The Archimedes "Eureka!" moment is probably the most popular cited example of insight problem solving. According to the legend, the king had ordered a new crown, consisting of solely pure gold but he suspected that the goldsmith had combined the gold with impurities. The king asked Archimedes to prove that the crown contained impurities without damaging the crown. Archimedes racked his brains over the problem for a while, but reached an impasse where he seemed to be "stuck" not making any progress toward a solution, and so he decided to not think about the problem for a while and have a relaxing soak at the bath house. As Archimedes lowered himself slowly in, he noticed that the water level rose. When he arose from the bath, the water level went back down. Then, suddenly, he instantly realized that the displacement of the water had to be exactly the same volume as his body, and that he could use water displacement to calculate the density of the King's crown in order to find out if it was made of pure gold. Archimedes was ecstatic, and rushed out running wildly through the streets crying out 'Eureka!' So strong was his emotional experience that he ran out without wearing his clothes first! Since then, psychologists have been fascinated by the nature of insight or the "Aha!" moment used to describe the feeling of an insight mainly because of its distinct characteristics that differentiate it from problems solved in a more systematic analytical manner without insight.

Other accounts of insight moments include: Sir Isaac Newton's discovery of gravity; Kekule's discovery of the ring structure of benzene; and Albert Einstein's theory of relativity. In all these cases, insight occurred when these historical figures either seemed not to be thinking about the problem at all, or allowed their thoughts to wander in order to avail themselves of hints in the environment. For instance, Newton formulated his theory of gravity at the sight of an apple falling to the ground; Kekule had supposedly had his insight of the ring structure of benzene when he awoke from a dream where he dreamt of a snake that held its own tail; and Einstein formulated his relativity theory when he allowed his thoughts to wander to the idea of free fall where he suddenly realized that a person would not feel his weight during free fall unless there was a link between motion and gravity. Even though these are the world renowned examples of insights, insights are ubiquitous and can happen to anyone but they are rare, which makes it hard to study.

Here, we have devised an experiment where solvers are able to generate many insights so that we have enough sample power to be able to study both the behavioral and neural basis of insight solving using functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) techniques. We believe that to generate insights, one needs to generate many ideas, but then one also needs to be able to discard those ideas that do not work in order to converge to the correct solution/solution path, similar to the processes involved in creative problem-solving.

In my thesis, in Chapter 2, I first talk about insight being a form of creativity but being distinct from analytical systematic methods of problem-solving. Next, I discuss the Compound Remote Associate (CRA) paradigm we use to study insights in terms of discussing how it is an ideal paradigm to study both the behavioral processes involved as well as the neural basis of insight as participants tackle the CRA problems while we measure their brain activity using fMRI and EEG techniques. I then discuss the cognitive and neural processes that are emphasized during insight solving in order to explain which processes are likely to facilitate insights. I illustrate this point by first exploring whether it is the ability to make a connection in the form of integrating different ideas or concepts that is important to insight? I then discuss whether it is the ability to restructure or reframe the problem elements into a new holistic concept that may facilitate insights? Finally, I expound on whether it is a combination of the above processes that are guided by top-down cognitive control processes in the frontal cortex, which regulate the processes of integration and restructuring to control what associations solvers need to inhibit, and what associations they need to switch to and select in order to have an insight – the "Aha!" I then briefly explain our neural findings at the moment of solution when participants solve CRA problems with an insight compared to a more analytical approach. In this analysis, I investigate all the brain regions that show greater solution-related activation for insights compared to analytical solutions, where the 2 largest regions that show an insight solution-related effect are the regions involved in making distant connections (i.e., the right superior and middle temporal gyri (R.S/MTG)) as well as the frontal region involved in exerting top-down control (i.e., anterior cingulate cortex (ACC)/medial prefrontal cortex (mPFC)). I explain why these results suggest that the ACC works in cohort with the right S/MTG to exert greater control so that solvers are better able to access these distant connections, at a subthreshold level to increase the number of competing solution related and unrelated processes (increased neural responsivity in the right STG) that compete for attention, potentially leading to a switch to select the correct solution (ACC and PFC) when there is a gain in strength to conscious threshold activation, resulting in a sudden sensation of "wholeness" or "Aha"

I then delve into the neural processes that bias solvers to solving the imminent problem with insight even before presentation of the problem (i.e., while they are preparing for the next problem). I discuss the neural basis of the distinct mental preparatory states that predispose solvers toward an insight compared to more analytical methods of solving. This leads into the various factors we measured that could potentially modulate this pre-problem preparatory brain state to facilitate an insight, and why the specific state of a positive mood is important to the facilitation of an insight.

In Chapter 3, I explore the literature on positive mood to demonstrate that positive mood has shown to enhance each of the fundamental processes that are important for insight solving. I first discuss the influence of positive mood in terms of enhancing integration processes through the broadening of attention and through enhancing the semantic interrelatedness of items. Then, I discuss the positive mood literature in terms of its influence on modulating switching processes which help to restructure and reframe the problem into a new holistic element. Finally, I explore the effects of a positive mood on modulating control to switch between different attentional modes (i.e., between a broad and local attentional foci) and/or switch between strategies (i.e., switching away from dominant yet irrelevant concepts) to select the correct solution. I discuss how through this exertion of greater top-down control, participants in a positive mood are better able to modulate the shift between enhancing integration processes in terms of enhancing divergent thinking (thinking of many ideas) but are also able to enhance convergent thinking so that solvers are better able to know which ideas to inhibit, and which ideas to switch to and select. I conclude this chapter by proposing, based on the prior positive mood literature evidence, that a positive mood would likely enhance insights by guiding these top-down control mechanisms in the frontal cortex, specifically by enhancing ACC activation as the current demands of the task necessitate, to regulate both divergent thinking where solvers generate many ideas as well as convergent modes of thinking where solvers are able to hone in and suddenly detect the correct association in an "Aha!".

In Chapter 4, I explain the neural basis of how a positive mood facilitates insight using our CRA paradigm. Here, we assess mood and personality variables across 79 participants before they attempt to tackle the CRA problems that can be solved either by an insight or analytic strategy. We show that participants higher in positive mood solved more problems overall, and specifically more with insight, compared to participants lower in positive mood. We demonstrate that a positive mood was associated with increases in brain activity within the ACC during a preparatory interval preceding each solved problem. I explain how a positive mood modulated this preparatory activity in ACC to bias people to solve either with insight or analytically by conducting three analyses where: (a) the first examined whether mood modulated activity in brain areas that showed changes in activity during preparation; (b) the second examined whether mood modulated activity in areas showing stronger activity for insight than trials solved without insight either during preparation or solution; (c) the third examined whether insight effects occurred in areas that showed mood-related effects during preparation. Across these three analyses, the ACC showed sensitivity to both positive mood and insight, demonstrating that positive mood alters preparatory activity in ACC, biasing participants to engage in processing conducive to insight solving. Finally, I discuss how this result suggests that positive mood enhances insight by modulating attention and cognitive control mechanisms via the ACC, likely regulating the shift between divergent thinking to detect various remote solution candidates and convergent thinking to hone in on the correct solution. In other words, I explain how this shift in solving strategy toward an insight involves increased cognitive control as participants need to up-regulate control to be able to overcome the impasse that is frequently associated with insight, to switch away from prepotent yet errant associations in order to select the correct remote association.

In Chapter 5, I induce positive, neutral and anxiety mood states in each participant to confirm whether manipulating a positive mood compared to a neutral mood would modulate the shift in solving toward more of an insight. I manipulate these differential mood states using film clips and demonstrate that a positive mood was both induced and maintained throughout the positive mood induction blocks of CRA trials. From our results in chapter 4 on the influence of assessed positive mood on insight, it remains possible that insight may be modulated directly by another factor which covaries with positive mood. In this chapter, I draw stronger causal inferences by specifically inducing a positive, neutral and anxious mood state in each participant to demonstrate that inducing a positive mood enhances overall CRA solving, and specifically enhances insight solving compared to a neutral mood. Further, in the second part, I replicate my neural findings in the assessed positive mood study where I demonstrate here that induced positive mood states also modulate preparatory activity in ACC to bias processing towards insight similar to that of the earlier assessed positive mood study.

In Chapter 6, I conclude my thesis by stating that the induction of a positive mood facilitates overall solving by specifically enhancing insight solving, similar to the influence of our assessed positive mood effects on insight solving, through the modulation of ACC activity. These behavioral and neural results strongly suggest that an induced positive mood also modulates insight by similar cognitive and neural processes as demonstrated in our assessed positive mood CRA study. In other words, we believe that a positive mood enhances insight solving by enhancing cognitive control mechanisms in ACC as the current demands of the task necessitate – probably by modulating the shift between enhancing the detection of competing distant semantic associations (i.e, divergent thinking), and overriding irrelevant prepotent associations likely activated strongly in the left hemisphere in order to switch to focus on the solution-relevant weakly activated distant association (i.e., convergent thinking), allowing it to gain in strength and rise to a conscious threshold to be detected suddenly in the form of an "Aha!"

# Chapter 2: Insight Problem Solving

Since more than a century ago, one of the primary areas of interest in psychology has been in understanding the nature of problem solving. Problem solving may be broadly classified into 2 distinct categories: creative versus analytical. Creativity is required for problems that we face in day to day living where there is no straightforward systematic way of solving such problems. Unlike analytical solving which involves a step by step structured approach to the solution, creative problem solving quite often involves going “outside the box” to consider various seemingly unrelated remote possibilities in order to generate a novel, meaningful solution. The combination of finding a novel yet valid solution involve both divergent thinking to explore a wide range of possibilities as well as convergent thinking to hone in on a meaningful solution. Since there is no methodical and systematic way to reach the solution, creative problem solving is particularly interesting principally because the exact processes that lead to solution remain a mystery not only to psychologists but to the solvers themselves (Terzis., 2001; Bowden & Jung-Beeman., 2007; King et al., 1996). Insight is a good example of this form of creative cognition that occurs when solvers let go of traditional ideas to restructure the problem in order to form a novel concept.

## The nature of insight

Insights do not happen often, and frequently involve being stuck at an impasse when trying to find a solution, but on the rare occasion that the solution does suddenly “hit” it's a definite thrill! Although insights may not happen often, they are ubiquitous since all of us have experienced this "Eureka!" experience at some point in our lives, when trying to find the solution of a seemingly difficult problem. Insights are a form of creative problem solving. Creativity and insight both involve the integration of concepts or problem-solving elements so that solvers are able to suddenly recognize these connections that had previously eluded them, and instantly see the solution in a new light in the "Eureka!" experience. Additionally, for both general creative solving and for specifically insight solving, the solver has to "go outside the box" to integrate existing concepts in a novel way to the solver. Performance on insight problems is associated with creative thinking and is not associated with performance on analytical problems (Schooler & Melcher., 1997). So the question is, how do creative insight solutions differ from analytical solutions which require more systematic approaches? We have found that insights differ from analytical solutions in a number of different ways. We used a combination of behavioral subjective measures (i.e., using confidence ratings that measured how certain solvers were of solutions, and warmth ratings that measured how close solvers thought they were to the solution), as well as somewhat more objective neural measures (i.e., using fMRI and EEG to measure brain activity as subjects solved trials either with an insight compared to an analytical approach). Firstly, from subjective reports, solvers often reach an impasse where they feel that they are not making progress toward a solution just, as Archimides did while puzzling over how to determine that the King's crown was made of pure gold (Duncker, 1945; Schooler et al., 1993; Jung-Beeman et al., 2004). Secondly, solvers usually cannot report the processing that enables them to overcome the impasse (Maier, 1931). Indeed, insight often occurs when people are not even aware they are thinking of the problem and are in a more relaxed phase, as reportedly happened to Archimedes while in the baths. This relaxation phase allows the brain to switch to using more unconventional strategies, and to be more open to more remote possibilities so that existing concepts can be restructured in novel way. Finally, solvers experience their solutions as sudden and unexpected, and when they eventually do arrive at the solution, it appears to be obviously correct, and solvers do not have to double-check their solution but are instantly confident of the solution. In other words, upon arriving at the solution, solvers have an Aha! experience, which is considered the main defining feature of insight problems (Schooler et al., 1993; Jung-Beeman et al., 2004). For instance, in the legend, Archimedes ran out into the streets from the baths shouting "Eureka!" forgetting to wear his clothes first.

However, if insight only occurs very rarely, the question is how do we measure insight to understand more about the cognitive and neural underpinnings? Indeed, some researchers have suggested that the characteristics of insight solutions differ from analytical solutions only in emotional intensity, and involve the same cognitive mechanisms (Weisberg, 1986; Perkins, 2000). Here, we use a paradigm modified from the Remote Association Task (explained below) called the Compound Remote Association (CRA) task to describe the neural activation patterns involved during insight solutions versus more systematic analytical solutions. The CRA task is useful to measure insight because it allows us to give solvers many problems that are not too easy or too difficult, such that participants are able to solve a good proportion of these trials in 15 seconds and are also able to have insights (or analytical solutions) on roughly half of the solved trials. In this way, we have enough power in terms of the number of insight and analytical solutions to provide neural evidence to challenge the theory that insight differs from analytical solving only in the emotional response, as we show the distinct *cognitive neural processes* that predict and lead to insight compared to analytical solutions. For instance, we have demonstrated that as solvers reach an insight solution, the regions that show the strongest insight effect are not regions thought to be involved in emotional processes. We, therefore, refute the claim that insights are distinct from analytical solutions in solely an emotional, rather than a cognitive sense (see Chapter 4). Additionally, the CRA task enables us to examine the neural basis of how certain factors (i.e., individual differences) may promote insight by shifting the bias in CRA solving toward more of an insight (see Chapters 4 and 5). There are several other reasons, described below, why we modified the RAT to create the CRA problems. First, let us explore the nature of the RAT, which was the initial measure of creative cognition and insight using word association triads (Mednick., 1962).

**Quantifying creative problem solving and insight: Remote Association Task**

The remote association task (RAT) was created by Mednick (1962) as a quantifiable way of assessing creative problem solving. The items in the RAT consist of three seemingly unrelated words that are associated with a third solution word in different ways. For instance, the words: tennis, stick and same are associated with the solution MATCH by formation of a compound word (matchstick), by semantic association (tennis match) and by synonymy (same = match). Therefore, this ability to solve Mednick's RAT items requires both divergent thinking where solvers would need to engage in a broad set of associations, as well as convergent thinking where the solver would need to hone in to find the single word that forms a meaningful phrase. Often the first, predominant association retrieved is not correct. For instance, the word "ball" fits with tennis by semantic association but it does not fit with "same." Therefore, solvers must inhibit this predominant association and think of a more remote association which connects all three words. RAT items have an advantage in comparison to classic insight problems in that they are not as complex as classic insight problems but do involve the same component processes associated with traditional classic insight problems that distinguish insight solutions from analytical solutions (Bowden et al., 2003b). For instance, while solving RAT items:

(1) solvers are usually misdirected (or do not pursue the correct solution path) and get stuck at an impasse.

(2) solvers often cannot report the processing that led to the solution.

(3) solvers often have the Aha! experience.

Additionally, problem solvers' success on items from the original RAT correlates with their success on classic insight problems (Schooler & Melcher, 1997). Because the RAT items are not as complex as classic insight problems, participants are able to attempt many problems in an experimental session rather than just one or two in the case of complex classic insight problems. This allows us to disentangle the various component processes of insight compared to analytical solutions across a large number of trials. Problem solving in general is complex in that it requires a network of shared cortical areas across all types of solutions, so solving problems with insight versus analytically would recruit many shared cognitive processes and neural mechanisms. At the same time, if insight does involve distinct cognitive processes, insight solving should recruit different regions and/or regions that are common to both strategies but which will be emphasized during insight solving in comparison to analytical solutions. If, as some researchers suggest, insight merely differed from analytical solutions in an emotional but not cognitive sense, then we would expect regions involved in emotional processes to be recruited at the moment of solution (i.e., the Aha!) for insight versus analytical solutions. In contrast, if insight involves distinct cognitive processes, this insight versus analytical contrast will reveal the distinct underlying brain activity at the time-point just prior to solution where differential cognitive neural components will be engaged or emphasized just prior to solvers reaching the solution with insight compared to arriving at the solution through analytical means.

We did not think Mednick's (1962) original 30-itemed RAT was ideal to test the processes involved in insight versus analytical solutions because the solution word for each item was associated with the words in a triad in several different ways, which makes them difficult to solve. Therefore, we chose to simplify this even more by modifying the RAT into the Compound Remote Association (CRA) task, which has many more trials than the RAT and for which the solution word forms a compound with each of the three target words. For instance, in the CRA task, the solver is given 3 words such as "horse" "over," and "plant" and is asked to think of a fourth word that can be combined with all three to form a compound word or phrase. The solution word can be placed either before of after any of the three words in the triad to form the compound word. In this case, "power" is the solution word, which forms the compounds "horsepower" "overpower," and "power-plant."

**Modification of RAT into Compund Remote Association (CRA) Task**

All the CRA trials used in the experiments reported here can be solved by at least 15% of participants during a limited time (15s), based on normative data across 289 participants (Bowden & Beeman, 2003b). This enabled us to generate lots of trials (i.e., 135 trials) so that we had enough sample power to contrast trials solved with insights versus trials solved analytically.

We designed the CRA trials to be different from the RAT in 2 major ways: Firstly, as aforementioned, each of the trials have only one single solution word that is related to all the three words in the triad in a single consistent way where the solution word forms a compound word or phrase. In this way, the neural processes when tackling different problems are not confounded by increased complexity as in the case of the RAT where the solution word may be associated with each of the three words in as many as three different ways (i.e., semantically, through synonymy, and by forming a compound word). These RAT trials would likely have confounding cognitive (and, therefore, neural) variables such as that of possibly recruiting additional neural components (or enhancing activity in certain regions) as a function of increased complexity compared to the simpler RAT trials where the solution word is associated with all three words in only one way (compound word). Through solely compound word production the simplicity of our CRA trials, compared to the RAT, allow us to have more consistent neural effects at various time points of interest (i.e. preparation periods prior to even viewing the problem; problem onsets when the problem is first presented and solution production) with fewer confounding variables across trials.

Secondly, in the CRA after solvers have arrived upon the correct solution word, we asked them to make judgments of whether they arrived at the solution with an insight or through a step by step analytical process. Specifically, instructions to participants regarding these judgments involved participants assessing various aspects of their solutions. For instance, participants were asked to evaluate:

(i) whether they arrived at the solution by a conscious strategy such as a trial and error approach where they would have to try out each possible word combination, perhaps first testing words that went with "horse," then "over" and then with "plant" or whether solvers were unaware of the solving process.

(ii) they became aware of the solution suddenly or an incremental manner;

(iii) how confident they were of their solution (i.e., whether they needed to verify the answer);

(iv) whether they experienced an "Aha!" sensation possibly right after switching to a new association or solution candidate.

By comparing processing for insight versus analytical solutions on identical problem types, we isolated distinct neural components associated with the subjective experience of an insight. Usually participants who solved a trial analytically had to work incrementally toward a solution and were able to verbalize the process by which they arrived at the solution, but also need to double-check that the solution fit with all 3 words. In contrast, when solvers reached the solution with insight, they usually were unaware of the process by which they arrived at the solution. Insight has been termed an "all or none" phenomenon wherein the solution appears to come from nowhere and the solver, upon reaching solution, is suddenly and instantly confident of the solution and does not have to go back and verify the answer. We know from our earlier studies that insight solutions categorized in this manner are associated with distinct patterns of neural and cognitive processes different from analytical solutions (Bowden & Beeman, 1998; Bowden & Jung-Beeman., 2003a; Jung-Beeman et al., 2004; Subramaniam et al., In Press). Additionally, our approach extends the traditional insight literature wherein a priori categorizations of insight and analytical solutions were based on the *problems* themselves rather than the *solutions*. Classic insight problems can be solved analytically by some people; and classic analytic problems sometimes require an insight en route to solving (unpublished pilot data from our lab). In these studies, we focus on insight versus analytic processing, rather than problem categories.

Thirdly, unlike traditional classic insight problems and riddles which may become less insight-like as the solver learns a specific strategy with the experience of solving that type of problem, CRA problems require finding different associates each time and, therefore, do not depend on a certain strategic association for gaining a solution. Take, for instance, The Hole Problem and The Fake Coin Problem wherein the solution lies in the solver realizing that there are inherent flaws within the initial problem constructs themselves (see below).

**The Hole Problem**

How much dirt is there in a hole, six metres long, 2 metres wide and one metre deep?

Solution: There is no dirt in a hole (Ansburg & Dominowsky, 2000)

**The Fake Coin problem**

A stranger approached a museum curator and offered him an ancient bronze coin. The coin had an authentic appearance and was marked with the date 544 BC. The curator had happily made acquisitions from suspicious sources before but this time he promptly called the police and had the stranger arrested. Why?

Solution: Nothing authentic can be dated 'BC' (Weisberg, 1995)

In The Hole Problem, participants are asked: 'How much dirt is there in a hole, six metres long, 2 metres wide and one metre deep?' The solution is that there is no dirt in a hole. In The Hole Problem, the solver needs to reframe the problem to realize that a hole cannot be a hole if it has dirt filled to capacity. In The Fake Coin Problem, participants are asked: 'A stranger approached a museum curator and offered him an ancient bronze coin. The coin had an authentic appearance and was marked with the date 544 BC. The curator had happily made acquisitions from suspicious sources before but this time he promptly called the police and had the stranger arrested. Why?' The solution is that nothing authentic can be dated 'BC'. Similarly, in The Fake Coin Problem, the solver needs to realize that there is an inherent flaw with the problem construct in that a coin marked 544BC could not have had the BC marking before Christ was born (see Appendix). In contrast, with the CRA, such a strategy cannot be used. If any "strategy" is used to solve a CRA with insight, it would likely be focusing on, paradoxically enough, remaining "unfocused" so as to generate as many solution candidates, which could come either before or after any of the three words. Therefore, it is unlikely that the solutions might become less insight-like as the solver gains experience by understanding a specific strategy within the specific type of problem.

However, it may be argued that the problem itself may facilitate more of an insight or analytical method of solving. For instance, we might think that switching the order of the solution word so that it comes *before* one CRA word *and after* another word could facilitate switching/restructuring mechanisms that would lead to an insight. In the example provided above, the CRA words are "horse, " "over" and "plant" where the solution word "power" comes after two of the words "horse" and "over" to form the compounds "horsepower" and "overpower" but comes before the word "plant" to form "power-plant." Yet, we have shown that in correct trials across 79 participants, if the order of the solution word is *mixed* in that it could come *before at least one word and after at least one word,* it is not any more likely to be solved with an insight compared to *one-way* trials where the order of the solution word is *either before all 3 words or after all 3 words.* In fact, just prior to the experiment, the solver is specifically told that the solution word can come either before or after any of the 3 words, and, therefore, has to try various possibilities before and after each word. We argue that it is the sudden switch *in semantic or associative space*, rather than in the specific trial itself (i.e., switching the order of the solution word between the 3 CRA words), that makes solvers more likely to recognize the solution as an insight. Therefore, whether a particular solver will have an insight is participant dependent and not trial specific. This is why, even though insights involve restructuring of information, we do not see a greater proportion of insights for mixed trials versus one-way trials. In other words, a certain solver may come up with the word ‘power’ by thinking of all the associations that combine with ‘over’ as in ‘over-age, over-priced’…and then may suddenly hit upon the solution, realizing “Oh! Power!” when the solver “just knows” it works with all 3 problem words. A less potent insight may occur when a solver places the word ‘power’ after all 3 words at first, and it is only when he restructures the internal conceptual problem-space in his mind that he is able to suddenly realize that power has a new meaningful sense only when it comes before, and not after, plant that he has the sudden realization of an insight. For instance, one might think “Overpower… horsepower… and plant-power? Hmmmm….oh, of course power-plant!” In contrast, another solver, may arrive at the word “power” through a very systematic step by step trial and error analytical approach by coming up with various possibilities and rejecting them one by one after placing each candidate before and after each CRA word until the solver finds that power fits with all 3 words.

Some earlier researchers argued that creativity (and insight) generally was participant-specific, and made a distinction between personal creativity (P-creative) and historically creative (H-creative) ideas (Boden., 1994; cited from Bowden & Jung-Beeman., 2007). An idea is P-creative if the person who has the idea has not had it before, regardless of the number of times other people have already had the same idea. Thus, a person could solve a problem with insight that is solved by most people without insight just as a person can also solve a problem without insight that most people solve with insight. The GRE Analytical Problems, for example, are good examples of problems typically solved in an analytical step by step approach. Take, for example, the following problem: "Bacteria placed in a jar doubles the area they cover every day. If the dish is uncovered after 10 days, on what day was it only 1/4 the size of day 10." Most people would get the solution by working backward in a step by step approach, realizing that on day 9 the jar would be half full, and therefore, on day 8, it would be half of that half, which is one-quarter. However, if a certain solver is focused on the wrong forward path, thinking of one bacterium which doubles the $2^{nd}$ day and then multiplies by four on the third day and so on, he may arrive at the solution with more of an insight for this problem when he restructures his solving path to suddenly realize that the correct solution path is to work backward instead of forward. Hence, the presence or absence of insight lies in the solver's *solution* rather than in the *problem*. Therefore, we have chosen to rely on reports from the solvers themselves to determine when an insight has occurred in the CRA task, rather than making a priori categorizations that solving all CRA problems would lead to an insight.

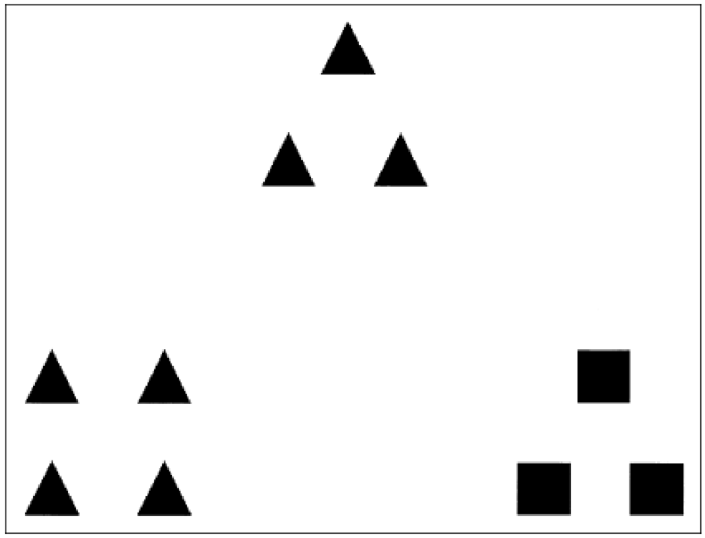
To clarify, we are not stating that when participants solve a CRA trial with insight, they have to employ solely insight methods in their solving process. As previously noted, problem solving is a multifaceted behavior in which both insight and analytical solving share similar cognitive and neural elements. Thus, when solvers confront a problem, they engage multiple mechanisms, but either due to their state of mind or due to the way they perceive the specific stimulus itself, an insight or analytical mechanism will be favored as the solver arrives at the solution. In other words, the solver may begin the solving process by using a more systematic, analytical, trial and error approach, but then may switch to using a more insight approach later on in the solving process. For instance, when the solver seems to be stuck at an impasse, the solver may exert increased control to be able to switch strategies, or switch from a narrow (local) to a broader (global) mode of attention, permitting entry of more distant solution-relevant associations which were up to this point only weakly activated in the right hemisphere (see part (B) on Integration below). The frontal cortex (anterior cingulate cortex and prefrontal cortex) guide these top-down control processes to inhibit prepotent associations that are strongly activated, likely in the left hemisphere (i.e., in the CRA example, the word 'ride' could be a more prepotent association which fits with 'horse' and 'over' but not with 'plant'). When this strong, overshadowing activation of the prepotent association subsides, it allows the weakly activated solution word (i.e., power) to gain in strength and rise to a conscious threshold. Once a conscious threshold is reached, the solver is suddenly able to detect the correct solution, which seemed to appear from nowhere, and the solver is instantly confident that 'power' is the answer without being aware of the solving process that led him to have an "Aha!" once he detected the solution. In this manner, a problem can be solved with more of an insight even though at the beginning of the solving phase, the solver uses more of an analytical approach.

Thus, the crucial question is to understand what behavioral and neural processes are involved during insight solving, so that we may be able to facilitate its occurrence by enhancing those behavioral and neural processes. For instance, is the critical distinctive feature of insight generating a diverse range of associations? Or integrating remote ideas? Or switching attention or strategies to restructure the initial problem elements in a new way? Or is it perhaps inhibiting irrelevant conventional associations? Or is it really the final detection and selection of the correct response? Since problem solving involves multifaceted complex processes, it is likely that insights involve not simply one of the above-mentioned processes but a combination of all these processes. We will explore all these possibilities. We begin by investigating whether the facilitation of integration processes enhances insights, then we will look at the influence of restructuring/switching processes on insights, and then finally we will investigate whether increasing control to enhance inhibition, switching and/or selection process modulates insights.

**A) Integration : RH versus LH**

Within the insight literature, according to the Gestalt perspective, integration is defined as combining all the parts into a “whole” percept in a new way by which the final product is more than the sum of its parts. It therefore makes sense to think that adopting a more holistic and global mode of thought may facilitate these integration processes that may, in turn, facilitate an insight. If a holistic mode of thought could facilitate insight, we could test this by using items from a global-local focus test (Kimchi & Palmer, 1982) to prime participants to use either a holistic versus local mode of thought, and then test whether the subsequent CRA trial is more likely to be solved with insight if primed by global versus local level-of-focus figures.

**Global versus Local Paradigm**



**Item from global-local focus test (Kimchi & Palmer, 1982, p.526)**

Priming paradigms are particularly useful in demonstrating whether people make a faster response if they are already prepared to make that response. A holistic focus of attention is thought to be associated with relative increased right hemisphere (RH) processing. Therefore, if a global mode of thought biases insight, we might expect to see relatively increased RH processing for insight versus analytical solutions. Indeed, in our CRA solution priming experiments, participants showed greater priming (faster RTs) for naming solution words relative to unrelated words presented to the RH than for those presented to the Left Hemisphere (LH) (Beeman & Bowden, 2000; Bowden & Beeman, 2003a). This result was particularly interesting because it demonstrated a RH advantage for responding to words, which has been typically thought of as more of an LH specialty. Furthermore, participants' experience of insight ratings correlated better with solution priming for RH targets. Priming effects were also found during unsolved trials in the RH as opposed to the LH. These integration processes may be undertaken at a largely subconscious level, which is why participants still show solution activation for the target in the RH (but not the LH) on unsolved trials, when they are not consciously aware of the solution – indicated by the fact that they do not solve the problems (Bowden & Beeman, 2003a). Indeed, when contrasting insightfully-solved trials with analytically-solved trials both at problem presentation and just prior to solution, we have found that the strongest insight effect from our convergent results using both fMRI and EEG was in the RH, specifically in the right anterior superior and middle temporal gyri (RaM/STG) (Subramaniam et al., In Press). We now explain these hemispheric asymmetries in terms of the underlying neural architecture to attempt to explain why we think the CRA solution word in these priming experiments is activated faster in the RH than the LH, and why increased RH (specifically RaM/STG) facilitates insight solving by enhancing this integration of distant associations.

According to one theory, the RH is more adept at integrating a wider range of inputs, as in the case of the CRA task, because the RH performs relatively "coarser semantic coding" to activate a broad range of distantly-connected associations (Beeman, 1994; Jung-Beeman, 2005). The LH, by contrast, is more adept at honing in on close associations, performing relatively "finer semantic coding" (Beeman et al, 1994; Bowden et al., 1998; Bowden & Jung-Beeman, 2003a). This hemispheric specialization may partly be explained in terms of the cytoarchitectonics where the RH is generally more interconnected than the LH, having a greater proportion of white matter to form connections between neurons. Furthermore, dendrites in the RH branch more distally from the soma with a larger number of dendritic spines to make it more adept at receiving a wider range of distant semantic associations (Hutsler & Galuske, 2003; Jung-Beeman, 2005).

Siegler (2000) considers the solving of an insight problem a kind of unconscious 'spreading activation' between the relevant concepts. In other words, distantly related concepts such as the word 'power' in the CRA example 'horse,' 'over' and 'plant' is activated earlier in the RH than in the LH. It is only when these mutually activated concepts summate both temporally and spatially in terms of neuronal excitation that the word 'power' rises to a conscious threshold level and can then be detected. However, if solvers strongly focus on close associations activated more in the LH such as horse-'*rider*,' or horse –'shoe,' then the solver is likely to reach an impasse. It is when solvers inhibit these prepotent associations and break this mental set to allow more diffuse activation among competing associations in the RH to rise to conscious threshold that they are able to overcome impasse and suddenly detect the relevant solution 'power,' in the "Aha!" moment where the answer seems to come from nowhere but nonetheless, they are instantly confident of the answer.

Prior studies done on people with RH damage have indicated that they can have difficulty integrating distant concepts or concept with multiple meanings and, consequently, do not get jokes, are unable to make inferences during a story, and often get lost following themes in stories or during complex discourse (Brownell et al., 1986; Beeman, 1993; Beeman & Bowden, 2000; Bowden & Beeman, 1998; Jung-Beeman, 2005). All these tasks require integration of a wide range of information for which the RH seems to be particularly adept. Studies may also, therefore, be undertaken in these RH damaged patients to test whether they have particular difficulty in solving problems with insight given that they show the above-mentioned impairments at performing "coarse semantic coding." The corollary of this would be that RH damaged patients should demonstrate less difficulty at arriving at analytical solutions, which do not rely as much on integration of distant associations needed for insight.

An alternate way of investigating whether the RH is integral for insight is through inducing Transcranial Magnetic Stimulation (TMS) over the right STG to both inhibit and stimulate activity within this region. We could test whether stimulating right STG increases the proportion of CRA insights, and inhibiting right STG decreases the proportion of CRA insights, compared to normal. According to the semantic theory, if a specific word elicits a semantic field in each hemisphere – a focused one in the LH and a more diffuse one in the RH, then we might predict that stimulation in the R M/STG would enhance activation and integration of a large number of remote associations, one of which is likely to be the solution (Beeman et al, 1993, Bowden & Beeman, 1998; Beeman et al, 1994).

However, one also needs to consider the other regions that are needed for insight. It would be no use stimulating this region of the RaSTG, if the solution is not able to be selected by the frontal cortex. This is when top down cognitive control mechanisms become important. Would we really want to stimulate the right anterior S/MTG to facilitate integration of distant associations, or rather stimulate the right prefrontal cortex to be able to exert cognitive control processes to *select* among these competing distantly-connected concepts already activated in the right STG? We have found that the Left Inferior Frontal Gyrus (IFG) demonstrates increased activation at problem onset possibly due to selection of close but incorrect associations, but then as the solver approaches solution, activity in the Left IFG subsides and the Right IFG increases, possibly associated with the detection and selection of the correct distant solution. Our fMRI findings suggest that the left IFG is activated at an earlier time-point than the right IFG; however, we cannot be certain of this timing due to the sluggishness of the hemodynamic response delay. Nonetheless, prior researchers have additionally found that the right IFG is activated during other more remote association verbal tasks such as that of unusual verb generation tasks (i.e. selecting the word 'decorate' instead of 'eat' when given the word 'cake') (Seger et al., 2000). Perhaps stimulating (or inhibiting) the right IFG via TMS is really the key to facilitating (or inhibiting) insights? We will now consider the role of these cognitive control mechanisms involved in restructuring the problem elements during insight solving.

**B) Restructuring the problem**

To many insight researchers, restructuring the problem is an integral element of insight. But what is the definition restructuring? If restructuring is merely recombining elements to change its configuration, then by this token tidying up a room could lead to insight. A more accurate definition of 'restructuring' according to the Gestalt tradition is: "a global shift in one's perspective of the problem such that the solver initially sees the problem one way but in an entirely different light the next moment." (Schooler & Melcher, 1997). This definition introduces the concept of problem-solving and switching perspectives, and hints at the concept of the suddenness involved (in insights) in which the solver sees the problem a different way *in the next moment.* They thought restructuring first involved having a holistic representation of the problem in order to perceive the gaps that would then lead to unconscious restructuring processes which mutually reinforce each other to culminate in the suddenness and surprise qualities of an insight when the solution is consciously detected (Schooler & Melcher, 1997). Ansburg (2000) and Ohlsson (1984) also believed that restructuring was crucial to insight solving and expanded the definition to include shifts to a *new* problem-space. Ansburg (2000) defined insight as the following: "Insight occurs when a solver *restructures* a previously intractable problem such that a *new* understanding of what needs to be done appears in consciousness." Dominowski and Dallob's (1995) definition is that "Insight will be characterized as a form of understanding (of a problem and its solution) that can result from restructuring, a change in a person's perception of a problem situation." Indeed, restructuring seems to be a key element in many classical insight problems as well as riddles where the solution is arrived through insight as in The Man-Marrying Problem (see below)**:**

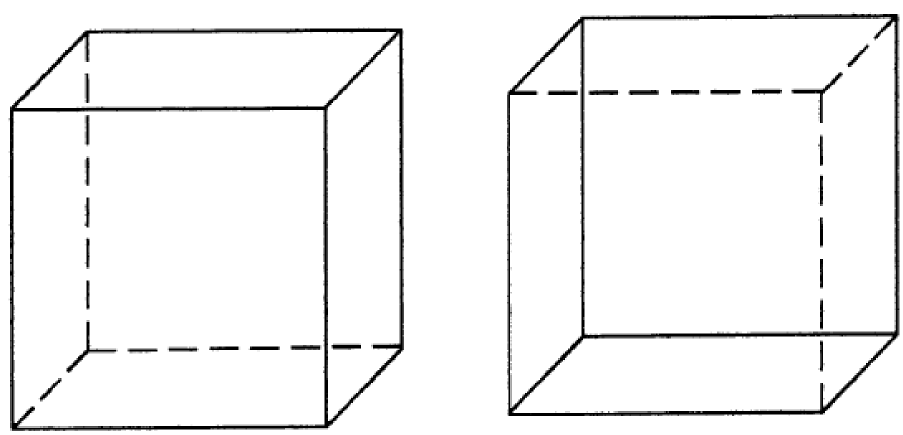
**The Man-Marrying Problem**

"A man in a town married 20 women in the town. He and the women are still alive, and he has had no divorces. He is no bigamist and is not a Mormon and yet he broke no law. How is that possible?"

Solution: He is a minister (Weisberg, 1995).

To most people, the dominant meaning of 'marry' is 'to marry one's husband/wife.' Therefore, they would need to restructure the problem so as to inhibit this dominant interpretation of "marry" and reinterpret the story to give it a *new* meaning such that 'marrying' can also be achieved by a minister who is the 'man' in the problem. However, if this same problem was given to another solver whose father, for instance, is a minister, he would likely solve the problem without an insight since activation of the word "marry" would also access the closely semantically connected nodes "minister" and "father." Thus, the same problem would not require much restructuring of the problem itself in terms of switching to the more remote meaning of 'marry,' which is already strongly activated and would, therefore, likely be solved without an insight to this particular solver.

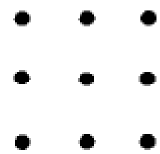
Another well-known example of restructuring similar to an insight is the Necker Cube. Initially, the cube seems to have only one orientation, but when one looks a little longer, this orientation shifts to another. This shift is usually sudden and unpredictable, illustrating the cube from a different perspective.



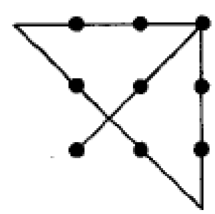
Restructuring perspective of the Necker Cube

Similarly, in the classic insight nine-dot problem, solvers often have an insight when they stumble upon the correct solution path, realizing that they need to be able to “restructure” their perspective to literally think “outside of the dots,” in order to be able to solve the problem and draw lines outside the ‘square’ of the nine dots.

**The 9-dot Problem**



Solution:



(Weisberg, 1995).

Therefore, the process of restructuring during insight solving occurs across domains of visual and verbal solving. Perceptual visual restructuring, as measured by the ability to recognize blurred pictures was also found to highly correlate with insight performance (Schooler & Melcher, 1997).

We also used blurred images to investigate insight versus analytical recognition within the visual rather than verbal domain, but with the added measure of fMRI. We hypothesized that similar to the verbal CRA trials solved with insights, restructuring processes would be needed for these 'visual Aha!' trials in order to reframe the initial fragmented images into a new holistic image. The sudden holistic recognition of this new picture would be associated with an insight i.e., a “visual Aha!" Because insight involves integration and restructuring processes which for the most part are thought to be largely unconscious to the solver as the Gestalts also suggested, it is not surprising that we found RaMTG activation for insight versus analytical solutions in our verbal CRA task since this region is particularly adept at integrating distant concepts (see part (A) on Integration above). In the visual Aha! study, increased activation in the RaMTG ($p < .01$, cluster > 500mm) for insightful versus analytically recognized images replicated our earlier insight effect demonstrated in the verbal CRA task. Additionally, similar to our EEG findings in the verbal CRA task, we found increased activation in bilateral mid occipital gyri for analytical > insight solutions in the visual Aha! which is associated with externally directed bottom-up visual attentional processes. These results suggest that insight, as compared to a step by step analytical approach, involves restructuring and integration processes largely unconscious to the solver associated with RaMTG activation, where the solution is able to come seemingly 'all at once' to the solver once it is selected by frontal regions (prefrontal cortex and anterior cingulate cortex). We believe that the frontal cortex guides these restructuring and integration processes by exerting cognitive control so that solvers realize what associations to inhibit, and when to switch strategies to restructure the problem elements in order to be able to select the correct solution path. We will now describe the role of cognitive control processes during insight solving.

**C) Cognitive control processes**

As aforementioned, insight is not a single process but arises from different sets of processes which include integrating multiple associations; inhibiting irrelevant yet prepotent associations; and breaking mental set to restructure and switch perspectives to select the correct solution (or solution path). All these multifaceted processes recruited during insight solving require cognitive control mechanisms. Several researchers have asked: 'How is this cognitive control controlled?' (Botvinick et al., 2001; Mayr et al., 2003). According to the conflict monitoring model, there is an increase in control when there is an increase in conflict, in which frontal regions such as the anterior cingulate cortex (ACC) have shown to be consistently activated. These studies were largely based on Stroop tasks, AX-Continuous Performance tasks and Eriksen Flanker tasks, where ACC activation was observed in correct trials during the override of prepotent but irrelevant stimuli when response competition was high as well as during erroneous responses (Carter et al., 1998; Botvinick et al., 1999; Botvinick et al., 2001; Mayr et al., 2003). ACC also showed increased activation during go/no go EEG studies tasks where ACC has been associated with errors of commission (i.e. Error Related Negativity) (Dahaene et al., 1994). Studies by Barch and colleagues (2001) have shown that ACC activation increased in response to the selection of weakly associated verbs with nouns (i.e hear with bell) as opposed to more strongly associated verbs with nouns (i.e. ring with bell). This is because activation of weakly associated verbs would involve increased competition amongst distant associations as well as inhibition of stronger more prepotent candidates, thereby recruiting increased ACC activation to enhance top-down cognitive control processes. In a similar vein, we hypothesized that solving problems with insight would require increased ACC activation because insights, compared to more systematic analytical approaches, require greater recruitment of cognitive control processes to inhibit prepotent irrelevant associations as well as to select the correct response amongst competing weakly activated distant associations. Recall that to solve CRA problems with insight, one must generate a large number of associations but one also needs to exert control to overcome impasse and be able to focus on weakly related solution information which compete for attention, and rises to a conscious threshold, culminating in the "Aha!" when solvers suddenly recognize the solution. Getting stuck at an impasse may also, result from irrelevant concepts strongly activated in the LH. To overcome impasse, in this case, one would need to inhibit this misdirected activity to permit access to weakly-activated distant associations in the RH to be able to switch and select the correct non-prepotent solution. Based on this cognitive control literature, it is not surprising that, after the RH aS/MTG, the second largest area showing an insight effect in fMRI signal was the dorsal ACC/medial frontal gyrus implicated in cognitive control (Subramaniam et al., In Press). To solve CRA problems, individuals must be able to adopt both a divergent form of thinking as well as to exert cognitive control to know when to adopt a convergent mode of thinking to hone in and select the correct association amongst competing alternatives.

**Inhibition of prepotent associations**

It is suggested that inhibitory interneurons contribute to creative problems solving (and insight), by coordinating the timing of previously uncoordinated groups of pyramidal cells involved in cognitive processes to synchronize the firing of these neurons (Terzis, 2001). It may be this unusual facilitatory synchronicity that contributes to the sudden increase in high-frequency EEG gamma-band oscillations peaking at 40 Hz occurring about .3 sec before insight (compared to analytical) solutions (Jung-Beeman et al., 2004). This burst of gamma-band activity was found at right anterior superior temporal electrodes with no significant insight effect in the left anterior temporal lobe. We think that this right anterior temporal activity reflects the sudden emergence into consciousness of the correct solution (Jung-Beeman et al., 2004). The reason why cognitive control processes are emphasized in insight is because greater control is required to modulate the shift in solving strategies in order to be able to overcome impasse and access these distantly activated concepts in the R S/MTG. For example, the inhibition mentioned above could also prevent an insight if the solver narrows the spotlight of attention to focus on selecting only conventional associations, inhibiting seemingly irrelevant associations and "distractions" that may actually be pertinent to the sudden breakthrough of an "Aha!" moment. Therefore, cognitive control mechanisms in the ACC and prefrontal cortex regulate which processes to inhibit, which to switch to, and which to select. In this particular example of an overly constrained system with a very narrowly focused spotlight of attention, cognitive control processes recruited to facilitate an insight would likely entail a switch in attentional strategy, possibly involving the switch between hemispheric processes (from LH to RH) to access a wider range of associations in the RH to allow more remote solution candidates to filter into consciousness. To clarify, the recruitment of cognitive control processes facilitates the inhibition of close associations that are strongly activated in the left hemisphere during impasse to enable the rise of more distant but weaker associations in the right hemisphere, which come into conscious access through a combination of temporal and spatial neuronal excitation of mutually activated nodes. For instance, the solution to the CRA example: 'horse,' 'over,' and 'plant,' is 'power' forming 'horsepower,' 'overpower,' and power-plant. The solver would need to inhibit stronger association nodes with horse such as "rider" or "shoe" to switch and select a weaker association node 'power' that can be successfully combined with all three words.

Inhibition of the prepotent association is also an important component for classic insight problems. Consider the following doctor-patient insight puzzle:

‘A man and his son are in a serious accident. The father is killed and the son is rushed to the emergency room. Upon arrival, the attending doctor looks at the child, and gasps, “This child is my son!” How is this possible?’

Solvers would need to inhibit the stronger assumption that doctors are always men and restructure the problem to realize that the doctor in the puzzle is the boy’s mother. [Therefore, it is through cognitive control processes in the frontal cortex that solvers are able to make the discontinuous jump from being stuck at an impasse focused on dominant but irrelevant associations (more strongly activated in the LH), to having an 'Aha!' which, possibly after a switch was made to select the correct solution, likely to be weakly activated in the RH.

**Distinctiveness and discontinuity of Insight**

Other researchers have measured this discontinuity of the insight solving process through feeling of warmth (FOW) ratings, indexing how close the solver is to attaining the solution (Metcalfe & Wiebe., 1986). Insight solving appears to have a distinct step function reflecting an all or none processing mechanism, versus the gradual incremental FOW changes during analytical solving. These FOW ratings, thus, provide a useful measure of demonstrating that the ratings for insight solutions are distinct from problems solved analytically such as algebraic problems (Metcalfe & Wiebe., 1986). Additionally, other researchers have shown that, during problem solving, autonomic responses such as heart rate are affected by the strategy used to solve the problem. For instance, analytical problems are accompanied by a steadily increasing heart rate, while insight problems can be recognized by a steady heart rate that suddenly increases just prior to solution (Jausovec & Bakracevic, 1995). Once again, this is because it is only when cognitive control processes are exerted in the frontal cortex that the solver is able to suddenly recognize the solution and have an Aha! moment, prior to which point the solution seems to be elusive to the solver – only being weakly activated, largely through subconscious processes in the RH, and overshadowed by stronger misdirected activation of errant concepts in the LH. These findings are consistent with Schooler's (1993) work demonstrating that when participants solved problems with insight, they were less likely to draw on step by step analytical methods. Therefore, making them verbalize their solution progress impaired overall solving ability (i.e. verbal overshadowing) because it interfered with these non-conscious non-reportable processes important for insight. In contrast, analytical solving was not impaired by this verbalization as it involved a conscious step by step systematic approach toward solution.

Although we have shown that insight versus analytical solving involve distinct cognitive and neural mechanisms, we are not stating that only one strategy is used the whole time the solver encounters a problem. Since problem solving is a complex process, both insight and analytical methods may be used initially, but then each solver shifts the balance of processes to use more of one strategy or another, depending on which strategy is perceived to be more conducive to the current demands of the task. It is these processes that determine whether the solution will be ultimately be attained through insight or incremental analytic processes. We now explore both the cognitive and neural processes that we have found during insight and analytical solving in order to link the behavioral data with neuroimaging (fMRI and EEG) data to explain the processes that are needed for insight versus analytical solutions at various different time points in problem-solving.

**Investigating neural processes underlying Insight**

Recent advances in theories of brain function and neuroimaging techniques have made it possible to predict and view the neural activity associated with differences between insight and analytical problem solving. For instance, during earlier classic insight problems such as the nine dot problem, it was believed that solving this particular problem involved restructuring and integration of the problem. We can now test this for all classic insight problems, insight riddles, and CRA problems using fMRI and EEG techniques by enabling solvers to judge whether they reached the solution with an insight versus an analytical solution, and then look at the neural components that are emphasized for insight and analytical solving. This inform us of the cognitive processes that are specific to the regions of interest that are emphasized for insights (or analytical trials), and at what times these different brain regions come into play.

Our experiments provide a tightly controlled comparison of the neural activation patterns for insight versus analytical solving. Even though problem solving involves a shared network common to both insight and analytical solutions, this contrast of comparing insight to analytical trials would reveal distinct neural processes specific to insight only if insight does truly reflect distinct cognitive processes. For instance, if integration is a more critical component for insight than for analytical solutions, then the regions involved in "integrating distant associations" should be emphasized for insight versus analytical trials at different points in the problem solving phase (i.e. prior to solutions). In this way, our CRA paradigm is optimal for investigating insight processes as it allows us not only to be able to isolate the neural components of insight but also enables us to investigate what specific states would modulate these fundamental processes involved in insight to facilitate its occurrence.

**Insight Solution Processes**

We used a combination of both fMRI and EEG techniques to investigate the neural components of insight compared to analytical solving on the CRA task (described in detail in chapter 4). In an earlier fMRI study using 13 participants, the strongest insight effect just prior to solution (i.e., regions that showed more solution-related activation for insight versus analytical trials) was manifested in the right anterior Superior Temporal Gyrus (aSTG) ($p < .005$; cluster > 500mm) (Jung-Beeman et al., 2004). EEG recordings also revealed a sudden burst of gamma-band neural activity in the same area about 0.3 s prior to insight solutions. This increased activation in RH aSTG is not simply due to an emotional response associated with insight because activation within this area increased at problem onset when there should be no emotional response generated and also because the RaSTG is not a region that is typically involved in emotional responses in any case. This insight effect in the right aSTG prior to solution point (when solvers suddenly get access to the solution that had previously eluded them) was replicated in our subsequent fMRI study with a much larger sample size (30 participants) and with a stricter threshold ($p < .001$; cluster > 500mm) (Subramaniam et al., In Press). There was no insight effect that met threshold within temporal cortex of the left hemisphere at solution ($p < .005$; cluster < 500mm). Therefore, we can infer from these converging fMRI and EEG findings that insight solving involves the integration of a wide range of remote associations because we found an insight effect in the right (RH) aSTG, which has found to be involved in integrating distant concepts (Kircher et al., 2001; Jung-Beeman et al., 2004). This makes sense in terms of the cytoarchitectonics where the neurons in the RH have large overlapping receptive fields and more distally connected dendritic branches and spines making it more adept than those in the LH to integrate distantly related concepts (Hutsler & Galuske, 2003; Jung-Beeman, 2005). Together, these fMRI and EEG results provide compelling evidence that insight solving is associated with distinct neural processes associated with integrating distant associations, and is also not simply an emotional response as some researchers suggest (Weisberg & Alba, 1981; Weisberg, 1986).

The second largest region after the R M/STG that showed an insight effect in terms of cluster size was the ACC/dorsal medial prefrontal cortex in our replicated fMRI study ($p < .001$; cluster > 500mm) as well as the initial study ( $p < .005$; cluster = 453). We hypothesized that the ACC/medial PFC would be emphasized for insight solutions because insight involves increased cognitive control processes (see part (C) above) and these regions have been implicated in cognitive control (MacDonald, 2000, Carter et al., 1998; Botvinick et al., 1999; Botvinick et al., 2001; Mayr et al., 2003). In other words, we found that two largest clusters of activation for insight versus analytical solutions demonstrated the importance of the collaboration of both R M/STG to integrate distantly activate concepts as well as medial PFC to engage in cognitive control processes to switch to select the distant but correct association activated in the R M/STG. Other regions that showed increased activation that met threshold criteria in our replicated fMRI study (i.e., threshold = $p <.005$ and cluster > 500mm) included posterior cingulate cortex implicated in visual attention (Small et al., 2000), and bilateral parahippocampal gyri which is not surprising given that insights have been associated with distinct memory encoding (Wills et al., 2000).

**Insight Preparatory Processes**

We also explored biases during preparatory states that could influence subsequent neural processes to facilitate insight. We hypothesized that just as insights involve distinct solution processes, they may also involve distinct preparatory processes where participants' mental states, even before problem presentation, can predispose them to solve the next problem with insight. We used both fMRI signal and EEG topography to examine neural activity as participants prepared for each problem, prior to its presentation. It has been suggested that individual differences in the ability to maintain a more diffuse mode of attention as opposed to a more focused attentional state may also promote creativity (Ansburg & Hill., 2003). Here, we explore the preexisting neural processes that are emphasized during preparatory states leading to creative insight solving. We first examined fMRI signal change, from onset of the preparation period (marked by onset of the fixation cross) to peak response and back down to baseline, throughout the brain, across all subjects to identify regions that showed increased signal change suggesting active processing during preparation. These regions included Anterior Cingulate Cortex (ACC), Posterior Cingulate Cortex (PCC) and Right Angular Gyrus (AG) ($p < .005$; cluster >500mm). All other regions showed deactivation relative to baseline (Subramaniam et al., In Press).

Next we contrasted preparation that led to insight versus preparation that led to analytical solutions. We showed that mental preparation leading to insight involved increased activity in medial frontal areas associated with top-down cognitive control mechanisms implicated in inhibiting irrelevant associations, switching attention, or selecting amongst competing responses (Kounios et al., 2006; Badre & Wagner, 2004; Botvinick et al., 2004; Kerns et al., 2004). According to this model, increased ACC activity reflects increased top-down cognitive control.

There are several possible interpretations of increased ACC activity prior to problems that are subsequently solved with insight. First, ACC maybe involved in suppressing irrelevant thoughts during this preparatory phase in order to start the next problem with a clean slate (Kounios et al., 2006; Wyland et al., 2003). This would, therefore, mean that insight solving must also be more susceptible to internal interference than analytical processing and should require increased ACC activation for greater control to suppress irrelevant thoughts (Kounios et al., 2006; Schooler et al., 1993). Second, the increased ACC activity may indicate that the ACC is prepared to detect more competing brain activations (associations, potential interpretations, and potential responses). Another theory that may be considered is the possibility that ACC may be involved in default mode of attention (Raichle et al., 2001). We do not think this is likely given that areas involved in the default mode typically decrease during task performance and we observed ACC to turn on prior to solutions, and specifically for insight compared to analytical solutions.

Other regions that showed increased activation for insight preparation compared to analytical preparation included bilateral temporal areas associated with semantic processing, with the left temporal cortex preparing to retrieve many close prepotent associations, and the right temporal cortex preparing to detect weaker, more distant associations (Kounios et al, 2006). As in the case of insight solutions, we think that during insight preparation, cognitive control mechanisms modulate activity in brain areas related to semantic processing, wherein solvers get ready to initially focus on selecting the prepotent associations; during actual problem solving, if this activation does not lead to solution, solvers would possibly arrive at an impasse (Bowden et al., 2005; Jung-Beeman et al., 2004; Subramaniam et al., In Press). Solvers may overcome impasse by switching attention to weakly activated solution candidates in the RH (Beeman &

Bowden, 2000). These weakly active solution candidates compete for attention so that attention can be shifted to solution-relevant information which are then mutually reinforced to summate and increase in strength to rise to conscious access, guided by top-down cognitive control processes.

The EEG topography (and to a somewhat lesser extent, the fMRI pattern) suggested that analytical preparation, in contrast, involved increased occipital activity associated with an increase in externally directed bottom-up visual processes. These differences in preparation biasing solutions leading to insight compared to analytical solutions were not due to participants entering a mode of insight that resulted in temporal clustering of insight trials. These trial-by-trial preparatory changes in neural activity indicate differential preparation prior to the presentation of each problem (Kounios et al., 2006).

Therefore, we have demonstrated that differential mental preparation can modulate activity in different brain regions to predispose the solver to solve the upcoming problem either through insight or through analytical methods. This raises the question as to what factors can modulate this pre-problem preparatory brain state. We hypothesized that positive affect (PA) states could modulate activity in the ACC before the actual problem onset, biasing the solver toward cognitive processing that would facilitate insights. PA has been shown by Isen and colleagues to facilitate creative problem solving generally and insight specifically (Isen, 1999a; Ashby, Isen, & Turken, 1999). There are several suggested mechanisms for this facilitation (see Chapter 3). In Chapter 4, we explain how we use our CRA paradigm to investigate where in the brain, when and how positive mood modulates the processes which are fundamental to insight in order to provide an explanation as to what cognitive processes may be facilitated with a positive mood to predispose the solver to lead to an insight.

**Promoting Insight**

Now that we understand the neural processes underlying insight, we need to investigate what circumstances or qualities are ideal for promoting insight. For instance, the technique of relaxing constraints in order to break mental set has been used to bias insights (Oellinger & Knoblich, 2003). Neurally, alpha power is thought to reflect this idling of the cortex, and correlates with a state of relaxation to make the brain more receptive to novel and unusual ideas (Pfurtscheller, 1996; cited from Kounios et al., 2006). Additionally, occipital alpha is thought to reflect an inhibitory gating mechanism regulating the intake of visual information to protect more resource-intensive top-down cognitive control processes from interference by bottom-up stimulation (Ray and Cole 1985; cited from Jung-Beeman et al., 2004). It is possible that if participants manifest low alpha power in key brain regions, they would likely have a strongly constrained system and would not be open to access new possibilities or to avail themselves of hints that are given to them in the environment, as in the Archimides legend. This legend might not exist if Archimedes had utilized a strongly constrained spotlight of attention while in the bath, as such focus would impede recognizing that the water rising in the bathtub could relate to his problem with determining the volume of the King’s crown; instead, he recognized that water displacement could be used to do so. Additionally, in certain models of insight, relaxing constraints in the form of incubation from the problem is considered an important precursor to insight solving in that it allowed the mind to wander and not to "focus" on the problem at hand, allowing this entry of more remote associations, one of which may be the solution (Wallas, 1926;

Mumford et al., 1994). Furthermore, a more diffuse compared to focused attention appears to promote creativity (Ansburg & Hill, 2003; Carson et al., 2003).

The question remains as to what mental state could promote these processes that facilitate creativity in terms of relaxing constraints to be more open to switch from conventional associations to select new possibilities? Specific mental states have been emphasized to promote creativity through the use of various inventories including personality traits within the five-factor model (FFM) of personality, Gough's Creative Personality Scale, and the NEO-Personality Inventory, (Gough, 1979; King et al., 1996; Barron and Harrington., 1981) Specifically, in terms of both the theoretical rationale as well as empirically speaking, prior studies have shown a link between openness to experience and creativity and a much stronger association between positive mood and creativity. Using Gough's Creative Personality Scale, the NEO-Personality Inventory, and measures of divergent thinking, openness to experience was significantly positively correlated with measures of creativity and divergent thinking (McCrae, 1987). However, the validity of the Openness construct has been questioned by Martindale (1989) who stated that openness to experience and creativity were really synonyms used to describe the same set of traits, and, therefore, openness cannot be included as one of the factors that promote creativity.

Positive mood, by contrast, has shown to facilitate creativity across a broad range of settings (see Chapter 3). We predicted that positive mood would manifest a strong correlation with creative insight problem solving because it allows the solver to relax constraints, maintain a more global diffuse attentional state to promote access to distant associations, and to facilitate the processes described above (i.e., through enhancing integration, restructuring and cognitive control processes) that are fundamental to insight solving. The next chapter explores this association between positive mood and creative insight problem solving. Although we hypothesized that positive mood would promote insight solving, it was also possible based on prior research that other variables such as motivational approach states (measured by the Behavioral Activation Scale (BAS)), openness, and even schizotypy could be linked to insight solving as well. We, therefore, used various state and personality trait inventories to explore all the different associations between mood/personality with creative insight solving in the CRA task. We found that only positive mood indicated a strong association with overall CRA solving, as well as with insight solving specifically (Chapter 4). In the next chapter, we explore the positive mood literature and its strong link with creative solving and insight in order to move toward a clearer understanding in terms of the cognitive processes as to why a positive mood is especially important for promoting insight solving.

# Chapter 3: Positive Mood Effects on Cognition and Insight Problem Solving

Until recently, there was little interest in studying the effects of positive mood on cognition. This was largely because, as Seligman (2002) states, "psychology after World War II became a science largely devoted to healing" rather than a science devoted to optimizing well-being. Essentially, positive mood-cognition interactions had been limited to mood-congruent effects on cognition (i.e. enhancing encoding and retrieval of pleasant memories when in a happy mood) (Seligman, 2002). However, in the past couple of decades or so, a substantial amount of research has been done to demonstrate that a positive mood not only enhances mood-congruent effects but also enhances assimilative and holistic processing in general to modulate attention, learning and memory, decision-making, and creative cognition (Bolte et al., 2003; Fredrickson et al., 2005; Gasper & Clore., 2002; Isen et al., 1985; 1987; 1991). For instance, a positive mood compared to either a neutral or sad mood, has been shown to facilitate unusual word-associations, flexible decision strategies, integration processes in terms of seeing the relatedness among atypical items and creative insight problem-solving (Isen, 1984; Isen et al., 1985; Isen et al., 1987). The facilitatory effects of positive mood on integration processes, on enhancing access to remote unusual associations and on enhancing cognitive control and flexibility are all important mechanisms by which positive mood likely enhances creative cognition and insight. Indeed, a positive mood has been shown to directly facilitate creative problem-solving on classic insight problems such as Duncker's candle task (see below) as well as on Mednick's creative RAT task (Isen et al., 1987; Rowe et al., 2007).

**Duncker's Candle Task:**
Attach a candle to a wall in way that it will burn without dripping wax on the floor. Tools at your disposal are a book of matches and a box of box of tacks.

**Solution:** Use the box from the tacks as a platform for the candle

In the next chapter, we show that these facilitatory effects of positive mood will enhance overall solving and will specifically enhance insight solving in our CRA task.

So far, we have examined the fundamental processes that are important for insight solving in the prior chapter. Recall from the prior chapter that the three mechanisms shown to be important for insight solving include (A) restructuring/switching, (B) integration, and (C) cognitive control processes. We now explore the positive mood literature to investigate which of these cognitive (and neural) mechanisms are modulated by a positive mood to facilitate insight. We then explain why a positive mood is most likely to influence cognitive control processes to facilitate insights rather than solely influencing either integration or restructuring processes. This will lead into the next two chapters where we discuss how our present study extends this literature in terms of providing both a behavioral and neural account of *how* a positive mood facilitates insight solving in the CRA task (see Chapter 4). Specifically, we will demonstrate in the next chapter that participants' mood predicted whether they would solve the imminent problem with insight by modulating *cognitive control processes* directed by the frontal cortex. In the present chapter, we now explore the positive mood literature to examine its facilitatory effects first on integration, then on restructuring and then finally its influence on cognitive control and insight. This will help us understand why a positive mood is most likely to modulate cognitive control processes specifically to facilitate insights.

**A) Positive mood facilitates Integration**

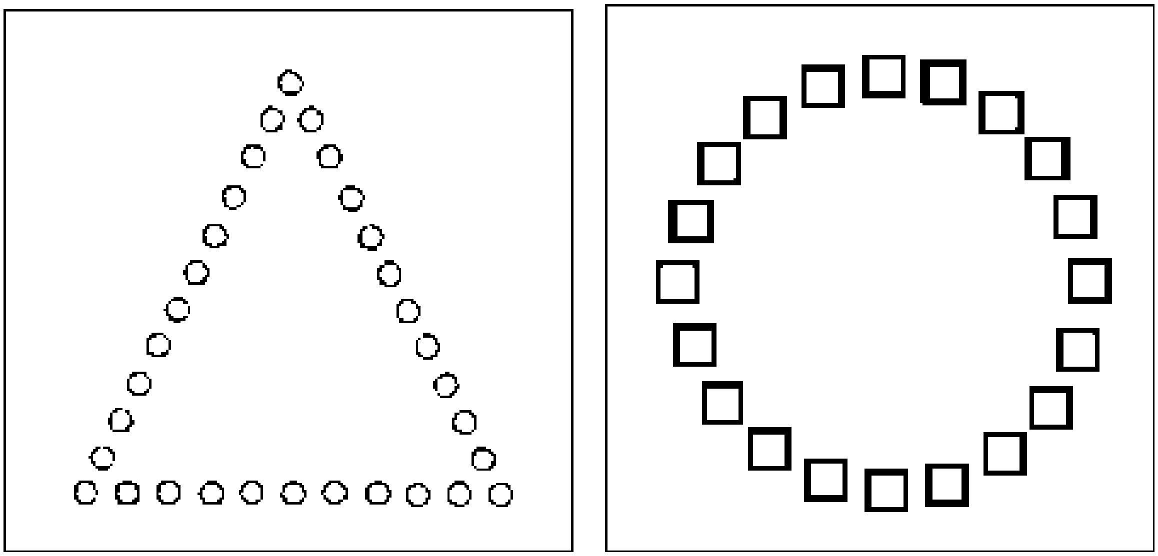
There has been an abundance of evidence to show that both a positive mood and positive material enhance integration processes, enhancing access to remote and unusual associations (Isen et al., 1987; Estrada et al., 1987; Federmeier et al., 2001; Bolte et al., 2003). Indeed, a positive mood not only enhances a global, holistic style of processing which is thought to facilitate integration processes, but also enhances integration processes by facilitating access to positive material in memory, which is considered to be more extensive than neutral or negative material (Gasper & Clore., 2002; Federmeier et al., 2001; Fredrickson, 2001; Matlin & Stang, 1978, cited from Isen et al., 1985). This enriched organization that arises from positive material is thought to additionally augment the integration processes that are already being enhanced during a positive mood state itself. As reviewed in the prior chapter, from priming studies, fMRI evidence and EEG studies, the RH seems to be particularly adept at integrating a broader range of associations which has shown to be an important component of insight solving. Recall that these differences in integration processes between the RH and the LH are likely to be explained by the differences in the neural cytoarchitecture. In fact, our findings in the CRA study demonstrate that the RH, specifically the right S/MTG, involved in integrating distant associations showed the largest insight effect at solution (insight solutions > analytical solutions) across 30 participants, across both fMRI and EEG methodologies, replicating earlier work using a smaller sample size (Subramaniam et al., In Press; Jung-Beeman et al., 2004). Thus, it is possible that a positive mood may be able to modulate these integration processes in right S/MTG, promoting access to the correct remote association to facilitate insight solving in our CRA task.

**Positive mood facilitates integration across a diverse range of settings**

Some examples of how a positive mood enhances integration processes arise from word association tasks. In these tasks, positive affect subjects responded to neutral words with a broader range of first associates than control subjects (Isen et al., 1985). Additionally, positive affect subjects gave more unusual examples of members of a category than subjects in the neutral affect control condition (Isen & Daubman, 1984). For instance, positive affect subjects gave higher ratings to the atypical exemplars 'elevator, camel, and feet' being members of the category 'vehicle' than did subjects in control conditions. These positive mood effects on integration are widespread in terms of influencing a diverse range of tasks as well as influencing a diverse range of populations. These effects range from college students doing word association tasks and classic insight tasks, through to business people engaging in industrial negotiations, to doctors doing creative insight tasks (RAT) and also being able to integrate information earlier in their own field while solving a medical case (Carnevale et al., 1986; Estrada et al., 1994, 1997; Isen et al., 1987; Rowe et al., 2007). For example, physicians in whom a positive affect was induced integrated information earlier while solving a rare case of chronic hepatitis disease in that they considered "liver disease" at an earlier stage in their diagnoses than neutral affect controls (Estrada et al., 1997). Furthermore, Estrada et al (1997) found that a positive mood induced in both physicians and students enhanced creative problem solving in the RAT task. Therefore, we can consider that a positive mood facilitates creative insight solving by modulating integration processes. It is thought that a positive mood may enhance these integration processes by broadening attention and/or broadening semantic access.

**Positive mood enhances integration by broadening scope of attention**

Prior research suggests that a positive mood broadens attention, thoughts and actions (Fredrickson, 2001, 2005; Gasper, 2002; Bolte et al., 2003). Furthermore, by signaling an absence of danger, a positive mood may promote a more explorative global mode of thought which facilitates creative insight solving in terms of accessing unusual associations to think outside the box and to switch to select the non-dominant but correct solution path. By contrast, negative moods signal the presence of obstacles and are thought to restrict semantic activation to focus on close dominant associations, facilitating a more analytical mode of processing (Bolte et al., 2003; Baumann et al., 2002). These mood-attention relationships were illustrated by Gasper and Clore (2002) who used a visual matching test (Kimchi and Palmer, 1982) in which participants had to indicate which one of two sample figures looks most like a target figure. Each figure was either a square or a triangle (global feature) made up of smaller squares or triangles (local feature). As predicted, positive affect participants were more likely to match the objects on the basis of global features than participants in a negative-mood condition or compared to a neutral affect condition (Gasper & Clore., 2002; Fredrikson et al., 2005) .



**Global-local Task:** Two sample items from the global-local shape task (Kimchi & Palmer., 1982; cited from Baumann & Kuhl., 2002). In the left item, the target shape "circle" is present on a local dimension. In the right item, the target shape is present on a global dimension. Other items did not contain the target shape (e.g., a square composed of smaller triangles).

**Positive mood enhances integration by broadening semantic access**

Additionally, positive affect has been shown to broaden internal conceptual semantic space. For example, Federmeier et al (2001) used ERP to investigate the influence of positive affect on semantic relatedness. They looked at the N400 response, as an index of semantic relatedness on a sentence completion task. Participants read sentence pairs ending with (1) the most expected word, (2) an unexpected word from an expected semantic category, or (3) an unexpected word from a different (related) category. Half the pairs were read under a neutral mood and half under a positive mood. An example of a sentence would be: `They wanted to make the hotel look more like a tropical resort. So, they planted rows of... ' .ending with (1) the most expected ending, would be `palms' while an unexpected item from the same semantic category would be `pines' (i.e., a within category violation); and an unexpected item from a different semantic category would be tulips (i.e., a between category violations). They found that a positive mood compared to a neutral mood reduced the N400 amplitude to between category exemplars, thus shortening the 'semantic distance' of these unexpected distant exemplars. Federmeier's findings were a replication of earlier studies using near and distant category exemplars (Kirson et al, 1990). In these tasks, sentences contained exemplars that were a near associate as well as a distant associate (i.e., A robin/parrot is a bird). A positive mood shortened the semantic distance between distant exemplars (i.e., parrot) and their categories (i.e., bird). This was also confirmed by Rowe et al (2007) who showed that a positive mood broadens the scope of semantic access in the RAT task as well as broadening visual attention in the Eriksen flanker task to enhance processing of spatially adjacent flanker distracters. Furthermore, they showed that individual differences in enhanced semantic access correlated with the degree of broadened visual attention (i.e., increased processing of flankers). These results indicate that a positive mood may facilitate integration processes by relaxing constraints to enhance both semantic distance as well as breadth of attention.

**Positive mood, Integration, Intuition and Insight: RH Implications**

A positive mood has also been shown to enhance intuitive thinking through its facilitation of a broader more 'holistic mode of attention' which, in turn, helps to increase access to remote associations (Bolte et al, 2002; Rowe et al., 2006). Intuitive thinking is similar to insight solving in that it involves solving problems and making decisions without consciously knowing the solving process (i.e., making decisions intuitively), unlike analytical strategies that rely on a deliberate conscious step by step solving approach. To give an example, intuitive ratings were made on word triads similar to the RAT but in this case participants were required to simply rate word triads as coherent or incoherent (Bolte et al., 2003; Baumann et al., 2002). For instance, in this task the triad "goat, pass and green" should be considered coherent as each word is associated with a fourth word "mountain." On the other hand, the words "bird, green and road" should be considered incoherent since they cannot be associated with one single solution word. Participants in a positive mood made this above chance discrimination between unsolved coherent and incoherent triads reliably better than participants in a negative or neutral mood. On the other hand, participants in a negative mood performed at chance level on making coherent judgments. This result revealed that even when subjects did not know the answer (i.e., unsolved triads), they had an intuition (i.e., made an above-chance judgment) that the triad was solvable (i.e., coherent) or unsolvable (i.e., incoherent).

The system that contributes to this sense of intuition in the form of implicitly extending a semantic network is referred to as 'extension memory' within a theory referred to as Personality Systems Interaction (PSI) (Baumann & Kuhl., 2002). It is essentially the same concept that we referred to earlier as an "RH advantage" during the solving of CRA word triads illustrated in Beeman and Bowden's priming experiments (Bowden & Beeman., 1998; Beeman & Bowden., 2000; Bowden & Beeman; 2003a). Recall that in these experiments, there was a RH advantage for naming the solution word of CRA triads that were solved, and for making faster solution decisions for unsolved targets that were presented to the RH versus the LH. For solved triads, after producing the solution, participants showed greater solution-related priming (i.e., faster RTs for naming solution words than for unrelated words) for targets presented to the RH compared to LH targets. Furthermore, after unsuccessful effort for unsolved triads, participants made faster solution decisions for targets presented to the RH than for target words presented to the LH. Additionally, after these unsolved triads, participants showed greater priming in the RH for solutions they rated as having elicited an insight as opposed to those solutions that did not elicit an insight. These results indicate that there is greater activation of solution information in the RH than the LH overall, and that this priming effect in the RH is related to the insight rating, suggesting that the RH is more adept at activating distant associations, which is useful in attaining insight solutions. Priming for solutions to problems that were not solved suggests that the solution word is activated at a subconscious level in the RH but does not have enough strength to rise to a conscious threshold during problem-solving. It is this subconscious activation that is thought to contribute to both intuitive thinking as well as the sudden realization of an insight solution because in both cases the solving process is unknown to the solver since the solution is largely activated at a subthreshold level (Bolte et al., 2003; Beeman & Bowden, 2000; Bowden & Beeman, 2003; Baumann et al., 2002; Metcalfe & Wiebe., 1987). It is only in the case of an insight that when the solution rises to conscious threshold and is selected, that the solver experiences a sudden "Aha!" where the solution seems to come from nowhere. Also, recall from the prior insight chapter that Seger and colleagues (2000), showed increased activation in left inferior prefrontal cortex when participants generated typical verbs in response to novel nouns, whereas increased activation was observed in right frontal gyri when participants generated unusual verbs. These behavioral and neuroimaging results, together with cytoarchitectonic evidence which demonstrate that the RH has larger receptive fields and dendrites branching more distally from the soma to make it more adept at integrating distant associations as the coarse semantic coding theory suggests (see Prior Chapter for details). To summarize, if a positive mood does specifically enhance this integration of distant associations, we would expect a positive mood to enhance relative activation in the RH, specifically in the right anterior STG, which has shown to be particularly adept at integrating a wide range of inputs during insightful compared to analytical solutions (Subramaniam et al., In Press; Beeman et al., 2004).

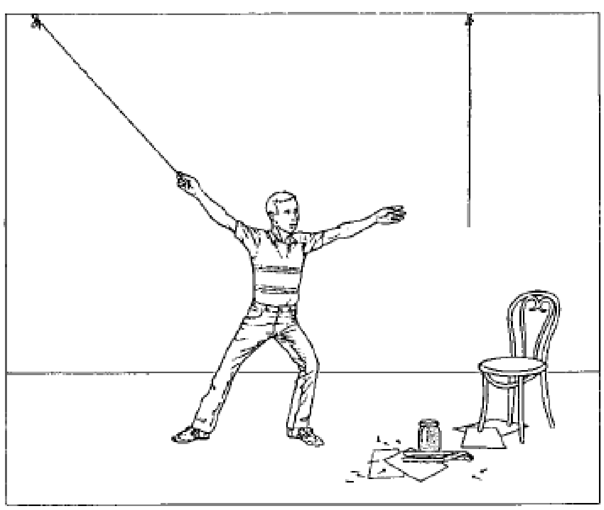
**Does positive mood enhance CRA solving by enhancing RH activation?**

To summarize, we have demonstrated that the RH, specifically the right S/MTG is important for insights in the integration of distant associations to restructure the problem elements into a new holistic concept. Prior research has also demonstrated that a positive mood helps creative problem solving in both classic insight problems and in the RAT task. We extend these positive mood facilitatory findings on insight solving to our CRA studies where we assess and induce a positive mood (see Chapter 4 and 5). For instance, in the assessed positive mood CRA study, we show that participants higher in positive mood solved more problems, and specifically more with insight, compared to participants lower in positive mood. Similarly, in the mood induction (MI) study, when participants were in the positive mood induction, they solved more problems overall, and more with insight than when they were in the neutral MI or compared to the anxious MI (see Chapter 5). Therefore, the question is whether a positive mood facilitates insight solving in the CRA task *by enhancing integration to distant associations,* in which case we would expect to observe relative increased right S/MTG activation in high versus low positive affect participants. We will now examine evidence from the schizophrenia literature as well as briefly mention our own fMRI activation patterns during the assessed positive mood CRA study (see Chapter 4) to attempt to answer why a positive mood does not enhance insights by enhancing integration processes alone or by simply promoting a global focus of attention to enhance integration.

Indeed, in our assessed mood CRA study, positive mood did not modulate activity in the RH (or LH) not even in the right anterior STG which showed the strongest insight effect at solution (Subramaniam et al., In Press). Positive mood did, however, correlate with neural activity during preparation within the ACC, which was the only region that also showed increased sensitivity to insight compared to analytical trials at preparation (i.e., while subjects were getting ready to solve the imminent CRA problem) as well as just prior to solution (for details see Chapter 4). These results suggest that it is more likely that a positive mood enhances insights by modulating top-down cognitive control processes overall (i.e., enhancing ACC activation) to modulate processing in both hemispheres rather than in only the RH. To clarify this point, cognitive control processes would be required to modulate overall attention, or restructuring processes in both hemispheres, rather than just the RH in order to facilitate a switch in strategies, for example, away from errant concepts strongly activated in the LH to solution relevant associations weakly activated in the RH. Similarly, cognitive control processes would be required to modulate attentional shifts either from a more global focus of attention (i.e., thought to involve increased RH processing) to a more local mode of attention (i.e., increased LH processing) or vice versa in order to modulate the balance between switching to distantly-related concepts and shielding from irrelevant distracters to maintain strong solution-relevant information (Dreisback & Goschke., 2004; Rowe et al., 2007; Baumann & Kuhl., 2005)

**Evidence from attention**

Still other researchers have suggested that positive affect or approach-related emotions increase activation in the frontal lobe but particularly in the left rather than right hemisphere (Davidson et al., 1990). We make no claims one way or another as to any hemispheric asymmetries regarding positive mood's effect on insight solving for the reasons mentioned above. Rather, we do believe that to facilitate insight solutions, a positive mood would have to enhance attention and cognitive control mechanisms in the frontal cortex to be able to modulate processing in *both hemispheres* to either facilitate a shift between strategies and/or between a global or local mode of processing when the task necessitates it. For instance, while a global mode of attention would aid in increasing sensitivity to remote associations (Fredrickson et al., 2005; Federmeier et al., 2001), it can also impair both attentional and semantic processes to include irrelevant stimuli (Rowe et al., 2007). By contrast, having a very narrow spotlight of attention would likely inhibit processing of solution-relevant remote associations. To give an example, if subjects had a narrow focus of attention while solving insight problems, they would not be able to gain more solutions from the hints in the environment in Maier's two-string problem or Duncker's candle task (see below).



**2) Classic Insight Problem: The two-string problem.** How can the two strings be tied together? You may use any of the objects in the room.

**Solution:** Attach the pliers (placed in front of the jar) to one of the strings. Then swing the string in a pendulum motion close enough to the other string to tie the two strings together (Maier., 1931)

In Maier's two string problem, he found that subjects solved the problem faster when he brushed one of the strings setting in a pendulum motion. In Duncker's candle task, subjects in the facilitative display condition had more solutions compared to the control normal condition by retrieving environmental cues. In the same candle task experiment, the positive mood group (without the facilitative display) was able to modulate attention and cognitive control processes to restructure their perspective from viewing the matchbox as a typical container to viewing it in a more unusual way as a platform. In this way, the positive mood group and the facilitative display group gained more solutions compared to the neutral affect control group. These results demonstrate that a positive mood modulates attention and cognitive control processes, (rather than RH processing specifically) to facilitate the restructuring of existing concepts to form a new solution. Therefore, we believe that a positive mood would facilitate both overall solving and creative insight solutions in our CRA task by modulating attention and cognitive control related processes within the ACC, rather than by enhancing processing within a specific hemisphere. This positive mood modulation of attention and cognitive control mechanisms would facilitate the restructuring of the problem elements by likely modulating a shift between global and local attentional foci which would also likely involve a shift in processing from one hemisphere or from one strategy to another (see B). As above-mentioned, this attentional modulation would involve a shift in balance between switching to distantly-related solution relevant concepts in the CRA task and shielding from irrelevant distracters to maintain strong solution-relevant information as the current demands of the task necessitate (Dreisback & Goschke., 2004; Rowe et al., 2007; Baumann & Kuhl., 2005)

Our hypothesis on positive mood modulating insight solving through the modulation of attention and cognitive control processes corroborates Baumann's findings (2002) where uses a global/local attentional paradigm to demonstrate the facilitation of cognitive control processes in positive affect subjects (see Appendix). Specifically, Baumann and colleagues (2005) demonstrated that positive mood participants respond faster to local targets after positive compared to neutral and negative prime words when the task necessitates it. They interpreted this as positive affect increasing cognitive flexibility, indicated by the ability to overcome a global precedence and to respond to non-dominant local features. Additionally, negative affect slowed response times to local targets compared to neutral affect. This was interpreted as negative affect inducing more restrictions on exerting cognitive flexibility, resulting in slower shifts to a non-dominant local mode of processing from a default global mode of processing. A part of cognitive flexibility and insight solving, therefore, involve restructuring/switching between global and local modes of attention, between hemispheres and/or between solution strategies. We now explore the facilitatory effects of positive mood on these restructuring processes.

**(B) Positive mood facilitates restructuring/switching and selection**

Positive mood has been shown to enhance restructuring or switching between different cognitive sets (Isen, 1999; Isen & Daubman, 1984). This is not surprising since a positive mood is known to influence cognitive organization to promote flexibility in terms of switching to reinterpret material in different ways. Switching can occur between strategies, between global and local modes of attention, and between hemispheres (Dreisbach & Goschke., 2004; Baumann et al., 2002). As mentioned above, a positive mood is thought to promote a more global focus of attention to enhance access to remote associations when the task necessitates it. A shift from a local to a global attentional state can influence the scope of semantic access to defocus attention enough and relax constraints such that it could promote switching to thinking outside the box to consider alternative unusual possibilities on classic insight problems such as Duncker's candle task. For example during insight solving, cognitive control mechanisms would be needed to dampen activation from more prepotent associations strongly activated in the LH (associated with a local mode of attention) to allow a switch to solution-related associations weakly activated in the RH (i.e., a shift to a global mode of attention) allowing these associations to rise to a conscious threshold to be selected. Selection of the correct solution would then require a shift to a more local focus of attention. A positive mood has also shown to enhance attentional shifts from a global to a local mode when solvers need to maintain solution-relevant information, and inhibit irrelevant distracters (Baumann & Kuhl., 2005).

**Positive mood and Restructuring in Classic Insight Problems: Duncker's Candle Task**

Let us illustrate these concepts of restructuring and cognitive control using Duncker's candle task as an example. In this task, subjects are presented with a box of tacks, a candle, and a book of matches and are asked to attach the candle to the wall in a way that it will burn without dripping wax on the table or floor. Subjects in a positive, compared to a neutral mood, were able to 'break set' and literally think outside the box (of matches) to shift their perspective from viewing the box as a container to viewing the box as a platform for the upright candle which would then be tacked from the matchbox to the wall. Subjects who were presented with empty boxes with the matches on the side in a facilitative display to enhance switching their perspective to view the box as a platform rather than a container had more solutions than the control normal display condition where the box was filled with matches. Similarly, subjects in a positive mood had more solutions compared to subjects in a neutral mood. Here, solvers needed to restructure their perspective to switch away from the prepotent view of perceiving the box as a container to viewing it as a platform. This new solution path is mutually reinforced so that it gains in strength, and reaches a conscious threshold where the solver can then adopt a more local focus of attention to select this solution at a conscious level without being distracted by other stimuli. This sudden detection of the solution would likely culminate in an insight when the solution arises as if from nowhere but really from increasing activation of solution relevant subconscious processes in the RH guided by cognitive control mechanisms in the frontal cortex (Schooler & Melcher, 1997; Ansburg, 2000; Ohlsson, 1984). Additionally, as mentioned earlier, Estrada and colleagues (1994) showed that physicians in whom a positive affect was induced demonstrated less anchoring in terms of being more willing to switch cognitive set to diagnose a rare case of liver disease. Finally, a positive mood was also shown to reduce perseveration in terms of facilitating the switching away from distracters which were once relevant (i.e., when a former target color becomes a distracter color on the next trial) (Dreisbach & Goschke., 2004). These results were taken as evidence to demonstrate that positive mood facilitates restructuring processes needed for creative problem solving. As mentioned in the prior chapter, restructuring the problem to shift to a new problem-space is thought to be an important, if not a necessary, component of cognitive control and insight solving.

**Positive Mood, Restructuring, Dopamine and Insight**

Recently, Ashby et al (1999, 2002) proposed a neuropsychological and computational model which accounts for the restructuring effects of positive affect on creative cognition and insight in which they used 3 tasks including word association tasks, the RAT, and Duncker's candle task. They argued that a positive mood induces increased levels of dopamine particular in frontal regions such as the anterior cingulate cortex and prefrontal cortex. They further postulated that dopamine release in the frontal cortex facilitates switching and selection. Furthermore, their model corroborated other research which showed that dopamine antagonists impair cognitive set shifting, and that patients with Parkinson's disease have reduced dopamine levels and are also impaired at tasks that require set shifting (Berger et al., 1989). However, an optimal release of dopamine is needed - too much release may also result increased distraction and impaired attentional processing (i.e., in the case of increased processing of the flanker distracters at the expense of paying attention to the central letter in the Eriksen flanker task). Therefore, an optimal dopamine release in the frontal cortex functions as a gating mechanism where cognitive control processes are directed to maintain initial active representations of the solution candidate so that they can either be inhibited and switched away from in the case of irrelevant information, as well as maintained and selected in the case of solution relevant material. Positive mood is thought to enhance this dopaminergic release so as to enhance the exertion of these cognitive control mechanisms in the frontal cortex. Of course, this is a very simplistic account of the dopaminergic hypothesis of how positive mood influences cognitive control mechanisms in ACC and PFC. In reality, the relation between dopamine and cognitive control is very complex. For instance, D1 receptors are thought to enhance the cognitive effects of dopamine in terms of enhancing switching and selection in positive mood subjects. Additionally, anti-psychotic medications act as dopamine antagonists that are used to treat the positive symptoms in schizophrenia but not the negative symptoms that are associated with frontal hypoactivation (i.e., impaired attention, working memory and cognitive control). Normally, if there is too much dopaminergic release, D2 inhibitory receptors inhibit second messenger systems to prevent further release of dopamine, along with dopamine transporters and enzymes that inactivate dopamine to protect people from switching too much so that they get distracted by irrelevant information at the expense of maintaining and updating task goal-relevant material. It would be interesting to test whether extreme states of positive mood as in elated states or states of mania, associated with an over-release of dopamine, would impair insights. One would presume so since this would also lead to increased switching between cognitive sets at the expense of solution-selection, impairing attention and cognitive control processes compared to an optimal level of dopamine release associated with a positive mood. Unfortunately, for the purposes of our study, we cannot answer this question yet as we do not test states of elation but are only assessing the effects of a mild positive mood on insight solving.

**Restructuring involves Cognitive Control**

So the question is if positive mood modulates switching between cognitive sets during CRA insight solving, we need to understand what the processes are that are involved in switching? For instance, in terms of insight solving in the CRA task (see prior Chapter), does switching occur only *after selection* - that is only after weakly activated concepts in the RH are mutually reinforced and allowed to gain in strength to rise to a threshold to be selected? Or does switching occur only *after inhibition* of prepotent incorrect associations which are strongly activated in the LH? We think that inhibition of a cognitive set (i.e., a prepotent association) is not a precursor to switching because we do not think that inhibition per se is *necessary* for insight, although it may facilitate the switching to a new cognitive set and, therefore, enhance insight solving processes. Ashby and colleagues argued that the act of switching attention occurs after selection. First, the new cognitive set must be selected, and then only, attention can be switched from the old set to the new one. Not surprisingly, we see that restructuring/switching to a new cognitive set involves multifaceted cognitive control processes directed by the frontal cortex. This leads us to the next portion (see C), in which explore how positive mood facilitates cognitive control mechanisms.

**C) Positive mood facilitates cognitive control and flexibility**

It is now well-recognized that positive affect leads to greater cognitive flexibility and facilitates creative problem solving across a broad range of settings (e.g., Aspinwall & Taylor, 1997; Carnevale & Isen, 1986; Estrada et al., 1994; Isen et al., 1985; Isen et al., 1987). For instance, in Mednick's original creative RAT task where 7 items of moderate difficulty were used, positive affect subjects produced more solutions compared to controls, both in a sample of college students as well as in practicing physicians. Positive mood has shown to facilitate less anchoring and more cognitive flexibility in medical decision-making (Estrada, Isen, & Young, 1997), in industrial negotiations (Carneval et al., 1986) and in creative problem solving tasks (Isen et al., 1985; Isen et al., 1987; Rowe et al., 2006). As explained above, during insight solving greater cognitive control is particularly needed to overcome impasse which usually (but not always) occurs when solvers are misdirected in their solving process to focus on dominant associations. Therefore, solvers would need to be guided by top-down cognitive control processes to inhibit and switch away from these errant associations in order to select the non-prepotent solution-relevant information that is weakly activated in the RH.

**Cognitive Control and Insight**

Therefore, cognitive control and flexibility are multifaceted concepts involving a combination of either inhibiting prepotent yet wrong associations, and/or switching between strategies, between attentional foci and between hemispheres to select the correct solution or solution path. As mentioned above, insights are thought to recruit greater cognitive control mechanisms than analytical problems because they do not involve a systematic step by step approach toward the solution that analytical solutions require. Insights, by contrast, are frequently associated with impasse wherein solvers feel stuck, thinking that they are making no progress toward the solution. To overcome impasse, solvers need to frequently inhibit prepotent irrelevant associations thought to be strongly activated in the LH in order to allow weakly activated yet solution-relevant concepts to rise to threshold in the RH. Therefore, a part of cognitive control mechanisms in insight solving requires knowing when a particular solving approach is irrelevant, and when switching to a new approach is required. By this token, if a positive mood does facilitate insights, it should also modulate cognitive control mechanisms in the frontal cortex to regulate which processes to inhibit, to switch to and to select. In fact, prior research has shown that a positive mood does indeed facilitate this balance between the maintenance and switching of cognitive sets (Dreisbach & Goshke, 2004). If cognitive control is necessary for insight, then the converse should also be true in that patients who demonstrate impaired cognitive control processes should have difficulty in producing insights.

**Impaired Cognitive Control, Impaired Insight: Evidence from Patient Populations**

Without having this sensitivity to inhibit irrelevant information and to switch and select alternate response options, solvers would either be perseverating on one solving approach or would constantly be distracted, switching from one association to another without being able to hone in and select the correct solution path. It is for this reason that thought disordered (TD) schizophrenia patients do not have many insights because they are not able to exert cognitive control processes to hone in and select the correct association even though they have enhanced switching in terms of their semantic associations spreading further and faster compared to non thought disordered schizophrenia patients (Spitzer et al., 1993). Indeed, the converse is also true where patients with prefrontal lesions exhibit difficulty in switching between different categorization rules such as those in the Wisconsin Card Sorting Task, and have increased perseverative errors and reduced cognitive flexibility (Dreisbach & Goshke, 2004). Additionally, the "utilization behavior" from which prefrontal lesioned patients suffer where they are unable to suppress well-practiced habits stems from a deficit in inhibiting a prepotent response. Thus, cognitive control mechanisms, guided by the frontal cortex, are required particularly during insight solving to modulate the delicate shift in balance between switching away from an errant set of associations, and maintaining solution-relevant information, shielding it from irrelevant distracters.

**The Neural Basis of Cognitive Control: ACC/PFC**

We have seen that schizophrenia patients and prefrontal lesioned patients show impairments in the frontal cortex, specifically in ACC and PFC, which are the two regions that have been associated with cognitive control processes that are recruited particularly during insight solving.

This network is thought to send top-down signals to posterior regions (i.e., right and left STG) to bias processing of task relevant information. The most frequently studied task that tests for cognitive control function has been the Stroop task. Here, participants are asked to name the color in which a color word is shown. The prepotent response is to read the word rather than state the color in which the word is displayed. Therefore, this means that response times are greater when there is an incongruency between the color that the word refers to and the color of the word (i.e., the word red shown in blue ink). Increased ACC activity is observed during this incongruent response condition compared to a congruent condition (the word red in red ink). During the incongruent trial, participants need to exert great control to override this prepotent tendency of reading the word (i.e., red) to state the mismatching color (in blue color) in which the word is displayed (Carter et al., 1995; Botvinick et al., 2001). ACC, specifically, has been implicated in tasks where an up-regulation of control is required such as in error detection (Carter et al., 1998) or conflict monitoring tasks (Botvinick et al., 2004; Kerns et al., 2004; Weissman et al., 2003). According to the conflict monitoring account, the ACC and PFC work in conjunction where the ACC increases activation during incongruent trial responses (or error-related trials), and sends a signal to the PFC to implement greater control for the upcoming trial. Therefore, the PFC has been observed to increase activation during the preparatory phase of an imminent trial (trial 'n') where the preceding trial (trial 'n-1') is an incongruent trial (MacDonald et al., 2000; Kerns et al., 2004). The corollary has also been found where reduced activity in ACC associated with lapses in attention in preparation for the upcoming trial, correlated with slower reaction times on the upcoming trial (Hedden & Gabrieli., 2006). Therefore, in terms of our CRA study, we would expect a positive mood to modulate insight solving through modulating cognitive control mechanisms in the frontal cortex (ACC/PFC) both at the preparation period as solvers prepare for the upcoming trial as well as just prior to solution.

**Positive mood modulates cognitive control and Insight by enhancing switching and selection**

Indeed, we demonstrate in our CRA study that a positive mood modulates these cognitive control processes in the frontal cortex (ACC/medial PFC) to predispose solvers toward more of an insight solving approach both at preparation when solvers are getting ready to solve the upcoming trial, and just prior to solution (Subramaniam et al., In Press). Cognitive control during insight solving not only usually involves an overriding of prepotent responses (i.e., in the CRA example: 'tooth, potato, heart,' the words 'ache' or 'pain' need to be inhibited) but also involve a shift to select a non-dominant association (i.e., a switch to select 'sweet'). Increased ACC activity has also been observed during other components of cognitive control involved in switching attention to select the correct response. Specifically, in one study, good performers at attentional shifting between 2 tasks in a dual task condition showed enhanced effective connectivity between ACC and DLPFC (in the RH) (Kondo et al., 2004). Therefore, in a similar vein, if a positive mood enhances cognitive control mechanisms by enhancing switching between cognitive sets, we would expect it to increase ACC/PFC. Recall that cognitive control processes during insight solving involve switching between strategies, modes of attention and/or hemispheres to a new problem space to be able to select the non-dominant correct solution path. We have reviewed a number of studies demonstrating how a positive mood facilitates restructuring (see B) between global and local modes of attention, between strategies to reduce perseveration tendencies in classic insight problems such as the Duncker candle task as well as in the RAT task (Bumann & Kuhl., 2005; Dreisbach & Gosschke., 2004; Isen et al., 1987). Let us now examine some evidence which suggests that a positive mood enhances the selection of unusual or non-dominant associations (Ashby et al., 2002).

Ashby and colleagues give an example of a stimulus '*pen'* where the subject needs to select among the various meanings of this word. The dominant interpretation is of *pen* as a writing tool in which neutral affect subjects are likely to respond with a high frequency associate, such as *pencil* or *paper*. In their connectionist model of cognitive set selection, a positive affect accounted for the enhanced selection of more unusual associations to facilitate creative solving ability. For instance, it predicted that positive affect participants would also include interpretations of '*pen'* to mean a fenced enclosure as well as the dominant interpretation of a writing implement so the model predicted that positive affect participants would respond with a low frequency associate, such as *barn* or *pig* as well as a high frequency associate such as paper. They interpret these facilitatory effects of positive feelings on word association, remote associates, and candle tasks to be due to increased dopamine release in the anterior cingulate and prefrontal cortex, which increases the ability to switch and select the correct association as mention earlier (see B above). This would extend to other insight problems and riddles such as the "Man Marrying Problem," the "Doctor-Patient Problem," (see below) and of course our own set of CRA problems. In all these problems, participants would need to inhibit and switch away from a prepotent association to reframe the problem and select a non-dominant solution path. In the Man Marrying Problem, for instance, participants need to inhibit the interpretation that 'marry' means marry one's husband/wife to be, and switch to a more unusual interpretation of 'marry' where marrying can also be achieved by a minister (see prior Chapter). Similarly, in the CRA example: 'tooth, potato, heart,' participants need to inhibit the dominant association 'ache' or 'pain' when they realize that pain does not fit with potato (i.e., ‘potato-pain?’), and must inhibit this association and switch to select an alternative non-dominant solution (i.e., ‘sweet’ forming sweet-tooth, sweet-potato, and sweetheart).

Recall that too much inhibition resulting in participants maintaining a narrow spotlight of attention can prevent insights, just as too much switching can lead to increased distractibility, also inhibiting insights. Therefore, an optimal amount of dopamine is needed to enhance cognitive flexibility in order to modulate the balance between switching between cognitive sets and selecting the correct solution path. The relation between positive affect, dopamine, cognitive control and insight is complex. Prior research suggests that phasic increases in dopamine in the frontal cortex up-regulate cognitive control mechanisms (Braver et al., 1999). We are not proposing that positive mood modulates dopamine to enhance cognitive control mechanisms by enhancing overall switching and inhibition in general. Indeed, prior research has demonstrated that positive mood reduces perseveration in terms of disengaging away from a formerly relevant task that become irrelevant but can also lead to increased distractibility (Dreisbach & Goschke, 2002; Rowe et al., 2007). Rather, we propose that a positive mood enhances cognitive control processing to enhance the dynamic balance between task shielding effects (i.e., to protect insight solving processes from interference by irrelevant distracters) and task switching effects (i.e., to maintain a broad enough attention to switch to accessing distantly-related solution-relevant information while at the same not be distracted by irrelevant stimuli). Recall from the previous chapter on insight solving that insight compared to analytical preparation involved increased activity over medial frontal regions, reflecting increased preparation to exert top-down cognitive control mechanisms to switch and select the correct solution (Kounios et al., 2006). Additionally insight compared to analytical preparation also involved occipital alpha activation (which inversely relates to neural activity) thought to shield top-down processes from interference by bottom up visual stimulation. The corollary is that analytical versus insight preparation, involved increased occipital activity thought to be reflective of externally-directed bottom-up visual attentional process that may correspond to a systematic step by step trial and error analytical solving approach (Kounios et al., 2006). An analytical solving style, for example, would involve solvers trying one CRA association before and after each of the 3 CRA words and then, when the first association does not work out they would move on to systematically try another association until one word fits with all three CRA words. We think that a positive mood is likely to modulate cognitive control processes in the frontal cortex to facilitate more of an insight solving approach. One likely mechanism by which a positive mood may enhance insights is by modulating the shift between task shielding effects (i.e., shown by visual occipital alpha activation during insight preparation) and task switching/selection effects (shown by enhanced ACC activation during insight preparation) both at the preparation period as well as during the solving phase. In this manner, a positive mood may predispose and facilitate an insight approach by enhancing the regulation of attention and cognitive control as the demands of the task necessitate so that solvers are better able to switch away from irrelevant prepotent associations and distracters in order to select the correct albeit non-dominant solution.

**Caveats Considered: Positive Mood and Insight Solving**

There are certain general caveats of the facilitatory effects of positive mood on cognitive flexibility and insight solving that may be discarded for the purpose of our CRA task. First, one may argue that if a positive affect is associated with arousal, then the effects of PA on creativity and insight may be attributable to arousal rather than to positive affect. For this reason, Isen et al (1987) included a group engaging in exercise (to represent arousal with no affective tone), along with a positive affect group, a neutral affect group and a negative affect group. Isen et al (1987) demonstrated that subjects in the exercise condition did not have any more solutions on classical insight problems such as Duncker's candle task compared to the neutral or negative affect condition. In contrast, the positive affect group (positive mood induced by watching a film clip) produced more solutions than the neutral, negative affect and exercise groups. This result suggests that the influence of positive mood on cognitive flexibility and insight is not due to arousal. Furthermore, in Federmeier's ERP studies, mood-related cognitive effects on enhancing semantic distance could not have been driven by arousal since the N400 response has not been shown to be influenced by arousal. Additionally, mood did not affect earlier ERP components (N1, P2), which are known to vary with both arousal. Finally, we mention in our assessed CRA study and our mood induction study that if the effects of positive mood on overall solving and insight solution were due to high arousal, then we should observe this same facilitatory effect in high anxious participants as well as in the anxious mood induction, which we do not (see Chapter 4). Moreover, arousal did not positively correlate (or negatively) with either overall solving or solving strategy in any one of the MI conditions (see Chapter 5). All this together confirms that the effects of positive mood on cognitive control and insight solving are due to positive mood specifically and not arousal.

Secondly, there have been claims that a positive mood facilitates a more heuristic, superficial mode of processing. For instance, positive mood participants have been suggested to use "satisfising" and superficial, rather than optimizing solving strategies (Kaufmann & Vosburg., 1997). Estrada and colleagues (1997) have found evidence to the contrary wherein physicians in whom positive affect was induced showed no evidence of superficial processing in terms of jumping to a diagnosis without having enough evidence in their treatment of a rare case of liver disease. Furthermore, we argue in our assessed mood CRA study and our mood induction study that superficial processing induced by a positive mood would lead to more premature and incorrect responses. Yet high and low positive mood participants made equally few errors. If anything, we find that the reverse case is true where participants who solved problems with insight were more likely to not solve the problem at all rather than make a premature incorrect guess at the solution compared to participants who solved problems analytically who were more likely to make incorrect responses (Kounios et al., 2008). Similarly, in our MI results when participants were in a positive mood compared to either a neutral or anxious mood, they made equally few errors, and did not show a difference in RT in either insight trials or analytical trials between the positive MI and other two conditions. There was also no difference in errors between insight and analytical solutions or in RTs. Therefore, we conclude that the nature of the task is important when one makes generalized conclusions about mood-cognition interactions. For instance, it is possible that positive affect subjects may engage in more superficial processing compared to neutral affect subjects simply because they find the task boring and detrimental to their mood state. We do not find this theory of a superficial processing style induced by a positive mood to be upheld in the CRA task.

Thirdly, some researchers believe that a positive mood reduces overall cognitive capacity (Mackie & Worth., 1989). For instance, it has been suggested that a positive mood may increase the load on working memory because it increases the incidence of positive mood-related thoughts that are more likely to interrupt processing on a given cognitive task (Seibert & Ellis, 1991). Indeed, Bush and colleagues (2000) think that separable areas within the anterior cingulate are involved in emotional and cognitive processes and that the relationship between these two areas may be inhibitory such that increasing the demand for emotional control may reduce capacity for control of cognitive processes. By contrast in our CRA task, rather than positive mood having a subversive effect on cognition, we show that high positive mood versus low positive mood participants specifically modulate the cognitive region of the ACC (BA 32, BA9) to enhance cognitive preparation for solving in general (i.e., positive mood preparation effect), as well as for insight solving specifically. This region that shows a positive mood preparation effect overlaps with the ACC region that shows increased activation for insight compared to analytical solutions (see Chapter 4). Therefore, in terms of our CRA task, we believe that a positive mood *enhances* cognitive processes by modulating activity within the rostral portion of the dorsal ACC to enhance overall preparation to solve the upcoming CRA trial, as well as to bias solving toward more of an insight.

## Chapter 4: A Brain Mechanism for facilitation of Insight by Positive Mood

As mentioned in the prior chapter, previous research has shown that people seem to solve insight or creative problems better when in a positive mood, though the precise mechanisms and neural substrates of this facilitation remain unclear. Here, we assess mood and personality variables in 79 participants before they attempted to solve the Compound Remote Association (CRA) problems that can be solved either by an insight or analytic strategy. We found that participants higher in positive mood solved more problems, and specifically more with insight, compared to participants lower in positive mood. We also investigate the neural basis of how a positive affect modulates cognitive insight solving as measured with functional magnetic resonance imaging (fMRI), while participants are tackling the CRA problems. Specifically, we demonstrate that a positive mood alters preparatory activity in ACC, biasing participants to engage in processing conducive to insight solving. This result suggests that positive mood enhances insight by modulating attention and cognitive control mechanisms via the ACC, perhaps also enhancing sensitivity to detect more distant non-prepotent solution candidates.

People can solve problems through methodical, analytic processing, through insight, or through some mix of both (for recent reviews: Bowden et al., 2005; Gilhooly & Murphy, 2005). These two strategies, or (sets of) processes can co-occur, overlap, and interact, yet they are phenomenologically, behaviorally, and neurologically distinct, as described below. It has previously been demonstrated that positive affect (PA) specifically facilitates people's ability to solve creative or "insight problems," i.e., problems that are more often solved with insight (Isen et al., 1987; Estrada, Isen, & Young, 1994; Isen, 1999 a,b; Rowe et al., 2007; Amabile, 2005).

Therefore, observing brain activity associated with shifts of problem solving approaches in different affective states provides fertile ground for examining the neural mechanisms of emotion-cognition interactions. Here, we show that distinct affect states change actual cognitive organization to modulate problem-solving processes beyond the well-documented mood-memory congruency effect (Teasdale & Fogarty, 1979).

The distinction between insight and analytic solving has been anecdotally recognized for millennia, and has been the subject of scientific inquiry for nearly a century (e.g., Duncker, 1945; Kohler, 1917; Maier, 1930). A plethora of behavioral evidence details how these two solving processes differ. Analytic processing involves deliberate application of strategies and operations to gradually approach solution. Insight, which is considered a type of creative cognition, is the process through which people suddenly and unexpectedly achieve solution through processes that are not consciously reportable. Insight solutions tend to involve conceptual reorganization, often occurring after solvers overcome an impasse in their solving effort, and are suddenly able to recognize distant or atypical relations between problem elements that had previously eluded them (Gilhooly & Murphy, 2005; Metcalfe, 1986; Metcalfe & Wiebe, 1987; Smith & Kounios, 1996; Schooler et al., 1993a; Schooler & Melcher, 1997; Weisberg, 1994). When solution is achieved, these factors combine to create a unique phenomenological experience, termed the Aha! or Eureka! moment.

PA has been shown to facilitate insight and creative problem solving across a broad range of settings (Isen et al., 1987; Ashby, Isen, & Turken, M., 1999; Estrada, Isen & Young, 1997; Isen, 1999b; Rowe et al., 2007). One description of this effect is that PA enhances cognitive flexibility in various settings, such as in classifying material (Isen & Daubman, 1984), in negotiation tasks (Carnevale & Isen, 1986), in medical diagnoses (Estrada et al., 1994) and in creative problem solving tasks (Isen et al., 1984; Isen et al., 1985). Various explanations have been proposed to explain this facilitation (also see Discussion). Briefly, one hypothesis is that PA promotes a more global scope of attention (Gasper & Clore, 2002; Bolte, 2003), enhancing access to distant or unusual associations (Isen et al, 1985; Federmeier, 2001; Friedman et al., 2003), which facilitates creative solutions to classic insight problems such as Duncker's candle task (Isen et al., 1987) and improves performance (Isen et al., 1987; Rowe et al., 2007) on the Remote Associates Test (Mednick, 1962). Another hypothesis is that PA enhances switching *between* global and local attentional modes (Bauman & Kuhl, 2005) or between strategies (Dreisbach & Goschke, 2004); or, similarly, that it enhances selection of different perspectives (Ashby et al., 1999).

In contrast, negative affect states such as anxiety and depression have been associated with deficits in attentional and cognitive control mechanisms (Mayberg et al., 1999; Bishop et al., 2004), often inducing a narrow scope of attention (Easterbrook, 1959). Therefore, anxiety in particular should impede cognitive flexibility, problem restructuring, and insight solving.

This study extends the existing literature in two ways. First, we examine not just the facility in solving a particular type of problem, but how mood modulates *which strategy*, insight or analytic, is preferred (or successful). Second, we measure brain activity as people solve these problems, to observe the neural mechanisms of insight problem solving that are modulated by mood.

Insight and analytic problem solving are associated with different patterns of brain activity, measured with both fMRI and electroencephalography (EEG), both at the moment people achieve solution (Jung-Beeman et al., 2004) and as people prepare for each new problem (Kounios et al., 2006). For one thing, the right hemisphere, generally, seems to make stronger contributions as people process insight problems and recognize their solutions (Beeman & Bowden, 2000; Bowden & Beeman, 1998; Bowden & Jung-Beeman, 2003a). More specifically, compared to solving problems without insight, solving with insight involves stronger activity in right temporal regions thought to be important for integrating distant semantic associations (Jung-Beeman et al., 2004). Additional brain regions showed similar but weaker "insight effects" in the earlier study, but manifest strong effects in the current study; these include: anterior cingulate, posterior cingulate cortex (PCC), parahippocampal cortex (PHC), right superior frontal gyrus (SFG) and right inferior parietal lobe (IPL).

Additionally, during a brief preparation period prior to the presentation of each problem, various brain regions are more active prior to problems solved with insight than prior to problems solved without insight (Kounios et al., 2006). That is, different patterns of brain activity are conducive to solving the subsequent problem with insight versus analytic processing. The distinguishing areas include bilateral temporal areas involved with semantic processing, posterior cingulate cortex putatively involved in attention, and anterior cingulate cortex thought to be important for cognitive control. Thus, each of these areas represents a reasonable candidate for affect-induced modulation of insight problem solving. The left temporal cortex is more adept at preparing to retrieve many close prepotent associations, while activity in the right temporal cortex enhances the readiness to pursue weaker associations (Jung-Beeman, 2005). On the other hand, the posterior cingulate is thought to be involved in visuospatial expectancy (Small et al., 2003) and the anterior cingulate is more likely to be involved in cognitive control, and possibly in switching between solution candidates (or other thought processes), which is likely an important component of insight.

**Anterior Cingulate and Insight Processes**

We have demonstrated that the rostral portion of the dorsal anterior cingulate cortex (dACC (BA 9, 24, 32)) showed a sustained increase in neural activity during the preparatory interval before participants actually see problems, and stronger ACC activity occurs prior to trials solved with insight than those solved more analytically (Kounios et al., 2006).

We hypothesized that insights would involve greater cognitive control and restructuring processes, and that the dorsal anterior cingulate cortex would be involved in the shift and selection of a new solution path. In tasks involving response competition, cognitive control is thought to be important for the monitoring of competing responses (Macdonald et al., 2000; van Veen et al., 2001; Weissman et al., 2003), in overcoming prepotent responses when strategic processes were less engaged and conflict high (Carter et al., 2000), and in shifting attention (Davis et al., 2005; Dreisbach & Goschke, 2004; Kondo et al., 2004). Such cognitive control mechanisms could be critical for insight because they enable problem solvers to detect competing solution candidates, rely less on dominant associations or strategies, and/or enable shifting attention from a prepotent but irrelevant association to the less potent, but correct, association. This could be an important component of what insight researchers variously term cognitive restructuring and flexibility, or "breaking set" and "overcoming functional fixedness."

**Anterior Cingulate, Positive Affect and Insight**

One possible mechanism by which PA could facilitate insight is through cognitive restructuring processes. PA is likely to facilitate insight by increasing a person's ability to switch and select alternative cognitive perspectives (Baumann & Kuhl, 2005; Isen, 1999b; Dreisbach & Goschke, 2004), reducing perseveration on one particular solution candidate or solving approach, thus increasing the probability of engaging in various cognitive restructuring processes. We propose that PA could modulate activity in the ACC (Lane et al., 1998) to make it more open to detecting competing (weak) activations, biasing a shift toward insight solutions. The modulated ACC activity might facilitate one or a combination of mechanisms such as: switching between global and local processing modes of attention (Baumann & Kuhl, 2005); switching from irrelevant to relevant solving strategies, and/or selecting the correct solution (Dreisbach & Goschke, 2004).

The ACC appears to be a particularly promising site for interactions between cognitive processes and affect states. Besides its involvement in modulating cognitive processes via attention shifting, conflict detection, response competition and/or selection mechanisms (Bush et al., 2000; Badre & Wagner, 2004; Dreher et al., 2003; Ruff et al., 2001; Kerns et al., 2004; Botvinick et al., 2004), the ACC also appears to be involved in emotional processes (Bush et al., 2000; Drevets et al., 1998; Whalen et al., 1998; Mayberg et al., 1999). Functional neuroimaging studies show overlapping activation patterns within the ACC between cognitive and affective tasks (Fichtenholtz et al., 2004; Papez, 1937; Lane et al., Teasdale et al., 1999). Electrophysiological studies have identified a population of dorsal ACC neurons that show increased activity to high versus low-conflict Stroop tasks, including those with emotional valence (Davis et al., 2005). Moreover, cytoarchitectonic studies suggest the involvement of specialized spindle cells of Brodmann Area 24 that integrate cognitive input with emotional overtones (Nimchinsky et al., 1999).

Given the ACC's involvement in cognitive control and emotional processes, and our prior evidence that activity in the ACC prior to solving problems is associated with solution strategy, we predict that affect states will modulate ACC activation, and thereby influence insight (versus analytic) solving processes. Specifically, we hypothesize that PA states will increase activity in the ACC before the actual problem onset, biasing the solver toward cognitive processing that is relatively conducive to insight.

**Hemispheric Asymmetries, Affect, and Insight**

Another possibility can be derived from the following considerations: 1) Right hemisphere (RH) processing seems to make strong contributions to insight solving overall (Bowden & Beeman, 1998; Jung-Beeman et al., 2004); 2) RH semantic processing activates or maintains activation of a broader set of semantic associations than does LH semantic processing (Beeman et al., 1994; Chiarello et al, 1991; Faust et al., 2007), and these broad associations seem very relevant for solving with insight; 3) Positive mood seems to broaden the overall pattern of semantic associations (Federmeier et al., 2001; Isen 1985); 4) Global or broad attention is associated with RH visual processing, creative problem solving (Ansburg & Hill, 2003), and positive mood (Gasper & Clore, 2002; Rowe et al., 2007); and 5) inducing an approach regulatory focus (with low arousal) increases measures of relative RH activation, as well as facilitating creative problem solving (Friedman & Forster, 2005) . Thus, it remains hypothetically possible that PA will directly increase overall activity in the right hemisphere, specifically in the right superior temporal gyrus (STG), which is, cytoarchitectonically more suited than the left STG at integrating distant semantic associates via coarse semantic coding (for review, Jung-Beeman, 2005). However, such an effect might seem to contradict some established associations between positive mood (or approach focus) and leftward asymmetries in electroencephalographic activity (Davidson, 1992; Tomarken et al., 1992; Herrington et al., 2005). Moreover, to us, it seems intuitively more likely that a global characteristic like positive mood would either modulate all semantic processing (in both hemispheres) to broaden the scope of semantic associations, or, more likely, to modulate attention or cognitive control mechanisms that make solvers better able to detect (and utilize) remote associations that are only weakly active (perhaps, mostly due to RH semantic processing).

**Experiment**

Insight typically occurs when people initially focus on an incorrect but dominant association (e.g., in Figure 1, *ache* can form compounds with tooth and heart, but not potato), and need to overcome this impasse and switch to the correct solving strategy to be able to reach a sudden (Aha!) understanding of the solution (Bowden & Jung-Beeman, 2003a, & Jung-Beeman et al., 2004). In many studies of insight solving, problems have typically been classified a priori, as either “insight problems” or as “noninsight problems” (Weisberg, 1994); but because any problem can be solved through insight, through straightforward (incremental, strategic) problem solving, or through a combination of both (Bowden et al., 2005) the a priori “insight” classification is not definitive.

We exploit this feature by asking participants to report directly which strategy they used predominantly to achieve solutions, in order to directly contrast trials that lead to insight solutions versus those that lead to noninsight solutions. This enables us to examine insight versus noninsight processing while holding task and stimulus type constant. Participants were presented with a large set of Compound Remote Associate (CRA) problems (Bowden & Jung-Beeman, 2003b). Similar problems (Mednick, 1962) are often used as “insight problems” or for creative problem solving (Isen, 1987; 1999a), and the ability to solve them correlates with the ability to solve other classic insight problems (Duncker, 1945; Maier, 1931). However, they can be solved either analytically or with insight (Bowden & Jung-Beeman, 2003a; review: Bowden et al., 2005).

The type of processing involved in successfully solving these problems varies across trials (Jung-Beeman et al., 2004; Kounios et al., 2006) and across individuals (Kounios et al., 2008), making this paradigm a strong candidate for investigating how affect can, in a general (rather than in only a mood-consistent way), modulate higher level cognition. Specifically, we examine the brain basis of how PA and anxiety modulate solving strategy, tipping the balance of processes toward insight or analytic strategies.

Mood state (including positive and negative affect, and anxiety) and personality measures, gathered prior to the experimental session, were related to performance and neuroimaging measures. For the participants who underwent fMRI scanning, we identified brain regions involved in various aspects of problem solving, and correlated the signal change in these regions with the mood and personality indices, as well as identifying areas that showed contrast in the brain activity during problem preparation between high- and low-positive mood individuals.

## METHODS

### Participants and Procedure

All 79 participants were neurologically healthy, right-handed and native speakers of English. After giving informed consent, all participants completed mood state inventories for PA and negative affect (PANAS), state anxiety (STAI), and a variety of other personality inventories measuring more stable individual traits (Behavioral Inhibition Scale-Behavioral Activation Scale, the Neuroticism subscale for the Big 5 Personality Mini-Markers, and the Magical Ideation Scale as an indicator of schizotypy). The mood state inventories (PANAS and STAI), given to all participants just before they performed the CRA task, measured the extent that participants were currently experiencing a positive (PANAS) or anxious mood (STAI). We examined correlations between all mood and personality scores and various problem solving measures (solving rate and proportion of problems solved with insight), as well as fMRI signal change.

Following these questionnaires, 52 participants performed the problem-solving task outside the scanner, providing only behavioral data, and 30 participants performed the problem-solving task in the scanner. Data from 3 participants were excluded – due to poor fMRI signal in two of the participants and due to one participant providing only two analytic responses.

**Problem solving paradigm**

We measured insight and analytical solving of 135 CRA problems (Bowden & Jung-Beeman, 2003b), adapted from a test of creative cognition (Mednick, 1962). For each problem, participants see three problem words (tooth, potato, heart), and must generate a solution (sweet) that can form a compound word or phrase with each problem word (sweet tooth, sweet potato, sweetheart). The solution word can precede or follow each problem word. Like most problems (even classic "insight problems"), these problems can be solved either with insight, or through more methodical or analytical processes. We relied on participants' trial by trial judgments to determine the type of processing that led to each solution. This method has reliably shown consistent differences in behavior (Beeman & Bowden, 2000; Bowden & Beeman, 1998; Bowden & Jung-Beeman, 2003a) and in brain activity (Jung-Beeman et al., 2004; Kounios et al., 2006, 2008). For instance, in our prior EEG study, the neural processes biasing the sudden (Aha!) that led up to an insight solution, were associated with increased neural activity (less alpha power) peaking over mid-frontal cortex and bilateral temporal cortices for insight versus analytical preparatory processes (Kounios et al., 2006). Using a different population sample and methodology, fMRI signal corroborated the EEG findings, specifically isolating the ACC as the medial frontal region that revealed increased neural activity for insight versus noninsight preparatory processing, and also showed increased activity within the bilateral temporal cortical areas revealed during EEG (Kounios et al., 2006). In another study, about a third of a second prior to the insight solution button press, a burst of EEG gamma activity in the right anterior superior temporal gyrus (aSTG) corresponded to the increase in fMRI solution-related signal within the same region (Jung-Beeman et al., 2004). This RH activation likely reflects the processing and integration of a broad range of semantic associations leading to solution (Beeman et al., 1994; Bowden & Jung-Beeman, 1998, 2003a; Jung-Beeman et al., 2004).

Prior to the current experiment, participants received instructions to make insight/noninsight judgments, emphasizing that they should respond "insight" if they achieved solution suddenly and surprisingly, possibly by switching their train of thought just prior to solution, and that as soon as they thought of the solution candidate, they were instantly confident it was the solution. In contrast, they should respond "noninsight" if they achieved solution incrementally, or by some analytical strategy, e.g., by strategically retrieving candidates and testing them out.

Each trial began with a fixation cross that remained on the screen for a variable rest period (from 0, 2, 4, 6, or 8 sec, randomized across all trials), during which participants prepared for the next trial (Fig.1). Such variable delays were used to jitter the events and optimize deconvolution of the fMRI signal from successive events. After this preparation period, the three problem words (tooth, potato, heart) were presented on the screen (horizontally centered, just above, at, and just below central fixation), and persisted until participants solved the problem, or a 15s time limit was reached. Participants attempted to produce a single solution word (sweet) that could form a compound word with each of the problem words. If participants solved the problem, they made a bimanual button press by pressing the 2 outer buttons with a finger on each hand when they arrived at the solution; after a variable (0-8s) delay, a solution prompt appeared, and participants verbalized the solution. After another variable delay (0-8s), an insight prompt ("Insight?") appeared. To control for motor response differences between insight and analytic ratings, participants pressed the two outer buttons with a finger on each hand if they had reached the solution with an insight; or, they pressed the two inner buttons if they had reached the solution through analytic noninsight means. After the insight/analytical solution rating, or after 15s elapsed on unsolved trials, the next preparation period began.

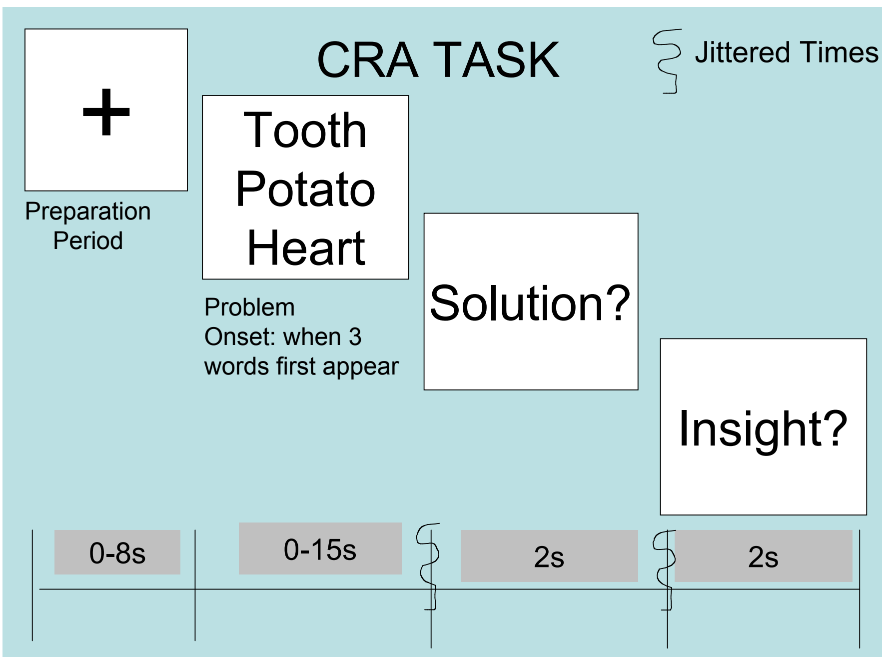



Figure 1. Sequence of events within a trial of the Compound Remote Associate (CRA) task. Each trial began with a central fixation cross, signaling the onset of the preparation interval, which lasted for a variable 0-8s, after which the problem was presented. Participants pressed the response buttons bimanually if/when they achieved solution, then verbalized the solution at the Solution prompt, and then reported whether they solved the trial with or without insight at the Insight prompt. The intervals between these events were jittered for a variable 0-8s.

**Image acquisition**

Thirty fMRI participants performed the CRA task during scanning, which for all participants occurred in the same Siemens Trio (3 Tesla) scanner and eight channel head coil, with the same scanning protocol, at Northwestern's Center for Advanced MRI. Head motion was restricted with plastic calipers built into the coil and a vacuum pillow. The functional imaging sequence was optimized for detection of the BOLD effect (Ogawa et al., 1992) including local shimming and 8 sec of scanning prior to data collection to allow the MR signal to reach equilibrium. Functional imaging used a gradient echo echo-planar sequence (TR = 2 sec for 38 3-mm slices, TE = 20 msec, matrix size 64x64 in 220-mm field of view). Participants solved problems during four scans of 10 min 20 s and a final fifth scan that was truncated when participants finished solving problems. Each functional scan was synchronized with the onset of the first problem in that block of trials; timing of subsequent trials was response-dependent, and not synchronized with image acquisition. Anatomical high-resolution images were acquired in the same plane, with T1-weighted images parallel to the ACPC plane.

**Image analysis**

Functional and anatomical images were co-registered through time, spatially smoothed with a 7.5 mm Gaussian kernel, and fit to a common template. Within each run, voxels were eliminated if the signal magnitude changed more than 20% across successive TRs, or if the mean signal level was below a noise threshold. Functional data were transformed (Collins et al. 1994) to a standard stereotaxic atlas (Talairach and Tournoux 1988) with a voxel size of 2.5 $mm^3$. The data were analyzed using general linear model analysis, as implemented in AFNI (Ward, "http://afni.nimh.nih.gov/afni"), that extracted average estimated responses to each trial-type, correcting for linear drift and removing signal changes correlated with head motion, as well as signal attributed to other temporally adjacent events to ensure that signal could be isolated to the event of interest. For example, when extracting signal related to preparation events, we included in the analysis: the preceding insight ratings, the subsequent problem onsets, and the subsequent solutions, to factor out signal more closely tied to those events than to the preparation event. Signal was estimated for all time points (TRs 0-10) within the same model, without regard to any presumed hemodynamic response function.

The primary focus of this report was fMRI signal, hence brain activity, corresponding to the preparation intervals. We examined changes in BOLD signal following the onset of this preparation period in three ways:

**(A) Areas that turned on, i.e., changed their activity, during preparation.**

We examined overall responsivity corresponding to the preparation interval, manifested as a rise and fall of BOLD signal from onset of the preparation period to peak response and back down to baseline. Specifically, for every voxel, signal corresponding to the peak of the preparation period (TRs 4, 5, & 6 following onset of preparation period; for comparison, there was a peak signal in motor cortex at TR 3, corresponding to the button press from the insight-rating preceding the preparation period) was contrasted with signal corresponding to the points preceding and following the preparation period (TRs 1, 9, & 10). We identified regions of signal change that were consistent across all 27 participants, with a significance threshold combining t values ($p < .005$) and cluster size (at least 1500 $mm^3$ in volume). The dorsal anterior cingulate cortex (dACC), posterior cingulate cortex (PCC), and the right angular gyrus (AG) clusters exceeded the above criteria, increasing preparatory activity. Of all these statistically reliable clusters (functionally defined ROIs), the dACC and the right AG were the only two ROIs where preparatory responsivity strongly correlated with positive mood across all 27 participants.

Because *any* changes (up or down) in activity could be meaningful, to be thorough we also examined areas that exhibited deactivation, i.e., a fall and rise of signal corresponding to the preparation interval. The left and right Inferior Frontal Gyrus (IFG) showed systematic preparatory deactivation in which the mean signal for the expected preparatory peak hemodynamic signal (i.e. TRs 4, 5, 6), was significantly lower than the mean baseline signal (i.e. the first TR and last two TRs). Neither of these areas exhibited correlations between signal change and mood.

**(B) Areas that showed insight-specific activity during preparation or solution.**

Peak preparatory signal specific to insight trials was calculated by comparing the difference between insight and analytic preparation events for each participant by extracting the mean signal within the 3 TRs (TRs 4,5,6) corresponding to the expected preparatory hemodynamic peak. For comparison, the preceding insight-rating button press elicited peak signal in motor cortex at 4 sec, just prior to the preparation onset peak signal (6 sec) for each participant. Similarly, peak insight solution related signal was calculated by examining differences between insight and analytic solution events for each participant by examining the mean signal within the 3 TRs (TRs 3,4,5 – we chose an early time window to minimize contamination from post-solution activity) corresponding to the expected peak signal leading up to the solution point (see Figure 9 for comparison). The subsequent button press elicited peak signal in motor cortex (10 sec) at the solution point. The significance threshold combined cluster-size and t-values for each voxel within a cluster (set at least 500 $mm^3$ in volume) in which each voxel was reliably different across participants, [t (26) = [3.09], p < 0.005 uncorrected], for insight versus noninsight preparation, and for insight versus noninsight solutions]. The ACC, PCC, left STG, and right MTG ROI clusters exceeded these criteria, manifesting stronger preparatory peak signal for insight versus analytical trials. Several regions showed stronger peak signal for insight versus analytical solutions including: ACC, PCC, right parahippocampal gyrus (PHC), left MTG, right MTG, right Inferior Parietal Lobe (IPL), and right Superior Frontal Gyrus (SFG).

We then extracted the mean preparatory hemodynamic responsivity signal for each participant, as described by (A), within the regions that showed an insight effect at preparation, and within the regions that showed an insight effect at solution, as described above. We correlated this preparatory responsivity within these "insight" regions with positive mood (PA-NA) and anxiety (STAI) scores. Of all the ROIs defined by the insight effect that corresponded to the time window at preparation and the time window leading up to the solution point, only the ACC ROI manifested strong correlations between overall preparatory signal change and positive mood.

**(C) Areas that showed mood differences in activity during preparation.**

To examine how individual differences in affect state influenced successful preparation preceding solved trials, a whole-brain analysis identified regions in which the 8 participants highest in PA showed different signal during preparation (as described in A) than did the 8 participants lowest in PA. The dorsal ACC (dACC), ventral ACC (vACC) and PCC all exceeded significance criteria, $t(14) = 3.32$, $p=.005$, $v > 500mm^3$), all showing stronger preparatory activation for participants high in PA than for participants low in PA.

The functional overlap, illustrated in a convergence map, between all the 3 analyses occurred only within the dorsal ACC at (-2, 42, 22). The analysis with the least stringent significance threshold corresponded to a $p < .005$, combined with a cluster size of at least $500mm^3$. Thus, the functional overlap between all three analyses, manifesting activation only within the dACC, suggests a much lower probability of a type I error.

In a final set of analyses, we examined whether insight effects (stronger peak signal for insight than for noninsight trials, across all 27 participants) occurred in any of the ROIs defined by the positive mood preparatory effect (C). We contrasted peak fMRI signal for insight versus noninsight preparation periods (defined above), as well as insight versus noninsight solutions (at the TRs corresponding to the last 2 sec of processing prior to solutions). Within these ROIs, consistently stronger signal for insight than for analytic preparatory events occurred only within the dACC. Similarly, within these mood-sensitive ROIs, stronger signal for insight than for analytic solutions occurred only in the dACC. None of the mood-sensitive ROIs showed stronger signal for analytic than insight trials, at preparation or solution. Insight versus analytic signal was not enhanced by positive mood at any other time points (all $p > .2$).

## RESULTS

### Behavioral measures

Participants correctly solved 41.0% (sd=11.4) of the problems, and identified 50.8% (sd = 16.3) of their solutions as insight (mean response time= 6.57 sec, sd= 1.31) and 46.8% (sd= 16.2) of their solutions as analytic/ without insight (mean response time= 7.35sec, sd= 1.23). Of trials with responses, 3.96 % (sd= 2.52) were errors. Participants solved problems faster with insight than they did analytically ($t(78) = [3.60]$, $p <.001$).

We examined how affect, assessed by a variety of state, trait and personality questionnaires, related to problem solving behavior. The range of scores on the affective scales was somewhat limited. In particular, only 5 out of 79 participants had a score higher than 20 on the Negative Affect (NA) scale, which ranges from 10-50. However, some participants had a high score on both the PA and NA scales, consistent with the assertion that the PA and NA scales are orthogonal (Watson & Tellegen, 1988). How should we compare the mood of a person scoring high on PA and NA with the mood of a person scoring high on PA but low on NA? Although results were as strong (sometimes stronger) if we used strict PA scores, we took into account NA scores by using PA-NA as an index of positive mood.

Consistent with prior studies, positive mood modulated solving rates: the top third most positive (PA-NA) participants (mean PA-NA score= 24.0, sd 3.77, see Table 1) solved more problems (mean solved: 60.0; mean solution response time: 6.66 sec) than did the bottom third, or least positive mood participants (mean PA-NA score= 5.35; mean solved: 51.3; mean solution response time: 7.19 sec), ($t(50) = [2.24]$, $p < .05$).

**Table 1. Behavior: Positive Mood Enhances Solving Performance and Solving with Insight while Anxiety Inhibits Solving with Insight**

| Out of 135 problems | Average Solved Number | Average Insight Number | Average Noninsight Number | Solve % | Insight % | Non Insight % |
|---|---|---|---|---|---|---|
| All 79 Participants | 55.3 | 28.1 | 25.9 | 41.0 | 50.8 | 46.8 |
| High Positive Mood Participants | 60.0<br>* | 34.5<br>*** | 24.9 | 44.4<br>* | 57.5<br>*** | 41.5<br>*** |
| Low Positive Mood Participants | 51.3 | 21.9 | 29.0 | 38.0 | 42.7 | 56.5 |
| High Anxious Participants | 52.3 | 24.1<br>** | 27.1 | 38.7 | 46.1<br>** | 51.8<br>* |
| Low Anxious Participants | 57.1 | 33.1 | 23.5 | 42.3 | 57.9 | 41.2 |

For all 79 participants tested, mean number of overall solutions, solutions with insight, and analytical noninsight solutions are given for each participant group (n = 26), high vs. low positive mood was calculated using PA-NA scores from the PANAS inventory; high vs. low anxiety scores from the STAI inventory (*p < .05, **p < .01 ***p < .0005). Solved percentages were calculated out of 135 trials; insight and analytical percentages were calculated out of the total solved number.

Positive mood was also related to which type of strategy, by self-report, led to solutions. As predicted, the number of insights differed significantly across the three levels of positive mood [F(2,76) = 7.364, p = .001]. By contrast, the number of problems solved analytically, i.e., without insight, did not differ [F(2,76) = 1.485, p = .233]. Therefore, positive mood specifically facilitated insights, but did not change the rate of analytical solutions (Figure 3A). Specifically, the highest positive mood participants solved more problems with insight (mean insights= 34.5; mean insight response time= 6.12 sec) than did the lowest positive mood participants (mean insights= 21.9; mean insight response time= 7.31 sec) (t (50) = [3.96], p<.0005). Overall, a regression analysis (partialing out all other mood and personality variables) showed that positive mood (PA-NA) was directly correlated with insight solving (r (77) = .40, p<.005) (Figure 2 below).

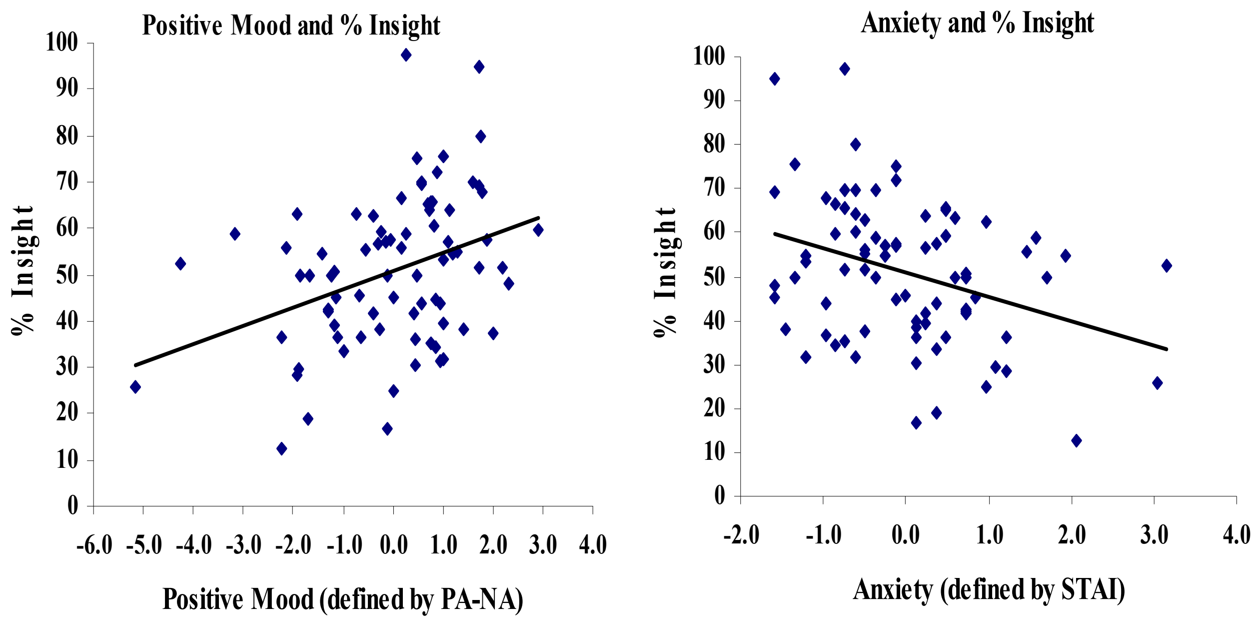
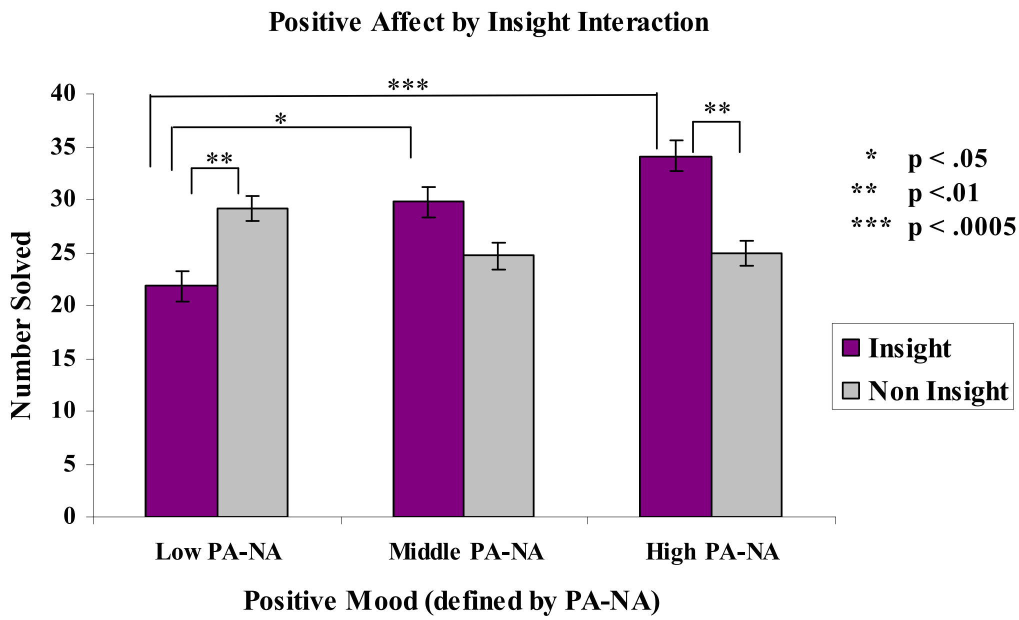



**Figure 2.** Scatter plots for all 79 participants indicating the relation between percent of solutions achieved by insight and (A) positive mood (PA-NA); and (B) anxiety (STAI), both presented in standardized z scores for illustration purposes, with regression lines and values obtained from multiple regression including all mood and personality measures.

Anxiety had the opposite effect (see Figure 3B) where the third of participants highest in anxiety (mean STAI score: 42.1, sd 3.77) solved fewer problems with insight (mean insights: 24.1; mean insight response time: 6.12 sec) than did the third of participants (t(50)= [2.75], p < .01) lowest in anxiety (mean STAI score: 24.7; mean insights: 33.1; mean insight response time: 7.31 sec), and anxiety was inversely correlated with solving with insight (r (77) = -.34, p<.005) (Figure 2). However, anxiety did not have a reliable effect on overall solving rates (top versus bottom third, t(50) = [1.277], p = .207). Anxiety enhanced the proportion of solutions achieved analytically without insight (t(50)= [2.189], p = .033) but did not reliably change the raw number of analytical solutions (t(50) = [1.235], p = .222).

**A.**




**B.**

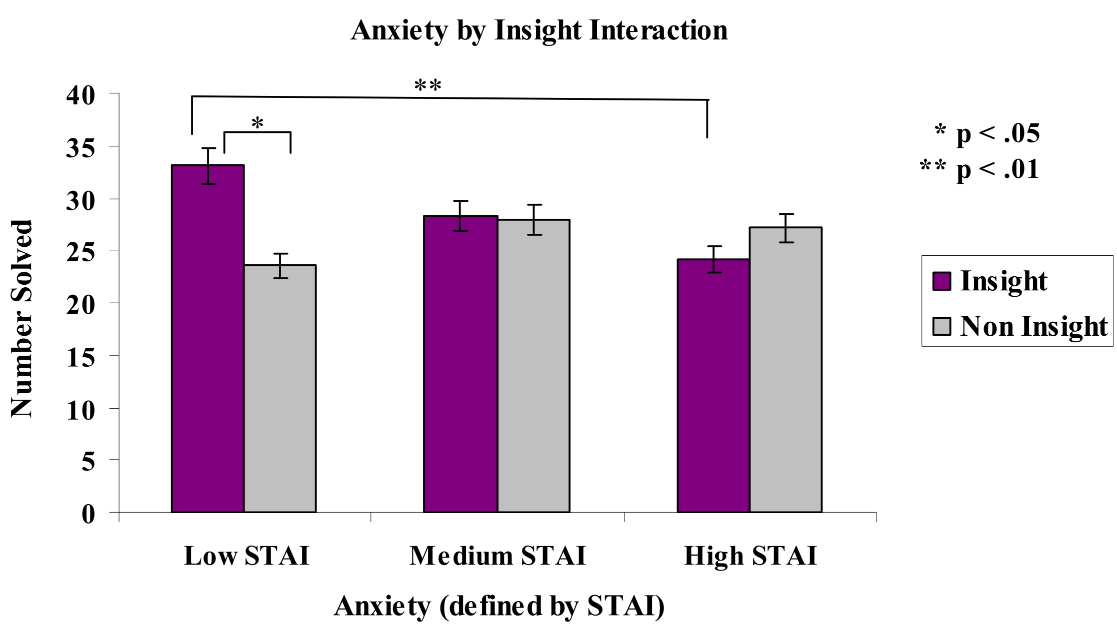



**Figure 3.** Subgroups of participants by high-, medium-, and low- positive mood (A) and Anxiety (B) scores, illustrating the number of correct solutions achieved with and without insight.

**Imaging measures**

We conducted 3 analyses to examine the neural basis of the interaction between positive mood and insight solving. In these analyses, we showed that PA modulates participants' pre-problem preparatory brain states to specifically facilitate insight solutions by enhancing signal within the rostral region of the dorsal ACC (see convergence map in Figure 7). These preparatory brain states were assessed by examining fMRI signal corresponding to the variable 0-8 seconds rest between the end of one trial and the beginning of the next 3-word problem, while participants fixate on a centrally located cross and prepare for the next problem (Kounios et al., 2006).

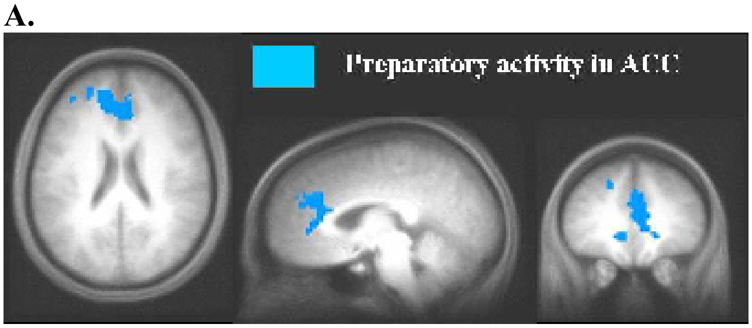
**(A) Do brain regions showing signal change at preparation show mood effects?**

As described in the Methods, we first identified regions of interest (ROIs) that showed changes in neural activity across all preparatory periods preceding trials that participants subsequently solved (Figure 4, Table 2). Across all participants, we then examined whether this preparatory activity correlated with PA, anxiety, solving rates, or solving strategy (solving with insight or noninsight). This analysis enabled us to investigate if certain regions that "turned on" at preparation were modulated by positive mood and anxiety states.

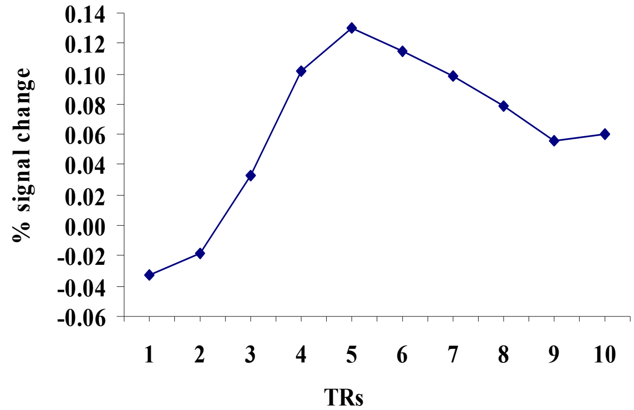
As illustrated by Table 2A, three areas showed increased activation during preparation: dACC, posterior cingulate cortex (PCC), and the right angular gyrus (AG). In two of these regions, as positive mood increased across all 27 participants, so did the amount of preparatory activity: in the ACC ($r(25) = 0.41$, $p < .05$, see Figure 4C); and in the right AG ($r(25) = 0.40$, $p < .05$). Preparatory activity in the rostral dACC also inversely correlated with anxiety, but this correlation was not statistically reliable ($r(25) = -0.34$, $p = .08$, Table 2). Preparatory activity in the PCC showed a mild but non-significant positive correlation with overall proportion of problems solved (r (25) = .36, p = .06, Table 2), but no correlation with positive mood.

Hypothetically, *deactivations* could be equally important to increases in activation. So, for completeness, we performed the same analyses looking at areas that deactivated during preparation. Two areas showed systematic deactivation compared to baseline: the left and right Inferior Frontal Gyri (IFG). This deactivation during preparation was negatively correlated with the overall proportion of problem solved, (left IFG: r (25) = -.40, p <.05; right IFG: r (25) = -.50, p <.05) (Table 2) but did not correlate with any mood variables (p's > .20). This analysis (A), therefore, demonstrates that among the ROIs showing changes in neural activity at preparation, only the dorsal ACC and right AG increased activation with positive mood.

**A.**



**B.**




**C.**

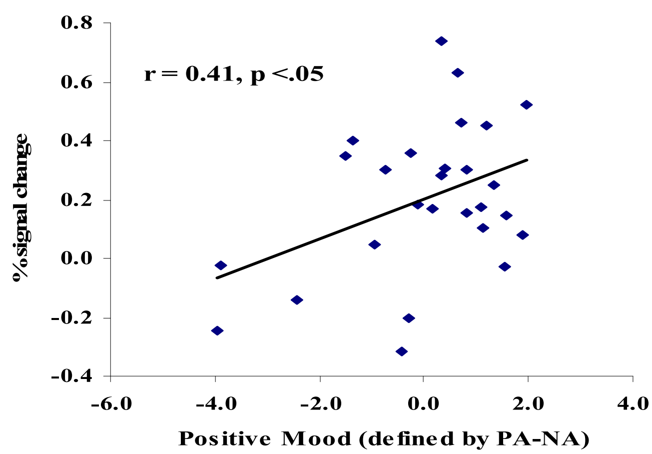



**Figure 4**. (A) Regions of interest (ROI) within dorsal ACC showing strongly increased signal ($p<.0001$), across all 27 participants, corresponding to the preparation interval, superimposed on the averaged normalized structural image of all participants. Brain images show (left to right) axial, sagittal and coronal images. (B) Average signal change across this dACC region, for the 20s following onset of the preparation interval (which lasted 0-8s). (C) Scatterplot illustrating the correlation between positive mood and increased preparatory activity in this dACC region (peak-baseline) across all 27 participants.

**Does brain activity at preparation predict brain activity at solution?**

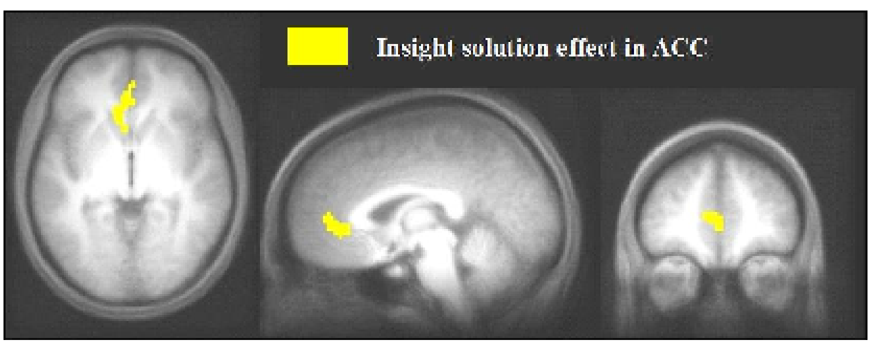
We examined whether preparatory brain activity predicted overall solution brain activity, and whether this preparatory activity then correlated with mood in regions showing specific insight effects. As mentioned above, the areas showing overall increased responsivity at preparation included the dACC, PCC and right AG. Each of these areas, therefore, represents a good candidate for preparatory activity predicting overall solution related activity. In order to examine where preparatory activity predicted overall solution-related activity, we identified regions that showed solution related responsivity, similar to the way we defined preparatory ROIs as described by analysis (A). For instance, we defined solution-related ROIs, by subtracting the mean signal across the 3TRs corresponding to baseline solution-related signal (TRs 1,6,7) from the mean signal across the 3 TRs (TRs 3,4,5) corresponding to peak signal leading up to the solution (see Figure 9 for comparison). These solution-related functional ROIs would, therefore, indicate regions of the brain that "turned on" upon arriving at solution. We then looked back at preparatory responsivity within these solution-active ROIs. We found that as preparatory activity increased, so did solution related responsivity, within one region only: the region of the dorsal ACC. This analysis demonstrates that preparatory activity within the dorsal ACC predicted overall solving activity.

**(B) Do brain regions showing insight specific activity at either preparation or solution correlate with mood?**

We next examined whether preparatory activity correlated with mood in regions identified as showing insight-specific processing [see Methods (B)]. We identified ROIs that showed an "insight effect," i.e., stronger peak signal for insight versus analytical processes, either during preparation (Kounios et al., 2006) or leading up to solution (as in Jung-Beeman et al., 2004). Within these "insight effect" regions, we examined whether overall preparatory responsivity (from preparation onset to peak response and back down to baseline) was modulated by positive mood states.

Regions that showed this "insight effect" at preparation – stronger signal during preparation preceding problems that were eventually solved with insight than during preparation preceding analytic solutions – included the ACC, the PCC and the right and left MTG (Table 2C), as previously described (Kounios et al., 2006). Within these ROIs, positive mood correlated (across all 27 participants) with preparatory responsivity only in the ACC (r (25) = 0.40, p <.05, Table 2C). This preparatory activity in the ACC also inversely correlated with anxiety (r (25) = -0.40, p <.05). Moreover, the peak of this preparatory activity in ACC correlated with the overall proportion of problems solved (r (25) = 0.37, p = .05). Positive mood did not correlate with preparatory activity observed in other areas showing insight effects during preparation (PCC: r (25) = 0.23, p = .27); left MTG: r (25) = 0.22, p = .27; right MTG: r (25) = -0.16, p = .42).

**A.**



B.

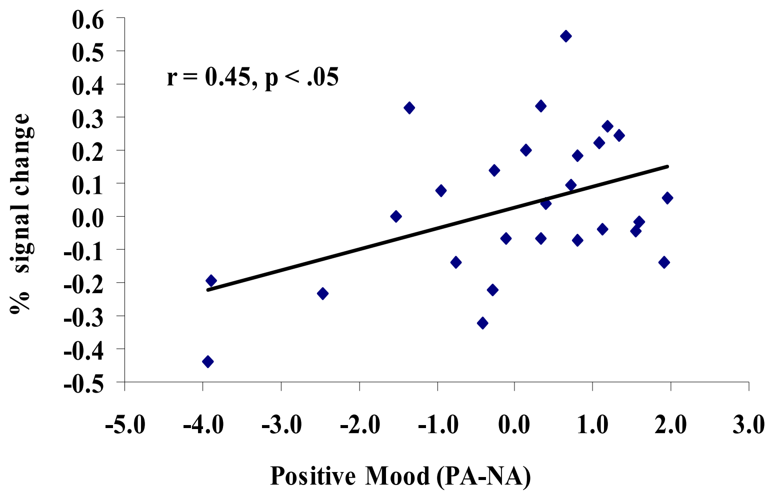



**Figure 5.** (A) The ROI within the rostral ACC showing stronger signal for insight (p <.001) than for noninsight solutions (as in Jung-Beeman et al., 2004), across all 27 participants. Brain images show (left to right) axial, sagittal and coronal images (with left hemisphere on left of axial and coronal images). (B) Scatterplot illustrating the correlation between positive mood and increased preparatory activity (peak-baseline) in this rostral ACC region showing an insight solution effect, across all 27 participants.

We next examined whether positive mood modulated preparatory activity in areas that showed an "insight effect" at *solution* (see Figure 9). We identified several regions showing insight effects at solution, i.e., stronger signal for insight solutions than for noninsight solutions. These ROIs included the right anterior STG, ACC, PCC, right PHC, bilateral MTG (stronger in right than left), right SFG, and the right IPL (Table 2D). These data, with more participants and better imaging protocols, match well with earlier results showing smaller effects, but in the same general regions, with right anterior STG again showing the largest effect (Jung-Beeman et al., 2004). Within all these ROIs showing insight effects at solution, preparatory activity correlated with positive mood only within the ACC (r (25) = 0.45, p <.05, see Figure 5, Table 2D). Again, ACC preparatory activity negatively correlated with anxiety (r (25) = -0.44, p <.05), while preparatory peak signal positively correlated with the overall proportion of problems solved (r (25) = 0.37, p = .05).

**(C) Are brain regions showing positive mood effects during preparation involved in solving with insight?**

In the above analyses, we identified ROIs by overall preparatory responsivity (A) and by insight effects (B), and then found that preparatory activity within the ACC ROIs specifically consistently correlated with positive mood across all participants. Analysis (C) does the converse, first identifying ROIs that show mood effects in preparation for all trials, then determining whether an insight effect (stronger signal prior to insight solutions than prior to noninsight solutions) occurred within these ROIs. The positive mood preparatory effect indicated which brain regions manifest increased preparatory responsivity, across all trials, for the 8 participants highest in positive mood compared with the 8 participants lowest in positive mood, regardless of whether the hemodynamic response demonstrated a rise and fall of signal (Figure 6).[1] For instance, some areas showed decreasing activity during preparation (left and right IFG), but more rapid decreases in Low Positive Mood than in High Positive Mood participants. The ACC and the PCC showed more preparatory responsivity for the eight participants highest versus the eight participants lowest in positive mood. In the ACC region showing a mood group effect across all trials (specifically, the rostral portion of the dorsal ACC, see Figure 6), the preparation signal was stronger, across all participants, preceding problems subsequently solved with insight than preceding problems subsequently solved analytically (t(26)=[2.3], p = .03) (see Figure 8). In contrast, the PCC region that showed stronger preparation signal for the high positive than for the

---

[1] Although the top third of participants would technically be 9 participants, matching PA scores made it impossible to use more than eight participants on either end of the distribution

low positive participants did not show any insight effect during preparation (t < 1.0).

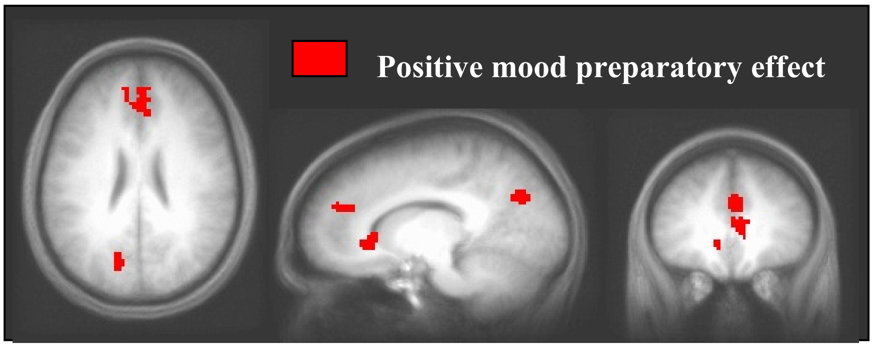



**Figure 6.** All ROIs showing stronger signal change (peak-baseline) corresponding to the preparation interval for high positive mood than for low positive mood participants (p<.005). Reliable clusters include dorsal and ventral ACC, as well as PCC. (No reliable clusters showed the reverse, i.e., stronger signal for low positive mood participants).

We then tested whether these same regions (showing mood effects during preparation) showed insight effects leading up to solution. Indeed, across all participants, there was stronger fMRI signal for insight solutions than for noninsight solutions in the dorsal ACC (t(26)= [3.97], p < .0005, see Figure 9), the ventral ACC (t(26)= [3.8], p < .001), and the PCC (t(26)= [3.8], p < .001). These effects were not due to making the insight rating at the end of each trial, as there were no effects within any of these ROIs on the BOLD signal corresponding to the insight rating button press, (all t's < 1.2).

Thus, some brain areas – particularly the ACC – in which positive mood modulated activity during the preparation for upcoming trials, do seem especially involved in processing that leads to insight solutions. The functional overlap of areas showing both mood and insight effects is illustrated in a convergence map (Figure 7), which shows that only the rostral portion of the dACC manifests the mood-insight correspondence in all three analyses described above.

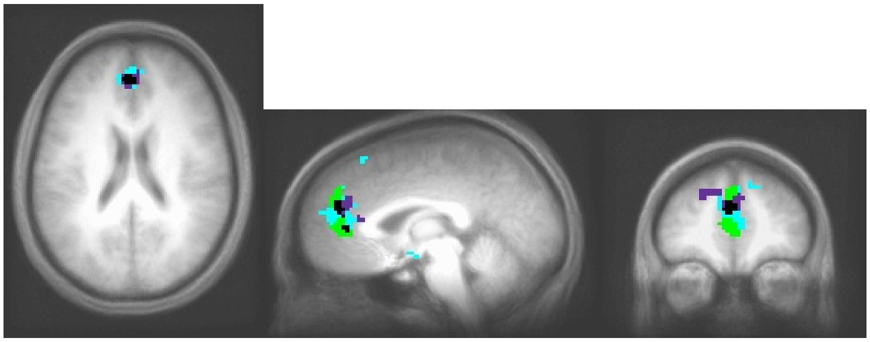


**Figure 7.** Convergence map, showing all voxels within each of the three types of analyses: Voxels showing reliable signal change (peak-baseline) corresponding to preparation (blue); voxels showing both preparation activity and insight solution effects (green); voxels showing both preparation activity and stronger preparation signal in high- than in low-positive mood participants (purple); and voxels showing all three effects (black).

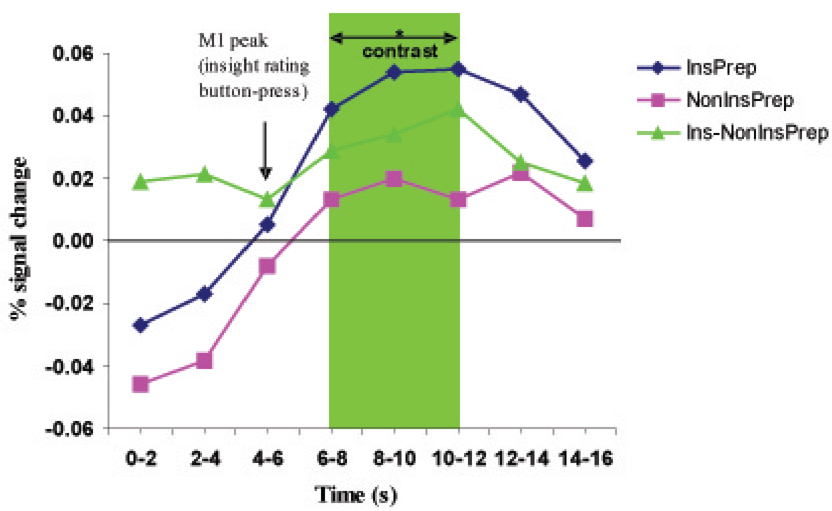



**Figure 8.** Insight preparation effect in mood sensitive ROI: Average percent signal change over time, corresponding to the preparation interval across all voxels in the ROI showing a reliable mood effect (stronger preparation activity in the high- than in the low-positive mood

participants). The blue line shows signal change for preparation prior to problems solved with insight, pink shows preparation signal prior to problems solved without insight, and the green line shows the difference, which was near-constant throughout the epoch. The green shaded region (i.e. TRs starting at 6 sec through TR ending at 12 sec), showing stronger signal for insight versus noninsight preparation (* p < .05) corresponds to the peak signal for the preparation period. For comparison, the preceding button press elicited peak signal in the motor cortex (M1) at 4sec, which corresponded to the insight rating button press from the prior trial.

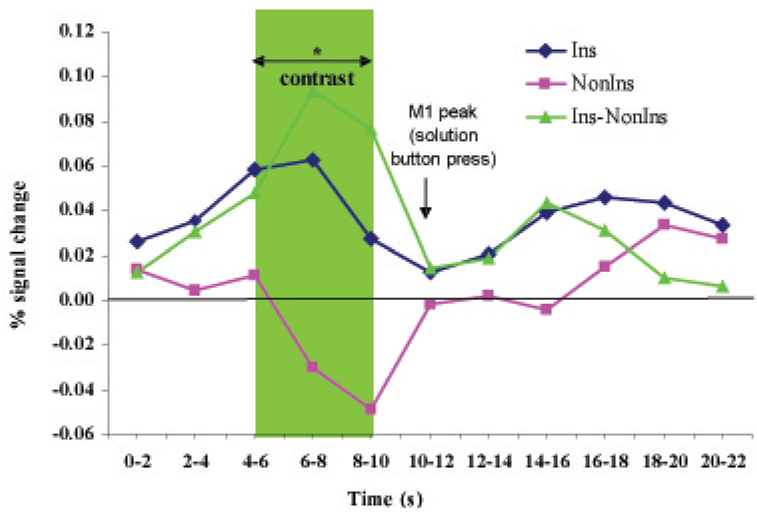



**Figure 9**. Insight solution effect in mood sensitive ROI: Average percent signal change over time, corresponding to the solution interval (i.e., 0 sec corresponds to a solution event 2 seconds prior to the solution button press), across all voxels in the ROI showing a reliable mood effect at preparation. The blue line shows signal change prior to problems solved with insight, pink shows signal change prior to problems solved without insight, and the green line shows the difference, which was near-constant throughout the epoch. The green shaded region (TR starting at 4 sec through TR ending at 10 sec) showing greater solution-related signal (* p < .0005) for insight versus noninsight trials, corresponds to the peak signal leading up to the solution. For comparison, the subsequent solution button press elicited peak signal in the motor cortex (M1) at 10 sec (i.e., 8 seconds following the button press).

**Table 2. Neuroimaging: Positive Mood States Predict Increased Preparatory Activity in the ACC to Enhance Solving with Insight**

| | Correlations | | | | | Center Coord. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Structure | Pos. Mood | Anxiety | Solve % | Brod. Areas | Volume (mm) | X | Y | Z | Mean % sig | Max % sig | Mean t | Max t |
| A. Preparatory activity | | | | | | | | | | | | |
| L. IFG | 0.22 | -0.24 | -0.40* | 9, 6 | 4375 | -42 | 3 | 26 | -0.07 | -0.11 | 6.6 | 9.1 |
| R. IFG | 0.2 | -0.26 | -0.50* | 6 | 3219 | 47 | -13 | 41 | -0.06 | -0.1 | 5.5 | 7 |
| ACC | 0.41* | -0.34 | 0.27 | 9, 32 | 1562 | 1 | 47 | 13 | 0.1 | 0.15 | 5.5 | 6.5 |
| PCC | 0.29 | -0.32 | 0.36 | 31,23 | 6641 | -1 | -48 | 33 | 0.05 | 0.1 | 3.5 | 4.4 |
| R. AG | 0.40* | -0.22 | 0.41* | 40 | 6031 | 47 | -60 | 39 | 0.07 | 0.1 | 3.4 | 4.2 |
| B. High Pos. Mood Preparatory State > Low Pos. Mood Preparatory State | | | | | | | | | | | | |
| D ACC | 0.50* | -0.44* | 0.20 | 32, 9 | 3188 | 0 | 36 | 21 | 0.08 | 0.12 | 3.8 | 5.3 |
| v. ACC | 0.44* | -0.47* | 0.21 | 24 | 938 | -10 | 26 | 0 | 0.07 | 0.09 | 4 | 6.2 |
| PCC | 0.40* | -0.34 | -0.23 | 31, 30 | 875 | 6 | -44 | 25 | 0.05 | 0.1 | 3.8 | 4.6 |
| C. Insight Preparation > Analytical Preparation | | | | | | | | | | | | |
| PCC | 0.23 | -0.28 | 0.10 | 31 | 6641 | -24 | -10 | -10 | 0.07 | 0.09 | 3.5 | 4.4 |
| ACC | 0.40* | -0.40* | 0.37* | 32 | 1047 | -3 | 43 | 5 | 0.08 | 0.1 | 3.5 | 4.4 |
| L p.M/STG | 0.22 | -0.41* | 0.21 | 22, 19, 39 | 797 | 50 | 59 | 1 | 0.08 | 0.07 | 3.4 | 4.2 |
| R.p.M/STG | -0.16 | -0.15 | -0.10 | 39, 37 | 562 | 46 | 69 | 24 | 0.07 | 0.07 | 3.4 | 4.2 |
| D. Insight Solution > Analytical Solution | | | | | | | | | | | | |
| R M/STG | 0.27 | -0.38* | 0.02 | 21, 22 | 2156 | 57 | -33 | 2 | 0.08 | 0.1 | 4 | 4.8 |
| PCC | 0.27 | -0.24 | 0.26 | 31 | 2047 | 2 | -42 | 34 | 0.08 | 0.12 | 4 | 4.9 |
| R. PHC | -0.05 | -0.01 | -0.01 | 34 | 1984 | 20 | -11 | -13 | 0.08 | 0.12 | 3.8 | 5.6 |
| ACC | 0.45* | -0.44* | 0.37* | 24, 32 | 1984 | -4 | 36 | 3 | 0.09 | 0.13 | 3.4 | 4.1 |
| L. M/STG | 0.22 | 0.18 | 0.25 | 21 | 1516 | -59 | -19 | -5 | 0.05 | 0.1 | 3.4 | 4 |
| R. SFG | 0.18 | -0.27 | 0.30 | 9 | 1234 | 8 | 51 | 28 | 0.09 | 0.11 | 3.4 | 4.2 |
| R. IPL | 0.24 | -0.16 | 0.08 | 40 | 703 | 55 | -39 | 38 | 0.06 | 0.07 | 3.4 | 4.1 |

Each value in the correlations section is a correlation value of either positive mood (PA-NA), anxiety (STAI) or overall solving proportion with activity in the corresponding cluster that represents the signal difference between the contrasted conditions as a percent of average signal within the cluster (*$p < .05$). (A) shows ROIs identifying significant signal change within the 3 TRs corresponding to the expected peak preparatory signal (i.e. TRs starting at 6 sec through 12 sec) compared to the 1$^{st}$ and last 2 TRs, corresponding to the baseline preparation signal. (B) shows the positive mood preparatory ROIs with increased fMRI preparatory activity for the top 8 participants highest in Positive Mood than the bottom 8 participants lowest in positive mood (C) shows ROIs with stronger fMRI peak signal for insight preparation than for analytical noninsight preparation (D) shows ROIs with stronger fMRI signal within the 3 TRs corresponding to the expected peak signal just prior to insight solutions than for analytical solutions. No clusters showed the opposite effect at this strict threshold.

**DISCUSSION**

Participants higher in positive mood showed different patterns of brain activity during preparation periods preceding each solved problem, and solved more problems overall, compared to participants lower in positive mood. The mood related facilitation in solving was limited to solving with insight, as high positive mood participants solved many more problems with insight, and somewhat fewer without insight, compared to the low positive mood participants. The results reported above used PA-NA scores as an index of positive mood, and are maintained or stronger when using PA alone as the index of positive mood. In regression analyses with all mood and personality measures, PA yielded a nominally stronger correlation with insight % ( $r$ (77) = .41, $p < .0005$) than did PA-NA ( $r$ (77) = .40, $p < .0005$). Furthermore, the same pattern of HRF peaks and group differences were attained if PA was used rather than PA-NA. However, some participants scored high on both PA and NA (consistent with prior literature claiming PA and NA scores on the PANAS inventory are orthogonal, e.g. Watson & Tellegen, 1988), so it is unclear whether they should be considered high in positive mood. Therefore, we decided to consistently use PA minus NA scores throughout all the analyses.

Interestingly, as positive mood seemed to be increasing overall solving productivity, as well as shifting the type of processing employed to specifically facilitate insight solving, anxiety had somewhat the opposite effect, decreasing insight solutions, but not affecting solving performance as reliably or as consistently as positive mood.

The experimental paradigm relies on retrospective self-report measures to categorize solutions as insight versus noninsight. It is thus important to note that positive mood affected not just whether participants reported insight, but also their overall ability to solve problems (higher positive mood participants actually solved more of these problems, and all the "extra" solutions were reported to be with insight). Thus, mood affects solving behavior.

This trial-by-trial reporting method does not assume participants solve problems with insight based on a priori categorization of the problems. (Our own pilot research shows that for solving classic insight problems, participants report "insight" solutions about 65% of the time, report "analytic" solutions 25% of the time, and the remaining 10% of the time report "other" solutions when they solve without insight and without analytic methods). Even if we did rely on relatively more 'objective' measures such as GSR measures or warmth ratings, we would still have more confidence in self-report measures. For instance, if a participant reports to have had an insight but shows gradual continuous changes in warmth ratings as he/she progresses toward the solution, rather than the sudden discontinuous jump associated with insights upon reaching the solution, we would still have more trust in the participant's self report assessment rather than warmth ratings.

Moreover, in prior studies, participants manifest different patterns of behavior and neural activity when they report solving (or recognizing solutions) with insight compared to when they report solving without insight. E.g., recognizing solutions with insight occurs faster, and with more priming of solutions (suggesting semantic activation of the solution prior to solving) than recognizing solutions without insight (e.g., Bowden & Beeman, 2003a).

Within the current study, the different solution categories were associated with qualitatively distinct patterns of brain activation preceding solution (see Fig. 9), including differently shaped hemodynamic response functions; yet there were no consistent differences at the point of insight judgments. This suggests the decisions were based on some differences in prior processing leading up to solutions, rather than posthoc decisions

Also, the high positive mood group and the low positive group both showed identical solution latency patterns (in this experiment, slightly faster insight than noninsight solutions), and parallel hemodynamic responses in fMRI signal within each category (insight vs. noninsight), suggesting that high and low positive mood participants used roughly the same processes and decision-making criteria for identifying insight and noninsight solutions.

Besides affecting behavior, positive mood also correlated with brain activity as people prepared for each new problem (in the task-free preparation interval). Specifically, we examined brain regions that changed activity during this preparation period; regions that showed insight effects (more activity during insight than noninsight trials) during this preparation period; and regions that showed insight effects at solution. Across all these analyses, only dACC consistently showed brain activity during this (resting) preparation interval that increased as positive mood increased (see Table 2, Figure 7). The corollary was also true: the ACC region that was more responsive (showed greater increase of fMRI signal corresponding to the preparatory period) in highly positive than in less positive participants also showed insight effects across all participants (Figures 8, 9). All these affect-related effects occurred despite a somewhat limited range of variability in affect (particularly in terms of negative affect).

Thus, we have strongly demonstrated that positive mood is reliably associated with preparatory states that increase responsivity in the rostral dACC, and that this modulation is associated with processing that leads to insight solutions. We are not arguing that the activation in the ACC represents a neural correlate of positive mood, or that positive mood states induce insight. We are concluding that positive mood is one factor that enhances activity in the rostral dACC, and that this mediates the shift toward insight solutions.

The precise mechanism by which positive mood facilitates insights through correspondingly modulating cognitive control processes within the ACC is not entirely obvious. Cognitive control is itself a multifaceted concept, involving the recruitment of frontal regions – including the dorsal ACC, but also DLPFC, particularly in the LH – implicated in the detection of competing responses, overcoming prepotent response tendencies, and switching attention to select the correct response (Weissman et al, 2003; Carter et al, 2000; Kondo et al., 2004; Weissman et al., 2004; Hedden & Gabrieli, 2006). ACC, specifically, has been implicated in several processes, such as error detection (Carter et al., 1998) or conflict monitoring (Botvinick et al., 2004; Kerns et al., 2004; Weissman et al., 2003).

We did not examine conflict monitoring in our study per se, and this study was not designed to tease apart the exact role of ACC in cognitive control. However, we favor a view by which the ACC is involved in monitoring not just conflict, but a variety of competing responses, such as multiple associations or strategies involved in solving problems. One way of putting it is that the ACC sets a parameter of detecting such competing activations, that allows either task shielding (ignoring other stimuli or thoughts to remain focused) or task switching (detecting competing stimuli, so that other components of cognitive control networks can switch attention to them; see Dreisbach & Goschke, 2004). One mechanism by which PA facilitates insight is by increasing this parameter for detecting multiple competing associations, which provides the solver a better chance of suddenly switching attention to the correct solution (or to solution-related information), thus facilitating insights. In line with our 'competing activation' hypothesis, we think that PA enhances insights by possibly enhancing the detection of semantic associations (Rowe et al, 2007) facilitating shorter solution RTs, which would also partly explain why insight trials tended to be slightly faster than noninsight trials. In contrast, if insights only involved greater conflict monitoring, we would predict longer RTs for insight versus noninsight trials in our task.

PA previously has been linked to modulation of cognitive control processes to enhance cognitive flexibility, at the expense of perseveration or maintained focus (Dreisbach & Goschke, 2004). Further, prior theoretical explanations have attributed increases in cognitive flexibility to the effect of PA at enhancing phasic dopaminergic activity in the ACC and the prefrontal cortex (Ashby et al., 1999; 2002), consistent with other models of dopamine's effect on cognitive control (e.g., Braver et al., 1999, Daw et al., 2006).

When people encounter a problem to solve (or any input to understand), they frequently engage multiple possible solving mechanisms. However, under various circumstances, different mechanisms are favored – due to individual states or traits, or due to the problem itself (which is why some problems are more likely to be solved with insight, and others more analytically; Ansburg & Hill, 2003; Oelling & Knoblich, 2003; Bowden et al., 2005). PA likely shifts the balance of which mechanisms will be most effective. As noted in the introduction, solving problems with insight requires cognitive flexibility (hence cognitive control), because it benefits from "cognitive restructuring" of the problem, enabling the solver to pursue a new strategy or a new set of associations. Several putative mechanisms could explain (in whole or in part) how PA enhances such flexibility. It may alter the selection process through which information enters working memory (Ashby et al, 1999; 2002); it may tip the balance toward a more global focus of attention (Gasper & Clore, 2002), or a broader attention to both external visual space and internal conceptual space (Rowe et al, 2007) allowing more problem elements to simultaneously influence solution efforts; it may facilitate switching between different modes of attention (Baumann & Kuhl, 2005; Kondo et al., 2004), or switching from irrelevant to relevant solving strategies

(Dreisbach & Goschke, 2004). These putative mechanisms may overlap, or may work in combination. The bottom line is that solvers appear to be better able to switch from pursuing a dominant but errant set of associations to a solution-relevant set.

Note that such a proposal does not mean that PA facilitates solutions by directly enhancing access to a broader range of semantic associations, e.g., by increasing RH semantic processing. Recall that another hypothetical mechanism by which positive mood could facilitate insight would be through enhanced RH processing, given the demonstrated importance of RH semantic processing for processing a broad set of semantic associations (Beeman et al., 1994; Chiarello et al., 1998) generally, and for insight solutions specifically (Bowden & Beeman, 1998; Jung-Beeman et al., 2004). Several pieces of evidence suggest that PA could enhance relative RH activation. First, PA increases sensitivity to a larger range of semantic associations (Fredrickson et al., 2005; Federmeier et al., 2001) which, as noted, is characteristic of RH semantic processing. Second, induced positive mood increases a global focus of attention (Gasper & Clore, 2002), which is usually associated with RH visual attention, whereas a local focus of attention is associated with LH processing. Third, inducing an approach regulatory focus (which is often associated with PA) enhances both overall RH activation, as measured by a line-bisection task, and creativity (e.g., Friedman & Forster, 2005). Finally, compared to people who solve anagrams analytically, people who solve with insight show increased brain activity at rest in mostly right-lateralized regions, according to resting state EEG (Kounios et al., 2008). However, a great deal of research using frontal asymmetries during resting-state EEG associates LH activity with PA or approach regulatory focus, (e.g., Sutton & Davidson, 1997). Further, effects that shift processing towards biases that are associated with one or the other hemisphere could occur due to modulation of medial attention or cognitive control related processes.

Regardless, in the current experiment, PA did correlate with signal change during the preparation period in one lateral (rather than midline) cortical region, the angular gyrus of the RH; however, this area did not show other mood-related effects, nor did it show an "insight effect" (stronger activity for insight than noninsight trials) at either solution or the preparation period. Rather than simply increasing RH semantic processing, it appears that PA heightens solvers' sensitivity to solution-relevant processing, which may often occur within the RH semantic processing network (Jung-Beeman, 2005), working in co-operation with cognitive control processes in the frontal cortex to make the switch to converge to the correct solution. Still, it remains possible that a wider range of assessed (or induced) PA would reveal enhanced RH relative activation associated with a high positive mood.

There are several potential alternative explanations that can be considered and rejected. First, one might wonder whether positive mood did not alter the processing that led to solution, but instead simply affected participants' willingness to label a solution as "insight." This is unlikely, as we mentioned earlier, because participants higher in positive mood actually solved more problems than participants lower in positive mood – they solved more with insight, and almost equally as many without insight as the lower positive mood group. Moreover, the high and low positive mood subgroups showed similar solution reaction times for insight versus noninsight solutions (for both groups, slightly faster insight than noninsight solutions). Furthermore, both subgroups showed nearly identical hemodynamic responses for insight solutions and likewise for noninsight solutions; that is, the solution types differed, but the groups did not, suggesting that both groups used the same processes for solutions they labeled as insight.

Given that insight solutions were (in this study) faster than noninsight solutions, the possibility arises that participants higher in positive mood were more likely to adopt simpler decision heuristics before responding that they achieved solution. For instance, positive mood has been suggested to the use of "satisfising", rather than optimizing solving strategy (Kaufmann & Vosburg., 1997), or even suggested to be related to reduced overall cognitive capacity (Mackie & Worth., 1989). However, such a strategy should lead to more premature and incorrect responses, i.e., trials on which participants press the button indicating solution, but then give an incorrect response. Yet high and low positive mood participants gave equally few incorrect responses ($p>.20$); indeed, in other studies, participants who demonstrate a preference to solve without insight are more likely to make incorrect responses (Kounios et al., 2008).

Another possibility to consider is that PA enhances all neural activity (or perhaps enhances hemodynamic response, such as caffeine does), and that the PA-associated enhancements during preparation only occur in ACC because that is the primary area showing increased signal during that epoch. However, we observed no PA-related enhancement of signal change in brain areas showing large responses corresponding to either problem onset or solution (e.g., the insight effect in right aSTG was no bigger in high positive mood than in low positive mood participants).

Given that the "Aha!" experience has an affective component, we also considered the possibility that differences during the preparation period were remnants of activity from the preceding trial. Immediately before the preparation period, participants made their insight versus noninsight rating of the prior trial (if it was solved). However, hemodynamic responses directly related to these ratings did not differ depending on the type of rating made (no reliable clusters of activation were observed). The enhanced activation of dACC also did not relate to whether the prior trial was solved at all, so it was not a form of increased attention in response to failure or error evaluation on the prior trial (Bush et al., 2000).

The difference between insight preparation and noninsight preparation cannot be attributed to simple lack of attention, because we analyzed only preparation periods preceding problems that were solved, not solved versus unsolved problems. Moreover, the mood-related difference in preparation activity within the dorsal ACC was not attributable to increased arousal (Critchley et al., 2005), because if anything it was inversely related to anxiety. If increased arousal drove the effect then it should be stronger in high-, rather than low-anxiety participants. Indeed, given the inverse relation between positive mood and anxiety, it's possible that some effects discussed here could be attributable to lack of anxiety (Beversdorf et al., 1999; Beversdorf et al., 2002), rather than presence of positive mood. However, all behavioral and neuroimaging measures correlated more consistently with increasing positive mood than with decreasing anxiety, whereas few of the effects correlated with the anxiety measure. Further, the effects of PA have been shown to be distinct from "affectless arousal" (Isen et al., 1987). If anything, arousal is thought to impede creativity, facilitating a narrow range of attention and perseveration on the prepotent response, thereby inhibiting overall cognitive flexibility (Easterbrook, 1959; Kischka et al., 1996; Martindale, 1995).

Finally, others have noted increased activation during what they term the default state of attention in MPFC (including dorsal ACC) and PCC (Raichle et al., 2001). It is at least possible that mood-associated changes in ACC in the current study reflect modulation of a default state network. However, we have no assessment of such default activation in the current study, so it would be a leap to make solid claims one way or the other.

Whether default state or task-related preparation, positive mood enhances activity within dACC in a manner conducive to solving with insight. This modulation may promote a more global (Gasper & Clore, 2002) or diffuse focus of attention, which has previously been linked to improved insight or creative problem solving (Ansburg & Hill, 2003; Rowe et al., 2007). Thus, we believe that one mechanism by which positive mood facilitates the shift toward an insight is by modulating ACC activity, at both the preparation and solution time periods, in a manner that enhances the detection of multiple competing associations. Therefore, a solver focused on an incorrect association (or solution path) is better "prepared" to detect and switch attention to the correct association; if this attention suddenly brings the correct solution into awareness, the solver experiences an "Aha!"

# Chapter 5: Effects of Induced Mood States on Insight Solving

## a) Behavioral effects of Induced Mood States on Insight Problem Solving

In the current study, we build upon the relation between differential mood states assessed immediately prior to the CRA task and fMRI brain activity measured during the CRA task, as described in the previous chapter. We now induce positive, neutral and anxiety mood states in each participant to confirm whether manipulating mood will modulate problem solving strategy, via predicted changes in brain activity. It remains possible that positive mood may not modulate insight directly, but that insight may be modulated directly by another factor which covaries with positive mood. Therefore, in order to draw stronger causal inferences as to whether inducing PA will modulate problem solving strategy, we use film clips to induce positive, neutral and anxious states to confirm that induced PA states will modulate insight solving. Based on our prior results on assessed mood with 79 participants, we predicted that induced positive mood states will increase the proportion of problems solved with insight and will also increase the total number of problems solved compared to the neutral mood inductions. We also predicted that anxious mood inductions would decrease the proportion of problems solved with insight compared to neutral mood inductions.

## METHODS

### Participants and Procedure

Forty two undergraduate students participated in the study, all of whom were neurologically healthy, and native speakers of English. After giving informed consent, all participants completed mood state inventories for positive affect and negative affect (PANAS), state anxiety (STAI), and a variety of other personality inventories measuring more stable individual traits (Behavioral Inhibition Scale-Behavioral Activation Scale (BIS-BAS), the Neuroticism subscale for the Big 5 Personality Mini-Markers, the Schizotypy Personality Questionnare-Brief, and the Openness scale). Following these questionnaires, all participants performed the problem-solving task. Stimuli were presented using Presentation 11.3 software on a Pentium 4 Dell PC laptop. The Presentation software generated a data file containing all stimuli presentation events and participant responses. We examined correlations between all mood and personality scores and various problem solving measures (solving rate and proportion of problems solved with insight). Data from the very first participant was excluded because the stimuli defaulted to 18 trials per run, instead of the required 16 trials per run. Insight/analytical data were excluded from one more participant who identified all the solutions as being "analytical."

All participants received 144 CRA trials in 9 blocks of 16 trials per block (balanced for solving difficulty and insight likelihood based on our prior study from 79 participants on assessed mood). Each participant received 3 positive, 3 neutral and 3 anxious mood induction (MI) blocks. We randomized the order of the MI conditions (positive and anxious) to counterbalance the order sequence between participants so that alternating 50% of participants got the 3 positive mood induction blocks first while the other half got the 3 anxious MI blocks first. The 3 neutral film clips always came in the middle to ascertain that the after-effects of the first MI condition were minimized. Overall, each MI condition was 6 minutes in length (2 minutes per clip on average). Films were selected on the basis of being validated by prior studies (Gross et al., 1995) and our own pilot data from 12 graduate students. For the positive MI condition, participants were given 3 clips from "Robin Williams Live," for the neutral MI we used 3 clips from a "C-Span Quantum Electronics" talk, and for the anxious MI we used 3 clips from either "The Shining" or "Silence of the Lambs," depending on which film participants had not seen before. To avoid demand characteristics, participants were not told that their mood would be manipulated. Instead, we explicitly stated "We are using film clips in this pilot study for testing purposes. You will not be questioned on the content of the film clips but will still need to pay attention to them."

**Problem Solving Paradigm**

In our prior study, we measured the effects of assessed mood (positive affect and anxiety states) on insight and analytical solving of 135 CRA problems (Subramaniam et al., In Press), adapted from a test of creative cognition (Mednick, 1962). In the current study, we now expand upon these results to examine whether induced positive and anxious mood states modulated problem solving strategies (solving with insight or analytically). As mentioned in the introduction, one limitation of our prior study on assessed mood was the possibility that solving strategy (i.e. solving with insight) may have been modulated by another factor that covaried with positive mood, and not facilitated by positive mood itself. In the current study, we manipulate mood by inducing differential mood states (positive neutral and anxious) to ascertain whether induced positive mood states, for example, specifically facilitate solving with insight. It might still be possible that positive mood does not enhance insights directly but indirectly by modulating another factor, which facilitates insight solving. However, by manipulating positive mood, we can now eliminate the possibility that another factor, which may have covaried with positive mood in our assessed mood analyses, had a causal role in facilitating insights, rather than positive mood itself. Therefore, in this paradigm, if induced positive mood states compared to neutral mood stated enhance insight solving, we can now make the causal inference that positive mood facilitates insight either directly or more likely indirectly through modulating other factors (i.e., such as attention and cognitive control processes) that we have shown are fundamental to insight solving.

Each block began with a modified version of the Differential Emotional Scale (DES) to assess affect state pre-mood induction. Participants rated the strength of their emotions in 4 different categories of 4 lines consisting of 4 discrete categories of happiness, sadness, anxiety and arousal. For each category, the 0 end of each line was labeled "I do not feel at all …." and the 20 cm end was labeled "I feel extremely…" The DES was followed by a short film clip whose content depended on the type of MI condition (positive, neutral or anxious). This was then followed by the DES again to assess whether there was an increase in the target mood post mood induction compared to pre mood induction. A "Ready?" prompt then appeared and participants pressed a button that triggered a fixation cross indicating that they were ready to begin the CRA problem solving task. Each trial began with this fixation cross that remained on the screen for a variable rest period (from 0, 2, 4, 6, or 8 sec, randomized across all trials), during which participants prepared for the next trial.

As in our prior study on assessed mood (Subramaniam et al., In Press), in our current behavioral mood manipulation study, after the variable preparatory period (from 0, 2, 4, 6, or 8 sec), three problem words (i.e. tooth, potato, heart) were presented on the screen (horizontally centered, just above, at, and just below central fixation), and remained until participants solved the problem, or a 15s time limit was reached. Similarly, for each problem, participants saw three problem words (i.e., tooth, potato, heart), and had to generate a solution (i.e., sweet) that can form a compound word or phrase with each problem word (sweet tooth, sweet potato, sweetheart). The solution word can precede or follow each problem word. Recall that each of these problems can be solved either with insight, or through a more methodical or analytical processes, depending on the participant. We, therefore, relied on participants' trial by trial judgments to determine the type of processing that led to each solution. Prior to the experiment, participants received similar instructions to make these judgments in our current MI study as those given to our 79 participants in our prior study on assessed mood (Subramaniam et al., In Press). Specifically, we stated that they should respond "insight" if they achieved the solution suddenly and surprisingly, possibly by switching their train of thought just prior to solution, so that as soon as they thought of the solution candidate, they were instantly confident it was the solution. In contrast, they should respond "analytical" if they achieved solution incrementally e.g., by strategically retrieving candidates and testing them out. These self-report measures have been validated through numerous prior studies which have reliably shown consistent differences in behavior (Subramaniam et al., In Press; Bowden & Jung-Beeman, 2003b) and in brain activity across different populations and methodologies (Jung-Beeman et al., 2004; Kounios et al., 2006).

If participants solved the problem, they made a bimanual button press by pressing the 2 outer buttons with a finger on each hand when they arrived at the solution. After a variable (0-8s) delay, a solution prompt appeared, and participants verbalized the solution. Then, after another variable delay (0-8s), an insight prompt ("Insight?") appeared, and participants pressed the 2 outer buttons when they reached the solution with an insight, or pressed the 2 inner buttons at the insight prompt when they reached the solution through analytic means. After the insight/analytical rating, or after 15s elapsed on unsolved trials, the next preparation period began following the button-press to the "Ready?" prompt. Each CRA block consisted of 16 trials at the end of which we assessed affect again using the DES to ensure that the target mood state was maintained at the end of the run. The DES was then followed by the next MI clip.

**RESULTS**

Participants correctly solved 42.9% (sd=8.9) of the problems, identified 50.0% (sd = 14.1) of their solutions as "insight" (mean response time= 6.89 sec, sd= 6.9) and identified 49.9% (sd= 13.5) of the solutions as "analytical" (mean response time= 8.76sec, sd= 13.54). Of trials with responses, 3.53 % (sd= 2.38) were errors. Unlike the assessed mood results (see prior chapter), participants did not solve problems significantly faster with insight than they did analytically (t (39) = [3.60], p =.45), although on average insight trials were faster than analytical trials.

We also examined if more stable trait and personality measures assessed immediately prior to the experiment, related to problem solving behavior. Overall, a partial correlation analyses, adjusting for the effects of all other mood and personality variables (see Methods) showed that only BIS related to solving strategy. Neither BIS nor BAS correlated with solving performance (all p's > .05). However, BIS scores related to the overall proportion of analytical solutions (r(30) =.49, p =.004) and inversely correlated with the proportion of insights (r(30) = -.49, p =.004). This effect was not driven by performance in any one MI condition because the proportion of analytical solutions correlated with BIS in the anxious MI condition (r(30) = .43, p = .01), in the positive MI condition (r(30) =.42, p = .02) and marginally in the neutral MI condition (r(30) = .34, p =.058). The corollary is that the proportion of insight solutions inversely correlated with BIS in the positive MI condition (r(30)= -.42, p =.02), in the anxious MI condition (r(30) = -.43, p = .01) and marginally in the neutral MI condition (r(30) = -.34, p =.058). In contrast, BAS did not reliably correlate with either the total proportion of problems solved across all conditions or problems solved in any of the specific MI conditions (all p's > .05). BAS did not correlate with overall proportion of insights or analytical solutions across all conditions or in any one MI condition (all p's > .3)

**Affect Manipulation Check**

We conducted 4 separate repeated-measures ANOVAs with three levels of MI condition (positive, neutral and anxious) on each DES rating (i.e., happpiness, sadness, anxiety, arousal) with order and gender as between subject factors. We found an effect of the positive MI on happiness ($F(3,37) = 21.09$, $p < .0001$), and an effect of the anxious MI on anxiety $F(3,37) = 23.59$, $p < .0001$). We did not find an effect of the neutral MI on any of the valence ratings ($F(3,37) = 0.20$ $p > .66$) or an MI effect on sad ratings ($F(2,37) = .07$, $p = .80$). We also found an effect of the anxious MI on arousal $F(2,36) = 6.56$, $p = .015$). There was no effect of order or gender interactions for any of the MI conditions or DES scales (all p's > .3). Across all 41 participants, our results from affect ratings before and after each of the 3 types of MI demonstrate that during the positive MI, participants increased happiness compared to the neutral ($t(40) = 6.41$, $p < .0001$) and compared to the anxious MI conditions ($t(40) = 5.65$, $p < .0001$). Planned comparisons indicate that happiness increased in comparison to each of the other ratings: sadness ($t(40) = 7.36$, $p < .0001$), anxiety ($t(40) = 6.73$, $p < .0001$), and arousal ($t(40) = 4.04$, $p = .0002$) during the positive MI. There was no difference in happiness between the neutral and anxious MI conditions ($t(40) = .39$, $p = 0.7$) and there was no difference between the sad and anxiety ratings during the positive MI ($t(40) = .19$, $p = .85$), demonstrating that the positive MI had a specific effect at increasing happiness. The positive MI also increased happiness compared to the beginning of the run ($t(40) = 2.98$, $p = .005$).

During the anxious MI participants increased their anxiety compared to the neutral (t(40) = 4.34, p<.0001) and positive MI (t(40) = 4.67, p<.0001) conditions. Again, the effects of the anxious MI were specific in that anxiety increased relative to sadness (t(40) = 3.8, p<.0001) and happiness (t(40) = 3.67, p<.0001) during the anxious MI. There was no difference between the sad and happy ratings during the anxious MI (t(40) = .81, p=.42) and there was no difference in anxiety between the positive and neutral MI conditions (t(40) = .05, p=.96), confirming the specificity of the anxious MI. Subsequent t-tests showed no difference of MI condition on sadness: positive versus neutral MI (t(40) = .05, p=0.96); neutral versus anxious MI (t(40) = .27, p=0.79); and positive versus anxious MI (t(40) = .48, p=0.63). Further t-tests between the neutral MI and beginning of the experiment showed that after the neutral MI participants' positive mood decreased compared to the beginning of the experiment (t(40) = 2.99, p = .005). However, there was no difference in sadness, anxiety, and arousal after the neutral MI compared to the beginning of the experiment (all ps > .5).

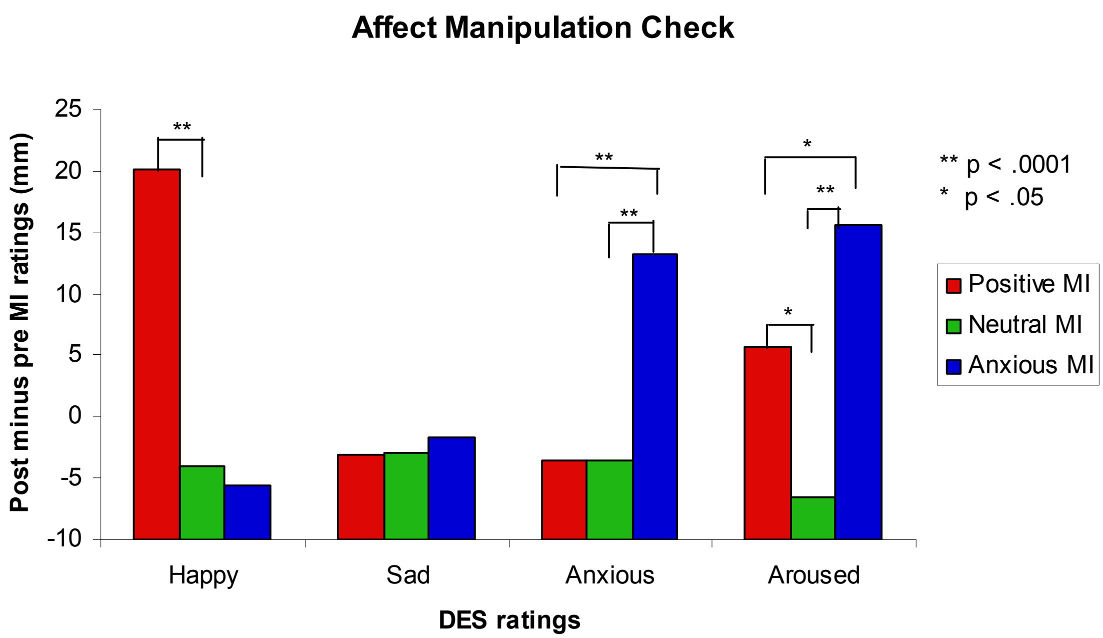
**Affect Maintenance Check**

To ensure whether the target mood was maintained at the end of the run, we assessed affect at the end of each MI run (averaged across the 3 runs for each MI condition) for each participant, and for each DES. As with the affect manipulation check, We conducted 4 separate repeated-measures ANOVAs with three levels of MI condition (positive, neutral and anxious) on each DES rating (i.e., happpiness, sadness, anxiety, arousal) measured at the end of each MI run with order and gender as between subject factors. We found an effect of the positive MI on happiness (F(1,37) = 26.67, p <.0001). We found that happiness was maintained at the end of the positive MI as happiness was still higher compared to the neutral MI (t(40) = 5.8, p <.0001), compared to the anxious MI (t(40) = 5.16, p <.0001), and also compared to each of the other valence ratings within the positive MI condition: sad ($t(40) = 11.01$, $p<.0001$)., anxious ($t(40) = 4.34$, $p<.0001$)., and arousal ($t(40) = 11.45$, $p<.0001$). Further t-tests showed that happiness did not decrease at the end of the run compared to the post positive MI happiness score ($t(40) = 1.55$, $p =.13$), and was still higher than the initial happiness rating prior to the positive MI ($t(40) = 3.06$, $p =.004$). These results confirm that positive mood was maintained throughout the positive MI condition.

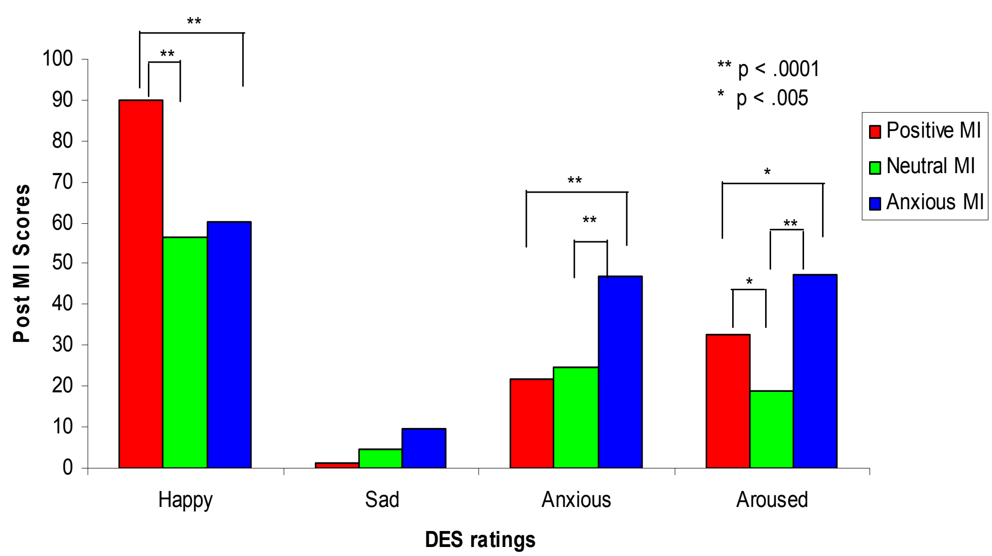
However, we did not find an effect of the anxious MI condition on anxiety at the end of the anxious MI ($F(3,37) = 2.92$, $p<.095$). Subsequent t-tests indicated that anxiety was not higher at run-end than either the neutral MI ($t(40) = 1.71$, $p = .09$) or the positive MI (($t(40) = 1.7$, $p = .09$). However, at the end of the run, anxiety was higher compared to sadness ($t(40) = 3.90$, $p <.0001$), and still remained strongly correlated with arousal ($r(39) = .79$, $p < .0001$). Although the anxious MI was successful at increasing anxiety at the post anxious MI compared to the beginning of the run ($t(40) = 2.17$, $p =.037$), anxiety decreased at run-end compared to the post anxious MI condition ($t(40) = 5.35$, $p < .0001$), indicating that anxiety was not maintained at run-end.

Overall at the end of the run, MI condition did not have an effect on either arousal ($F(2,37) = 2.31$, $p =.14$) or sad ratings ($F(2,37) = 3.084$, $p =.087$). We did not find an effect of the neutral MI on any of the valence ratings ($F(3,37) = 0.65$ $p >.43$) or an effect of order or gender interactions for any of the MI conditions or DES scales (all p’s > .4).

**A.**


Affect Manipulation Check
Post minus pre MI ratings (mm)
25
20
15
10
5
0
-5
-10
Happy
Sad
Anxious
Aroused
DES ratings
** p < .0001
* p < .05
Positive MI
Neutral MI
Anxious MI

**B.**


Post MI Scores
100
90
80
70
60
50
40
30
20
10
0
Happy
Sad
Anxious
Aroused
DES ratings
** p < .0001
* p < .005
Positive MI
Neutral MI
Anxious MI

C.

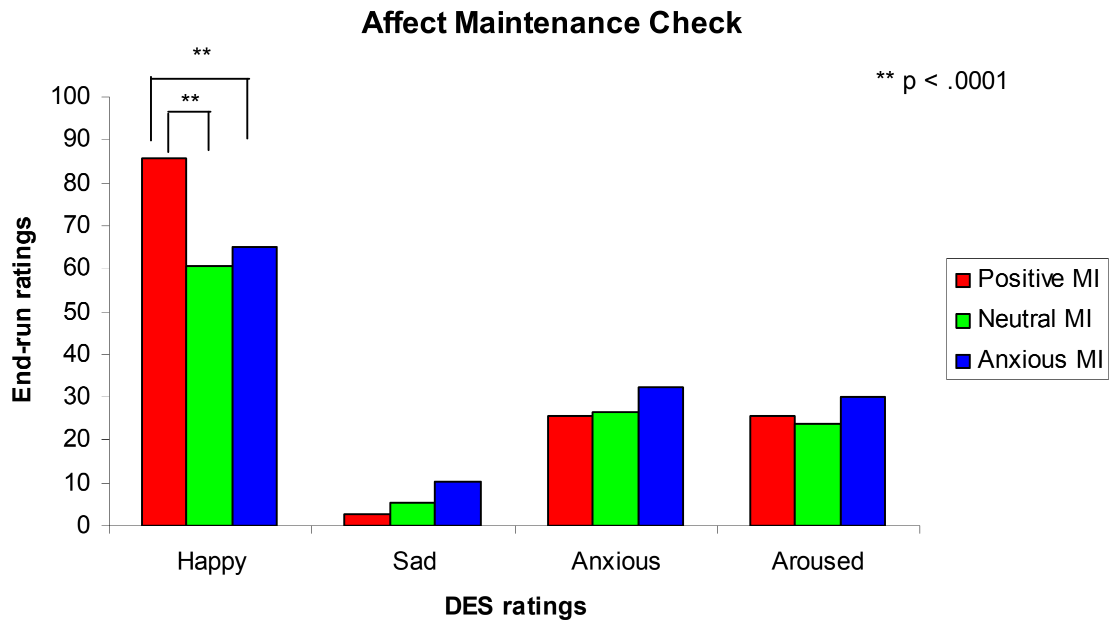
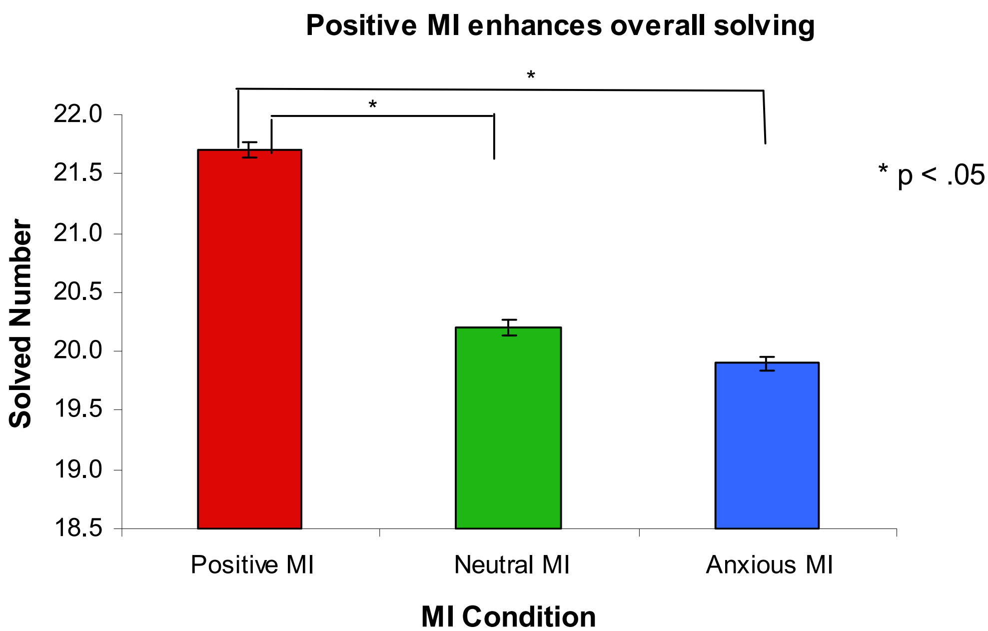



**Figure 1**. A. Post minus Pre-MI ratings indicate that in the Positive MI happiness increased compared to each of the other DES valences, and compared to the Neutral and Anxious MI conditions. In the Anxious MI, anxiety and arousal increased compared to each of the other scales, and compared to the Neutral and Positive MI. B. Post MI scores indicate that overall happiness was also higher right after the Positive MI compared to the Neutral MI and compared to the Anxious MI as well as compared to each of the other DES ratings within the Positive MI condition. Anxiety was also higher in the Anxious MI compared to the Neutral and Positive MI C. End of run rating indicate that in the positive MI, happiness increased compared to each of the the DES scales, and compared to the neutral and anxious MI conditions. Anxiety did not increase compared to the neutral or positive MI conditions.

**MI effects on Problem-Solving**

We have shown that the positive MI was effective at both inducing and maintaining the target positive mood. We now demonstrate that there was an effect of MI condition on overall solving ($F(2,36) = 4.74$, $p = .036$) and specifically on the number of problems solved with insight ($F(2,37) = 9.09$, $p = .004$) taking into account between-subject order and gender interactions. This effect on solving productivity was attributable to the positive MI as participants in the positive MI solved more problems overall than when they were in the neutral MI (t(40) = 2.09, p = .04) or compared to the anxious MI (t(40) = 2.18, p =.03). Furthermore, we found that the increase in positive mood (i.e. post MI minus pre-MI happy ratings) in the positive versus neutral MI correlated with the change in the proportion of problems solved between the positive and neutral MI conditions (r(40) = .31, p =.05). This overall enhanced solving effect was maintained throughout the positive mood conditions as the maintenance of happiness at the end of the run also strongly correlated with increased solving in the positive compared to the neutral MI conditions (r(40) = .41, p =.007). This increase in solving productivity throughout the positive MI condition was specifically due to participants solving more problems with insight. Participants in the positive MI solved more problems with insight than when they were in the neutral MI (t(40) = 2.34, p = .02) or compared to the anxious MI (t(40) = 3.02, p = .004). By contrast, participants in the positive MI did not solve more problems analytically compared to the neutral MI (t (39) = [.440], p = .662) or anxious MI (t(39) = 0.968, p = .34). Therefore, our induced positive mood effects corroborate our prior results on assessed positive mood, indicating that positive mood enhanced solving by specifically enhancing the number of insights but did not modulate the number of analytical solutions. We, therefore, showed that the positive MI was effective at both inducing and maintaining positive affect throughout the three positive MI runs to be able to successfully enhance the overall number of solutions by specifically enhancing the number of insight solutions compared to the neutral and anxious MI runs.

A.




B.

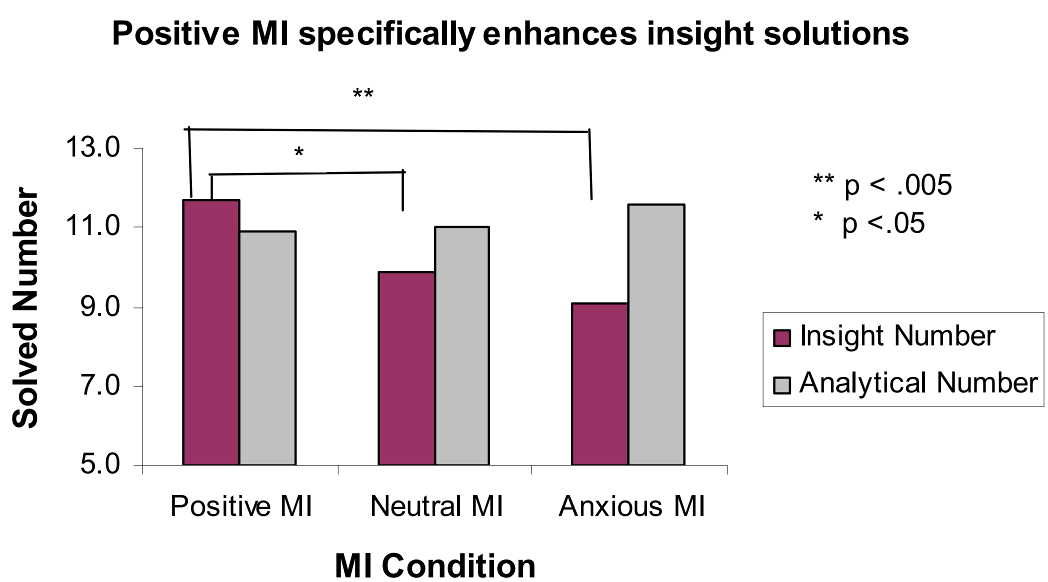



**Figure 2.** Positive MI enhances overall solutions compared to neutral and anxious MI conditions (A). Positive MI enhances insight solutions compared to neutral and anxious MI conditions (B).

In contrast, the anxious MI was effective at inducing anxiety but was not as reliable at maintaining anxiety throughout the run. Therefore, anxiety did not affect problem solving performance as consistently as positive mood. The anxious MI when compared to the neutral MI did not have as reliable an effect on either overall solving rate or solving strategy as did the positive MI. There was no difference in the overall solving ability (t(40) = [0.327], p =.745), or in the number of insight solutions (t(39) = [1.025], p =.312] when participants were in the anxious MI compared to the neutral MI. However in the anxious MI, participants did solve fewer problems overall (t(40) = [2.151], p =.038] and also solved fewer problems with insight (t(39) = [3.015], p =.004] compared to the positive MI. Not surprisingly, solving fewer problems overall and identifying fewer of these solutions as insights, contributed to participants solving a greater proportion of problems analytically in the anxious MI compared to the positive MI (t(39) = [2.642], p =.012), but not compared to the neutral MI (t(39) = [1.318], p =.195). The actual number of analytical solutions was not significantly greater in the anxious MI compared to either the positive MI (t(39) = [0.968], p =.339), or the neutral MI (t(39) = [0.601], p =.551). There were no interaction effects when comparing the proportion of insights minus the proportion of analytical solutions (Ins%-Analytical %) between the neutral and anxious MI t(39) = 1.32, p = .19), but only when comparing the anxious MI to the positive MI (t(39) = 2.61, p =.013). These less consistent effects between the anxious MI and neutral MI on overall solving and on solving strategy could be partly attributable to anxiety not being maintained throughout the run, perhaps due to participants engaging in a mood-repair process.

To examine the distinction between affect and arousal, we correlated the amount of change in affect with the change in arousal before and after each of the MI conditions. We found that the amount of change in positive affect before and after the positive MI did interestingly correlate with the change in arousal (r(40) = .45, p =.003) and also when compared to the neutral MI (r(40) = .32, p =.04). However, neither overall solving nor solving strategy correlated with arousal in the positive MI (all p's > .12) or in the anxious MI (all ps > .35).

**Discussion**

In the positive MI condition, participants solved more problems overall compared to when they were in the neutral MI condition. As with our assessed mood results (see prior chapter), our current MI results show that this overall solving facilitation is attributable to solving with insight as participants in the positive MI condition specifically solved more problems with insight, and a similar number of problems analytically compared to when they were in the neutral MI condition. We used the happy scale on the modified version of the DES as an indicator of positive mood to ensure that the positive MI condition specifically increased happiness within and across all participants as compared to each of the other MI conditions and DES ratings. This self-report visual analog scale provided an accurate manipulation check since it minimized a scale bias, disentangled positive mood effects from neutral mood effects both in terms of inducing and maintaining a positive mood throughout the positive MI condition, and enhanced overall solving and insight effects. Therefore, the DES proved to be a reliable measure of positive affect discreteness and specificity, as did our positive film clips which proved to be a valid and reliable procedure for inducing and maintaining a positive mood. Indeed, we found that the increase in positive mood (i.e. post MI minus pre-MI happy ratings) in the positive versus neutral MI correlated with the change in the proportion of problems solved between the positive and neutral MI conditions. Therefore, positive mood induced during the positive MI demonstrated similar facilitatory effects on overall solving and on insight solving as shown by our prior results on assessed positive mood.

However, unlike our results on assessed mood which showed that anxiety decreased insight solutions, anxiety during the anxious MI did not inversely correlate with either overall solving or the proportion of insight solutions (all p's >.25). Anxiety did not enhance the proportion of analytical solution compared to the neutral MI (r(39) = .22, p =.17). However, the proportion of analytical solutions across all MI conditions did correlate with one trait measure, the behavioral inhibition scale (BIS). BIS assesses the predisposition toward inhibition tendencies. This association between BIS and analytical solutions was not driven by any one MI condition as the relation persisted in the positive MI condition as well as the anxious MI condition. This could mean that the proportion of analytical solutions is not driven as much by mood manipulation as by motivational tendencies. BIS did correlate with state anxiety (STAI) (r(40) = .42, p = .01) assessed prior to the experiment. During the anxious MI, anxiety did not enhance the number or proportion of analytical solutions even though the anxious MI was successful at inducing anxiety compared to the neutral MI condition, and compared to each of the other DES scales (i.e happiness and sadness). As mentioned previously, the lack of a solving effect could be partly due to the fact that the anxious MI was not successful at maintaining anxiety throughout the anxious MI condition. Indeed, at the end of the anxious MI condition, anxiety was not higher than that of the neutral MI or positive MI conditions. Therefore, the possibility that it is really BIS (which correlated with anxiety), but not anxiety on its own that modulates the proportion of analytical solutions must be considered. This correlation with anxiety in both our assessed mood data (r(77) = .32, p = .004) and in the current mood induction data, (r(39) = .42, p = .007) may mean that BIS predisposes participants to adopt a negative mood. Recall that negative moods signal the presence of obstacles and are thought to restrict semantic activation to focus on close dominant associations, facilitating a more analytical mode of processing (Bolte et al., 2003; Baumann et al., 2002). Therefore, it would not be surprising if solvers high in BIS are predisposed to adopt a more negative mood, and thus, biased toward a more systematic analytical style of problem-solving. Higher BIS has been associated with greater responsivity to threat, and these predictions of negative outcome are related to higher perseveration tendencies. If higher BIS did lead to greater perseveration at focusing on incorrect dominant associations, and promoted a more cautious, analytical style of solving which would be considered more adaptive, then we would expect longer RTs for analytical versus insight solutions, which we do observe both in the current study as well as in our prior data on assessed mood.

By contrast, in line with our 'competing activation' hypothesis for insight facilitation, we believe that a positive mood enhances insights not necessarily by enhancing conflict monitoring per se but by enhancing cognitive control mechanisms - through a combination of enhancing detection of competing semantic associations (Rowe et al., 2007), inhibiting perseverative tendencies and overriding irrelevant prepotent associations in order to make the switch to select the correct association (see Discussion in prior chapter). Recall that when solvers prepare for the problem, they engage in a variety of solving mechanisms which are modulated by state differences (i.e. positive mood), trait differences (i.e. BIS) and differences due to the problem itself (Ansburg & Hill, 2003; Oellinger & Knoblich, 2003; Bowden et al., 2005). Upon problem onset, solvers may employ both insight and analytical solving processes at the same time; yet being in a positive mood can shift the balance toward more of an insight where a positive mood may help solvers to exert greater cognitive control to overcome impasse in order to select the correct solution. Greater recruitment of control is required during insight particularly for the override of irrelevant prepotent information to facilitate the switching and selection of the correct solution which is associated with the sudden realization of the solution (i.e., the "Aha!") when subconscious solution-relevant information that was weakly activated gains enough strength to reach a conscious threshold.

Note that we are not proposing that either being in a positive mood or solving with insight benefits from solvers being more willing to take a risk in terms of making premature guesses at the solution. If this were the case, then such a strategy should lead to more errors and faster RTs for the positive versus neutral MI condition. However, our MI results demonstrate that when participants were in a positive mood compared to either a neutral or anxious mood, they made equally few errors, and did not show a difference in RT between the positive MI and other two conditions (all p's > 3). There was also no difference in errors between insight and analytical solutions (p > 2.5) or in RTs (p > .4). Our current results also support some prior studies which have demonstrated that there are no varying risk-taking tendencies between people who are in a positive versus neutral mood (Yuen et al., 2003). Therefore, solvers are not solving more simply because of a response bias to make more solution guesses.

Another possibility that can be considered and rejected, also discussed in the prior chapter, is that positive mood merely enhances the willingness to say "insight" but does not necessarily enhance the actual insight process. As with the prior data on assessed mood, we demonstrate here that the positive vs. neutral MI enhanced actual overall solving ability wherein the number of analytical solutions was similar in both conditions, which means that all the remaining extra solutions in the positive MI were insight solutions. If positive mood only enhanced the demand to make a decision of insight but not the actual solving mechanism that led to an insight solution, then the overall number of solutions between the two conditions would be the same so that only the proportion of insights (i.e., insight percent) would be facilitated in the positive MI condition while the proportion of analytical solutions would be reduced when compared to the neutral MI, which is not the case in the current MI study. In fact, not only did a positive mood help to increase the total number of solutions by enhancing the number of insights in the PMI versus NMI but also the actual increase in positive mood (i.e. post MI minus pre-MI happy ratings) in the positive versus neutral MI correlated with the change in the proportion of problems solved between the positive and neutral MI conditions. These results demonstrate that the positive MI enhanced overall solving and specifically biased and facilitated the solving mechanisms that led to insight solutions.

A third possibility that can be discarded is the theory that our positive MI effect on overall solving or on insight solving was in fact a motivational, rather than a mood effect. Firstly, BAS and PA (from the PANAS scale) assessed just prior to the actual CRA task, did not correlate with each other ($p > .59$). This eliminates the possibility that it is trait approach motivational factors (i.e., BAS) which may have correlated with positive mood which would facilitate solving. If this were the case, then the positive mood which was induced and maintained should not have influenced either solving or insight when compared to the neutral MI, which is not the case here. Secondly, as we have demonstrated, when participants were in the positive MI, they increased and maintained a positive mood throughout the condition which helped to facilitate overall CRA solving by enhancing insight solutions compared to when they were in the neural MI. Thirdly, BAS did not correlate with either overall solving or solving strategy in any one MI condition or across all conditions (all p's > .80). Therefore, we do not think that either overall solving or insight solving was facilitated by motivational influences in trait rather than a positive mood. In contrast, from the anxious MI data, we know that anxiety was not successful at modulating solving or solving strategy when compared to the neutral MI. Therefore, in this case, one possibility is that analytical solutions may actually be facilitated by trait inhibitory motivational tendencies (i.e., BIS) which did, in fact, correlate with anxiety, and with the proportion of analytical solutions.

A final possibility is that arousal drove the solving effect rather than a positive mood. Indeed, the amount of change in positive affect before and after the positive MI did correlate with the change in arousal. Yet, neither overall solving nor solving strategy correlated with arousal in the positive MI. This result confirms that overall solving and specifically insight-solving is attributable to positive mood rather than arousal. If increased arousal did indeed drive overall solving, and/or insight solving, then we would have observed insights being facilitated during the anxious MI condition also where the correlation in post anxious MI scores between anxiety and arousal is much stronger ($r(40) = .9$, $p = .0001$) than that of positive mood and arousal ($r(40) = .45$, $p = .003$).

However, as far as analytical solutions are concerned, it still may be argued that arousal, rather than BIS or anxiety, facilitated analytical rather than insight solving. Indeed BIS correlated with analytical solving in the positive and anxious MI conditions where mood correlated with arousal in both conditions, but only marginally in the neutral low arousal MI condition. Therefore, it could be possible that high arousal is the driving factor which correlates with the BIS measure to facilitate the number of analytical solutions. Still, the amount of change in arousal before and after either the positive MI or the anxious MI did not correlate with the change in analytical solving when compared to the neutral MI. Therefore, it seems unlikely that arousal on its own is the driving factor that facilitates analytical solutions. However, further investigation would need to be undertaken to see whether it is anxiety or BIS that could potentially facilitate the number of analytical solutions. Future research may be undertaken to conduct a successful mood induction experiment where anxiety is induced and maintained throughout the CRA blocks to draw stronger causal inferences to test whether anxiety specifically modulates analytical solving compared to a neutral mood induction in a regression analysis factoring out all other variables.

The current paradigm is different from the paradigm we used in the prior chapter to assess mood in 79 subjects in a few important ways aside from the obvious difference of the mood manipulation procedure we use via film clips. Firstly, here we use a within-subject design to manipulate 3 differential mood states within each participant to see whether a particular MI condition is able to enhance overall solving or solving strategy compared to the neutral MI condition. In contrast, our results on assessed mood relied only on a between-subject comparison where we found that the third of participants higher in positive mood versus the third of participants lower in positive mood showed different patterns of brain activity (i.e. increased ACC activation) that facilitated overall solving, and specifically insight solving. Secondly, because insight/analytical judgments rely on retrospective self-report measure, we minimize insight demand characteristics further in the current paradigm by instructing participants to identify their solving strategy as "Insight" or "Analytical" as opposed to "Insight" or "Non-Insight" which was the case in the prior chapter on assessed mood. Thirdly, participants press a button at the "Ready?" prompt, which is indicative of a more active preparation for the next problem. Recall that in the prior chapter on assessed mood, stimuli were programmed so that the preparation period for the next trial automatically began with a fixation cross once participants made an insight/non-insight judgment to the prior trial. Given the modifications described above, we provide an even more tightly controlled paradigm in which we successfully induced and maintained positive mood to observe the same facilitatory effects of the positive MI on overall solving and solving strategy (i.e., insights) as shown by the assessed positive mood CRA study in the prior chapter.

To conclude, we believe that insight solving is related to an all or none processing style, which relies on the mutual reinforcement of activating and integrating distant solution-related associations (right STG) enabling spatio-temporal summated activation to rise to a conscious threshold resulting in the "wholeness" or the sudden "aha" experience. This sudden realization of the solution has been associated with an increase in fMRI signal in the right anterior superior temporal gyrus where the representation of the correct solution had been activated at a subconscious level prior to its sudden detection into conscious awareness (Jung-Beeman et al, 2004; Bowden & Jung-Beeman, 2003). As mentioned in the prior chapter, we did not find that a positive mood directly facilitates these RH subconscious processes or enhances RH activation by directly enhancing access to a wider range of semantic associations, given that the RH is more adept at performing more "coarse semantic coding" (Beeman et al., 1994). However, we did find that a positive mood enhanced insight by modulating activity within ACC, involved in cognitive control. Therefore, we believe that a positive mood facilitates the sudden upsurge of subconscious information to awareness by operating in cohort with cognitive control process in the frontal cortex to activate more parallel operations at a subthreshold level to increase the number of competing solution related and unrelated processes in the right STG that compete for attention, potentially leading to a switch to select the correct solution (ACC and prefrontal cortex) when there is a gain in strength to conscious threshold activation, resulting in a sudden sensation of “wholeness” or “Aha.”

# Chapter 5

## b) fMRI effects of Induced Mood States on Insight Problem Solving

We use a similar experimental design with the exception of making one more modification to the behavioral experimental design described in part (i) of this chapter. Here, we now use fMRI to explore the **neural mechanisms** of how **induced positive mood** modulates overall solving to shift the balance toward insight solving. In this study, we selected to eliminate the anxious MI condition in our fMRI mood induction study since the anxious MI was neither successful at maintaining an anxious mood, nor did it have an effect on either solving or solving strategy (insight or analytical solutions). We, therefore, only compare neural activation patterns between the positive MI and the neutral MI to investigate whether induced mood states (positive mood) influences problem-solving at the preparation period prior to stimuli onset to enhance overall solving and insight solving. We, therefore, not only explore the neural mechanisms by which induced positive mood states predict and facilitate insight solving but we also test whether they do so in the same way that assessed positive mood states enhance insights – through the modulation of cognitive control processes within the ACC even before stimuli onset at the preparation period to bias solving processes toward an insight.

## METHODS

### Participants and Procedure

Nine students (both undergraduate and graduate) participated in the study, all of whom were neurologically healthy, and native speakers of English. After giving informed consent, all participants completed the same mood state inventories, used in the behavioral MI study, for positive affect and negative affect (PANAS), state anxiety (STAI), and the other personality inventories measuring more stable individual traits (Behavioral Inhibition Scale-Behavioral Activation Scale (BIS-BAS), the Neuroticism subscale for the Big 5 Personality Mini-Markers, the Schizotypy Personality Questionnare-Brief, and the Openness scale). Following these questionnaires, all participants performed the CRA problem-solving task in the scanner. Stimuli were presented using Presentation 11.3 software on a Pentium 4 Dell PC laptop. The Presentation software generated a data file containing all stimuli presentation events and participant responses.

Each block began with the same Differential Emotional Scale (DES), used in the behavioral MI study, to assess affect state pre-mood induction. The DES was followed by a short film clip whose content depended on the type of MI condition (this time only positive or neutral). Because the anxious MI was not successful at either maintaining an anxious mood or at having an effect on solving/solving strategy, we decided to examine the fMRI effects of the positive MI to the neutral MI on solving, without including the anxious MI. Each participant received 6 alternating positive mood induction (PMI) and neutral mood induction (NMI) blocks of CRA trials with 22 trials per block. The odd numbered subjects received the positive MI first (i.e., subjects 1, 3, 5, 7, 9) and ended the experiment with the neutral MI (i.e., PMI, NMI, PMI, NMI, PMI, NMI) while the even numbered subjects received the neutral MI clip first and ended with the positive MI clip. Each mood clip was then followed by the DES again to assess whether there was an increase in the target mood post mood induction compared to pre mood induction. A “Ready?” prompt then appeared and participants pressed a button that triggered a fixation cross indicating that they were ready to begin the CRA problem solving task. Each trial began with this fixation cross that remained on the screen for a variable rest period (from 0, 2, 4, or 6sec, randomized across all trials), during which participants prepared for the next trial. We used such variable delays in the current study to jitter events and optimize deconvolution of the fMRI signal from successive events. As in our behavioral mood manipulation study, after the variable preparatory period, the three-word CRA trial was presented on the screen and remained until participants solved the problem with the correct compound word, or a 15s time limit was reached. Then participants made a 2 choice button press (inner/outer) to state whether they arrived at the solution through an insight or via analytical means. Prior to the experiment, participants received the similar instructions to make insight/analytical judgments as in our behavioral MI study (see Prior Chapter).

Specifically, if participants solved the problem, they made a bimanual button press by pressing the 2 outer buttons with a finger on each hand when they arrived at the solution. After a variable (0-6s) delay, a solution prompt appeared, and participants verbalized the solution. Then, after another variable delay (0-6s), an insight prompt ("Insight?") appeared, and participants pressed the 2 outer buttons when they reached the solution with an insight, or pressed the 2 inner buttons at the insight prompt when they reached the solution through analytic means. After the insight/analytical rating, or after 15s elapsed on unsolved trials, the next preparation period began following the button-press to the "Ready?" prompt. Each CRA block consisted of 22 trials at the end of which we assessed affect again using the DES to ensure that the target mood state was maintained at the end of the run. The DES was then followed by the next MI clip.

**Functional MRI Acquisition**

Nine fMRI participants performed the CRA task during scanning, which for all participants occurred in the same Siemens Trio (3 Tesla) scanner and ten channel head coil, with the same scanning protocol, at Northwestern's Center for Advanced MRI. Head motion was restricted with plastic calipers built into the coil and a vacuum pillow. The functional imaging sequence was optimized for detection of the BOLD effect (Ogawa et al., 1992) including local shimming and 8 sec of scanning prior to data collection to allow the MR signal to reach equilibrium. Functional imaging used a gradient echo echo-planar sequence (TR = 2 sec for 38 3-mm slices, TE = 20 msec, matrix size 64x64 in 220-mm field of view). Participants solved problems during six blocks of 22 trials per block. Each block consisted of 250 volumes, including 4 initial volumes that were discarded to allow for equilibrium of scanner signal. Each functional scan was synchronized with the button-press to the "Ready?" prompt that marked the onset of the preparation period for the first trial. Timing of subsequent trials was response-dependent, and not synchronized with image acquisition. Therefore, if a participant solved 22 trials before the 250 volumes were acquired, fMRI data acquisition for that block would also include a portion of the movie clip that followed the 22 CRA trials in that block until acquisition of the 250 volumes. However, we excluded the move clip time for our fMRI analyses so that our fMRI analyses only included the CRA solving phase. Anatomical high-resolution images were acquired in the same plane, with T1-weighted images parallel to the ACPC plane.

***fMRI Data Analysis***

Data were analyzed using MATLAB and the Statistical Parametric Mapping SPM2 package (Wellcome Institute of Cognitive Neurology, London). Data processing began with standard pre-processsing steps. Functional images were first corrected for motion by realigning all images with respect to the first, and were corrected for differences in slice acquisition times by resampling all slices in time to match the middle $19^{th}$ slice. The participant's structural image was coregistered to the mean of the realigned functional images and then segmented to separate out gray matter, which was normalized to the gray matter in a template image in Montreal Neurological Institute (MNI) stereotactic space (Cocosco, Kollokian, Kwan, & Evans, 1997). The realigned echo-planar images were then spatially normalized using the structural normalization parameters, resampled into 3-mm3 voxels, and spatially smoothed with a 7.5-mm full-width, half-maximum isotropic Gaussian kernel. A high-pass filter of 1/128 Hz was used to remove low-frequency noise, and an AR(1) model corrected for temporal autocorrelation. Data were submitted to a whole-brain general linear model analysis, fitting a reference hemodynamic response function to each event. Whole-brain contrasts of interest were performed on individual

subject data from correct trials in both conditions. For each subject, we performed the following contrasts at the preparation interval prior to all solved trials: positive preparatory mood states > neutral preparatory mood states; and insight preparation > analytical preparation. Second-level 1-sample t-tests were performed on the combined individual results to create random-effect group analyses for these contrasts for the subjects. For each contrast at the group level, statistical parametric brain maps were generated that displayed the t value (in signal intensity) of each voxel that met a threshold of $P < 0.05$ uncorrected for multiple comparisons. For the group-level results reported here, these images were overlaid onto SPM2's single-subject canonical T1 image in MNI space. Data from two subjects were excluded due to technical glitches with the scanner stopping at the beginning of run 4, and due to poor fMRI signal from the other subject as a result of having too few solved trials overall (i.e., 10 insights and 15 analytical solutions).

## Results

### Behavioral Measures

Participants correctly solved 38.5% (sd=10) of the problems, identified 54.4% (sd = 13.4) of their solutions as "insight" (mean response time= 6.28 sec, sd= 1.7) and identified 45.6% (sd= 13.4) of the solutions as "analytical" (mean response time= 7.12sec, sd= 1.9). Of trials with responses, 1.25 % were errors. Participants did not solve problems significantly faster with insight than they did analytically ($t(8) = [1.08]$, $p = .3$), although on average insight trials showed a slightly faster trend than analytical trials.

We conducted 4 separate repeated-measures ANOVAs with two levels of MI condition (positive and neutral) on each DES rating (i.e., happpiness, sadness, anxiety, arousal). We found an effect of the positive MI on happiness ($F(3,8) = 10.2$, $p < .0001$). We did not find an effect of the neutral MI on any of the valence ratings ($F(3,8) = 4.8$, $p = .06$).

### Affect Manipulation Check

Across 9 participants, our results from affect ratings before and after each of the 2 types of MI demonstrate that during the positive MI, participants increased happiness compared to the neutral ($t(8) = 6.29$, $p < .0005$). Subsequent t-tests indicate that happiness increased in comparison to each of the other ratings: sadness ($t(8) = 5.35$, $p < .001$), anxiety ($t(40) = 4.9$, $p < .001$), and arousal ($t(40) = 2.58$, $p = .03$) during the positive MI. There was no difference between the sad and anxiety ratings during the positive MI ($t(8) = .52$, $p = .62$), demonstrating that the positive MI had a specific effect at increasing happiness even with only 9 participants.

Subsequent t-tests showed no difference of MI condition between positive versus neutral MI on sadness (t(8) = .32, p=0.76) or anxiety (t(8) = .42, p = 0.68), although arousal increased in the positive MI compared to the neutral MI (t(8) = 2.98, p = 0.02).

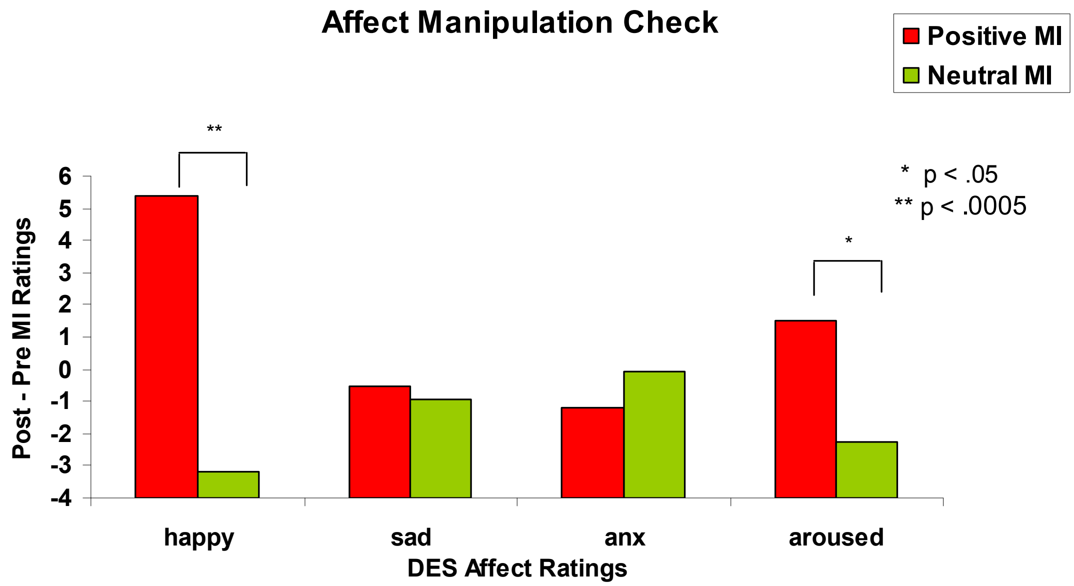



**Figure 1.** Post minus Pre-MI ratings indicate that in the Positive MI happiness increased compared to each of the other DES valences, and compared to the Neutral MI condition

**Affect Maintenance Check**

To ensure whether the target mood was maintained at the end of the run, we assessed affect at the end of each MI run (averaged across the 3 runs for each MI condition) for each participant, and for each DES. As with the affect manipulation check, We conducted 4 separate repeated-measures ANOVAs with two levels of MI condition (positive, and neutral) on each DES rating (i.e., happpiness, sadness, anxiety, arousal) measured at the end of each MI run. We found an effect of the positive MI on happiness (F(3,8) = 25.19, p <.001). We found that happiness was maintained at the end of the positive MI as happiness was still higher compared to the neutral MI (t(8) = 3.7, p <.006), and compared to each of the other valence ratings within the positive MI condition: sad (t(8) = 3.64, p<.007)., anxious (t(40) = 5.08, p<.001)., and arousal (t(8) = 4.63, p<.002). These results confirm that positive mood was maintained throughout the positive MI condition. Overall at the end of the run, MI condition did not have an effect on sadness, (t(8) = .35, p =.74), or anxiety (t(8) = .04, p =.97). However, the positive MI did increase arousal compared to the neutral MI at run end (t(8) = 2.8, p =.02).

**A.**

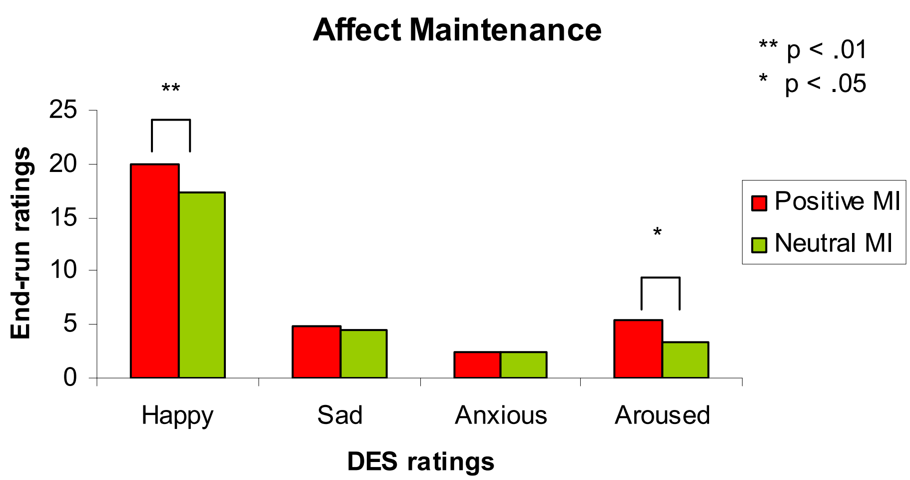
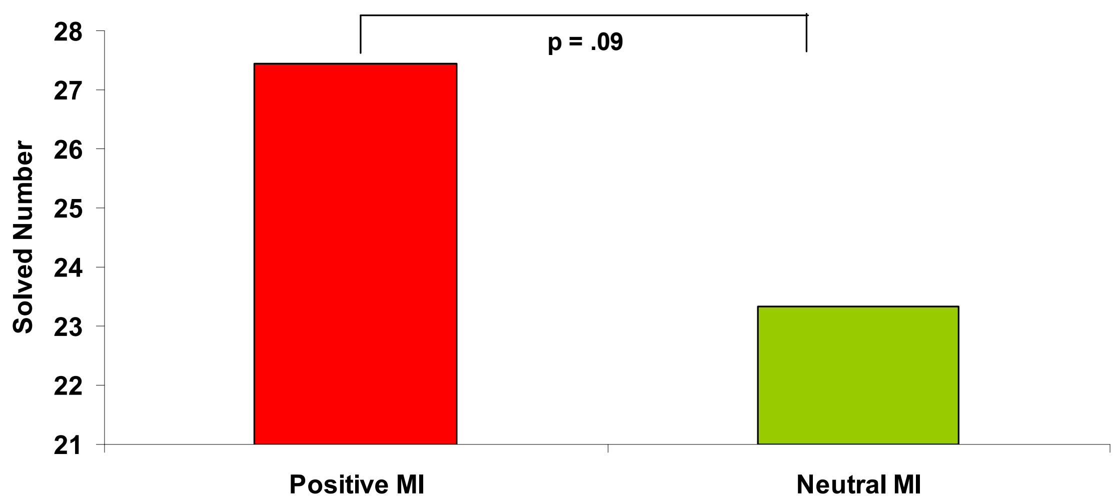



**Figure 2.** End of run ratings indicate that in the positive MI, happiness was still higher compared to each of the DES scales, and compared to the neutral MI (B).

**MI effects on Problem-Solving**

We have shown that even with 9 participants the positive MI was effective at both inducing and maintaining the target positive mood. We also show that when participants were in the positive MI they showed a trend towards solving more problems overall compared to when they were in the neutral MI (F(1,8) = 3.6, p =.09). Again, we find that this enhanced overall solving effect was attributed to insights. When participants were in the positive MI they solved marginally more problems with insight compared to when they were in the neutral MI (t(8) = 2.17, p = .06) but did not solve more problems analytically compared to the neutral MI (t (8) = [.94], p = .37).

**A.**




**B.**

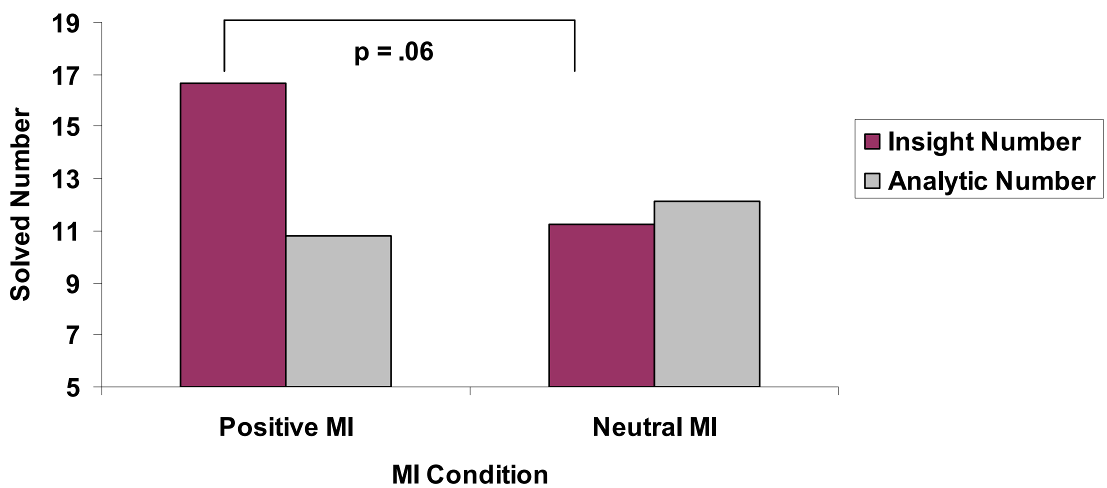



**Figure 3.** Positive MI marginally enhances overall solutions compared to neutral MI condition (A). Positive MI marginally enhances insight solutions compared to neutral MI condition (B).

**Imaging measures**

We conducted 2 analyses to see if we could replicate our prior assessed mood results which showed that PA modulates participants' pre-problem preparatory brain states to specifically facilitate insight solutions by enhancing signal within the rostral region of the ACC. Here, we show that even with only 7 participants, an induced positive mood does indeed increase preparatory signal within the rostral ACC, biasing participants to engage in processing conducive to insight (see convergence map in Figure 6). As in the assessed mood results, these preparatory brain states were assessed by examining fMRI signal corresponding to the variable 0-6 seconds of the preparatory interval which begin with participants making a button-press to a "Ready?" prompt to indicate that they were ready to view the next CRA problem.

**A) Which brain regions show greater insight specific preparatory activity?**

In this first analysis, we identified ROIs that showed an "insight effect," i.e., brain regions that showed greater preparatory activity that led to insight versus analytical solutions. The region that showed this "insight preparatory effect" most robustly was the ACC (BA32) area extending into the medial Frontal Gyrus ($p < .05$, volume = 6024mm). Moreover, this region of the ACC (center x, y, z co-ordinates at -6, 46, 4) strongly overlapped with the insight preparatory effect in our assessed mood study (center x, y, z co-ordinates at -3, 43, 5).

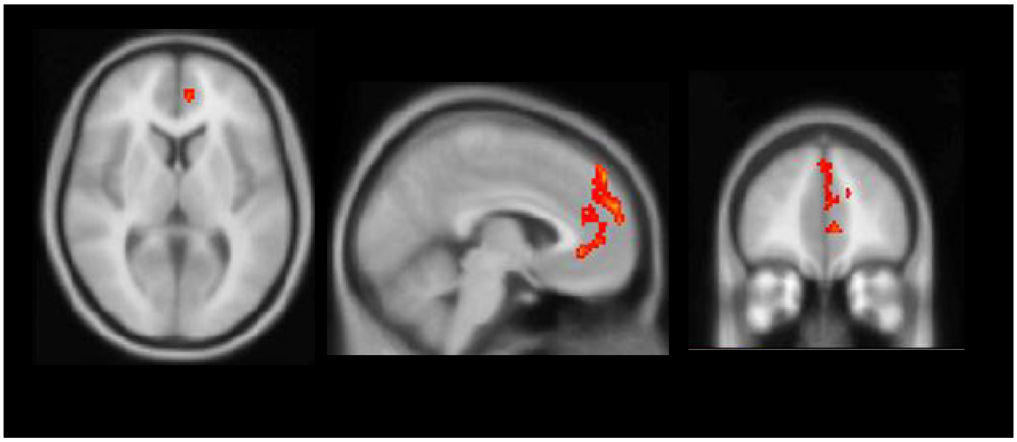


**Figure 4.** The ROI within the rostral ACC shows stronger signal for insight preparation than preparation that led to analytical solutions across all 7 participants (p <.05, volume = 6024mm$^3$). Brain images show (left to right) axial, sagittal and coronal images (with left hemisphere on left of axial and coronal images).

**B) Which brain regions show greater preparatory signal when participants are in a positive mood compared to when they are in a neutral mood?**

We next identified ROIs that showed greater preparatory signal prior to all solved trials when participants were in a positive mood compared to when they are in a neutral mood. The ventral region of the rostral ACC (BA 32) demonstrated this positive mood preparatory effect most strongly (center x, y, z co-ordinates = 2, 38, -6; p < .05, volume = 2480mm). Another more dorsal region within the rostral MFG demonstrated this positive mood preparatory effect less robustly (center x, y, z co-ordinates = 14, 46, 4; p < .05, volume = 1088mm).

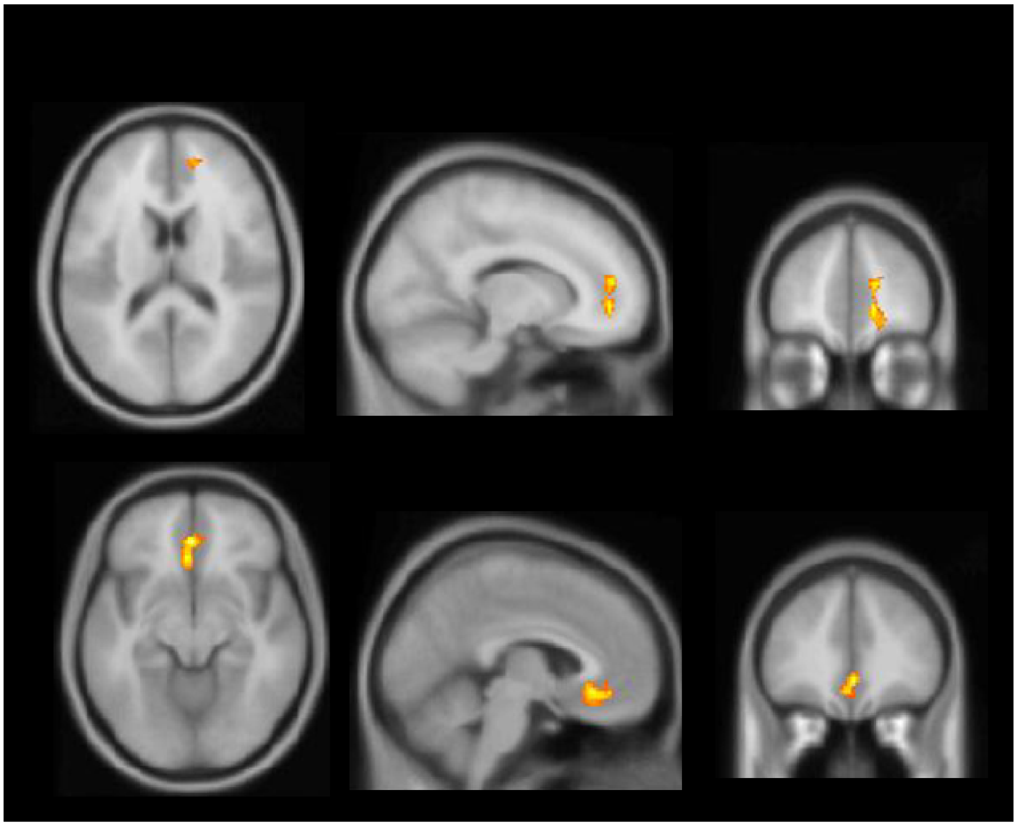


**Figure 5.** All ROIs showing stronger preparatory signal change when participants are in a positive mood (PMI) compared to when they are in a neutral mood (NMI). Top row shows increased activation for PMI versus NMI contrast in more dorsal ACC/MFG ($p<.05$, volume = 2480mm$^3$). Bottom row shows increased activation for PMI vs. NMI contrast in more ventral ACC regions ($p<.05$, volume =1088mm$^3$)

**Positive mood interaction with insight**

In order to look for a positive mood interaction with insight, we looked throughout the brain for regions that showed overlap between analyses (A) which showed the insight preparatory effect and analyses (B) which showed the positive mood preparatory effect. We illustrated the regions that showed this positive mood-insight interaction in the form of a convergence map (see Figure 6 below). The ventral region of the ACC showed the largest region of overlap at center x, y, z co-ordinates 0, 37, -8 with each analysis set to a threshold of $p < .05$. The only other region that showed a hint of overlap was the region within the region of the dorsal rostral portion of the ACC/MFG (at center x, y, z co-ordinates 14, 46, 3).

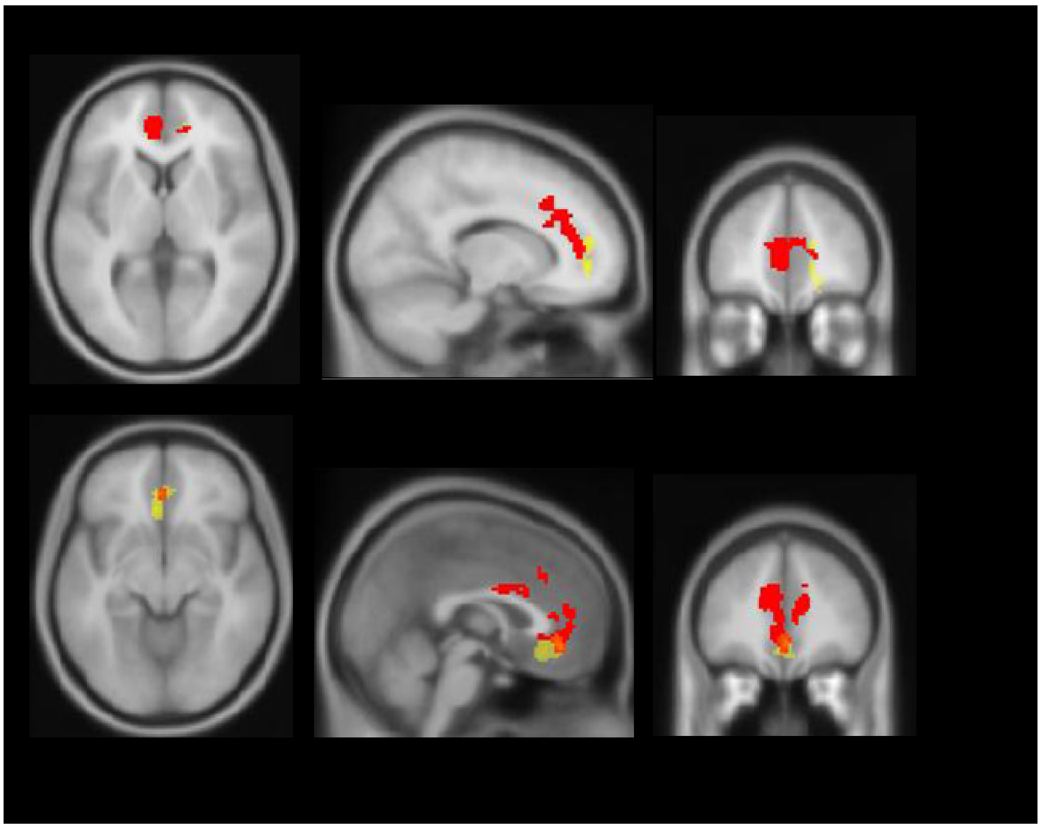


**Figure 6.** Convergence map, showing all voxels within each analysis: Voxels in red show reliable preparatory signal change greater for preparation that led to insight versus analytical solutions; voxels in yellow show greater preparation activity when participants are in a positive mood versus neutral mood; voxels in orange show the positive mood-insight interaction in the overlap between the two analyses.

Thus, even with a small and different sample size of 7 participants and the use of different analytical tools, using SPM2 rather than AFNI, to analyze brain images, we replicate our earlier results from the assessed positive mood-insight analyses. Specifically, here we provide a neural account to show that an induced positive mood modulates preparatory processes within the ACC similar to the way assessed positive mood affects problem-solving to bias participants to solve the imminent problem with an insight. The functional overlap of areas showing both positive mood and insight effects is illustrated in a convergence map (Figure 6), which shows that only the rostral portion of the ACC manifests the mood-insight correspondence in the two analyses described above.

**Discussion**

When our seven participants were in the positive MI condition, they increased and maintained their positive mood throughout the positive MI conditions. Further, when participants were in the positive MI, they showed increased brain activity during preparation periods preceding each solved problem, and solved marginally more problems overall compared to when they were in the neutral MI condition. As in the assessed positive mood study, this positive mood related facilitation in solving was limited to solving with insight, as participants solved marginally more problems with insight, compared to when they were in the neutral MI condition. The current work replicates our earlier neural account for this modulation of problem solving by positive mood. Specifically, it suggests that positive mood enhances insight by modulating attentional and cognitive control mechanisms within the ACC to either allow more sensitivity to detect competing solution candidates, to enhance switching and/or to enhance selection processes to converge to the correct solution.

As in the prior study on assessed mood, it is important to note that positive mood did not simply affect whether participants reported insight, but also enhanced their overall ability to solve more problems. When participants were in a positive mood, they actually solved more of these problems, and all the "extra" solutions were reported to be with insight, while they solved almost equally as many analytically compared to when they were in a neutral mood. Thus, we have shown that a positive mood enhances overall solving to shift solving strategy towards an insight. Further, positive mood increased brain activity in ACC as solvers prepared for problems compared to when they were in a neutral mood. Specifically, we examined brain regions that changed activity during the preparation period that showed greater activation when participants were in a positive compared to a neutral mood; and regions that showed insight preparatory effects (more activity during insight than noninsight trials) during this preparation period. Across all these analyses, only ACC consistently showed brain activity during this preparation interval that increased when participants were in a positive versus neutral mood, and particularly for trials about to be solved with insight (see Figure 6). Thus, we replicate our earlier study on assessed positive mood to strongly demonstrate here that positive mood is reliably associated with preparatory states that increase responsivity in the rostral ACC, and that this modulation is associated with processing that leads to insight solutions.

Some prior research has suggested that increased activation in the ACC during this preparatory interval may represent activation during a 'default state of attention.' The term "default" as defined by Raichle et al (2001) refers to a set of regions that had shown to be consistently deactivated during task-engagement but active during "rest." If we adhere to this definition in our study, then it does not seem that mood-associated activation in ACC is associated with this default mode because ACC is also active during the task upon problem onset and also prior to solution, not only at preparation or during pre-stimulus 'rest' intervals. Our results seem to be more consistent with Fransson's theory (2005) where he shows that the ACC is not tonically active at ‘rest’ but that ACC activation during a ‘rest’ interval (which we call a preparation interval here) really arises from low spontaneous BOLD signal fluctuations reflecting an actual active preparedness to detect changes in the external environment. This active preparation mediates the shift from an introspective to an extrospective mode of attention. Indeed, in the present study, we made a modification to the experimental design such that the preparatory period is more active in that it begins when participants press a button in response to a ‘Ready?’ prompt to indicate that they are ready to view the next 3 CRA words. We still observe that ACC increases in activation during this more active preparatory state particularly when subjects are in a positive mood and specifically when they are about to solve the next trial with an insight. In either case, regardless of whether default or active preparation observed in readiness to detect task-related changes, we show in both our assessed mood study where preparation began more passively, and in the current study indicating a more ‘active’ preparation, that during this preparation period, positive mood modulated pre-problem brain states by enhancing ACC activity to bias solvers toward solving the upcoming trial with an insight.

Another point of interest is that the positive mood-insight interaction in ACC is more ventral in the current study than the interaction illustrated by the convergence map in the prior assessed mood study, although it is still within the same region of BA32 in ACC. One hypothesis for this more ventral ACC activation could be due to the actual mood induction and mood ratings which make participants more conscious of their mood, and may, in turn, shift ACC processing toward more ventral regions implicated in more emotional processes. To clarify, we are not stating here that ACC is segregated into rostral emotional and dorsal cognitive portions as some prior researchers suggest (Bush et al., 2000). Neither are we stating that this more ventral ACC activation represents a neural correlate of more consciously induced positive mood. By contrast, we replicate results from our earlier study to show that a positive mood (albeit stronger here and made more conscious within each subject in the positive MI than in the prior study) is able to specifically modulate cognitive processes in ACC to modulate processing toward insight solutions. This is consistent with later research by Davis et al (2005) in which they have shown emotion-cognition interactions in ACC where ACC is involved in cognitive demanding tasks (counting stroop) including those tasks with emotional demands (emotional stroop). We can also conclude that our positive mood effects on insight solving are not due to another factor that co-occurred with positive mood, enabling us to draw strong causal inferences that induced positive mood modulates preparatory activity in ACC in a similar way to that of assessed positive mood in our earlier study to bias solvers to solve the upcoming trial with insight.

It is also important to note that we made some changes to the experimental design and fMRI acquisition data in the induced mood study compared to the assessed mood study in terms of modifying the preparatory interval to start with a "Ready?" prompt; modifying the variable jitter at preparation between 0-6s instead of using the earlier jitter from 0-8s to deconvolve successive events; and finally using a ten channel head coil as opposed to an eight channel coil which we used in our earlier study. Additionally, to find the positive mood preparatory effect in the current study, we used a within-subject design where primary contrasts for the positive MI versus neutral MI were calculated for each subject at preparation prior to all solved trials. This is a tighter stronger contrast compared to the positive mood preparatory effect we showed in our earlier assessed mood study. For instance, in our earlier study, to find regions that showed the positive mood preparatory effect, we looked across subjects in a between-subject comparison where we looked throughout the brain to find where the third of subjects highest in positive mood showed greater preparatory signal compared to third of subjects lowest in positive mood. In the current within-subject design, each participant tackles CRA problems when they are in a positive mood as well as when they are in a neutral mood. Thus, in both the positive and neutral mood conditions, problems are solved using a network of processes common to both conditions. If positive mood does indeed emphasize regions in the brain (i.e., ACC) that modulate a pre-problem brain state to enhance overall solutions, then the contrast in analysis (A) should reveal this positive mood preparatory effect. Indeed, analyses (A) showed that ACC specifically increased during preparation prior to solved trials when participants were in the positive MI compared to when they were in the neutral MI. Similarly if preparation that led to insight reflects distinct cognitive processes, different from preparation that led to analytical solutions, the primary within-subject contrast in analyses (B) should reveal the brain regions (i.e., ACC) that are emphasized for insight versus analytical preparation in each subject as we have shown. Finally, as mentioned in the Methods section, brain images in the current study were analyzed using SPM2, unlike the prior study where we used AFNI. Here, we used SPM2 to generate linear contrasts to obtain these subject-specific estimates for each of the primary contrasts in analyses (A) and (B). These estimates were then entered into a second random-effects analyses, using one-sample t tests across subjects. Thus, even with all these changes to fMRI acquisition data, the experimental design, a different population sample and the use of different analytical tools, we are able to replicate our earlier study where we show here that positive mood modulates a pre-problem brain state in ACC to bias solving with an insight.

One obvious limitation of the current study is the small sample size. In order to see if we attain a more reliable induced positive mood facilitatory effect on insight-solving within the ACC, we need to scan more participants. If we find this positive mood-insight interaction within the ACC is upheld, we could next conduct dynamic causal modeling (DCM) analyses to look at effective connectivity between regions in positive MI versus neutral MI. Specifically, we predict that strength of connections between ACC and right STG would increase in positive MI versus neutral MI, and that this increase in connectivity would likely predict overall CRA solving (or insight solving).

To conclude, we find that across both our assessed positive mood (see Chapter 4) and our induced positive mood studies (see Chapter 5 (i)), we show that positive mood enhances overall solving by enhancing the number of insights through the modulation of a pre-problem brain state within the ACC. Recall from Chapter 4 that this positive mood-insight interaction is illustrated within the ACC across 27 participants in the convergence map which demonstrates the functional overlap between the positive mood preparatory effect and the insight preparatory effect. In the current study, we use a within-subject design to induce positive and neutral mood states in each subject and we are still able to replicate this positive mood-insight interaction in the ACC within and across all 7 participants. In this study, the positive mood preparatory effect is observed where participants in the positive MI demonstrate greater preparatory-related signal compared to when they are in the neutral MI. Because the ACC is implicated in cognitive control, and shows greater preparatory activity for trials that led to insight versus analytical solutions, these results strongly suggest that a positive mood modulates solving by enhancing insights through the facilitation of cognitive control mechanisms in the ACC. Cognitive control is needed to modulate the delicate shift in balance between divergent and convergent thinking which is required to solve the CRA problems. These processes work in combination as the current demands of the task necessitate. Divergent thinking aids in enhancing the detection of competing distant semantic associations and in the switching away from irrelevant prepotent associations likely activated strongly in the left hemisphere during impasse so that solvers are better able to access more distant solution-relevant information weakly activated in the right hemisphere (RH). Convergent thinking is required to focus on this weakly activated solution-relevant information which may be initially be overpowered by stronger activation from prepotent yet irrelevant associations in the LH. This convergent focus on the solution-relevant information in the RH would facilitate its gain in strength and rise to a conscious threshold to be detected suddenly in the form of an "Aha!" without the solver getting distracted by competing irrelevant information (i.e., task shielding effects). That being said, it is possible that the ACC works in cohort with the right S/MTG, involved in making the connections between distant associations, so that when solvers are in a positive mood, they are better able to know when to inhibit irrelevant information and when to switch to solution-relevant non-prepotent information activated in the right S/MTG to allow it to gain enough strength and be suddenly detected in the "Aha!"

# Chapter 6: Conclusion

In my thesis, I have demonstrated that a positive mood (both assessed and induced) enhances overall CRA solving by specifically enhancing insight solutions. I provide a neural account of these effects where I demonstrate the mechanism by which a positive mood modulates these cognitive processes involved in insights. I have shown that these assessed positive mood effects on insight solving are related to preparatory brain activity in the ACC. Specifically, in the assessed positive mood study, preparatory activity increased in the ACC more for high-positive than for low-positive mood participants, biasing participants to engage in problem processing that is conducive to solving with insight. Similarly, in the induced positive mood study, preparatory activity in ACC increased when participants were in a positive mood compared to a neutral mood state, and also increased particularly for problems about to be solved with an insight. The ACC has been implicated in exerting top-down cognitive control, and is also particularly activated for insight solutions, compared to analytical solutions. We suggest that this increased ACC activity is associated with the recruitment of greater cognitive control particularly for insights since insights do not involve a systematic solving approach and are frequently associated with impasse which needs to be overcome as a result of a restructuring of the problem to facilitate the "Aha!" This Aha! moment occurs when solvers are suddenly able to integrate distant concepts in a new way, when guided by top-down cognitive control processes to restructure the problem in order to be able to suddenly recognize the solution that was previously elusive. We believe that a positive mood enhances insight solving by enhancing the exertion of these cognitive control mechanisms in the ACC as the current demands of the task necessitate. In other words, cognitive control is a multifaceted concept and requires the modulation of various processes at different times in the solving phase. For instance, a positive mood helps solvers exert greater control by possibly modulating the shift between divergent thinking (i.e., also referred to as task switching) and convergent thinking (also referred to as task shielding). Divergent thinking aids in enhancing the detection of competing distant semantic associations and in the switching away from irrelevant prepotent associations likely activated strongly in the left hemisphere during impasse to access more distant solution-relevant information likely activated weakly in the right hemisphere. Convergent thinking is required to focus on solution-relevant information and allow this information to gain in strength and rise to a conscious threshold to be detected suddenly in the form of an “Aha!” without the solver getting distracted by competing irrelevant information (i.e., task shielding effects). The delicate balance of these processes is modulated by cognitive control processes in ACC so that solvers in a positive mood are better able to know when to inhibit irrelevant associations to restructure the problem and switch to focus on the correct non-dominant association which culminates in the Aha! when solvers are able to restructure the problem in a new way to suddenly realize the solution to the problem.

**REFERENCES**

Amabile, T. M., Barsade, S.G., Mueller, J.S., Staw, B.M. (2005). Affect and creativity at work. *Administrative Science Quarterly, 50,* 367-403.

Andreason, N.J.C. & Powers, P.S. (1975).Creativity and psychosis: an examination of conceptual style. Archives of general Psychiatry, 32, 70-73.

Ansburg, P.I. (2000). Individual differences in problem solving via insight. *Current* Psychology, 19(2), 143-146.

Ansburg, P.J. & Dominowski, R.L. (2000). Promoting insightful problem solving. *Journal of Creative Behavior, 34(1)*, 30-60.

Ansburg, P.I., & Hill, K. (2003). Creative and analytic thinkers differ in their use of attentional resources. *Personality and Individual Differences, 34,* 1141-1152.

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

Ashby, F. G., Valentin, V.V., & Turken, M. (2002). The effects of positive affect and arousal on working memory and executive attention: Neurobiology and computational models. In S. Moore & M. Oaksford (Eds.). Emotional Cognition: From Brain to Behaviour. Amsterdam: John Benjamins, 245-287.

Aspinwall, L. G., & Taylor, S. E. (1997). A stitch in time: Self-regulation and proactive coping. *Psychological Bulletin*, 121, 417-436.

Badre, D., & Wagner, A.D. (2004). Selection, integration, and conflict monitoring: assessing the nature and generality of prefrontal control mechanisms. *Neuron, 41,* 473-487.

Barch, C.M., Sabb, F.W., Braver, T.S., & Noll, D.C. (2000). Anterior cingulated and the monitoring of response conflict: Evidence from an fMRI study of verb generation. Journal of Cognitive Neuroscience, 12, 298-305.

Barron, F., & Harrington, D. M. (1981). Creativity, intelligence, and personality. *Annual Review of Psychology,* 32, 439–476.

Baumann, N., & Kuhl, J. (2002). Intuition, affect, and personality: Unconscious coherence judgments and self-regulation of negative affect. *Journal of Personality and Social Psychology*, *83,* 1213–1223.

Baumann, N & Kuhl, (2005). Positive affect and Flexibility: Overcoming the precedence of global over local processing of visual information. *Motivation and Emotion, 29, 2,* 123-134.

Beeman, M. J. (1993). Semantic processing in the right hemisphere may contribute to drawing inferences from discourse. *Brain & Language*, 44, 80-120.

Beeman, M.J., Friedman, R. B., Grafman, J., Perez, E., Diamond, S., et al. (1994). Summation priming and coarse semantic coding in the RH. *Journal of Cognitive Neuroscience, 6,* 26-45.

Beeman, M.J. & Bowden, E.M. (2000). The right hemisphere maintains solution-related activation for yet-to-be solved insight problems. *Memory & Cognition, 28,* 1231-1241.

Berger, H. J. C., van Hoof, J. J. M., van Spaendonck, K. P. M., Horstink, M. W. I., van den., Bercken, J. H. L., Jaspers, R., & Cools, A. R. (1989). Haloperidol and cognitive shifting.*Neuropsychologia,* **27**, 629-639.

Beversdorf, D.Q., Hughes, J.D., Steinberg, B.A., Lewis, L.D & Heilman, K.M. (1999). Noradrenergic modulation of cognitive flexibility in problem solving. *NeuroReport, 10,* 2763-2767.

Beversdorf, D.Q., White, D.M., Chever, D.C., Hughes, J.D & Bornstein, R.A. (2002). Central B-adrenergic modulation of cognitive flexibility. *NeuroReport, 13,* 2505-2507.

Bishop, S., Duncan, H., Brett, M &Lawrence, A.D. (2004). *Nature Neuroscience, 7, 2,* 184-188.

Boden, M.A. (1994). Behavioral and Brain Sciences,17, 519–570.

Bolte, A., Goschke, T & Kuhl, J. (2003). Emotion and Intuition: Effects of positive and negative mood on implicit judgments of semantic coherence. *Psychological Science*, *14*, 416-421.

Botvinick, M., Nystrom, L., Fissell, K., Carter, C.S., & Cohern, J.D. (1999). Conflict monitoring versus selection for action in anterior cingulated cortex. Nature, 402, 179-181.

Botvinick, M., Braver, T.S., Carter, C.S., & Cohen, J.D. (2001). Conflict monitoring and cognitive control. Psychological Review, 108, 3, 624-652.

Botvinick, M.M, Cohen, J.D., Carter, C.S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences, 8*, 539-546.

Bowden, E. M. & Beeman, M. J. (1998). Getting the right idea: RH contributions to solving insight problems. *Psychological Science, 9,* 435-440.

Bowden, E. M., & Jung-Beeman, M. (2003a). Aha! Insight experience correlates with solution activation in the RH. *Psychonomic Bulletin and Review, 10,* 730-737.

Bowden, E. M., & Jung-Beeman, M. (2003b). Normative data for 144 compound remote associate problems. *Behavior Research Methods, Instruments, & Computers, 35*, 634-639.

Bowden, E. M., & Jung-Beeman, M., Fleck, J & Kounios, J. (2005). New approaches to demystifying insight. *Trend in Cognitive Sciences, 9*, *7,* 322-328.

Bowden, E. M., & Jung-Beeman, M. (2007). Methods for investigating the neural components of insight. Methods, 42, 87-99.

Braver, T.S., Barch, D.M., & Cohen, J.D. (1999). Cognition and control in schizophrenia: a computational model of dopamine and prefrontal function. *Biological Psychiatry, 46*, 312-328.

Brownell, H.H. et al. (1986) Inference deficits in right brain-damaged patients. Brain Lang. 27, 310–321.

Bush, G., Luu, P & Posner, M. (2000). Cognitive and emotional influence in anterior cingulate cortex. *Trends in Cognitive Sciences, 4*, 215-222.

Carnevale, P. J. D., & Isen, A. M. (1986). The influence of positive affect and visual access on the discovery of integrative solutions in bilateral negotiation. *Organizational Behavior and Human Decision Processes, 37,* 1–13.

Carson, S.H., Peterson, J.B., & Higgins, D.M. (2003). Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *Journal of Personality and Social Psychology, 85*, 499-506.

Carter, C.S., Mintun, M., & Cohen. J.D. (1995). Interference and facilitation effects during selective attention: An H2 O PET study of Stroop task performance. *Neuroimage, 2, 264-272.*

Carter, C.S., Braver, T.S., Barch, D.M., Botvinick, M.M., Noll, D., & Cohen, J.D. (1998). Anterior cingulate cortex, error detection and the online monitoring of performance. *Science, 280,* 747-749.

Carter, C.S., McDonald, A.M., Botvinick, M., Ross, L.L., Stenger, V.A., Noll, D., & Cohen, J.D. (2000). Parsing executive processes: Strategic vs. evaluative functions of the anterior cingulate cortex. *Proc Natl Acad Sci USA, 97,* 1944-1948.

Chiarello, C. (1991). Interpretation of word meanings in the cerebral hemispheres: One is not enough. In P. J. Schwanenflugel (Ed.) The psychology of word meanings (pp. 251-275). Hillsdale, NJ:Erlbaum.

Chiarello, C. (1998). On codes of meaning and meaning of codes: Semantic access and retrieval with and between hemispheres. In M.J. Beeman and C. Chiarello (Eds). Right hemisphere language comprehension: Perspectives from cognitive neuroscience (pp.141-160). Mahwah, NJ: Erlbaum

Collins D.L., Neelin P, Peters T.M., Evans A.C. (1994). Automatic 3D intersubject registration of MR volumetric data in standardized Talairach space. *J. Comput Assist Tomogr, 18, 2,* 192-205.

Critchley, H.D., Tang, J., Glaser, D., Butterworth, B., & Dolan, R.J. (2005). Anterior cingulate activity during error and autonomic reponse. *NeuroImage, 27,* 885-895.

Dahaene, S., Posner, M.L., & Tucker, D.M. (1994). Localization of a neural system for error detection and compensation. Psychological Science, 5, 303-305.

Davidson, R.J.. Ekman. P.. Saron. CD., Senulis., J.A., & Friesen,W.V. (1990). Approach/withdrawa! and cerebral asymmetry. Emotional expression and brain physiology. *Journal of Personality and Social Psychology. 58.* 330-341.

Davidson, R.J. (1992). Emotion and affective style: Hemispheric substrates. *Psychological Science, 3,* 39-43.

Davis, K.D., Taylor, K.S., Hutchison,W.D., Dostrovsky, J.O., McAndrews, M.P., Richter, E.O., & Lozano, A.M. (2005). Human anterior cingulate cortex neurons encode cognitive and emotional demands. *Journal of Neuroscience, 25, 37,* 8402-8406.

Daw, N.D., O'Doherty, J.P., Dayan, P., Seymour, B., & Dolan, R.J. (2006). Cortical substrates for exploratory decisions in humans. *Letters to Nature, 44,* 876-879.

Derryberry, D & Tucker, D.M. (1994). Motivating the focus of attention. In P.M. Neidenthal & S. Kitayam (Eds). The heart's eye: emotional influences in perception and attention, pp 167-196. San Diego, CA: Academic Press.

Dominowski, R.L. & Dallob, P. (1995). Insight and problem solving. In Sternberg, R.J. & Davidson, J.E. (Eds.), *The nature of insight,* 33-62. MIT Press.

Dreher, J. C. & Grafman, J. (2003). Dissociating the roles of the rostral anterior cingulate and the lateral prefrontal cortices in performing two tasks simultaneously or successively. *Cerebral Cortex, 13, 4,* 329-339.

Dreisbach, G & Goschke, T. (2004). How PA modulates cognitive control: reduced perseveration at the cost of increased distractibility. *Journal of experimental psychology: Learning, Memory & cognition, 30, 2,* 343-353.

Drevets, W.C., & Raichle, M.E (1998). Reciprocal suppression of regional cerebral blood flow during emotional versus higher cognitive processes; implications for interaction between emotion and cognition. *Cognitive Emotion, 12,* 353-385.

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

Easterbrook, J.A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66,* 183-201.

Estrada, C.A., Young, M., & Isen, A.M. (1994). Positive affect influences creative problems solving and reported source of practice satisfaction in physicians. *Motivation & Emotion, 18,* 285-299.

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

Faust, M & Mashal, N. (2007). The role of the right cerebral hemisphere in processing novel metaphoric expressions taken from poetry: A divided visual field study. *Neuropsychologia, 45,* 860-870.

Federmeier, K. D., Kirson, D. A., Moreno, E. M., & Kutas, M. (2001). Effects of transient, mild mood states on semantic memory organization and use: an event-related potential investigation in humans. *Neuroscience Letters, 305,* 149-152.

Fichtenholtz, H.M., Dean, H.L., Dillon, D.G., Yamasaki, H., McCarthy, G. & LaBar, K.S. (2004). Emotion-attention network interactions during a visual oddball task. *Cognitive Brain Research, 20,* 67-80.

Fransson, P. (2005). Spontaneous Low-Frequency BOLD Signal Fluctuations: An fMRI Investigation of the Resting-State Default Mode of Brain Function Hypothesis. Human Brain Mapping, 26, 15-29.

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: the broaden-and-build theory of positive emotions Am. Psychol. 56, 218–226.

Fredrickson, B. & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires, *Cognition & Emotion, 19,* 313-332.

Friedman, R., Fishbein, A., Förster, J. & Werth, L. (2003). Attentional priming effects on creativity. *Creativity Research Journal, 15,* 277-286.

Friedman, R. & Förster, J. (2005). Effects of motivational cues on perceptual asymmetry:

Implications for creativity and analytical problem solving. *Journal of Personality and Social Psychology, 88,* 263-275.

Gasper, K. & Clore, G. L. (2002). Attending to the big picture: Mood and global versus local processing of visual information. *Psychological Science, 13,* 34-40.

Gilhooly, K.J., & Murphy, P. (2005). Differentiating insight from noninsight problems. *Thinking & Reasoning, 11*, 279-302.

Gough, H. G. (1979). A creative personality scale for the Adjective Check List. *Journal of Personality and Social Psychology*, *37*, 1398-1405.

Gross, J.J., & Levenson, R.W. (1995). Emotion elicitation using films. Cognition and Emotion, 9, 87-108.

Hedden, T., & Gabrieli, J,D.E. (2006). The ebb and flow of attention in the human brain. *Nature Neuroscience, 9*, 863-865.

Herrington, J.D., Mohanty, A., Koven, N.S., et al. (2005). Emotion modulated performance and activity in left dorsolateral prefrontal cortex. *Emotion, 5,* 200-207.

Hutsler, J. and Galuske, R.A.W. (2003) Hemispheric asymmetries in cerebral cortical networks. Trends Neurosci. 26, 429–436.

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

Isen, A.M., Mitzi, M.S., Johnson, Mertz, E. & Robinson, G.F. (1985). The influence of PA on the unusualness of word associations. *Journal of Personality and Social Psychology, 48*, 14713-1426.

Isen, A.M., Daubman, K.A., & Nowicki, G.P. (1987). PA facilitates creative problem solving. *Journal of Personality and Social Psychology, 32,* 112-1131.

Isen, A.M., Rosenzweig, A.S., & Young, M.J.(1991). The Influence of Positive Affect on Clinical Problem solving. *Med Decis Making,* 11: 221-227.

Isen A.M. (1999a). Positive Affect. *Handbook of Cognition and Emotion*, 521-539.

Isen A.M. (1999b). On the relationship between affect and creative problem solving. In Russ S.W. (Ed.), Affect, creative experience and psychological adjustment. Phila: Brunner/Mazel, pp. 3-17.

Jausovec, N. & Bakracevic, K. (1995). What can heart rate tell us about the creative process? *Creativity Research Journal, 8(1),* 11-24.

Jung-Beeman, M., Bowden, E.M., Haberman, J., Frymiare, J.L, Arambel-Liu, S., Greenblatt, R., Reber, P.J., & Kounios, J. (2004). Neural activity observed in people solving verbal problems with insight. *Public Library of Science - Biology. 2,* 500-510.

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Science, 9*, 512-518.

Kaufmann, G., & Vosburg, S.K. (1997). Paradoxical mood effects on creative problem-solving. *Cognition & Emotion, 11, 2,* 151-170.

Kerns, J.G., Cohen, J.D., MacDonald III A.W., Cho, R.Y., Stenger, V.A., Carter, C.S. (2004). Anterior cingulate, conflict monitoring and adjustments in control. *Science, 303,* 1023-1026.

Kimchi, R., & Palmer, S.E. (1982). Form and texture in hierarchically constructed patterns. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 521–535.

King, L.A., Walker, L.M., & Broyles, S.J. (1996). Creativity and the Five-Factor Model. Journal of research and personality, 30, 189–203.

Kircher TTJ, Brammer M, Andreu NT, Williams SCR, McGuire PK (2001) Engagement of right temporal cortex during linguistic context. Neuropsychologia 39: 798–809.

Kirson, D.A. (1990). The Effect of Mood on Access to Remote Category Associates, p.130.

Kischka, U, Kammer, T.H., Maier, S., Weisbrod, M., Thimm, M. & Spitzer, M. (1996). Dopaminergic modulation of semantic network activation. *Neuropsychologia, 34, 11,* 1107-1113.

Kohler, W. (1917). Intelligenzenprüfungen an Anthropoiden. Translated (1925). The mentality of apes, London: Routledge & Kegan Paul.

Kondo, H., Osaka, N., & Osaka, M. (2004). Cooperation of the anterior cingulate and dorsolateral prefrontal cortex for attention shifting. *NeuroImage, 23,* 670-679.

Kounios, J., Frymiare, J.L., Bowden, E.M., Fleck, J.I., Subramaniam, K., Parrish, T.B., Jung-Beeman, M. (2006). The Prepared Mind: Neural Activity Prior to Problem Presentation Predicts Subsequent Solution by Sudden. *Psychological Science, 17*, 882-890.

Kounios, J., Fleck, J.L., Green, D.L., Payne, L., Frymiare, J.L., Abrigo, E., Bowden, E.M., & Jung-Beeman, M. (2008). Neural correlates of spontaneous thought predict problem solving by sudden insight. *Neuropsychologia, 46,* 281-291.

Lane, R.D., Reiman, E.M., Axelrod, B., Yun, L & Holmes, A. (1998). Neural correlate of emotional awareness: evidence of an interaction between emotion and attention in the anterior cingulate cortex, *Journal of Cognitive Neuroscience, 10,* 525-535.

Levenson, R.W., Ekman, P., & Friesen., W.V. (1990). Voluntary facial action generates emotion-specific autonomic nervous system activity. Psychophysiology, 27, 363-384.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal cortex and anterior cingulate cortex in cognitive control. *Science, 288*, 1835-1838.

Mackie, D.M., & Worth, L.T. (1989). Processing deficits and the mediation of positive affect in persuasion. *J Pers Soc Psychol, 57,* 27-40.

Martindale, C. (1989). Personality, situation, and creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 211–232). New York, NY: Plenum Press.

McCrae, R. R., & Costa, P. T., Jr. (1987). Validation of the five-factor model across instruments and observers. *Journal of Personality and Social Psychology,* 52, 81–90.

Maier, N. R. F. (1931). Reasoning in humans: I. On direction. *Journal of Comparative Psychology*, *10*, 115-143.

Martindale, C. (1995). Biological bases of creativity. In R. Sternberg (Ed.) Handbook of creativity. Cambridge: Cambridge University Press.

Matlin, M. W., & Stang, D. J. (1978). The Pollyanna principle: Selectivity in language, memory, and thought. Cambridge MA: Schenkman.

Mayberg, H.S., Liotti, M., Brannan, S.K., McGinnis, S., Mahurin, R.K., Jerabek, P.A., J. Silva, J.A., Janet L. Tekell, J.L., Charles C., Martin, C.C., Jack L., Lancaster, J.L. & Fox, P.T. (1999). Reciprocal limbic-cortical function and negative mood: converging PET findings in depression and normal sadness. *American Journal of Psychiatry, 156,* 675-682.

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of cognitive control. Nature Neuroscience, 6,5, 450-452.

Mednick, S.A. (1962). The associative basis of the creative process. *Psych. Review, 69*, 220- 232.

Metcalfe, J. (1986). Premonitions of insight predict impending error. *Journal of Experimental Psychology: Learning, Memory and Cognition, 12,* 623-634.

Metcalfe, J., & Weibe, D. (1987). Intuition in insight and noninsight problem solving. *Memory and Cognition, 15*, 238-246.

Mumford, Reiter-Palmen & Redmond (1994). Problem construction and cognition. In M.A. Runco (Ed.), *Problem finding, problem solving and creativity.* Ablex Publishing Corporation.

Nimchinsky, E.A., Gilissen, E., Allman, J.M., Perl, D.P., Erwin, J.M. & Hof, P.R. (1999). A neuronal morphological type unique to humans and great apes. *Proc Natl Acad Sci USA, 96,* 5268-5273.

Oellinger, M., & Knoblich, G. (2003). Prioritizing the new: Insights creates set for familiar processes. Max-Planck Institute for Psychological Research, Amalienstr, 33.

Ogawa, S., Tank, D.W., Menon, R., Ellermann, J., Kim, S-G. et al. (1992). Intrinsic signal changes accompanying sensory stimulation: Functional brain mapping with magnetic resonance imaging. *Proc Natl Acad Sci USA 89,* 5951–5955.

Ohlsson, S. (1984). Restructuring revisited. I. Summary and critique of the Gestalt theory of problem solving. Scandinavian Journal of Psychology, 24, 65-78.

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

Perkins D (2000) The eureka effect: The art and logic of breakthrough thinking. New York: W.W. Norton, p292.

Pfurtscheller ,G., Stancak, A., & Neuper, C. (1996). Event-related synchronization (ERS) in the alpha band—An electrophysiological correlate of cortical idling: A review. Int Psychophysiol 24: 39–46.

Raichle, M.E., MacLeod, A.M., Snyder, A.Z., Powers, W.J., Gusnard, D.A. & Shulman, J.L. (2001). A default mode of brain function. *Proc Natl Acad Sci USA, 98, 2,* 676-682.

Ray, W.J, Cole, H.W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. Science 228: 750–752.

Rowe, G., Hirsch, J.B., & Anderson, A.K. (2007). Positive affect increases the breadth of attentional selection. *Proc Natl Acad Sci USA , 101, 1,* 383-388.

Ruff, C.C., Woodward, T.S., Laurens, K.R., & Liddle, P.F. (2001). The role of the anterior cingulate in conflict processing: evidence from reverse Stroop interference. *NeuroImage, 14,* 1150-1158.

Schooler, J.W., Ohlsson, S., & Brooks, K. (1993a). Thoughts beyond words: When language overshadows insight. *Journal of Experimental Psychology: General, 122,* 166-183.

Schooler, J. W., & Melcher, J. (1997). The ineffability of insight. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The Creative Cognition Approach* (pp. 249-268). Cambridge, MA: MIT Press.

Seger, C.A. et al. (2000). FMRI evidence for right hemisphere involvement in processing unusual semantic relationships. Neuropsychology,14, 361–369.

Seibert, P. S., & Ellis, H. C. (1991). Irrelevant thoughts, emotional mood states, and cognitive task performance.*Memory and Cognition, 19,* 507–513.

Seligman, M.E.P. (2002). Positive Psychology, positive prevention and positive therapy. In Snyder, & Lopez (Eds.), Handbook of positive psychology, (pp 3). Oxford University Press.

Siegler, R.S. (2000). Unconscious insights. *Current Directions in Psychological Science, 9(3)*, 79-83.

Small, D. M., Gitelman, D. R., Gregory, M. D., Nobre, A. C., Parrish, T. B., Mesulam, M. M. (2003). *NeuroImage, 18,* 633-641.

Smith, R.W & Kounios, J (1996). Sudden insight: all or none processing revealed by speed-accuracy decomposition. *Journal of Exptl. Psychology: Learning, Memory and Cognition, 22*, 1443-1462.

Spitzer, M., Braun, U., Hermle, L., & Maier, S. (1993). Associative semantic network dysfunction in thought-disorderes schizophrenia patients: Direct evidence from indirect semantic primin. Biological Psychiatry, 34, 864-867.

Subramaniam, K., Kounios, J., Parrish, T.B., & Jung-Beeman, M. (In Press). A brain mechanism for facilitation of insight by positive affect. Journal of Cognitive neuroscience, In Press.

Sutton, S.K., & Davidson, R.J., (1997). Prefrontal brain asymmetry: A biological substrate of the behavioral approach and inhibition systems. *Psychological Science, 8,* 204-210.

Talairach, J., & Tournoux, P. (1988). Co-planar stereotaxic atlas of the human brain. Thieme, New York.

Teasdale, J. D., & Fogarty, S. J. (1979). Differential effects of induced mood on the recall of pleasant and unpleasant events from episodic memory. *Journal of Abnormal Psychology, 88,* 248–257.

Teasdale, J., Howard, R.J., Cox, S.G., Ha, Y., Brammer, M.J., Williams, S.C.R. , Checkley, S.A. (1999). Functional MRI study of the cognitive generation of affect. *American Journal of Psychiatry, 156,* 209-215.

Terzis, G. (2001). How crosstalk creates vision-related eureka moments. Philosophical Psychology, 14, 4, 393-421.

Tomarken, A.J., Davidson, R.J., Wheeler, R.E., Doss, R.C. (1992). Individual differences in anterior brain asymmetry and fundamental dimensions of emotion. *J. Pers. Soc. Psychol, 62,* 676-687.

Van Veen, V., Cohen, J.D., Botvinick, M.M., Stenger, V.A., & Carter, C.S. (2001). Anterior cingulated cortex, conflict monitoring and levels of processing. *NeuroImage, 14,* 1302-1308.

Wallas, G. (1926). *The art of thought.* New York: Harcourt Brace Jovanovich.

Watson, D., Clark, L.A. & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *J. Pers. Soc. Psychol, 54,* 1063-1070.

Weisberg RW, Alba, J. (1981). An examination of the alleged role of "fixation" in the solution of several "insight" problems. J Exp Psychol Gen 110: 169–192.

Weisberg RW (1986) Creativity: Genius and other myths. New York: WH Freeman and Company, p169.

Weisberg, R.W.(1994). Genius and madness? A quasi-experimental test of the hypothesis that manic-depression increases creativity. *Psychological Science, 5,* 361-367.

Weisberg, R.W. (1995). Prolegomena to theories of insight in problem solving: a taxonomy of problems. In R.J. Sternberg & J.E. Davidson (Eds.), *The nature of insight,* MIT Press, 157-196.

Weissman, D.H., Giesbrecht, B., Song, A.W., Mangun, G.R., Woldorff, M.G. (2003). Conflict monitoring in the human anterior cingulate during selective attention to global and local object features. *NeuroImage, 19,* 1361-168.

Weissman, D.H., Warner, L.M & Woldorff, M.G. (2004). The neural mechanisms for minimising cross-modal distraction. *Journal of Neuroscience, 24, 48,* 10941-10949.

Whalen, P.J., Bush, G., McNally, R.J., Wilhelm, S., McInerney, S.C., Jenike, M.A. & Rauch, S.L. (1998). The emotional counting stroop paradigm: a fuctional magnetic resonance imaging probe of the anterior cingulate affective division. *Biological Psychiatry, 44,* 1219-1228.

Wills TW, Soraci SA, Chechile RA, Taylor HA (2000) "Aha" effects in the generation of pictures. Mem Cognit 28: 939–948.

Wyland, C.L., Kelley, W.M., Macrae, C.N., Gordon, H.L., & Heatherton, T.F. (2003). Neural correlates of thought suppression. *Neuropsychologia, 41*, 1863-1867.

Yuen, K.S., & Lee, T.M.C. (2003). Could mood state affect risk taking decisions? Journal of Affective Disorders, 75, 1, 11-18.

# Karuna Subramaniam: CurriculumVitae

**Home:**
737 Post Street
Apt 1123
Post Street Towers
San Francisco, CA 94109
Phone: (312) 375-9856

**Work:**
Schizophrenia Research Laboratory
4150 Clement Ave
Department of Mental health Research
Veteran Affairs Hospital
San Francisco, CA 94109

Date of Birth: Apr 19, 1980
Place of Birth: Chandigarh, India

E-mail: karuxe@gmail.com

**Professional interests**

Cognitive and affective neuroscience: neurological basis of affect-cognitive interactions; neuroimaging (fMRI and EEG), experimental and computational approaches to understanding how positive affect and anxiety states modulate brain activity to bias cognitive problem solving strategies and social cognition in healthy controls and schizophrenia patients; investigating whether neuroplasticity-based cognitive training improves self-referential source memory, working memory and cognitive control processes in schizophrenia patients; proficient in using AFNI/SPM/MATLAB/Linux environments.

## Education

2007-present — Post-doctoral research fellow at Veteran Affairs Hospital and UCSF, San Francisco, CA. Schizophrenia Research Laboratory. Supervisor: Dr. Sophia Vinogradov

2002-2007 — Ph.D. graduate student in NUIN (Northwestern University Institute of Neurosciences) GPA: 3.89. Supervisor: Dr. Mark Beeman

Summer 2001 — Medical University of South Carolina (undergraduate neuroscience internship)

Winter 2000 — University of Besancon, France (undergraduate off campus program)

Fall 2000 — University of Aberdeen, Scotland (off-campus neuroscience program)

1998-2002 — B.A. Double Major: Psychology and French, GPA: 3.73 (magna cum laude), Knox College

**Scholarships/Awards**

2001 — **National Science Foundation (NSF-REU) Summer Research Scholarship:** "Therapeutic Efficacy of Calpeptin and Methylprednisilone on a Rat Model of

Spinal Cord Injury." Medical University of South Carolina, Dept. of Neurology. Supervisor: Dr. Naren L. Banik.

2001 **Pew Award: Selected to present talk at Pew Sponsored Undergraduate Conference**: "Therapeutic Efficacy of Calpeptin and Methylprednisilone on a Rat Model of Spinal Cord Injury." Washington University in St. Louis.

2000 **Richter Scholarships**:

**(i) Clinical intern with Neurologist, Dr. Marc Katchen, Central Illinois Institute**: Main focus on the behavioral/cognitive functioning and treatment of patients with Multiple Sclerosis.

**(ii) Clinical intern with Psychiatrist, Dr. Paul Sidandi, Lobatse Mental Hospital, Botswana, Southern Africa:** Main focus on counseling and making diagnostic evaluations (DSM IV) of patients with neurological and psychological disorders (e.g. Schizophrenia, Bipolar Disorder, AIDS, Substance Abuse and Conduct Disorders).

2000 **Psi Chi award: National Honor Society in Psychology**, Knox College, Faculty Advisor: Dr. Heather Hoffmann

2000 **Knox College Public Speaking Award**

**Publications**

**Subramaniam, K.,** Kounios, J., Parrish, T. & Jung-Beeman, M. Positive affect predicts cognitive preparation for insight solving within the dorsal Anterior Cingulate Cortex. *Journal of Cognitive Neuroscience (In Press).*

Fisher, M., Holland, C., **Subramaniam, K.** & Vinogradov, S. Neuroplasticity-based cognitive training in Schizophrenia: An interim report on the effects six months later. *Schizophrenia Bulletin (In Press)*

Fisher, M., Thangavel, A., **Subramaniam, K.**, Poole, J. & Vinogradov, S. Social and Self-Referential Cognition. *JINS (In Press).*

Kounios, J., Frymiare, J., Bowden, E., Fleck, J.I., **Subramaniam, K.,** Parrish, T.B., & Jung-Beeman, M. The prepared mind: Neural activity prior to problem presentation predicts subsequent solution by sudden insight. *Psychological Science, 17(10), 882-890.*

Conference Presentations and published Abstracts

1. **Subramaniam, K**., Luks, T., Aldebot, S., Hennig, P., Hearst, A., Fisher, M., Subhani, D., Simpson, G.V. & Vinogradov, S. (2007). Neuroplasticity-based cognitive training improves working memory and cognitive control processes in schizophrenia patients: Behavioral and fMRI assessments. Cognitive Neuroscience Society 2008 Annual Meeting, San Francisco, CA.

2. Vinogradov, S., **Subramaniam, K.,** Aldebot, S., Thangavel, A., Hearst, A., Fisher, M., Luks, T., & Simpson, G.V. (2007). Neuroplasticity-based cognitive training improves self-referential source memory in schizophrenia patients: Behavioral and fMRI assessments. Cognitive Neuroscience Society 2008 Annual Meeting, San Francisco, CA.

3. Fisher, M., Holland, C., **Subramaniam, K.,** Merzenich, M., & Vinogradov, S. (2007). The Beneficial Effects of Neuroplasticity-Based Cognitive Training in Schizophrenia Persist 6 Months Beyond Training. Cognitive Neuroscience Society 2008 Annual Meeting, San Francisco, CA

4. Khatibi, K., Findlay, A., Adcock, A., **Subramaniam, K.,** Aldebot, S., Hearst, A., Nagaranjan, S., & Vinogradov, S. (2007). Neuroplasticity-based cognitive training in schizophrenia normalizes auditory duration mismatch negativity responses in cortex. Cognitive Neuroscience Society 2008 Annual Meeting, San Francisco, CA

5. Fisher, M., Holland, C., **Subramaniam, K.,** Merzenich, M., & Vinogradov, S. (2008). Hear Today Learn Tomorrow: Neuroplasticity-Based Cognitive Training in Schizophrenia. Schizophrenia. Schizophrenia International Research Society, Venice, Italy.

6. **Subramaniam, K.,** Aldebot, S., Thangavel, A., Hearst, A., Garrett, C., Fisher, M., Holland, C., Luks,T., Simpson, G.V., & Vinogradov, S. (2008). Neuroplasticity-based cognitive training improves self-referential source memory compared to baseline performance in schizophrenia patients. Schizophrenia International Research Society, Venice, Italy.

7. Holland, C., Fisher, M., **Subramaniam, K.,** Pollock,B., & Vinogradov, S (2008). Serum Anticholinergicity on Cognition and Response to Cognitive Training in Schizophrenia. Schizophrenia International Research Society, Venice, Italy.

8. **Subramaniam, K.** & Jung-Beeman, M. (2006). Induced Mood Effects on Insight Problem Solving. 35th Annual INS Meeting (2007), Portland, OR.

9. **Subramaniam, K.** & Jung-Beeman, M. (2006). Positive Mood and Anxiety

modulate Anterior Cingulate activity and preparation for Insight. Proceedings of the 18th Annual Convention of the Association for Psychological Science, New York, NY.

10. **Subramaniam, K.** & Jung-Beeman, M. (2006). Mood Effects on Insight Problem Solving. Talk presented at the Proceedings of the 2006 MPA Conference, Chicago, IL.

11. **Subramaniam, K**., Haberman, J., Clancy, Z., Bowden, E., Parrish, T. & Jung-Beeman, M. (2005). Mood Effects on Creative Insight Problem Solving. Proceedings of the 12th Annual Cognitive Neuroscience Society Meeting, New York, NY.

12. **Subramaniam, K** & Banik, N. (2001). The Neuroprotective Effects of Calpeptin and Methylprednisilone on inhibiting Rat Apoptosis. Talk presented at the Medical University of South Carolina, Charleston, SC.

13. **Subramaniam, K** & Banik, N. (2001). Therapeutic Efficacy of Calpeptin and Methylprednisilone on a Rat Model of Spinal Cord Injury. Talk presented at the Pew Sponsored Undergraduate Conference, Washington University, St. Louis, MO.

## Cognitive/Clinical Research Experience

Present — **Current Research Project: "Neuroplasticity-based cognitive training improves self-referential source memory, working memory and cognitive control processes in schizophrenia patients."**

Supervisor: Dr. Sophia Vinogradov, Schizophrenia Research Laboratory, Veteran Affairs Hospital.

2005-2007 — **Dissertation: "Positive affect and anxiety modulate dorsal anterior cingulate activity and cognitive preparation for insight."**

Supervisor: Dr. Mark Jung-Beeman, Northwestern University.

2003-4 — **Research Project: "Cognitive-Behavioral Approaches to treat patients with Generalized Anxiety Disorder (GAD)."**

Clinical training with Dr. Richard Zinbarg, Northwestern University

2003 **Research Project: "The effects of Melatonin in the treatment of insomnia in patients with Delayed Sleep Phase Syndrome (DSPS)."**

Circadian Rhythm Research Project. Supervisor: Dr. Phyllis Zee, Northwestern University.

2002 **Research Project: "Covert visual spatial attention in Alzheimer's Disease subjects."**

Cognitive Neurology and Alzheimers' Disease Center. Supervisor: Dr. Dana Small, Northwestern University.

2001 **Research Project: "The therapeutic efficacy of calpeptin and methylprednisilone on a Rat Model of Spinal Cord Injury."**

Supervisor: Dr. Naren L. Banik, Medical University of South Carolina.

2000 **Research Project: "The cause, mechanism of action, and treatment of patients with Multiple Sclerosis."**

Internship with Clinical neurologist: Dr. Marc Katchen, Central Illinois Institute.

2000 **Research Project: "The neurocognitive aspects of schizophrenia."**

Internship with Medical Superintendent and Psychiatrist: Dr. Paul Sidandi , Lobatse Mental Hospital, Botswana, Southern Africa.

2000 **Research Project: "Visual Perception: The FINST mechanism."**

Supervisor: Dr. Roy Allen, University of Aberdeen.

1999 **Research Project: "The Dopaminergic Depleting Effect of 6-OHDA on Fine Motor Control."**

.
Research Advisor: Dr. Heather Hoffmann, Knox College

## Teaching Experience

2006 Teaching Assistant: Language and the Brain (graduate course in Psychology)
Professor: Dr. Mark Jung-Beeman, Northwestern University

2004 Teaching Assistant: Fundamentals of Neuroscience (1st yr NUIN graduate course)

Professors: Dr. Lee Miller & Dr. Mark Segraves, Northwestern University

2003 Teaching Assistant: Biology in the Information Age (undergraduate course). Professor: Dr. Teresa Horton, Northwestern University

1999-2002 Certified Neuropsychology and French tutor**,** Knox College

2000 Teaching Assistant**: "**Finger Instantiation method (FINST) of visual perception." Professor: Dr. Roy Allen, Psychology Department, University of Aberdeen, Scotland.

2001 Teaching Assistant: First Year Preceptorial Course
Professor: Dr. David Gourd, Knox College

## Organizations

International Neuropsychological Society 2006-present
American Psychological Society 2006-present
American Psychological Association 2006-present
Midwestern Psychological Association 2006-present
Cognitive Neuroscience Society, 2005-present
Psi Chi, 2000