Neural and cognitive mechanisms of creativity

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Cover design: Adrian Curtin, School of Biomedical Engineering, Drexel University

The research presented in this thesis was supported by a post-graduate scholarship (PhD) of the Iranian Ministry of Science, Research and Technology to Soghra Akbari Chermahini.

Neural and Cognitive Mechanisms of Creativity

Proefschrift
ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus Prof. mr. P.F. van der Heijden,
volgens besluit van het College voor Promoties
te verdedigen op dinsdag 25 oktober 2011
klokke 11.15 uur

door

Soghra Akbari Chermahini
geboren te Chermahin, Iran
in 1973

Promotiecommissie

Promotor:	Prof.dr. B. Hommel
Overige Leden:	Dr. L.S. Colzato
	Prof.dr. E. van Dijk
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	Prof.dr. N.O. Schiller

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CHAPTER 1

General Introduction

INTRODUCTION

Creativity has many implications for success in daily life, academic achievement, and plays an important role in human being progress. Underlying neuro-cognitive mechanisms of creative thinking are the subject of intense research efforts in behavioral and cognitive neuroscience. Many questions call for an answer: How does the brain generate creative ideas or solutions? Is there only one creative process or are there many? How we can measure creativity and what is the reliable test to measure it? Let us begin by asking what we mean by creativity and how creativity might be defined.

What is Creativity?

Creativity is arguably one of the faculties that have given the human species adaptive ability beyond any other organism. Many articles have been written about creativity, yet there is no consensus on its definition. Webster's Dictionary (Soukhanov, 1984) defines *creative* as having the ability to create, and *create as "to bring in to being"*. A second definition of *create* is "to produce through artistic effort". Another definition of *creative* is marked by originality. A large number of theories have been proposed to defined creativity as a psychological process that produces original and appropriate ideas, including Guilford's (1950) psychometric theory, Wertheimer's (1959) Gestalt theory, Mednick's (1962) and Eysenck's (1995) associational theories, Campbell's (1960) Darwinian theory, Amabiles's (1983) social-psychological theory, Sternberg and Lubart's (1995) investment theory, and Martindale's (1995) cognitive theory. All of these theories contribute to our understanding of creativity. However, modern creativity research is commonly said to begin with Joy Paul Guilford in 1950, when he pointed out the very important nature of creativity as a research topic, and in 1967, when he distinguished between divergent and convergent types of creative problem solving.

In our daily life, we are constantly faced with problems and situations that require the generation of creative and novel ideas, either by divergent or convergent thinking. Imagine, if there was a situation in which one was required to come up with as many solutions as possible to address that situation; for instance when being asked "*how do you spend your* *time productively if you have a week off?*". Or in a situation where there are few or just one correct solution to solve the problem, for example, *"Your car suddenly dies on its own while you are driving. Then you try to find what is the problem and how to solve it"*. In such kinds of scenarios, one needs to use divergent and convergent thinking modes, respectively, to solve the problems.

According to Guilford (1967), divergent and convergent thinking are two types of human response to a set problem. Guilford defined divergent or "synthetic thinking" as the ability to draw on ideas from across disciplines and fields of inquiry to reach a deeper understanding of the world and one's place in it. He, thus, associated divergent thinking with creativity, appointing it with several characteristics:

1. **fluency** (the ability to produce a great number of ideas or problem solutions in a short period of time);
2. **flexibility** (the ability to simultaneously propose a variety of approaches to a specific problem);
3. **originality** (the ability to produce new, original ideas);
4. **elaboration** (the ability to systematize and organize the details of an idea in a head and carry it out).

Divergent thinking is a thought process or method used to generate creative ideas by exploring many possible solutions (Figure 1a) and typically occurs in a spontaneous, free-flowing manner, such that many ideas are generated in a random, unorganized fashion. Many possible solutions are explored in a short amount of time, and unexpected connections are drawn.

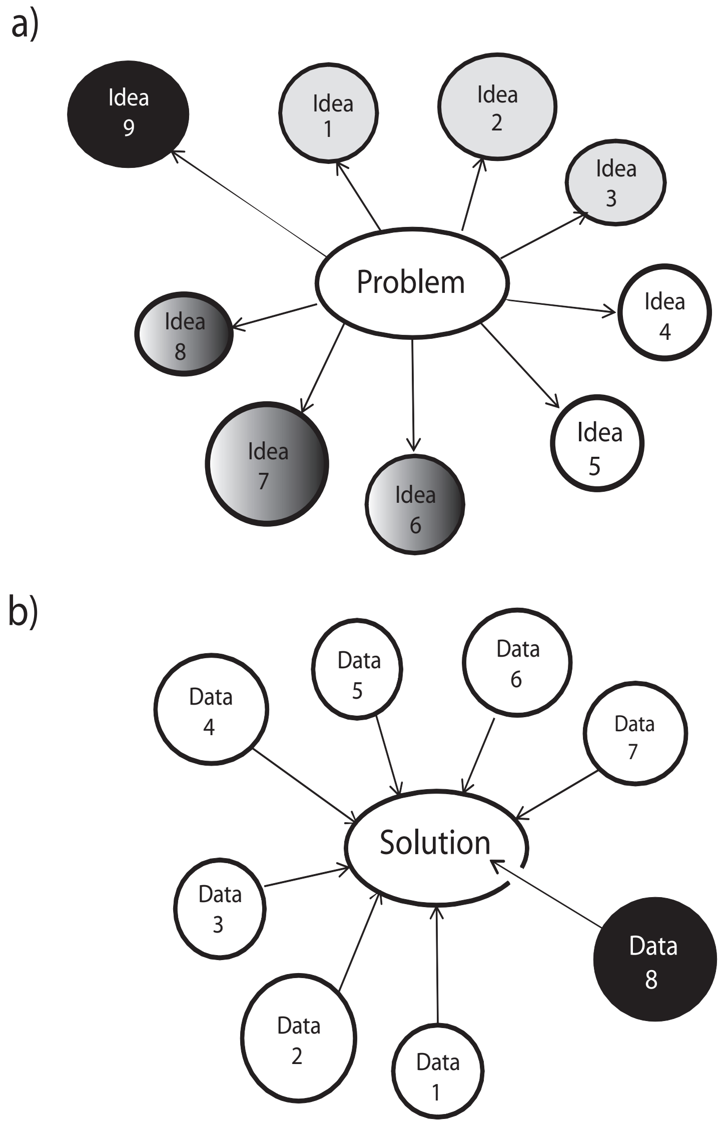

Figure 1: Hypothetical charts of divergent and convergent thinking. In the chart of divergent thinking (a), fluency, flexibility, originality, and elaboration are represented by number of circles, circles with same color, black circle with longest arrow, and size of the circles respectively. In the chart of convergent thinking (b), the correct solution is represented by a black circle.

Convergent thinking is a term developed by Guilford as opposite to divergent thinking. This type of creativity is oriented towards deriving the single best (or correct) answer to a clearly defined question. It has a strong emphasis on speed, accuracy, logic, and focuses on accumulating information, recognizing the familiar, reapplying set techniques, and preserving the already known. It is based on familiarity with what is already known (i.e., knowledge) and is most effective in situations where a ready-made answer exists and needs simply to be recalled from stored information, or worked out from what is already known by applying conventional and logical search, recognition and decision-making strategies. Convergent thinking is a style of thought that attempts to consider all available information and arrive at the single best possible answer (Figure 1b).

Divergent and convergent thinking are ideal types, and not mutually exclusive. In this thesis, divergent and convergent thinking are considered as two different types of creativity and not necessarily as opposites.

Dopamine and Cognitive Processes

The function of cortical dopamine has been known to play a role in cognitive performance of working memory in human (Kimberg, et al. 1997, 2001; Luciana, et al. 1992, 1998) as well as in animal research (Brozoski *et al.*, 1979; Goldman-Rakic, 1992; Williams & Goldman-Rakic, 1995; Castner *et al.*, 2000), reward based learning (Hollerman & Schultz, 1998; Schultz *et al.*, 2000), and in cognitive flexibility (Frank, 2005; Cools, 2008; Garcia-Garcia et al., 2010).

It has been reported that the age-related loss of dopamine (D2 receptors and DA transporters) is associated with decrease in prefrontal metabolism (Volkow, 2000) and with performance on tests of executive function (Volkow, 1998; Mozley LH, 2001). A variety of neuropsychological studies in clinical populations suggest a direct association between altered dopamine transmission in the prefrontal cortex and cognitive deficits (Müller et al, 1998) that have been described in disorders with a decrease in dopamine functioning, such as Parkinson's disease (Gotham et al., 1988), and ADHD (Volkow, 2009) and also in disorders in which an increase in dopamine functioning has been hypothesized, such as schizophrenia (Knable and Weinberger, 1997), Hungtington's disease (Cha et al. 1998, Iversen and Iversen, 2007) and depression (Jimerson,1987). This suggests that a specific level of dopamine is necessary for an optimal functioning of the prefrontal cortex, as described by an inverted U-shape curve (Cools et at., 2001; Vijayraghavan et al., 2007) (Figure 2).

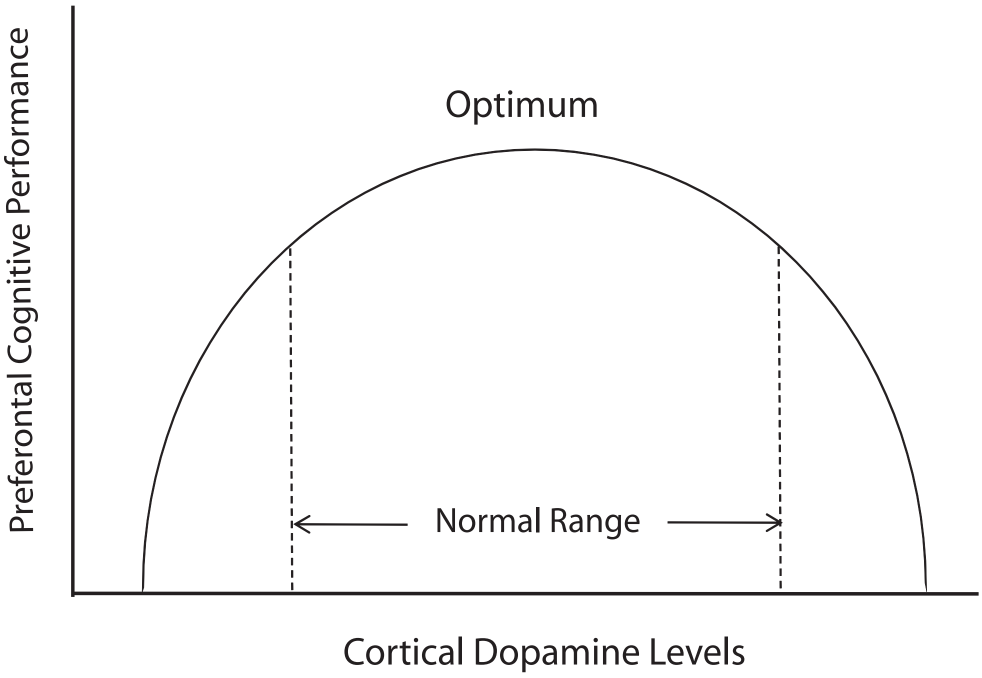

Figure 2: An inverted U-shaped relationship between cortical dopamine and cognitive performance. When either cortical dopamine levels activity are below the optimal range, as may occur in Parkinson's disease, or above the optimal range, as may occur in schizophrenia, cognitive performance is impaired (based on Williams & Goldman-Rakic., 1995; Lidow et al., 1998; Cools et at., 2001; Vijayraghavan et al., 2007).

Dopamine and Creativity

Until now, little is known about the biological underpinnings of creativity and neuroanatomical correlates. Both direct and indirect evidence suggests that the dopamine system may play a particular role in creative thinking. Findings suggest a relationship between the personality trait of SEEK and creativity (Reuter et al., 2005). The SEEK dimension is an interesting trait for creativity research because, on the one hand, it is conceptualized as having a strong biological basis and, on the other hand, it explicitly assesses aspects of creativity, like eagerness to solve problem and favoring activities related to exploring new things. There is substantial evidence that the personality traits linked to creativity are modulated by dopaminergic activity (Panksepp et al., 1998), in particular the activity of dopamine D2 receptors: Novelty seeking is correlated with D2 binding potential (D2BP) (Kaasinen, Aalto, Nagren, & Rinne, 2004; Suhara, et al., 2002), and has also been associated with polymorphisms of the dopamine D2 receptor gene - DRD2 (Berman, Ozkaragoz, Young, & Noble, 2002).

Further evidence comes from a recent behavioral genetics study where individuals with the DRD2 TAQ IA polymorphism (which results in a 30–40% reduction in DA-D2 receptor density) showed significantly better performance in creativity tasks (a divergent thinking test: the Inventiveness battery of the Berliner Intelligenz-Struktur-Test) (Reuter, Roth, Holve, & Hennig, 2006). This finding is consistence with functional imaging research showing the D2 system to be involved in attentional set shifting and response flexibility, which are important components of divergent thinking (Durstewitz & Seamans, 2008).

Furthermore, the finding indicates that divergent thinking is related to regional differences in D2 densities, since the DRD2-TAQ-IA polymorphism has been shown to modulate D2 binding potential (D2BP) in both striatal (Ritchie & Noble, 2003) and extrastriatal regions (Hirvonen et al., 2009). Evidence on where to expect regional D2 density differences related to divergent thinking comes from the link between creativity and psychopathology: in healthy individuals various creativity-related measures, including divergent thinking, have been associated with the personality traits psychoticism and schizotypy, as well as genetic liability for schizophrenia spectrum and bipolar disorders (Batey & Furnham, 2008; Burch et al., 2006; Eysenck, 1995; Folley & Park, 2005; Post, 1994; Richards et al., 1988). Particularly, the networks relevant to divergent thinking overlap to a great extent with regions and networks affected in schizophrenia and bipolar disorders. Furthermore, dopamine is known to influence processing in these networks and alterations in dopaminergic function and activity of D2 receptors have been linked to both positive and negative symptoms (e.g. Guillin et al., 2007; Cousins, Butts & Young, 2009; Weinberger & Laruelle, 2001). Manzano and colleagues (2010) have shown that the dopamine system in healthy, highly creative people has a lower density of D2 receptors in the thalamus than in less creative people, similar in some respects to what is seen in people with schizophrenia. Taken together, this is further evidence suggesting a link between brain dopamine function and creative performance.

Also of relevance for the research reported in this thesis is the modulatory role of dopamine in affect and creativity. As reviewed in the next section, it has been also shown that positive affect improves performance in several tasks that typically are used as indicators of creativity or innovative problem solving (Isen et al., 1987). Ashby et al. (1999) assumed that some of the cognitive influences of positive mood are due to increased levels of dopamine in frontal cortical areas that result from the events eliciting the elevation in mood. The theory developed by Ashby and colleagues (1999) described some of the neural pathways and structures that might participate in mediating the neural effect of positive affect and its influence on cognition with special emphasis on creative problem solving. So one might conclude that dopamine modulates effect of positive mood on creative performance.

Affect and creativity

The impact of positive and negative affect on cognitive processes has been shown in several studies. For example, positive affect enhances cognition of associative (Bar, 2009), and semantic priming (Haänze & Hesse, 1993), and negative affect narrows the focus of attention, increasing analytical processing, causal reasoning, and reliance on systematic processing (Pham, 2007). There is general agreement that tasks of creative thinking are mood sensitive, and among the many variables that have been shown to predict creativity, mood stands out as one of the most widely studied and least doubtful predictors (e.g., George & Brief, 1996; Isen & Baron, 1991; Mumford, 2003). For example, Ashby et al. (1999) noted that:

> "*It is now well recognized that positive affect leads to greater cognitive flexibility and facilitates creative problem solving across a broad range of settings. These effects have been noted not only with college samples but also in organizational settings, in consumer contexts, in negotiation situation….and in organizational on coping and stress (p.530).*"

Ashby et al. (1999) have postulated that this effect is due to the fact that a positive mood state results in increased dopamine levels in the brain, most notably in the prefrontal cortex and the anterior cingulate, which leads to greater cognitive flexibility and, consequently, enhanced performance on certain cognitive tasks where increased flexibility would be advantageous. These ideas are supported by evidence showing increased prefrontal activity during happy mood states (Davidson et al, 1990; Baker, Frith & Dolan, 1997).

In a similar vein, it has been concluded by Lyubomirsky, King, and Diener (2005) that people in a positive mood are more likely to have richer associations within existing knowledge structures, and thus are likely to be more flexible and original. Those in a good mood will excel either when the task is complex and past learning can be used in a heuristic way to more efficiently solve the task or when creativity and flexibility are required. Systematic empirical studies have examined the relationship between affect and creativity over the last 30 years. Some of these studies have focused on the direct impact of mood on creativity, in particular the effect of positive and negative states or mood on creative performance. Results from experimental studies diverge; in general, there are three groups. The first group consists of a large number of studies that compared positive and neutral moods, (e.g., Isen et al 1987; Ashby et al., 1999; Lyubomirsky et al., 2005), often concluding that positive mood facilitates creative problem solving. A second group compared negative and neutral mood, but here the findings are contradictory: some studies report that negative relative to neutral mood enhances creativity (such as Adaman & Blaney, 1995; Clapham; 2001), while others show a negative effect of negative mood (such as Vosburg, 1998), or no difference between negative or neutral mood (such as Verhaeghen, Joormann, & Khan, 2005). Such conflict in the results suggests that relationship between negative mood and creativity is very complex. The third group compared positive with negative mood, where positive mood sometimes favors (Grawitch, Munz, & Kramer, 2003) and sometimes inhibits creativity (e.g., Kaufmann & Vosburg, 1997), and sometimes negative mood promotes creativity more than positive mood does (Gasper, 2002).

A meta-analysis of mood-creativity relations in the three mentioned groups of studies (Baas, M. et al. 2008) revealed that in first group, positive mood relates to more creativity than neutral mood; in the second group the effect was small overall and non-significant, which means there is no significant effect of negative mood on creativity; and finally in the third group positive mood sometimes improved and sometimes impaired creativity. Taken together positive affect has a considerable effect on creativity, more than neutral and negative moods; however, the type and nature of this interaction is not well understood, and mediating factors like type of task (Davis, 2009) and motivational set (Baas et al., 2008) can play crucial roles.

One idea about how mood and creative processes might interact considers mood as the cause and changes in creativity as effect. More recently, however, authors have also considered the possibility of a more reciprocal relationship between affective and cognitive processes (Bar, 2009; Gray, 2004; Gross, 2002; Salovey, et al, 2002), which would allow creative thought to affect mood. Therefore, we can assume that particular mood states might facilitate or hinder particular types of thought processes but some types of thought processes might also facilitate or even induce particular mood states.

There seems to be particularly a close relationship between mood and creative thinking, but this relationship is unclear. To explain these divergent results, in this thesis we suggest that 'individuals' dopamine levels are a factor that might modulate the impact of mood states on creativity.

Cognitive control and creativity

As we have already mentioned, divergent thinking is taken to represent a style of thinking that allows many new ideas being generated with more than one correct solution; in contrast, convergent thinking is considered a process of generating one possible solution to a particular problem. There is some evidence to support the idea that creativity is not a homogeneous concept; instead it reflects an interplay of separate mental sets (convergent and divergent), and dissociable processes. In one of our studies (chapter 3), divergent thinking has been shown to benefit most from medium levels of dopamine, while convergent thinking was best with low levels. This suggests that divergent and convergent thinking are both related to dopamine, but to different degrees and in different ways. It has also been shown that creativity has an impact on current mood state but convergent and divergent thinking play different roles: convergent thinking decreases mood while divergent thinking increases it (chapter 5). So if divergent and convergent thinking are related to dopamine and change mood in different ways, then we can assume that there are different cognitive mechanisms behind them.

Further support for this dissociation comes from a recent EEG study, where EEG pattern differences between these two processes (convergent and divergent thinking) were found in $\theta 1$ (Theta1) and $\beta 2$ (Beta2) bands (Razoumnikova, 2000): In the $\theta 1$ range convergent thinking produced more coherence increases in the right hemisphere, and in divergent thinking coherence patterns in β2 indicated more interhemispheric communication. The result pattern possibly reflects topographic and frequency differences between *directional attention* during convergent thinking and *differential attention* while divergent thinking. More support comes from another EEG study by Mölle and colleagues (1996), which examined differences in the complexity of EEG activity during convergent analytical thinking in comparison to divergent creative thinking. The results provide evidence for comparable complexity over the frontal cortex during divergent thinking and a state of mental relaxation relative to reduced complexity during convergent thinking. Increased EEG complexity during mental relaxation was postulated to arise due to unfocused and loosened associational thinking. The similarity of EEG complexity during mental relaxation and divergent thinking was similarly held to be an expression of loosened attentional control during divergent thinking.

The social cognition literature has shown that mindsets are flexible (Gollwitzer, 1999), and can be manipulated on a short-term basis, such as in creativity (Friedman & Foster, 2005). In convergent thinking conditions individual's mindset can be characterized as focusing on the correct and inhibiting incorrect solutions; in contrast, in divergent thinking conditions attention tends to defocus and relax rather than inhibiting the ideas that come to the mind as possible solutions. Along these lines, in this thesis, creativity was considered as a *state of mind* rather than as a *trait*—suggesting that everyone can be sometimes more and sometimes less creative. Convergent thinking would seem to benefit from a strong degree of goal-directedness to find correct solution. In contrast, divergent thinking would not seem to benefit from strong top-down control but, if anything, from rather weak and "allowing" top-down guidance.

Top-down control or the influence of previously formed representations on the processing of incoming information with reference to relevant goals is orchestrated by the prefrontal cortex. Top-down influence mediates the activity of neural systems involved in several cognitive operations such as working memory, selective attention, goal definition, and action planning (Fuster, 1989; Desimone & Duncan, 1995; Miller, 2000; Miller & Cohen, 2001). These processes can be subsumed under 'executive functions', a term that refers to the control processes involved in planning, problem-solving, decision-making, task management, and intentional action (Shallice, 1982; Lezak, 1995; Eslinger, 1996).

These considerations suggest that the convergent- and divergent-thinking components of human creativity imply two different cognitive-control states that facilitate or even generate the respective thinking style. Results of 5 experiments represented in chapter 6 of this thesis show cognitive control induced by convergent thinking is beneficial for some cognitive tasks which apply strong cognitive control. In contrast divergent thinking induces cognitive control state and benefits tasks that apply less top-down control.

Overview of the experimental chapters

In the projects underlying this thesis my colleagues and I have investigated the functional and neuromodulatory basis of creativity and tried to identify optimal conditions for divergent and convergent thinking. The thesis consists of five empirical chapters (chapters 2-6) that report empirical work on divergent and convergent thinking.

Chapter 2 aims to develop and validate a Dutch version of the Remote Associate Task, which is assumed to assess convergent thinking. We used Item Response Theory (IRT) to analyze the data. IRT specifies the relationship between the abilities of, and the examinee's response to the specific item.

Chapter 3 investigated the relationship between dopamine, fluid intelligence, and creativity by means of three experiments. In experiment 1 subjects were asked to perform Raven's Advanced Progressive Matrices (APM: Raven, 1965) to measure fluid intelligence, Guilford's Alternative Uses Task (to measure divergent thinking), Remote Associate Task (to measure convergent thinking), and the individual's dopamine level was measured by the Spontaneous Eye Blink Rate (EBR). Experiments 2 and 3 replicated experiment 1 with different groups of subjects. Results show a significant U-shaped relationship between flexibility in the divergent thinking task and individual's EBRs. EBR failed to predict convergent thinking and fluid intelligence consistently. We conclude that performance in divergent-thinking tasks varies as a function of the individual dopamine level, with medium levels producing the best performance.

Chapter 4 investigates whether the influence of positive affect on creativity is mediated by individual levels of dopamine. Two groups of subjects attended to a mood induction experiment (either positive or negative mood induction). Their performance in divergent thinking was measured before and after mood induction. The results show that performance in divergent-thinking tasks varies as a function of individual dopamine level, with medium levels producing the best performance. Positive mood, which often has been assumed to improve creativity, affected different individuals in different ways: it improved creativity in people with low dopamine levels but no improvement for people with high dopamine levels.

Chapter 5 studied whether creative thinking might induce particular mood states. This assumption was tested by presenting participants with creative-thinking tasks and assessing whether this would lead to systematic mood changes. We tested the impact of divergent thinking (assessed by the Alternate Uses Task, AUT: Guilford, 1967) and convergent thinking (assessed by the Remote Associates Task, RAT: Mednick, 1962) on mood. The results show divergent and convergent thinking impact mood in opposite ways: while divergent thinking improves one's mood, convergent thinking lowers it. This provides considerable support for the assumption that mood and cognition are not only related, but that this relation is fully reciprocal.

In chapter 6, creativity was considered to induce a particular control state that affects the way cognitive operations are run. We wanted to know if there is any after-effect of carrying out a divergent or convergent thinking task on cognitive control states. Result of five experiments show that convergent thinking benefited performance in the global-local task (experiment 1), the semantic Stroop task (Experiment 2), and the Simon task (Experiment 3) more than divergent thinking did. These tasks are suspected to induce conflict between perceptual interpretations, semantic representation, and response codes, respectively. In contrast, the two creativity tasks had no specific impact on inhibiting response tendency in Stop-Signal task (Experiment 4). Divergent thinking benefited performance in Attentional Blink task that was assumed to benefit from a relaxation of top-down control (Experiment 5). Convergent and divergent thinking apparently induce different control states.

Chapter 7 provides a summary of the main findings and a discussion of relevant theoretical implications.

The following references correspond to the empirical chapters in this thesis.

Chapter 2: Akbari Chermahini, S., Hickendorff, M., & Hommel, B. (submitted). Development and validity of a Dutch version of the Remote Associate Task: An Item Response Theory approach.

Chapter 3: Akbari Chermahini, S., & Hommel, B. (2010). The (b)link between creativity and dopamine: Spontaneous eye blink rates predict and dissociate divergent and convergent thinking. *Cognition, 115*, 458-465.

Chapter 4: Akbari Chermahini, S., & Hommel, B. (submitted). More creative through positive mood? Not everyone!

Chapter 5: Akbari Chermahini, S., & Hommel, B. (in press). Creative mood swings: Divergent and convergent thinking affect mood in opposite ways. *Psychological Research*.

Chapter 6: Hommel, B., Akbari Chermahini, S., van den Wildenberg, W.P.M., & Colzato, L.S. (submitted). Cognitive control of convergent and divergent thinking: A control-state approach to human creativity.

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CHAPTER 2

Development and validity of a Dutch version of the Remote Associate Task:

An item-response theory approach

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ABSTRACT

The Remote Associates Test (RAT) developed by Mednick (1967) is known as a valid measure of creative convergent thinking.We developed a 30-item version of the RAT in Dutch language with high internal consistency (Cronbach's alpha =0.85) and applied both Classical Test Theory and Item ResponseTheory (IRT) to provide measures of item difficulty and discriminability, construct validity, and reliability. IRT was further used to construct a shorter version of the RAT, which comprises of 22 items but still shows good reliability and validity—as revealed by its relation to Raven's Advanced Progressive Matrices test, another insight-problem test, and Guilford's Alternative Uses Test.

INTRODUCTION

Most researchers agree that creativity is the ability to generate behavior and behavioral outcomes that are unique, useful, and productive (Sternberg, et al, 1996). Therefore, creativity is considered as a performance or ability, manifested in original, valuable, and socially accepted ideas, products, or works of art. The creativity level of an individual can be assessed by means of performance measures derived from creative thinking tasks. Guilford (1967), who can be considered the founder of modern creativity research, drew a distinction between convergent and divergent thinking. Convergent thinking aims for a single, highly constrained solution to a problem, whereas divergent thinking involves the generation of multiple answers to an often loosely defined problem.

Influenced by Guilford’s suggestions to distinguish convergent and divergent thinking, many creativity measures have been developed, such as Guilford’s Alternative Uses Test, considered to assess divergent thinking, and Mednick’s Remote Associates Test (RAT; Mednick, Mednick, & Mednick, 1964), considered to assess convergent thinking. The latter was designed in accordance with S. Mednick's (1962) associative theory of creativity. According to this theory, the creative thinking process consists inusing associative elements to create new combinations which either meet specified requirements or are in some way useful.

The test aimed at measuring creative thought without requiring knowledge specific to any particular field. Two college-level versions of the test were developed, each consisting of 30 items (Mednick, 1968; Mednick & Mednick, 1967). Each item consists of three words that can be associated in a number of ways, such as by forming a compound word or a semantic association. “Creative thought” is required to find a correct solution because the first and most obvious solution is often not correct, so that more remote connections need to be retrieved in order to relate the three words to each other. Even though this arguably introduced an aspect of divergent thinking, the basic structure of the RAT (finding a highly constrained, single solution) fits rather well with Guilford’s (1967) concept of convergent thinking. Notwithstanding Guilford’s distinction, in most studies of problem solving and creative thinking the RAT has been used as a test of general creativity (e.g., Ansburg, 2000; Beeman & Bowden, 2000; Bowers, Regehr, Balthazard, & Parker, 1990; Dallob &

Dominowski, 1993; Dorfman, Shames, & Kihlstrom, 1996; Schooler & Melcher, 1995; Shames, 1994; Smith & Blankenship, 1991). The RAT has also been employed in a wide range of research including studying psychopathologies (e.g., Fodor, 1999), success and failure experiences (e.g., Vohs & Heatherton, 2001), affect (e.g., Mikulincer & Sheffi, 2000).

Performance on the RAT is known to correlate with performance on classic insight problems (e.g., Dallob & Dominowski, 1993; Schooler & Melcher, 1995; Öllinger et al. 2008; Ansbug, 2000; Daialey, 1978), suggesting that at least some items in the RAT reflect insight. The materials used in the test involve verbal associative habits that could reasonably be assumed to be familiar to almost all individuals brought up in the United States, especially in the English speaking part of the US culture. However, it has been noted that the RAT is rather difficult for non-native speakers of English (e.g., Estrada, Isen& Young, 1994). Several non-English versions have therefore been developed: Hebrew, Japanese, and Jamaican (Baba, 1982; Hamilton, 1982; Levin & Nevo, 1978), but to our knowledge there is no Dutch version of this test available. Therefore, the aim of the current study was to develop a Dutch version of the RAT: a short, reliable, and valid measurement instrument to measure convergent thinking in the Dutch language. To do so we first developed and administered 30 Dutch RAT-like items. Next, we used Item Response Theory (IRT) to evaluate the psychometric properties of this 30-item test, and to shorten the test with the least possible loss of psychometric quality and information. To validate this short version, we related the RAT measures to measures from two other tasks that are assumed to assess aspects of convergent thinking: the Raven’s Advanced Progressive Matrices test (Raven, 1965), which is also considered to provide an estimate of fluid intelligence, and an insight-problem test. Finally, we contrasted RAT measures with estimates of divergence-thinking performance derived from Guilford’s Alternative Uses Test.

METHOD

Participants and Procedure

Participants were students from Leiden University, the Netherlands. All of them were native speakers of Dutch. The sample consisted of 158 participants (133 females and 25 males). Their age ranged from 18 to 32, with a mean of 20.4 (SD=2.9). They were tested individually in 60-min sessions, in which they worked through three paper-and-pencil-type tests (the Dutch RAT, an insight problem test, and the Alternative Uses Task, all described below), and a computer version test of Raven's Advanced Progressive Matrices.

Instrument

Remote Associate Test (RAT)

Of the original, English RAT (Mednick, 1962) two college–level versions have been constructed, each consisting of 30 items. For each item, three words are presented and the participant is required to identify the (fourth) word that connects these three seemingly unrelated words (e.g., "bass, complex, sleep", where the solution is "deep"). The solution word for each item can be associated with the words of the triad in various ways, such as synonymy, formation of a compound word, or semantic association. The link between the words is associative and does not follow common rules of logic, concept formation, or problem solving. Hence, with all items of the test the solution word is a remote, uncommon associate of each of the stimulus words, requiring the respondent to work outside of these common analytical constraints. The score is determined by the number of correct answers given in a particular time.

We constructed a Dutch version of the RAT as follows: First, native Dutch-speaking staff members of the psychological department of Leiden University were consulted to construct 50 sets of words. Each set consisted of three words that were associated with a solution word. Next, a group of students from Leiden University (all native Dutch speakers) were asked to respond to these 50 items, providing a check for strange or saliently uncommon items. Based on this screening process, 30 items were chosen. Finally, a separate group of 158 students—the actual participants of this study—were asked to respond to the 30 item within 10 minutes.

Raven's Advanced Progressive Matrices

Raven's Advanced Progressive Matrices (APM: Raven, 1965) test is considered to assess insight and has been constructed to provide a language-independent estimate of fluid intelligence and Spearman's g. We used 36 items on which participants worked for 25 minutes. Each item of this test consists of a visual pattern with one piece missing, which participants are to identify from a set of alternatives. The items get progressively harder and are assumed to need increasingly more cognitive capacity.

Insight Problem

An insight problem is a problem that requires participants to shift their perspective and view the problem in a novel way to achieve the solution. According to the domain-specific theory (see Baer in Runco, 1999), insight problems can be divided into coherent subcategories such as verbal, mathematical, and spatial insight problems (Dow & Mayer 2004). The insight problem test in this study (see Appendix) consisted of three questions that included all three subcategories of insight problems: a verbal and a spatial problem (both adopted from Metcalfe, 1986), and a mathematical problem (adopted from Sternberg & Davidson, 1982). Participants were asked to do the test in 15 minutes. The total number of correct responses was used as score.

Alternative Uses Task

In this task (based on Guilford, 1967), participants were asked to list as many possible uses for three common household items (*brick*, *shoe*, and *newspaper*) as they can within 10 minutes. Scoring comprised of four components:

Originality: Each response is compared to the total amount of responses from all of the participants. Responses that were given by only 5% of the group counted as unusual (1 point) and responses given by only 1% of them count as unique (2 points).

Fluency: The total of all responses.

Flexibility: The number of different categories used.

Elaboration: The amount of detail; e.g., "a doorstop" counts 0, whereas "a door stop to prevent a door slamming shut in a strong wind" counts 2 (1 point for explanation of door slamming and another for further detail about the wind).

Data analysis

Psychometric theory offers two approaches to evaluate the design, analysis, and scoring of tests: Classical Test Theory (CTT) and Item Response Theory (IRT; see Embretson & Reise, 2000). Both theories allow predicting outcomes of psychological tests by identifying parameters of item difficulty and the ability of test takers, and both provide measures to assess the reliability and validity of psychological tests.

CTT is widely used as a method of analysis in evaluating tests but it has some limitations. First, the observed total score is item dependent. That is, if two participants complete different tests that measure the same construct, the meaning of their total scores depend on the difficulty of the items in their respective tests. Often observed side-effects are floor and ceiling effects. Second, item statistics or the difficulty level and item discrimination are examinee dependent. That is, the commonly used CTT-statistic for difficulty level, the *P*-value (probability correct), depends on the ability level of the sample of test takers: the *P*-value will be higher in samples with high than with low ability levels. Moreover, the CTT-statistic for the discrimination of an item, the item-rest-correlation, will be highest if participants have around 50% chance to answer the item correctly. So, these statistics also depend on the specific sample of test takers.

IRT overcomes these limitations of CTT. In IRT, each item in a test has its own characteristic curve which describes the probability of answering the item correctly depending on the test taker's ability (Kaplan & Saccuzzo, 1997). One of the advantages of using IRT over CTT is IRTs sample-independent nature of its results. This means that item parameters are invariant when computed from different groups of different ability levels. As a result, the same measurement scale can be used in different groups of participants, and groups as well as individuals can be tested with a different set of items, appropriate to their ability levels. Their scores will be directly comparable (Anastasi & Urbina, 1997). Because of these advantages, we applied IRT modeling in this study in evaluating item and test properties to judge the test's reliability and validity. IRT asserts that the easier the question, the more likely a participant will be able to respond to it correctly, and the more able the participant, the more likely he or she will be able to answer the question correctly as compared to a student who is less able. In IRT models, it is assumed that there exists a latent (unobserved) ability scale, usually called θ, that underlies performance on a set of items. The probability that a person answers an item correctly is modeled as function of this person's latent ability, and a set of item parameters. The probability of a correct answer on an item increases with higher latent ability, following an S-shaped curve bounded by 0 and 1: the *Item Characteristic Curve*. There are three common item parameters: the difficulty, discrimination, and guessing parameter. The *difficulty* or location parameter manages the curve's point of inflection (the level of θ yielding a 50% probability of a correct answer), the *discrimination* parameter determines its slope, and the *guessing* parameter represents the lower asymptote.

Item characteristic curves provide important and useful information about item properties. IRT can also be used to study item and test *information functions*. *Item Information Curves* (or functions) indicate the range over θ where an item is best at discriminating among individuals. More information, determined by the item's discrimination parameter, indicates higher accuracy or reliability for measuring a person's trait level. Item information can be used to select a set of items that together provide much information on a desired range of latent the ability scale. *The Test Information Curve* (or function) indicates the amount of information (i.e., reliability) provided by the scale over the range of the construct continuum. The test information curve is simply the sum of the item information curves of the items in the test. *The Standard Error of Measurement* is reciprocally related to the test information function, and evaluates the accuracy of the test to measure people at different levels along the ability continuum.

RESULTS

Classical Test Theory

The mean RAT total score was 8.94 (SD =5.21). Internal consistency of the scale was determined using Cronbach's alpha as a function of the mean inter-item correlations among the 30 dichotomously scored items. The high alpha value (0.85) of the scale is a sign of very good internal consistency with this sample, indicating that the items are consistent in measuring the underlying construct. The first two columns in Table 1 show, for each item, the total probability correct in the sample (ranging from .02 to .72) and the item-rest correlations (ranging from .09 to .65). In general, the 30 items appear rather difficult, and all items are positively related to the overall test score, although this relation is stronger for some items than for others.

Item Response Theory

Two IRT models were compared in the analyses. A one-parameter logistic (1PL) model was specified in which item difficulties were freely estimated but item discriminations were constrained to be equal and item lower asymptotes (guessing parameter) were fixed at 0. A two-parameter logistic (2PL) model was specified in which item difficulties and discriminations were freely estimated but again lower asymptotes were fixed at 0. Because of the open-ended nature of the Remote Association Task items, it makes no sense to apply the guessing parameter, so the three- parameter model (3PL), which freely estimates difficulties, discriminations, and lower asymptotes is not useful here. The two IRT models (1PL and 2PL) were fit with Rizopoulos's (2006) IRT program for R language (R Development Core Team, 2009) (In this program, it is assumed that θ follows a normal distribution with mean zero and standard deviation 1). Model fit statistics are presented in Table 2.

Likelihood ratio tests revealed that the 2PL model provided significantly better fit than the 1PL model, LRT (29) = 68.21, $p<0.001$. The AIC-values (lower values imply better trade-off between statistical model fit and model complexity) also point to the 2PL model as the best fitting one. Item parameter estimates and item fit statistics for the 2PL model are presented in the last four columns of Table 1, with items ordered with respect to increasing difficulty level. The resulting Item Characteristic Curves are depicted in Figure 1.

Table 1: Classical Test Theory (CTT) Statistics, and Item response Theory (IRT) Item Parameter Estimates (With Standard Errors) and Fit Statistics for the Two-Parameter Logistic (2PL) Model of 30-Item RAT.

Item		CTT-Statistics		IRT-Item parameters		IRT-Item fit	
		Probability correct	*Item-Rest Correlation*	Difficulty	Discrimination	χ^2	*Boot strapped p-value*
1	bar/jurk/glas	0.72	0.65	-0.58 (0.12)	4.08 (1.13)	4.82	0.78
2	room/vloot/koek	0.59	0.31	-0.46 (0.24)	0.87 (0.22)	21.1	0.01
3	kaas/land/huis	0.63	0.51	-0.45 (0.17)	1.53 (0.32)	5.75	0.74
4	vlokken/ketting/pet	0.60	0.48	-0.34 (0.16)	1.59 (0.32)	3.83	0.97
5	val/melon/lelie	0.58	0.51	-0.25 (0.15)	1.69 (0.35)	10.4	0.31
6	vis/mijn/geel	0.56	0.48	-0.19 (0.16)	1.44 (0.30)	4.66	0.85
7	achter/kruk/mat	0.51	0.42	-0.03 (0.17)	1.25 (0.28)	13.63	0.12
8	worm/kast/legger	0.48	0.46	0.10 (0.15)	1.48 (0.32)	4.31	0.94
9	water/schoorsteen/lucht	0.46	0.52	0.16 (0.13)	1.93 (0.41)	12.75	0.18
10	trammel/beleg/mes	0.37	0.46	0.49 (0.14)	1.72 (0.38)	9.86	0.18
11	hond/druk/band	0.38	0.46	0.50 (0.17)	1.37 (0.32)	12.01	0.15
12	goot/kool/bak	0.35	0.46	0.58 (0.16)	1.58 (0.36)	7.92	0.52
13	controle/plaats/gewicht	0.36	0.45	0.58 (0.18)	1.33 (0.31)	9.61	0.36
14	kolen/land/schacht	0.32	0.51	0.60 (0.13)	2.44 (0.61)	4.55	0.84
15	schommel/klap/rol	0.37	0.33	0.63 (0.21)	1.07 (0.27)	10.03	0.30
16	kamer/masker/explosie	0.26	0.35	1.12 (0.28)	1.16 (0.32)	9.37	0.27
17	nacht/vet/licht	0.17	0.36	1.46 (0.31)	1.41 (0.40)	15.11	0.06
18	arm/veld/stil	0.20	0.24	2.04 (0.68)	0.74 (0.26)	10.6	0.27
19	olie/pak/meester	0.22	0.23	2.23 (0.83)	0.62 (0.24)	8.24	0.46
20	school/ontbijt/spel	0.04	0.29	2.45 (0.61)	1.80 (0.68)	11.9	0.14
21	kop/boon/pause	0.11	0.22	2.49 (0.79)	0.94 (0.34)	13.64	0.12
22	licht/dromen/maan	0.15	0.22	2.49 (0.84)	0.79 (0.30)	6.95	0.57
23	deur/werk/kamer	0.05	0.24	2.81 (0.83)	1.26 (0.49)	5.14	0.65
24	ga/daar/dag	0.11	0.22	2.98 (1.09)	0.78 (0.32)	13.08	0.13
25	strijkijzer/schip/trein	0.02	0.20	3.24 (0.99)	1.54 (0.67)	6.7	0.38
26	man/lijm/ster	0.12	0.21	3.30 (1.39)	0.64 (0.30)	9.92	0.21
27	bed/zee/school	0.02	0.21	3.42 (1.12)	1.42 (0.64)	17.72	0.05
28	riet/klontje/hart	0.10	0.18	3.43 (1.43)	0.69 (0.32)	2.84	0.98
29	palm/familie/huis	0.04	0.16	3.70 (1.44)	0.98 (0.46)	4.01	0.80
30	grond/vis/geld	0.08	0.09	5.29 (3.38)	0.49 (0.33)	8.25	0.47

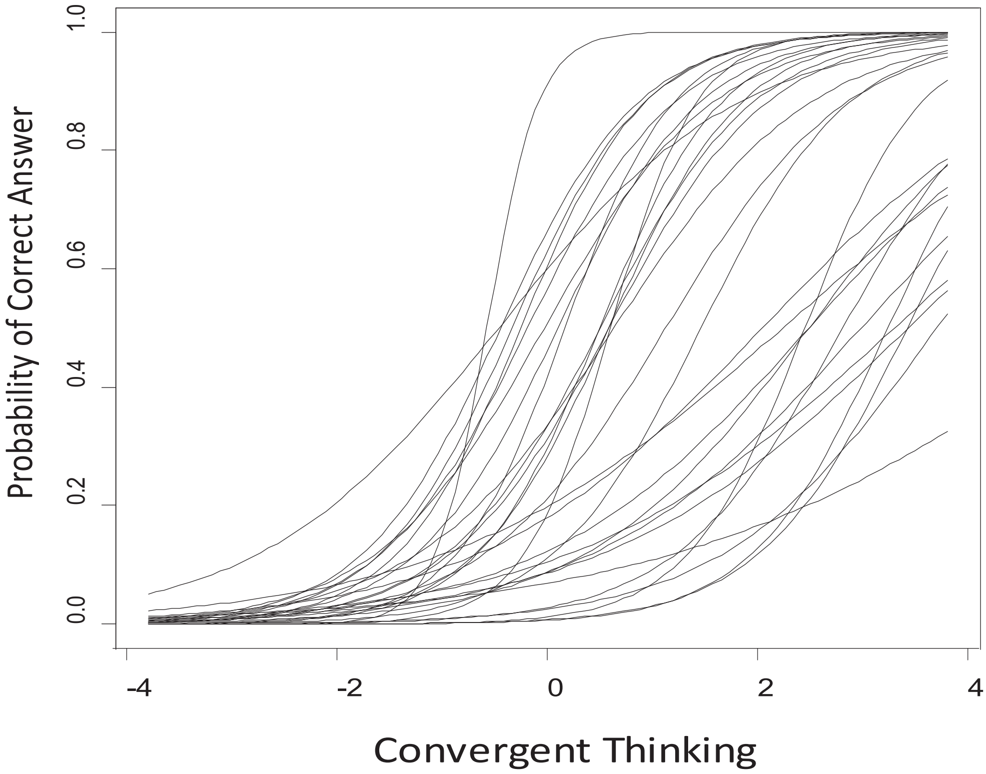

Figure 1: Item Characteristic curves for all 30 items of Remote Association Task. Functions were produced with a 2PL (two-parameter logistic)Item Response Theory model.

Table 2: Fit Statistics for the 1PL and 2PL Logistic Models of 30-item test

Test	Model	In*L*	No. of parameters	AIC	BIC
30- item	1PL	- 069.32	31*	4200.65	4295.59
	2PL	- 035.22	60	4190.43	4374.19

Note. 1PL = one-parameter logistic model; 2PL = two-parameter logistic model; In*L* = log-likelihood;

AIC = Akaike information coefficient

BIC = Bayesian information coefficient

*Thirty item difficulty parameters plus a common discrimination parameter.

Table 1 shows that the difficulty levels range between -.58 (fairly easy item) and 5.29 (extremely hard item). Only 7 items have a difficulty level that is below 0 (an item with difficulty parameter 0 would be solved correctly with 50% probability by a participant with average ability level); while 23 items have a difficulty level higher than 0. In particular, 13 items are very difficult with a difficulty level above 2.00, meaning that only participants with $\theta > 2.00$ have a probability of 50% or higher to answer these items correctly. Because it is rather unlikely that there are many individuals with such high ability levels (based on the standard normal distribution, only 2.5% of the participants have a θ-level of at least 1.96), it is not necessary that there are so many difficult items in this test. Therefore, 7 of these items, having a low discrimination parameter, were selected as candidates for removal. Moreover, one item (item 2) showed significant misfit to the 2PL model ($p<.01$), and was therefore also removed from the test.

Thus, 22 items were selected as the best items in terms of difficulty and discrimination levels. Another set of 1PL and 2PL models were carried out to analyze the data of the 22 selected items. Model fit statistics are presented in Table 3. Likelihood ratio tests revealed that also for the 22 selected items the 2PL model provided significantly better fit than did 1PL model, LRT (21) = 40.97, $p<0.01$.

Table 3: Fit Statistics for the 1PL and 2PL Logistic Models of 22-item test

Test	Model	In*L*	No. of parameters	AIC	BIC
22-item	1PL	- 626.85	23 *	3299.71	3370.15
	2PL	- 606.37	44	3300.73	3435.49

* Twenty-two item difficulty parameters plus a common discrimination parameter.

Item parameter estimates and fit statistic for the 2PL model are presented in Table 4 and Figure 2.Although there is still an overrepresentation of the more difficult items on this 22-item scale, the imbalance is much less extreme. In addition, the test was shortened by 27% of its length without losing much psychometric information, as comes forward from the test information curves of the 30-item test (Figure 3a) and the 22-item test (Figure 3b). More specifically, in the θ-range that comprises of approximately 95% of the participants (between -2 and +2) the test information decreased by only 10% by dropping 8 of the 30 items. Finally, the item fit statistics (Table 4) show that there are no items that show significant misfit to the 2PL model anymore. In conclusion, compared to the 30-item test, the 22-item test shows only minor loss in information, but a substantial shortening of the test. Cronbach's alpha of the 22-item test is still high at 0.84.

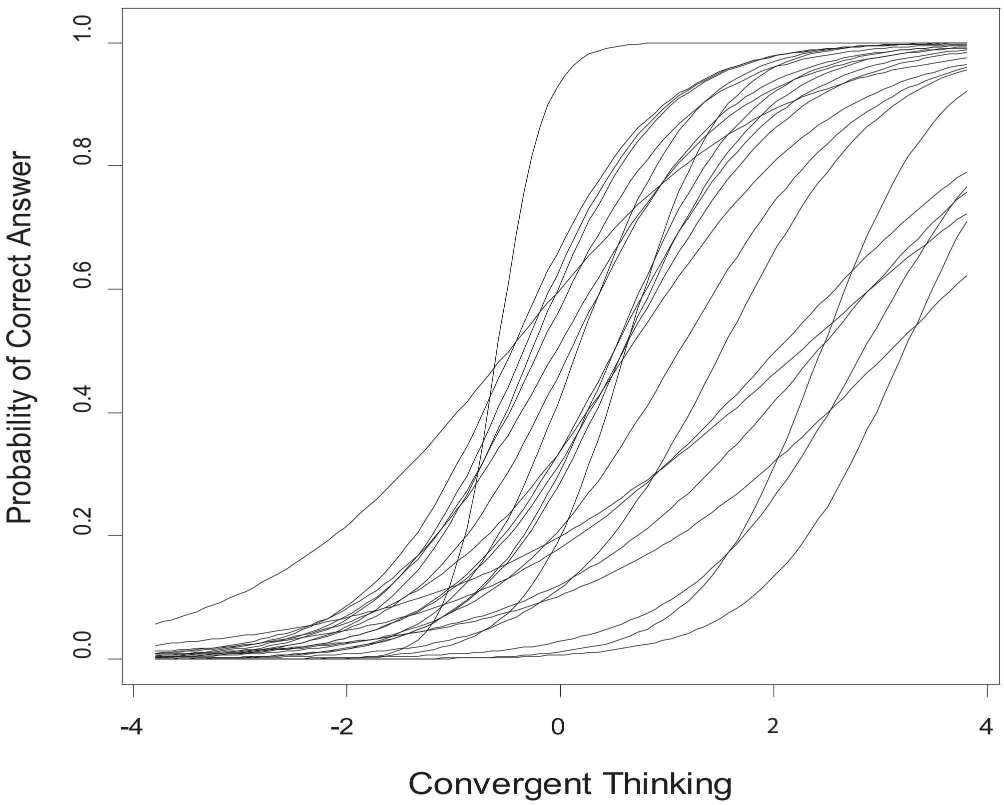

Figure 2: Item Characteristic curves for all 22 items of Remote Association Task. Functions were produced with a 2PL(two-parameter logistic) Item Response Theory model.

Table 4: Item response Theory (IRT) Item Parameter Estimates (With Standard Errors) and Fit Statistics for the Two-Parameter Logistic (2PL) Model of 22-Item RAT.

Item		IRT- Item parameters		IRT- Item fit	
		Difficulty	Discrimination	χ^2	*Bootstrapped p-value*
1	Bar/jurk/glas	-0.60 (0.12)	4.15 (1.25)	5.77	0.59
2	Kaas/land/huis	-0.45 (0.16)	1.61 (0.34)	7.64	0.56
3	Vlokken/ketting/pet	-0.35 (0.15)	1.59 (0.33)	6.54	0.71
4	Val/melon/lelie	-0.27 (0.15)	1.69 (0.35)	10.27	0.17
5	Vis/mijn/geel	-0.20 (0.16)	1.45 (0.31)	2.83	0.99
6	Achter/kruk/mat	-0.04 (0.17)	1.24 (0.28)	8.77	0.43
7	Worm/kast/legger	0.09 (0.15)	1.43 (0.31)	2.32	1.00
8	Water/schoorsteen/lucht	0.15 (0.13)	1.88 (0.39)	9.8	0.25
9	Trammel/beleg/mes	0.48 (0.15)	1.72 (0.38)	8.27	0.38
10	Hond/druk/band	0.49 (0.17)	1.34 (0.31)	7.55	0.57
11	Controle/plaats/gewicht	0.59 (0.18)	1.29 (0.31)	5.98	0.72
12	Goot/kool/bak	0.59 (0.17)	1.48 (0.34)	8.7	0.45
13	Kolen/land/schacht	0.61 (0.14)	2.20 (0.53)	9.3	0.31
14	Schommel/klap/rol	0.62 (0.21)	1.09 (0.27)	12.25	0.22
15	Kamer/masker/explosie	1.12 (0.28)	1.15 (0.31)	7.05	0.60
16	Nacht/vet/licht	1.59 (0.34)	1.31 (0.37)	8.48	0.45
17	Arm/veld/stil	2.02 (0.64)	0.75 (0.26)	5.5	0.74
18	Olie/pak/meester	2.28 (0.86)	0.61 (0.24)	5.21	0.84
19	School/ontbijt/spel	2.60 (0.66)	1.64 (0.61)	6.9	0.44
20	Deur/werk/kamer	2.86 (0.85)	1.23 (0.47)	4.86	0.83
21	Strijkijzer/schip/trein	3.28 (1.02)	1.51 (0.68)	7.37	0.44
22	Man/lijm/ster	3.49 (1.19)	1.38 (0.64)	18.21	0.11

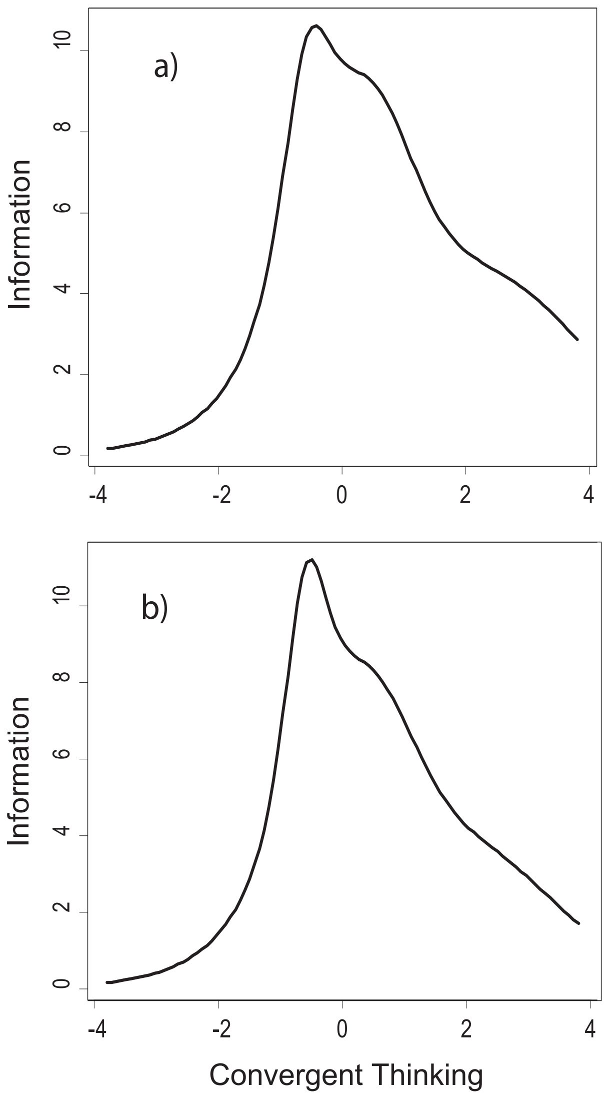

Figure 3: Test information function plotted against convergent thinking as a normally distributed latent factor for 30-item (a), and 22-item (b) tests.

Convergent and Discriminant Validity

Convergent validity has been defined as "how well the construct's measurement positively correlates with different measurements of the same construct" (Hair, 2003). Discriminant validity is the degree to which scores on a test do not correlate with scores from other tests that are not designed to measure the same construct.

In IRT, subjects answering the same number of items correctly typically do not have the same ability estimates unless they have answered exactly the same set of items correctly. Therefore, in this part of the research, individual scores on the RAT were derived from the 22-item IRT scale model parameters. We used Expected a Posteriori (EAP; e.g., Embretson, & Reise, 2000) scoring to obtain an ability estimate for each participant.

Convergent validity was evaluated using correlations between the scores derived from RAT (22-item), Raven's Advanced Progressive Matrices, and the Insight Problems—which were all assumed to represent aspects of convergent-thinking performance. To examine discriminant validity, correlations between RAT scores and the four scales of the Alternative Uses Task (a test to assess divergent thinking) were calculated.

As Table 5 shows, the correlations between RAT scores and both Raven scores and Insight Problem scores are significant. As both the Raven and the Insight problem tasks are assumed to assess aspects of convergent thinking—which explains why they also correlate with each other, this provides evidence for a substantial convergent validity of the developed RAT. Moreover, the results in Table 5 show that the RAT score correlate with none of the four AUT scores, which is consistent with Guilford's (1967) distinction between convergent and divergent thinking and demonstrates the discriminative validity of our version of the RAT.

Table 5: Coefficients and significance levels (** for p<.01 and * for p<.05) for tests of correlation between Remote Association Task (RAT: 22-item), Insight Problems (IP), Raven's Advanced Progressive Matrices (Raven), and Alternative Uses Task (AUT, FLU=fluency, FLE=flexibility, ORI=originality, ELA=elaboration).

	RAVEN	IP	AUT- FLU	AUT-FLE	AUT-ORI	AUT-ELA
RAT (22-item)	**0.47****	**0.39****	-0.07	0.07	-0.01	-0.13
RAVEN		**0.32****	-0.14	-0.05	-0.05	-0.08
IP			-0.12	0.02	0.02	-0.08

DISCUSSION

The aim of this study was to develop a short, reliable, and valid Dutch version of Mednick's (1967) RAT, which is widely used and considered a reliable measure of creative (convergent) thinking. To do so, we collected and analyzed data from a sample of Dutch university students. The CTT analysis revealed that the original 30-item test has high internal consistency (Cronbach's alpha =.85). The IRT analysis allowed us to reduce the 30-item set to a more efficient 22-item version that proved to be a high-quality instrument. The items were most consistent with a 2PL RIT model and they had unique discrimination and difficulty parameters. As expected, the Dutch 22-item RAT score was related to fluid intelligence scores, as measured by the Raven, and insight problem solving, as assessed by our 3-domain compound task, but not to divergent thinking. These findings provide strong evidence for the convergent and discriminant validity of our task version, respectively, which result in good construct validity. Furthermore, these findings encourage the use of the test as a good measure of creative convergent thinking.

Although the present study provides encouraging results, our sample (n=158) was not very large and restricted to university students. This is likely to be sufficient for standard experimentation, which usually considers student at participants, but may not provide a solid basis for investigating a more diverse population including children and elderly participants, or participants with a more diverse educational background. Accordingly, we regard the present evidence for the validity of the test preliminary. Although the 30-item is reliable and has high internal consistency, we recommend the 22-item version for most studies, as it is less time-consuming and does not contain very difficult and low-discriminant items. However, it is possible that studies in highly gifted individuals benefit from the inclusion of the highly difficult items that we excluded in the present study.

IRT-based models have been studied extensively and widely implemented in educational measurement for investigating the properties of tests, items, and examinees. IRT analyses can contribute to the improvement of the assessment instruments, ultimately enhancing the validity of the instrument. As far as we know, our study is the first to apply IRT to validate the RAT. To summarize, the Dutch 22-item version of the RAT developed in the present study provides a convenient and rather efficient test to measure convergent thinking with an instrument that possesses satisfactory psychometric properties.

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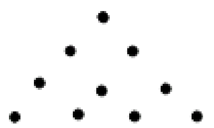
APPENDIX

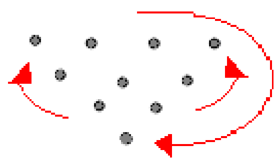
Instructions and solutions to the insight problems

1. ***Coin problem***: A dealer in antique coins got an offer to buy a beautiful bronze coin. The coin had an emperor's head on one side and the date 544 B.C. stamped on the other side. The dealer examined the coin, but instead of buying it, he called the police to arrest the man. What made him realize that the coin was fake? (Adopted from Metcalfe, 1986).
2. *Solution*: In 544 B.C. there was no knowledge of Jesus Christ as he was as yet unborn. A coin from that time thus could not be marked 'B.C'. Most initial false solutions concern whether the date matched the emperor ruling in 544 B.C., whether bronze was already discovered, etc.
3. ***Egg problem***: Using only one 7-minute hourglass and one 11-minute hourglass, how will you be able to time the boiling of an egg for exactly 15 minutes? (Adopted from Sternberg & Davidson, 1982).
4. *Solution:* Start both hourglasses at the same time. When the 7-minute hourglass runs out (and 4 minutes remain on the 11-minutes hourglass), start boiling the egg. After the 4 minutes have elapsed, turn it over the 11-minute hourglass again to obtain a total time of 15 minutes. An egg is customarily put into a pot of water as soon as it commences to boil. To arrive at the correct solution, the fixedness to approach the problem using this strategy must be overcome.
5. ***Triangle problem*** (spatial problem): The triangle of dots in the picture provided here points to the bottom of the page by moving only three dots? (Adopted from Metcalfe, 1986).
6. ***Solution*:** Dots to be moved are the dots on the bottom left, bottom right and the top. The correct solution requires a mental rotation.

Problem:



Solution:



CHAPTER 3

The (b)link between creativity and dopamine:

Spontaneous eye blink rates predict and dissociate divergent and convergent thinking

This chapter is published as: Akbari Chermahini, S., & Hommel, B. (2010). The (b)link between creativity and dopamine: Spontaneous eye blink rates predict and dissociate divergent and convergent thinking. *Cognition, 115*, 458-465.

ABSTRACT

Human creativity has been claimed to rely on the neurotransmitter dopamine, but evidence is still sparse. We studied whether individual performance (N=117) in divergent thinking (Alternative Uses Task) and convergent thinking (Remote Association Task) can be predicted by the individual spontaneous eye blink rate (EBR), a clinical marker of dopaminergic functioning. EBR predicted flexibility in divergent thinking and convergent thinking, but in different ways. The relationship with flexibility was independent of intelligence and followed an inverted U-shape function with medium EBR being associated with greatest flexibility. Convergent thinking was positively correlated with intelligence but negatively correlated with EBR, suggesting that higher dopamine levels impair convergent thinking. These findings support the claim that creativity and dopamine are related, but they also call for more conceptual differentiation with respect to the processes involved in creative performance.

INTRODUCTION

Creativity is the human capital one often says, especially in times of economic crises. And yet, very little is known about how creativity works (Sternberg, Kaufman & Pretz, 2002), which severely limits our possibilities to systematically develop that capital. To a substantial degree the lack of convergent theorizing on creativity has to do with disagreements on how to define it (by the processes underlying creativity vs. the products it brings about) and how to measure it (see Brown, 1989; Runco, 2007). Moreover, there is increasing evidence that truly creative acts do not reflect the operation of just one process, brain area, or faculty but, rather, the interplay of multiple cognitive processes and neural networks (e.g., Dietrich, 2004; Eysenck, 1993; Heilman, 2005). This raises the question of how this interplay is orchestrated, and there are reasons to believe that the neurotransmitter dopamine (DA) plays an important role in that.

Eysenck (1993) has related aspects of creativity to schizophrenia, and pointed out that schizophrenics and healthy creative individuals share a certain lack of constraints and inhibition in their thinking. Several authors since Bleuler (1978) have attributed schizophrenia to an impairment of the associative process in dealing with information, to a kind of “widening of the associative horizon” (Eysenck, 1993). This so-called “positive symptom” of schizophrenia is commonly treated with antipsychotic drugs that function as antagonists of binding DA (particularly at receptors of the D2 family), which has been taken to suggest that schizophrenia may result from hyperactive DA signal transduction (for a review, see Davis, Kahn, Ko, & Davidson, 1991). If so, and if one considers the possibility that schizophrenics and healthy creative individuals are more associative than the average for the same reasons, it makes sense to assume a link between creativity and DA (Eysenck, 1993). Indeed, Carson, Peterson, and Higgins (2003) have reported differences in latent inhibition (an effect that is modulated by DA-targeting drugs) between more and less creative individuals.

A similar conclusion was reached by Ashby, Isen, and Turken (1999) in their attempt to explain the beneficial effect of mood on creative behavior. They assume that higher DA levels are associated with greater cognitive flexibility and less inhibition between alternative thoughts (cf., Cohen & Servan-Schreiber, 1992). Under the additional assumption that positive mood leads to a further, phasic increase of the individual DA level, better mood would indeed be expected to yield better performance in creativity tasks. Further support comes from a recent behavioral genetics study, where individuals with the DRD2 TAQ IA polymorphism (which results in a 30-40% reduction in DA-D2 receptor density) showed significantly better performance in creativity tasks (Reuter, Roth, Holve, & Hennig, 2006). This fits with the fact that D2-antagonistic drugs alleviate the positive symptoms of schizophrenia. It also fits with computational considerations that relate DA-D2 receptors to inhibitory processes (Frank, Seeberger & O'Reilly, 2004) and with empirical observations that cocaine use—which is associated with a damage of D2 receptors—is accompanied by impaired performance in tasks tapping into stimulus and response inhibition (Colzato & Hommel, 2009; Colzato, van den Wildenberg, & Hommel, 2007).

The present study aimed at exploiting individual differences in performance in creativity tasks and in dopaminergic functioning, as indexed by the spontaneous eye blink rate (EBR). The spontaneous EBR is a well-established clinical marker (Shukla, 1985) thought to index striatal DA production (Karson, 1983; Taylor et al., 1999). Among other things, this assumption is supported by clinical observations in patients with DA-related dysfunctions, such as schizophrenics who show both elevated EBRs (Freed, 1980) and elevated striatal DA uptake (Hietala et al., 1999: Lindström et al., 1999). Likewise, EBR is reduced in recreational cocaine users (Colzato, van den Wildenberg & Hommel, 2008) and Parkinson patients (Deuschel & Goddemeier, 1998)—two population suffering from reduced functioning of DA-D2 receptors and severe losses of nigrostratial dopaminergic cells, respectively (Dauer & Przedborski, 2003; Volkow, Fowler, & Wang, 1999). In addition, pharmacological studies in nonhuman primates and humans have shown that dopaminergic agonists and antagonists increase and decrease EBRs, respectively (Blin et al., 1990; Kleven & Koek, 1996), and a genetic study in humans has demonstrated a strong association between EBR and the DRD4/7 genotype, which is related to the control of striatal DA release (Dreisbach et al., 2005).

EXPERIMENT 1

In Experiment 1, we considered two creativity tasks: the Alternate Uses Task (AUT: Guilford, 1967) and the Remote Associates Task (RAT: Mednick, 1962). The AUT has open-ended questions with multiple answers, and is thus diagnostic of divergent thinking. In contrast, the RAT has questions with only one, if unconventional answer, and is thus diagnostic of convergent thinking. According to Guilford (1967), divergent and convergent thinking are the main ingredients of creativity, but in the light of the above caveats we do not claim that these are the only processes involved.

The major question was whether the individual performance in the two creativity tasks would covary with the individual EBR and, in particular, whether a higher EBR (indicating a higher level of dopaminergic signal transmission) would be associated with better performance. Even though we have seen that a number of approaches assume that creativity and DA are related, it is not quite clear exactly how this relationship may look like. In fact, most accounts do not clearly define how divergent and convergent thinking are related to creativity, or to each other, and whether only one or both types of thinking are related to dopamine. However, if we consider Eysenck's (1993) assumption that both healthy creative thinking and positive schizophrenic symptoms reflect a certain lack of inhibition, it seems reasonable to assume that this would be more visible in a divergent thinking task, where a lack of inhibition between alternative thoughts would be beneficial, than in a convergent thinking task. If so, one might expect that the relationship between performance and EBR is stronger for the AUT than for the RAT. Moreover, the relationship between DA level and performance does not seem to be linear but follow an inverted U-shape (for a review, see Goldman-Rakic, Muly & Williams, 2000), which might suggest that creativity and EBR are related in a nonlinear fashion. Apart from divergent and convergent thinking, and EBR, we further considered fluid intelligence. Even though it seems clear that creativity is at least in part independent of intelligence (Runco, 2007), some links might exist, so that we were interested to see whether, and to what degree a possible relationship between creativity and EBR is mediated by intelligence.

Method

Thirty-five students of Leiden University volunteered in exchange for course credit or pay (30 females and 5 males; mean age was 20.6 years). Participants were informed that they were participating in a study on problem solving. Every participant underwent four tasks or measurements: a divergent thinking task (AUT), a convergent thinking task (RAT), a fluid-intelligence task (Raven's Advanced Progressive Matrices), and a measurement of the spontaneous EBR. EBR was always measured at the end of the session, while the order of the other tasks was balanced by means of a Latin square.

Alternate Uses Task (divergent thinking)

In this task (based on Guilford, 1967, and translated into Dutch), participants were asked to list as many possible uses for three common household items (brick, shoe, and newspaper) as they can within 10 min. Scoring comprised of four components:

Originality: Each response is compared to the total amount of responses from all of the subjects. Responses that were given by only 5% of the group count as unusual (1 point) and responses given by only 1% of them count as unique (2 points).

Fluency: The total of all responses.

Flexibility: The number of different categories used.

Elaboration: The amount of detail (e.g., "a doorstop" counts 0, whereas "a door stop to prevent a door slamming shut in a strong wind" counts 2 (1 point for explanation of door slamming and another for further detail about the wind).

Remote Association Task (convergent thinking)

In this task (based on Mednick, 1962, and translated into Dutch (Cronbach's alpha = .85), participants are presented with three unrelated words (such as time, hair, and stretch) and are asked to find a common associate (long). Our version comprised of 30 items, which were to be responded to within 10 min.

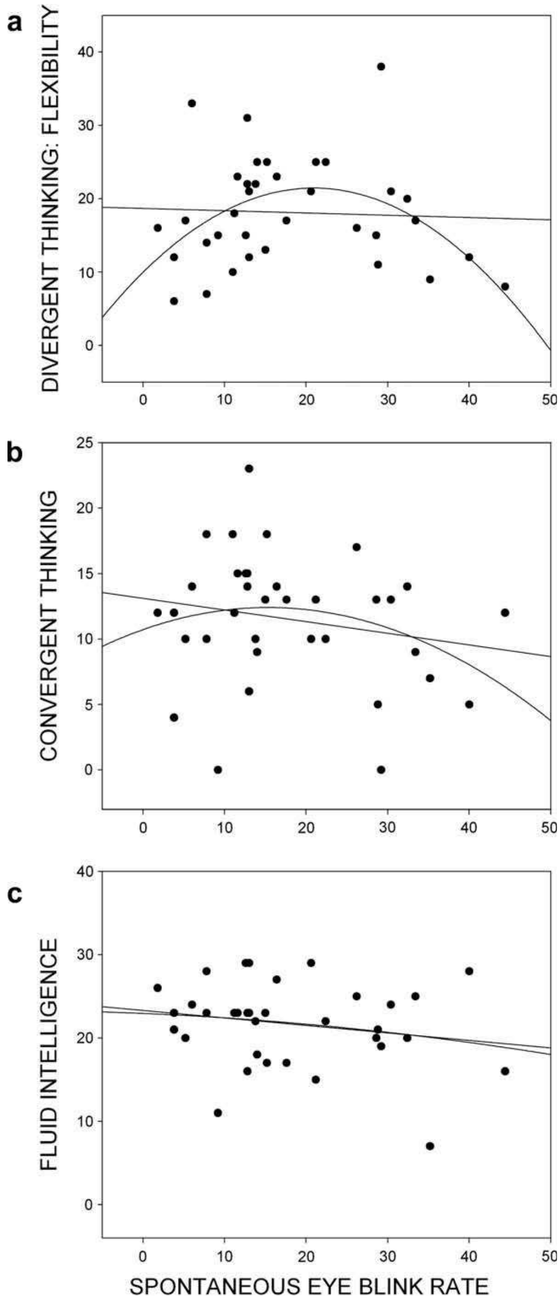


Figure 1: Performance in (a) the divergent-thinking task (flexibility score), (b) the convergent-thinking task, and (c) Raven's APM task in Experiment 1 as a function of spontaneous eye blink rate (EBR) per minute. Regression lines for linear and quadratic fits are also given.

Raven's Advanced Progressive Matrices (fluid intelligence)

Fluid intelligence was measured by means of 36 items of Raven's Advanced Progressive Matrices (APM: Raven, 1965) that were worked on for 25 min. This test has been constructed as a language-independent measure of intelligence efficiency and primarily measures Spearman's *g*. Each item of this test consists of a visual pattern with one piece missing, which participants are to identify from a set of alternatives. The items get progressively harder and are assumed to need increasingly more cognitive capacity.

Eye blink rate (dopamine marker)

A BioSemi ActiveTwo system (BioSemi Inc., Amsterdam) was used to record the EBR. We recorded with two horizontal (one left, one right) and two vertical (one upper, one lower of right eye) Ag-AgCl electrodes, for 6 min eyes-open segments under resting conditions. The vertical electrooculogram (EOG), which recorded the voltage difference between two electrodes placed above and below the left eye, was used to detect eye blinks. The horizontal EOG, which recorded the voltage difference between electrodes placed lateral to the external canthi, was used to measure horizontal eye movements. As spontaneous EBR is stable during daytime but increases in the evening (around 8:30 pm, see Babarto et al., 2000), we never registered after 5 pm. We also asked participants to avoid smoking before the recording. Participants were comfortably sitting in front of a blank poster with a cross in the center, located about 1m from the participant. The participant was alone in the room and asked to look at the cross in a relaxed state. The individual EBR was calculated by dividing the total number of eye blinks during the 6-min measurement interval by 6.

Results and Discussion

From the four tasks or measurements, seven measures were extracted for each participant: originality, fluency, flexibility, and elaboration scores from the AUT, the number of correct items from the RAT, the number of correct items from Raven's APM, and the EBR (per minute). Relationships between these measures were assessed by means of regressions (SPSS curve fitting procedure). We report the results (coefficients) for linear and quadratic fits (see Table 1); other types of relationships were also considered but did not provide better fits.

Table 1: Coefficients and significance levels (** for p<.01 and * for p<.05) for tests of linear (L) and quadratic (Q) relationships (fits) between tests of divergent thinking (DIV, ORI=originality; FLU=fluency, FLE=flexibility, ELA=elaboration), convergent thinking (CON), intelligence (IQ), and the spontaneous eye blink rate (EBR).

		DIV-FLU	DIV-FLE	DIV-ELA	CON	IQ	EBR
DIV-ORI	L	.42**	.58**	.53**	-.11	.02	-.01
	Q	.42*	.58**	.55*	.11	.21	.21
DIV-FLU	L		.84**	.10	-.35*	-.21	.03
	Q		.85**	.13	.36	.23	.23
DIV-FLE	L			.07	-.11	-.09	-.05
	Q			.13	.11	.36	.44*
DIV-ELA	L				.08	-.06	-.06
	Q				.13	.19	.11
CON	L					.37*	-.20
	Q					.37	.27
IQ	L						-.20
	Q						.20

Table 1 provides an overview of the results. Unsurprisingly, the subscales of the AUT were highly intercorrelated, except that the elaboration measure failed to correlate with fluency and flexibility. More interesting for our purposes, however, were the remaining three significant effects. Most importantly, EBR reliably predicted only one other measure, which was the flexibility score of the divergent-thinking measure. This correlation remained significant if performance in the Raven's task was entered into the equation, confirming that the relationship between EBR and flexibility is independent of intelligence. Also of importance, the resulting fit was quadratic, whereas the linear regression of EBR on flexibility was far from significant. As shown in Figure 1, the relationship followed an inverted U-shaped pattern, with medium EBRs being associated with the highest flexibility.

The second reliable measure refers to a linear increase of performance in the convergent-thinking task with the intelligence measure. The third significant correlation describes a negative relationship between convergent thinking and the fluency measure of the AUT: better convergent thinking was associated with less fluent divergent thinking.

EXPERIMENT 2

Before considering the theoretical implications of our findings, it is important to know how stable and replicable they are. We assessed this issue by running a second study that sought to replicate the crucial correlation between EBR and flexibility. We also kept the convergent-thinking task to see whether EBR would still be uncorrelated with convergent thinking. Note that even though the association measures failed to pass the significance threshold in Experiment 1, they did reach a considerable numerical size and the outcome pattern (see Figure 1b) looked not too different from that obtained for flexibility (Figure 1a).

Method

Thirty-three new students of Leiden University volunteered in exchange for course credit or pay (21 females and 12 males; mean age was 20.1 years). The method was as in Experiment 1 with the following exceptions: The APM was dropped and the AUT comprised of only one common household item (cup) with 5 min to list alternative uses. Only 22 of the participants performed the RAT.

Results and Discussion

The data were treated as in Experiment 1. Table 2 shows the results for linear and quadratic fits; again, other types of relationships were also considered but did not provide better fits.

Table 2: Coefficients and significance levels (** for p<.01 and * for p<.05) for tests of linear (L) and quadratic (Q) relationships (fits) between tests of divergent thinking (DIV, ORI=originality; FLU=fluency, FLE=flexibility, ELA=elaboration), convergent thinking (CON), and the spontaneous eye blink rate (EBR).

		DIV-FLU	DIV-FLE	DIV-ELA	CON	EBR
DIV-ORI	L	.39*	.66**	.27	-.05	.08
	Q	.40	.69**	.40	.31	.13
DIV-FLU	L		.81**	.08	.32	.02
	Q		.81**	.09	.34	.23
DIV-FLE	L			.13	.07	-.01
	Q			.25	.22	.42*
DIV-ELA	L				.24	-.12
	Q				.39	.17
CON	L					-.39
	Q					.46

As Table 2 shows, the subscales of AUT were again highly intercorrelated. The linear relationship between convergent thinking and fluency obtained in Experiment 1 did not replicate, and EBR again failed to predict convergent thinking. Most importantly, however, EBR again predicted the flexibility score, and the relationship was again quadratic (see Figure 2). That is, the main finding of Experiment 1 was successfully replicated.

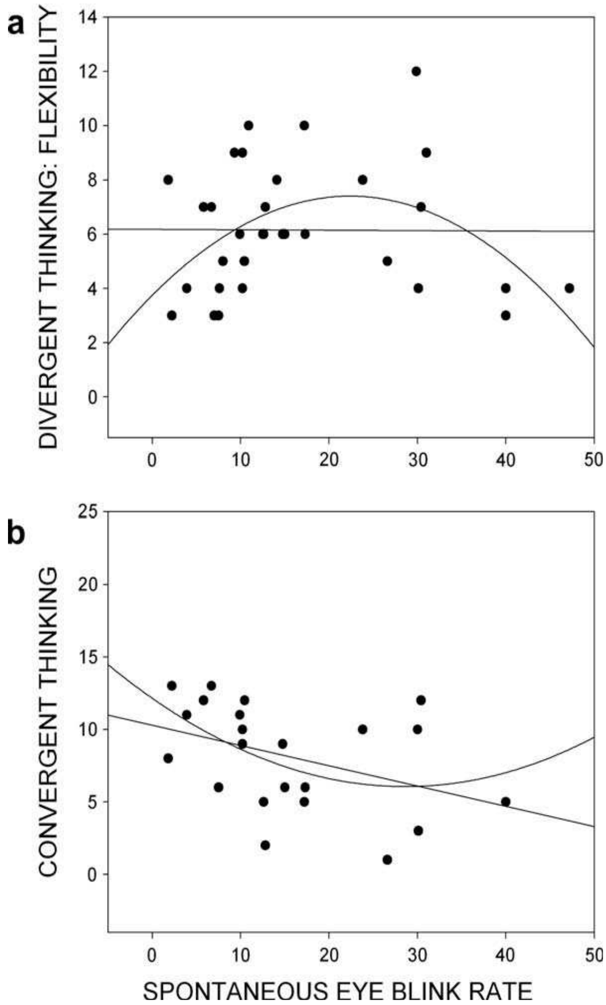


Figure 2: Performance in (a) the divergent-thinking task (flexibility score), and (b) the convergent-thinking task in Experiment 2 as a function of spontaneous eye blink rate (EBR) per minute. Regression lines for linear and quadratic fits are also given.

EXPERIMENT 3

As we take EBR as a measure of the individual dopamine level, the quadratic relationship between EBR and flexibility seems to support the hypothesis that divergent thinking relies on dopamine supply. However, given that we measured EBR at the end of the session, one might argue that this measure is actually more related to stress, or resistance to stress, than to the divergent-thinking process proper. In Experiment 1, all participants underwent an intelligence test, often before one or both of the thinking tasks. Given that people experience tests of their intelligence as stressful, performance in the thinking tasks may not provide a pure measure of the degrees of individual creativity but, rather, a measure of creativity under stress. Stress is known to have a strong impact on prefrontal dopaminergic activity (Moghaddam & Jackson, 2004), so that the EBRs might have been modulated by individual differences with respect to processing stress or to stress resistance. In other words, the individual differences in the thinking tasks might not, or not only reflect individual differences in the basic dopamine level of, rather, individual differences in stress processing.

Given that we were able to replicate the basic findings in Experiment 2, where intelligence was not assessed, alleviates this problem to some degree. However, one might argue that even the creativity tasks might produce some stress, which might render EBR measures equally difficult to interpret. To avoid problems of that sort, we ran another replication but measured EBR at the beginning of the session. EBRs could thus no longer be affected by task-induced stress, at least beyond whatever stress the mere participation in a psychological experiment might produce.

Method

Forty-nine new students of Leiden University volunteered in exchange for course credit or pay (35 females and 14 males; mean age was 21.3 years). The method was as in Experiments 1 and 2 with the following exception: EBR was always measured first, at the beginning of the session, while the order of the following other tasks was balanced. AUT comprised of only one common household item (pen) with 5 min to list alternative uses.

Results and Discussion

The data were treated as in Experiments 1 and 2. Table 3 shows the results for linear and quadratic fits; again, other types of relationships were also considered but did not provide better fits.

Table 3: Coefficients and significance levels (** for p<.01 and * for p<.05) for tests of linear (L) and quadratic (Q) relationships (fits) between tests of divergent thinking (DIV, ORI= originality; FLU=fluency, FLE=flexibility, ELA=elaboration), convergent thinking (CON), and the spontaneous eye blink rate (EBR) in Experiment 3.

		DIV-FLU	DIV-FLE	DIV-ELA	CON	EBR
DIV-ORI	L	.30*	.34*	.29*	-.01	.18
	Q	.33	.40*	.29	.30	.19
DIV-FLU	L		.54**	.01	.01	.25
	Q		.58**	.13	.13	.06
DIV-FLE	L			.14	-.13	.05
	Q			.14	.17	.41*
DIV-ELA	L				-.31*	.12
	Q				.32	.12
CON	L					-.19
	Q					.31

As Table 3 shows, the results were almost identical to what we observed in Experiment 2: The subscales of AUT were highly intercorrelated and EBR failed to predict convergent thinking but showed a quadratic relationship with flexibility (see Figure 3). Hence, measuring EBR before or after potentially stressing cognitive tasks does not seem to make much of a difference.

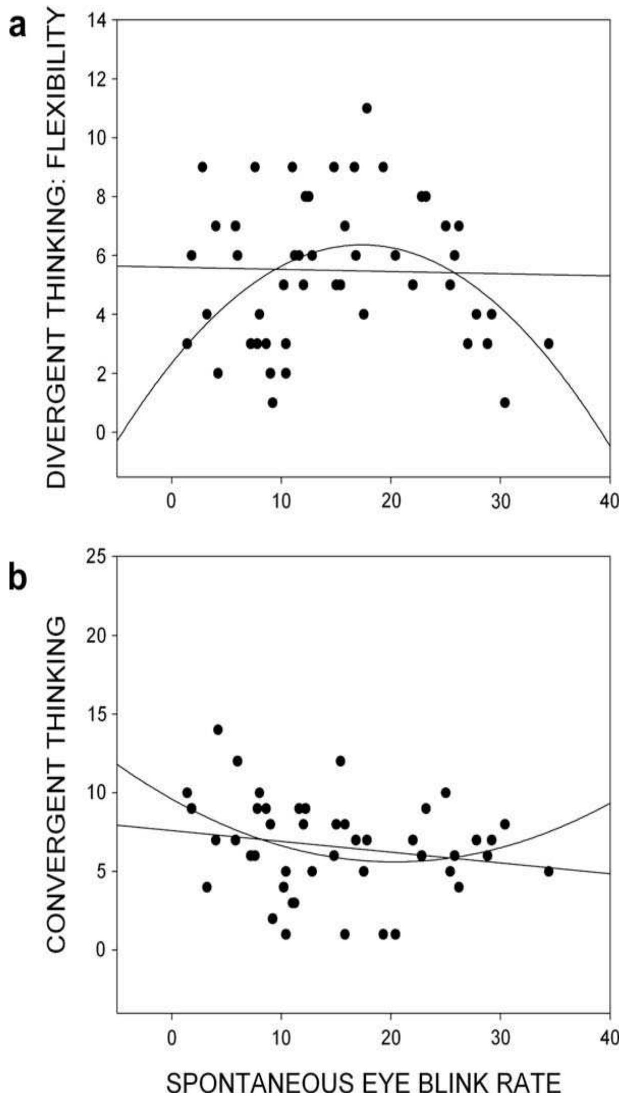


Figure 3: Performance in (a) the divergent-thinking task (flexibility score), and (b) the convergent-thinking task in Experiment 3 as a function of spontaneous eye blink rate (EBR) per minute. Regression lines for linear and quadratic fits are also given.

COMBINED ANALYSIS

To increase the power of our analyses we combined the data from the three experiments by normalizing (z-transforming) AUT, RAT, and EBR measures. As obvious from Table 4, the increase in power rendered the association between EBR and flexibility highly significant and even the association between EBR and convergent thinking is reliable by now. However, whereas the relationship between EBR and flexibility is still decidedly quadratic and inverted-U shaped (see Figure 4A), the relationship between EBR and convergent thinking is more or less linear (with a trend towards a slightly U-shaped function) and shows a negative relationship (see Figure 4B), implying that convergent thinking is increasingly impaired by higher dopamine levels. As we tested unequal numbers of male and female participants, we reran these analyses separately for men and women. The outcome was the same: reliable quadratic (inverted U-shaped) relationships (*p*s < 0.01), but no linear relationship (*p*s > 0.05), between EBR and flexibility, and reliable linear relationships (*p*s < 0.05), but no quadratic relationship (*p*s > 0.05), between EBR and convergent thinking. Hence, our findings do not seem to depend on the particularities of our samples.

Table 4: Beta coefficients and significance levels (** for p<.01 and * for p<.05) for tests of linear (L) and quadratic (Q) relationships (fits) between normalized (z-transformed) scores from tests of divergent thinking (DIV, ORI=originality; FLU=fluency, FLE=flexibility, ELA=elaboration), convergent thinking (CON), and the spontaneous eye blink rate (EBR) in Experiments 1, 2 and 3.

		DIV-FLU	DIV-FLE	DIV-ELA	CON	EBR
DIV-ORI	L	.38**	.51**	.35**	-.06	.09
	Q	.37*	.52**	.38**	.19	.12
DIV-FLU	L		.71**	.04	-.04	.01
	Q		.72**	.05	.06	.13
DIV-FLE	L			.10	-.08	.01
	Q			.13	.12	.42**
DIV-ELA	L				-.17	-.04
	Q				.13	.04
CON	L					-.26*
	Q					.25*

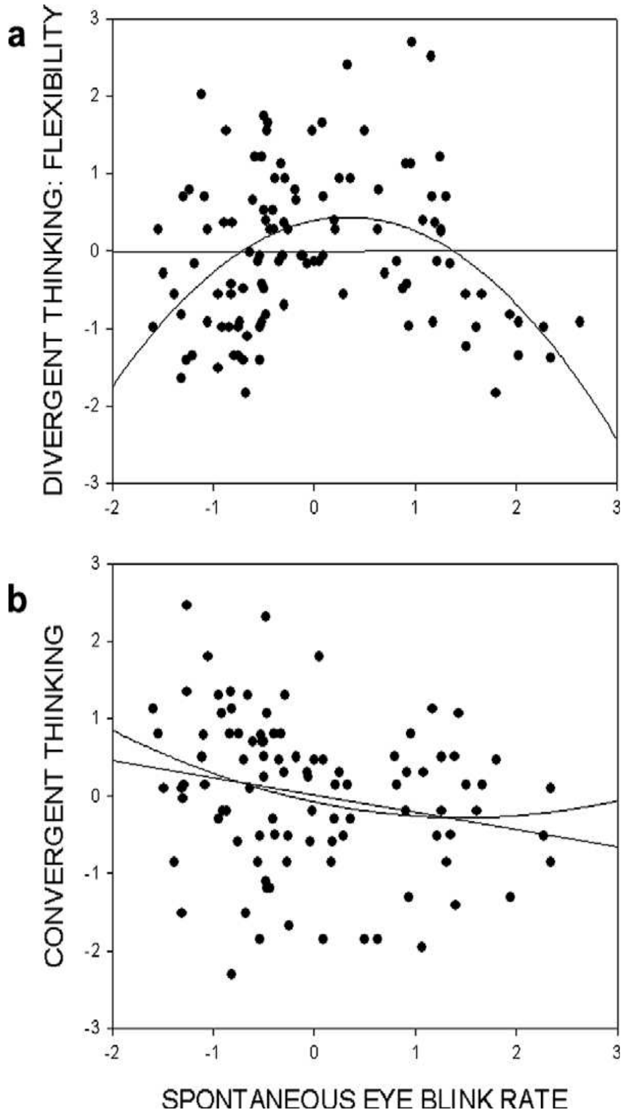


Figure 4: Normalized (z-transformed) performance in (a) the divergent-thinking task (flexibility score), and (b) the convergent-thinking task in Experiments 1-3 as a function of normalized (z-transformed) spontaneous eye blink rate (EBR) per minute. Regression lines for linear and quadratic fits are also given.

GENERAL DISCUSSION

The major aim of our study was to investigate whether individual measures of creativity would covary with the individual EBR, which may point to a connection between creativity and dopamine. The answer is clear but a bit more complex than expected: EBR predicted both the quality of divergent thinking, and flexibility of switching between multiple categories in particular, and the quality of convergent thinking, but not fluid intelligence. However, the two associations differed in type, pattern, and reliability: divergent thinking benefitted most from medium EBRs, while convergent thinking was best with low EBRs. If we take EBR as diagnostic of the individual level of dopaminergic functioning, this suggests that flexibility and convergent thinking are both related to dopamine, but to different degrees and in different ways. Our observations have a number of interesting theoretical implications.

First, they are consistent with the claim that creativity is not a homogeneous concept but reflects the interplay of separate, dissociable processes, such as convergent and divergent thinking (e.g., Guilford, 1967). Our findings do not fully fit with the idea that convergent and divergent thinking represent opposite poles of the same dimension (Eysenck, 1993), however. Even though Experiment 1 produced a negative correlation between convergent thinking and fluency in divergent thinking—suggesting that at least some aspects of divergent and convergent thinking are mutually incompatible—this association did not involve flexibility, the measure related to EBR, and could not be replicated in Experiments 2 and 3. The same holds for the negative correlation between convergent thinking and elaboration in divergent thinking, which we observed in Experiment 3 only. Hence, convergent and divergent thinking are not necessarily opposites but they are not the same either. In fact, it makes sense to assume that convergent thinking draws on executive functions that keep the participant "on target" until the solution is found. Duncan et al. (2000) have considered that working memory (a system that is driven by dopamine: Williams & Goldman-Rakic, 2002) and other functions related to the frontal lobe are responsible for maintaining a high degree of activation of the task goal, which organizes and constrains other cognitive processes so to keep people focused on the task. As the findings of Duncan and colleagues show, the ability to keep such a focus is highly related to fluid intelligence. If we consider that our intelligence measure correlated positively with convergent thinking and that keeping a strictly limited focus is more functional for convergent thinking than it is for divergent thinking, a negative relation between convergent thinking and aspects of divergent thinking seems to fit into the bigger picture.

A second conclusion is that different aspects of human creativity relate to dopaminergic functioning in different ways. As we have seen, convergent thinking benefited from low EBRs whereas flexibility in divergent thinking benefited most from medium EBRs. The observation that EBR could predict creative performance at all provides strong support for approaches that relate creativity to dopamine (Ashby et al., 1999; Eysenck, 1993; Reuter et al., 2006). At the same time, however, the obtained dissociation calls for a more differentiated approach that distinguishes between convergent and divergent processes and that allows for different creativity-dopamine functions. For instance, some approaches assume that the more dopamine the better (e.g., Ashby et al., 1999), which does not seem to fit with either of the two EBR-creativity functions. Other approaches imply that the performance-dopamine functions for convergent and divergent thinking should be mirror images of each other, with low dopamine levels supporting convergent thinking and high levels supporting divergent thinking (e.g., Eysenck, 1993). This fits better with the negative slope we observed for convergent thinking but not with the U-shaped function obtained for divergent thinking.

We should emphasize that EBR provides a very basic, subcortical measure of dopaminergic functioning that does not discriminate between the different dopaminergic pathways and receptors systems. Presumably, approaches that take these different pathways and/or receptor families into account (e.g., Frank et al., 2004) will be able to provide more specific, testable predictions with regard to the relationship between dopamine and creativity. As the observations of Reuter et al. (2006) suggest, genes related to the DA-D2 receptor family play a role in divergent thinking. In the same study, individual variations with respect to the COMT gene, which also regulates aspect of dopaminergic functioning, were unrelated to performance in the divergent-thinking task. Given that the COMT gene is known to affect working-memory performance (e.g., Egan et al., 2001) which again is related to intelligence (Duncan et al., 2000), our finding that intelligence predicts parts of convergent thinking may suggest that convergent thinking is related to the COMT gene. Indeed, working memory is mainly driven by mesocortical dopaminergic pathways, whereas receptors of the DA-D2 family dominate the nigrostriatal dopaminergic pathways, which raises the possibility that the former is more closely related to convergent thinking and the latter to divergent thinking.

A third, more methodological conclusion also refers to the way creativity apparently relates to dopamine. The connection between EBR and divergent thinking has an inverted U-shape, suggesting that a medium dopamine level allows for the greatest flexibility. Comparable patterns have been obtained in studies on the relationship between dopamine level and other types of performance (e.g., control of episodic retrieval: Colzato, Kool & Hommel, 2008; for a broader review, see Goldman-Rakic et al., 2000), which seems to point to a general characteristic of the manner in which dopamine regulates and supports at least some cognitive processes. An important implication of this characteristic and the resulting performance function is that studies investigating phasic changes of the dopamine level may be standing on shaky grounds—if, and to the degree that they fail to take individual differences in dopaminergic functioning into account. For instance, if it is the case that positive mood increases the dopamine level and that this is the mechanism to improve performance, as suggested by Ashby et al. (1999), then it seems close to impossible to predict the impact of mood-enhancing manipulations on performance. Participants with a relatively low level of dopaminergic functioning (who are located on the ascending, left half of the distribution, as shown in Figure 1) would be likely to benefit from better mood, whereas people with a relatively high level of dopaminergic functioning (located on the descending, right half of the distribution), such as individuals scoring high in psychoticism (Colzato, Slagter, van den Wildenberg & Hommel, 2009), would actually be expected to suffer from better mood. Depending on which part of the distribution happens to be more strongly represented in a given sample, the corresponding study may find a positive, negative, or no relationship between mood and the given performance measure. This may explain why the evidence on the relationship between mood and performance seems so confusing and contradictory (Baas, De Dreu & Nijstad, 2008; Davis, 2009), especially if one considers that divergent and convergent thinking (which often are treated as equivalent indicators of creativity) seem to relate to dopaminergic functioning in different ways. In fact, our observations suggest that increasing dopaminergic supply can be expected to actually hamper convergent thinking irrespective of the current level. If so, mood is unlikely to affect convergent and divergent thinking in the same fashion, which is one more reason to carefully distinguish between the different aspects of human creativity.

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More creative through positive mood? Not everyone!

Akbari Chermahini, S., & Hommel, B. (submitted). More creative through positive mood? Not everyone!

ABSTRACT

It is commonly assumed that positive mood improves human creativity and that the neurotransmitter dopamine might mediate this association. However, given the non-linear relation between dopamine and creative performance (Akbari Chermahini & Hommel, 2010), the impact of mood on creativity might depend on a given individual's tonic dopamine level. Indeed, our findings suggest that: the association between tonic dopamine levels and creativity (divergent thinking) follows an inverted U-shape function (with best performance for medium levels); positive and negative mood inductions raise and lower the dopamine level, respectively; so that individuals with low dopamine levels benefit from positive mood more thanindividuals with medium or high levels. This observation challenges the generality of the widely held view that positive mood facilitates creativity.

INTRODUCTION

Creativity is arguablythe most potent human resource both for the advancement of mankind in general and people’s individual progress and success in daily life in particular. And yet, the cognitive and neural mechanisms underlying creative behavior are poorly understood.Researchers agree that at least some forms of creativity vary with mood and two recent meta-analyses have concluded that performance in tasks tapping divergent (brainstorm-like) thinking can be reliably improved by inducing positive mood (Baas, De Dreu & Nijstad, 2008; Davis, 2009). This conclusion fits with earlier considerations of Isen (1987), who claimed that positive affect impacts cognitive processing by (1) increasing the number of cognitive elements available for association; (2) defocusing attention so to increase the breadth of those elements treated as relevant to the problem; and (3) increasing cognitive flexibility.

Exactly how positive mood manages to improve creativity is not yet clear, but in approaches that tackle this issue the neurotransmitter dopamine (possibly in concert with other neurotransmitter systems: Cools, Roberts & Robbins, 2008) plays a major role. Notably,Ashby, Isen, and Turken (1999) have pointed out that phasic changes indopamine levels, mood changes, and changes in creativity may be strongly interrelated. Their approach is inspired by insights into theneurobiology of reward,the encounter of which has been shown to induce both positive affect and phasic increasesof dopamine levels (e.g., Beninger, 1991; Bozarth, 1991; Philips, Blaha, Pfaus & Blackburn, 1992; Schultz,1992). Accordingly, Ashby and colleagues (1999) suggest that improved mood states are accompanied by phasic increases in dopaminergic supply provided by frontal and striatal pathways. These phasic increases might facilitate switching from one task set or item to another, thereby increasing cognitive flexibility in creativity task.This scenario is consistent with results fromneural-network modeling (Ashby et al., 1999; Cohen& Servan-Schreiber, 1992) and the observation that divergent-thinking performance interacts with individual differences in the DRD2 TAQ IA gene—which affects receptor density in the striatal dopaminergic pathway (Reuter, Roth, Holve, & Hennig, 2006). Moreover, the personality trait of “seek”, which has been claimed to rely on dopaminergic pathways (Panksepp, 1998), has been reported to be positively related to creativity (Reuter et. al., 2005).

To assess the connection between creativity and dopamine more directly, Akbari Chermahini and Hommel (2010) related individual performance in creativity tasks to spontaneous eye-blink rates (EBRs), a well-established clinical marker of the individual dopamine level(Blin et al., 1990; Karson, 1983; Kleven & Koek, 1996). Divergent thinking did in fact covary with EBR but the function relating these two measures was nonlinear and followed an inverted-U shape. That is, individuals with mediumEBRs were performing better than individuals with low or high rates did. If we take EBRs as a marker of the current dopamine level (presumably integrating tonic and phasic levels), this has a number of rather serious implications that we set out to test in the present study.

First, it suggests that increasing the dopamine level by means of a positive-mood induction is likely to facilitate divergent thinking in individuals with low tonic dopamine levels but not necessarily in individuals with medium or high levels. In other words, people with a low pre-experimental EBR would be expected to benefit from positive mood more than people with a medium or high pre-experimental EBR do.[1]

Note that this reasoning holds only if positive-going mood can actually be considered to increase the phasic dopamine level in humans, which is yet to be demonstrated. Accordingly, our second hypothesis was that the experimentally induced positive or negative mood changes should be reflected in corresponding increases or decreases in EBR.

Third, if we take both mood and EBR changes as reflections of phasic dopaminergic changes, the amount ofmood and EBR changes should be systematically related to changes in divergent thinking. That is, elevated mood and increased EBRs should be associated with

[1] Informal observations from our lab revealed that people with very high EBR levels are rare in our student population and more often than not report to have family members with schizophrenia. This fits with the distribution of EBRs in Akbari Chermahini and Hommel’s (2010) and in the present study, where the EBRs of the majority of participants falls on the left, ascending part of the inverted U-shaped function relating EBR to divergent thinking. If we later in this article distinguish between below- and above-median EBRs, it should therefore be kept in mind that even above-median EBRs in the present study are actually representing medium EBRs in the population. In other words, the present study actually compares individuals with low vs. medium EBRs rather than low vs. high EBRs.

improved performance in divergent thinking, whereas negative-going mood and decreased EBRs would be more likely to be associated with impaired divergent thinking.

We tested these hypotheses in the following way: Participants were first tested on general, pre-experimental mood (for both their general and their current mood state), on performance in divergent thinking, and on their pre-experimental EBR. Then two subgroups of participant underwent a positive-mood and negative-mood induction, respectively, before again being tested on mood, divergent thinking, and EBR.

METHOD

Eighty-one native Dutch students of Leiden University volunteered in exchange for course credit or pay. The study consisted of three phases. First, all participants filled out an inventory assessing their general mood (PANAS) and a mood inventory assessing their current mood state(MI1), before performing a divergent-creativity task (Alternate Uses Task: AUT1); finally, their spontaneous EBR were measured (EBR1). In the second phase, 43 participants received a positive-mood induction while 38 participants received a negative-mood induction. In the third phase, another version of the mood inventory (MI2) was filled out, EBR2 was measured, and another version of the creativity task was performed (AUT2). The order of the two versions of the mood inventory and the creativity task was counter-balanced across participants. EBR2 was measured after mood induction while subject continually was thinking about either happy or sad memory.

Positive and Negative Affect Scales (PANAS)

The PANAS(Watson, Clark, & Tellegen, 1988) is a 20-item self-report mood scale that measures general (“how do you feel generally?”)positive affect (PA) and negative affect (NA). It comprises of 10 positive and 10 negative adjectives rated on a Likert scale from 1 (very little or not at all) to 5 (very or extremely). We used a Dutch version of the scale with high internal consistencies for the PA (Cronbach's alpha=0.84) and the NA (Cronbach's alpha=0.80) subscale (cf., Hill et al., 2005).

Mood Inventory (MI)

Two Dutch versions of a mood inventory (developed by Phillips, Bull, Adams& Fraser, 2002, and similar to the scale of Isen, Daubman & Nowicki, 1987) were used to assess current mood in the first and the third phase of the experiment. Three of the five items of this inventory assess the hedonic quality of affect (Phillips et al., 2002). One version (Cronbach's alpha=0.75) used the following adjective pairs (Dutch words are given in parentheses) to measure valence: happy–sad (*blij-verdrietig*), peaceful–anxious (*verdig-angstig*), and carefree–serious (*zorgeloos-serieus*). The second version (Cronbach's alpha=0.85) used the pairs: positive–negative (*positief-negatief*), calm–uptight (*kalm-opgewonden*), and bright–dispirited (*helder-serieus*). Positive and negative words were presented on the left and right side of a page, respectively. Nine-point Likert scales separated the words of each pair and participants were asked to rate their current mood state (following Phillips et al., 2002). For analytical purposes the mood scores were reversed and then totaled, so that higher scores indicated more positive mood.

Alternate Uses Task (AUT)

Following Guilford (1967), participants were asked to write down as many possible uses for a common household item as they can within 5 min. Two different items were used: *cup*and *pencil*, with the order being balanced across participants. Responses can be scored with respect to four aspects (flexibility, originality, fluency, and elaboration). However, given that flexibility is most strongly and reliably related to EBR measures (Akbari Chermahini & Hommel, 2010) we focused on the flexibility score, which is derived from the number of different categories being used for each item.

Eye Blink Rate (EBR)

A BioSemi ActiveTwo system (BioSemi Inc., Amsterdam) was used to record the EBR. We recorded with two horizontal (one left, one right) and two vertical (one upper, one lower of right eye) Ag-AgCl electrodes, for 6 min eyes-open segments under resting conditions. The vertical electrooculogram (EOG), which recorded the voltage difference between two electrodes placed above and below the left eye, was used to detect eye blinks. The horizontal EOG, which recorded the voltage difference between electrodes placed lateral to the external canthi, was used to measure horizontal eye movements. As spontaneous EBR is stable during daytime but increases in the evening (around 8:30 pm, see Babarto et al., 2000), we never registered after 5 pm. We also asked participants to avoid smoking before the recording. Participants were comfortably sitting in front of a blank poster with a cross in the center, located about 1m from the participant. The participant was alone in the room and asked to look at the cross in a relaxed state to record EBR1. After mood induction (either positive or negative) EBR2 was recorded. The individual EBR was calculated by dividing the total number of eye blinks during the 6-min measurement interval by 6.

Mood Induction

We used the common mental-imagination procedure (e.g., Bodenhausen et al., 1994; Baas et al., 2008; DeSteno et al., 2004; Phillips et al., 2002; Strack et al., 1985) to induce positive and negative mood. Participants were asked to write down a couple of sentences about an event of their life that made them happy(in a calm, relaxed way) or sad(in a calm, non-angry way),respectively, for 5 min. Calmness was emphasized to keep the two emotional states comparable regarding activation and arousal. EBR2 was recorded right after the mood induction; participants were asked to stop writing but to keep thinking about the event during the measurementinterval. The session was completed by filling in the MI2.

RESULTS

Comparability of groups

Aset of independent t-test were conducted to check whether the two experimental groups were comparable before undergoing the mood induction. There was not any hint to any pre-experimental difference between the two groups with respect to either the positive or negative subscale of PANAS, and the hedonic-valence scores computed from the MI1, nor did any of these scales correlate with EBR1, all *p*s>.05. Table 1 provides the relevantinformation about the mood states in two experimental groups and the four subgroups.Interestingly, thelack of a correlation between EBR1 and pre-experimental mood suggests that mood does not depend on the tonic dopamine level but, if anything, on phasic changes.

Table 1: Means and Standard Deviations for Pre-experimental General Mood States (PANAS: positive and negative scales), and Current Mood States (only hedonic valence score) Before (MI1) and After (MI2) Mood Induction in the Two Experimental Groups, and Four Subgroups, as a Function of Low vs. (Relatively) High Pre-Experimental Eye Blink Rate.

State Mood Index		Mood Induction Groups					
		Positive			Negative		
		Total	Low EBR	High EBR	Total	Low EBR	High EBR
		(n=43)	(n=21)	(n=22)	(n=38)	(n=19)	(n=19)
PANAS–PA	M	34.1	33.1	35.1	34.1	33.2	35.1
	S.D.	4.5	4.9	3.9	5.5	4.6	6.1
PANAS-NA	M	16.1	16.2	16.4	16.2	16.4	16.1
	S.D.	4.8	4.9	4.9	6.1	7	5.4
MI1	M	18.06	17.54	18.61	19.86	18.44	20.77
	S.D.	3.08	2.57	3.5	4.05	4.63	3.24
MI2	M	20.95	20.36	21.57	13.36	13.05	13.66
	S.D.	3.06	2.93	3.13	4.7	4.26	5.21

Note: PANAS-PA, PANAS positive affect subscale; PANAS-NA, PANAS negative affect subscale.

Two more sets of independent t-tests assessed whether the groups were comparable with regard to the pre-experimental EBR1 and the flexibility score in the creativity task before the mood induction. Not any significant group difference was detected however, all *p*s >.05.

Manipulation check

Another set of paired-sample t-tests on the hedonic valence score in MI1 and MI2 served to check whether the mood manipulation worked. As expected, participants were significantly more happy after positive-mood induction than before (*M*=20.95 vs. 18.11), $t(42)= 5.74$, $p< 0.001$, $\eta^2= 0.44$, and significantly less happy after negative-mood induction (*M*=13.07 vs.19.65), $t(37)=7.76$, $p<0.001$. $\eta^2= 0.62$.This suggests that the mental-imagery procedure was effective in inducing the respective mood states.

Mood and Creativity

Paired sample t-tests assessed the impact of mood induction on performance in the creativity task by comparing flexibility scores before and after the mood manipulation. As expected, the induction of positive mood enhanced flexibility (*M*=7.1 vs. 5.7), $t(42)=3.26$, $p < 0.01$, $\eta^2= 0.20$. The induction of negative mood reduced flexibility (*M*=5.52 vs. 5.26), but this effect was not significant, $t(37)=0.84$, $p> 0.05$, $\eta^2= 0.02$. The correlation between change in creativity (AUT2-AUT1: flexibility score) and change in mood (MI2-MI: hedonic valence) was positive and reliable, $r = 0.44$, $p < 0.001$, suggesting that the degree of mood change statistically predicts the direction and degree of change in creativity.

Mood and EBR

Paired sample t-test revealed systematic changes in EBR after mood induction:As expected, the induction of positive mood led to a significant increase in EBR (*M*=18.79 vs. 14.1), $t(42)=3.8$, $p< 0.001$, $\eta^2= 0.26$. Negative-mood induction reduced EBR (*M*=16.78 vs.17.39) but this effect was not significant, $t(37)=0.64$, $p> 0.05$, $\eta^2= 0.01$.Moreover, the correlation between change in EBR (EBR2-EBR1) and change in mood (MI2-MI: hedonic valence) was positive and reliable, and the best fit was obtained for a linear function (Figure 1) relating EBR changes to mood changes, $r = 0.35$, $p = 0.003$, suggesting that the degree of mood change was associated with proportional phasic increases and decreases of the individual dopamine level.

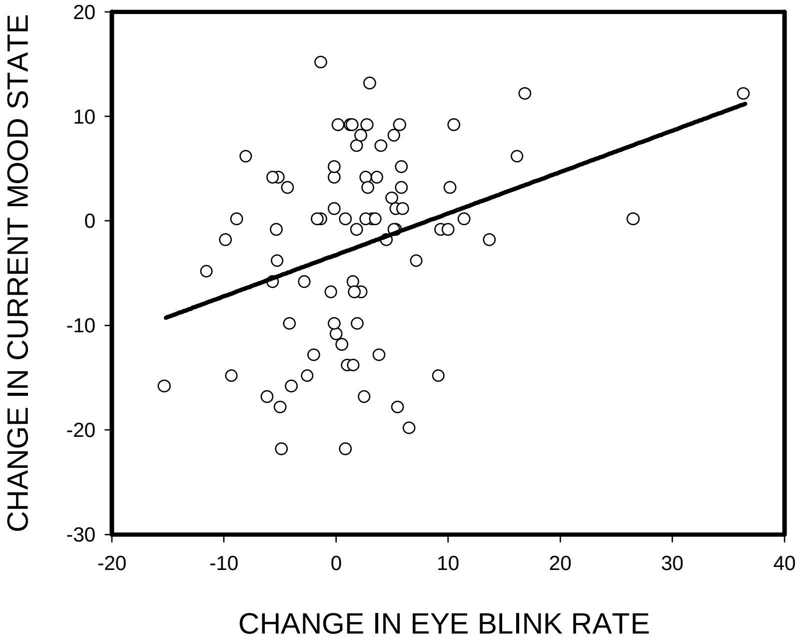

Figure 1: Correlation Between change in Eye Blink Rate (EBR2-EBR1) and Change in Current Mood State (MI2-MI1: hedonic valence) as a Function of Positive and Negative Mood Induction.

Interestingly, the impact of positive mood on EBR was mediated by the pre-experimental EBR level. Participants with a pre-experimentally low (i.e., below-median) EBR showeda pronounced and highly significant increase in EBR after positive mood induction from 7.57 to 14.14, $t(21) = 3.27$, $p = 0.004$, $\eta^2 = 0.34$, whereas participants with a pre-experimentally high (i.e., above-median) EBR only tended to show reliable change in EBR (from 20.9 to 23.5),$t(20) = 2.05$, $p = 0.054$, $\eta^2=0.19$.

Creativity and EBR

The relationship between performance in the creativity task (AUT1: flexibility score)and EBR1followed an inverted U-shapedfunction (Figure 2, quadratic fit= 0.36, p=.005), which confirms our previous observations (Akbari Chermahini & Hommel, 2010).The correlation between change in EBR (EBR2-EBR1) and change in creativity performance (AUT2-AUT1: flexibility score) was positive and reliable, r = 0.19, p = 0.047, suggesting that the degree of flexibility change was proportional to the phasic increases and decreases of the individual dopamine level.

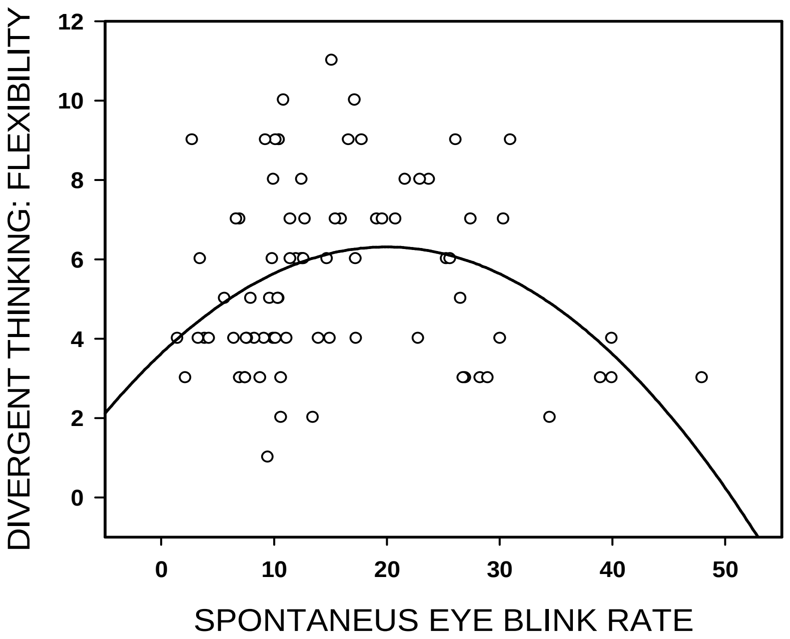

Figure 2: Performance in the creativity task (flexibility score) as a function of spontaneous eye blink rate (EBR) per min. Regression line for best (quadratic) fit.

Interactions between Mood, Creativity, and EBR

Importantly, the experimentally induced mood changes had the predicted impact on EBR and creativity: Individuals were becoming more creative to the degree that the positive-mood induction increased their EBR, r=.29, p=.03(Figure 3, line: P), and tended to become less creative to the degree that the negative-mood induction decreased their EBR, r=-.23, p=.09 (Figure 3, line: N).This pattern suggests that the extent of phasic increases and decreases of dopamine systematically predicts the degree of facilitation or impairment of creative behavior, respectively.

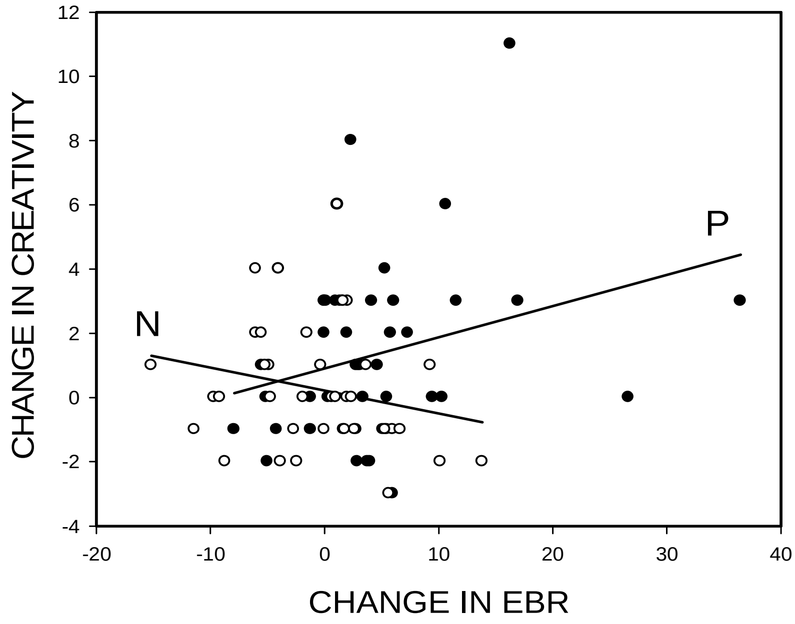

Figure 3: Mood-induced change in creativity performance (creativity score post minus creativity score pre mood induction) as a function of the mood-induced change in spontaneous eye blink rates (EBRs). Empty circles and regression line N for participants with negative-mood induction; filled circles and regression line P for participants with positive-mood induction.

Again, the mood-induced effect was contingent on the pre-experimental EBR1. As Figure 4a shows, positive mood increases EBR mainly in low (i.e., below-median) EBR1 individuals but not so much in high-EBR1 participants—even though the distribution of EBRs (see Figure 2) does not suggest that this might be due to a ceiling effect. Likewise, as shown in Figure 4b, the induction of positive mood improved performance in the creativity task onlyin low-EBR1 individuals (from 5.8 to 8.0 categories, $t(21)=3.54$, $p=.002$, $\eta^2= 0.37$)but not in high-EBR1 participants (5.7 vs. 6.1), $t(20)=.87$, $p=.4$).

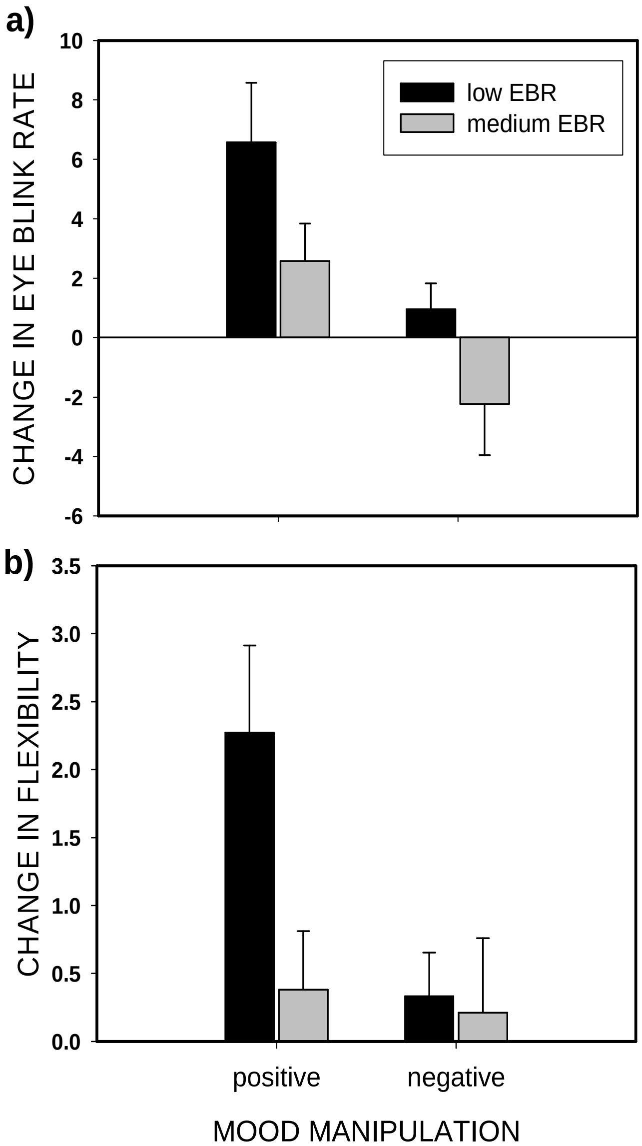

Figure 4: Change in spontaneous Eye Blink Rate (EBR) (**a**), and performance in creativity task (divergent thinking: flexibility) (**b**), as a function of mood induction (either positive or negative), and individual's EBR level (low and medium)

DISCUSSION

The aim of the present study was to investigate the relationship between mood, creativity, and phasic dopamine changes as reflected in EBRs. The mood induction manipulation work as expected, even though the induction of positive mood was more effective than the induction of negative mood. As implied by our second hypothesis, positive- and negative-going mood changes were accompanied by systematic increases and decreases of EBR, respectively. This suggests that EBR is a sensitive measure of mood-related phasic dopaminergic changes. Moreover, we were able to fully replicate the inverted U-shaped function relating flexibility in divergent thinking to pre-experimental EBR, first reported by Akbari Chermahini and Hommel (2010). If we assume that pre-experimental EBR (i.e., EBR1) reflects the individual tonic dopamine level, this replication confirms that EBR is a reliable index of tonic dopamine levels as well.

As implied by our third hypothesis, all three factors under investigation were systematically related to each other—even though, again, these relations were more pronounced in the context of positive-mood induction. Flexibility in divergent thinking was facilitated or tended to be impaired through the induction of positive or negative mood, respectively, and the degree of this improvement was predicted by the individual degree to which the mood induction manipulation was successful. Likewise, EBR increased or tended to decrease through the induction of positive or negative mood, respectively, and the degree of this phasic change was again predicted by the degree to which the mood induction manipulation was successful. Finally, the positive and negative changes in EBR predicted the increase or decrease of flexibility in divergent thinking, suggesting that phasic increases and decreases in dopamine facilitated or impaired divergent creativity, respectively. Hence, all three factors seem to be related to each other exactly as predicted, and even the asymmetry between the effects of the positive- vs. negative-mood induction is equally reflected in all three measures.

According to our first hypothesis, this interrelationship—together with the fully replicated inverted U-shaped relationship between EBR and creativity—suggest that individuals with low tonic dopamine levels might benefit more from the induction of positive mood than individuals with medium or high levels do. Indeed, mood-induced improvement of divergent thinking was only observed in individuals with a pre-experimentally low EBR and a presumably corresponding low tonic dopamine level. Not only does this fit with the nonlinear relation between EBR in divergent thinking reported by Akbari Chermahini and Hommel (2010), it is also likely to explain why unreliable findings and failures to replicate are still abundant in studies on the connection between mood and creativity (Baas et al., 2008; Davis, 2009).

Taken together, our findings support the assumption that phasic changes in dopamine levels provide the common currency underlying the relationship between mood and creativity, as suggested by Ashby et al. (1999) and others, and they provide the hitherto most direct evidence for the underlying interrelationship between mood, creativity, and dopamine. In particular, elevated mood seems indeed to increase the dopamine level and to improve creativity as assessed by our divergent-thinking task. At the same time, however, there is evidence that the reliability and, presumably, the direction of the impact of mood and associated phasic dopamine changes depend on the individual tonic dopamine level (but not the basic mood level!). This questions the generality of claims regarding the positive impact of mood on creativity and calls for closer consideration of individual differences. As our findings demonstrate, better mood may or may not facilitate (and may in some cases even impair) creative performance of a given individual. Depending on the specific characteristics of a given sample, this complication may well conceal the true connections between creativity, mood, and dopaminergic activity in empirical studies and applied settings.

In the light of our findings, a number of further questions present themselves. For instance, it remains to be seen whether a comparable interrelationship exists between mood, dopamine, and convergent thinking—which apparently relates to tonic dopamine levels in different, and in some sense opposite, ways than divergent thinking does (Akbari Chermahini & Hommel, 2010). Recently we observed that engaging in divergent thinking leads to more negative mood (Akbari Chermahini & Hommel, 2011), which would fit with this expectation. Moreover, it seems important to clarify the functional relationship between mood and phasic dopaminergic changes. After all, mood is a concept that relates to a personal level of description and relates to a person having and experiencing it. In contrast, changes in dopaminergic activity refer to the systems level of description, which may or may not correspond to personal-level concepts in a one-to-one fashion. Hence, it would be important to understand whether and to what degree dopaminergic changes are the neural reflection of being in a particular mood, or whether they are mere byproducts of particular mood states.

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Creative mood swings:

Divergent and convergent thinking affect mood in opposite ways

This chapter is published as: Akbari Chermahini, S., & Hommel, B. (in press). Creative mood swings: Divergent and convergent thinking affect mood in opposite ways. *Psychological Research*.

ABSTRACT

Increasing evidence suggests that emotions affect cognitive processes. Recent approaches have also considered the opposite: that cognitive processes might affect people's mood. Here we show that performing and, to a lesser degree, preparing for a creative thinking task induces systematic mood swings: Divergent thinking led to a more positive mood whereas convergent thinking had the opposite effect. This pattern suggests that thought processes and mood are systematically related but that the type of relationship is process-specific.

INTRODUCTION

In contrast to the commonsense concept of affect and reason as antagonistic factors that compete for the control of our thoughts and actions, recent research has revealed evidence for numerous types of fruitful cooperation between affective and cognitive processes. For instance, positive mood and affect have been shown to facilitate associative (Bar, 2009) and semantic priming (Hanze & Hesse, 1993), to enhance the recall of happy memories (Teasdale & Fogarty, 1979), and to support the processing of global perceptual information (Gasper & Clore, 2002); whereas negative mood and affect have been found to narrow the focus of attention (Rowe, Hirsh & Anderson, 2007), facilitating analytical processing, causal reasoning, and reliance on systematic processing (Pham, 2007), and to support forgetting (MacLeod, 2002; Bäuml & Kuhbandner, 2009). A particularly close relationship seems to exist between mood and creative thinking. Various authors have assumed that positive mood enhances creativity (e.g., Isen, 1999; Hirt, Melton, McDonald & Harackiewicz, 1996), and numerous findings are consistent with this idea (for reviews, see Baas, De Dreu & Nijstad, 2008; Davis, 2009). At the same time, however, the type and nature of this interaction is not well understood and mediating factors like type of task (Davis, 2009), motivational set (Baas et al., 2008), and individual differences (Akbari Chermahini & Hommel, 2011) can play decisive roles. Nevertheless, it seems clear that some sort of link exists between positive and negative mood on the one hand and creative thought processes on the other.

One idea regarding how mood and creative processes might interact considers mood as the cause and changes in creativity as effect. For instance, Ashby, Isen, and Turken (1999) assumed that mood creates particular brain states that facilitate or interfere with particular processing operations that are required for creative thinking. More recently, however, authors have also considered the possibility of a more reciprocal relationship between affective and cognitive processes (Bar, 2009; Gray, 2004; Gross, 2002; Salovey, Mayer & Caruso, 2002), which would allow creative thought to affect mood. For instance, Bar (2009) suggested an interactive relation between mood and cognitive control: The broad associative activation that is thought to coming along with positive mood may help gaining a broader perspective, which again might make people happier. Indeed, Srinivasan and Hanif (in press) reported that attending to the global aspect of visual stimuli facilitates the processing of happy as compared to sad faces while attending to the local aspects facilitates the processing of sad faces. Applied to the interaction between mood and creative thinking, this suggests that particular mood states may not only facilitate or hinder particular types of thought processes but some types of thought processes might also facilitate or even induce particular mood states.

In the present study, we tested this possibility by presenting participants with creative-thinking tasks and assessing whether this would lead to systematic mood changes. As divergent and convergent thinking have been attributed to different types of cognitive processes (Guilford, 1967) and given that they seem to rely on different neurocognitive states (Akbari Chermahini & Hommel, 2010), we tested the impact of divergent thinking (assessed by the Alternate Uses Task, AUT: Guilford, 1967) and convergent thinking (assessed by the Remote Associates Task, RAT: Mednick, 1962) on mood separately by means of a between-subjects design.

Divergent-thinking tasks require participants to generate as many target-related responses as possible, and the target constrains the selection of possible responses rather weakly. An example is Guilford's (1967) AUT, which requires participants to generate as many uses for a simple object, such as a pen, they can think of. Even though divergent thinking can be considered as just one of a number of component processes underlying creative acts (Guilford, 1967; Nijstad, De Dreu, Rietzschel & Baas, 2010; Wallas, 1926), recent reviews have revealed that the connection between divergent thinking and affect and mood is particularly strong and positive (Baas et al., 2008; Davis, 2009). Hence, more positive affect and mood improves divergent thinking. According to the reciprocity hypothesis under test, this suggests the divergent-thinking task can be expected to induce a more positive mood state.

In contrast to divergent thinking, convergent thinking requires focusing onto one possible response per item and thus calls for a strongly constrained search process. As an example, in Mednick's (1962) RAT participants are presented with three concepts per trial, such as "hair", "stretch" and "time", and they are to identify the one concept that fits with all three in terms of association, meaning, or abstraction—such as "long" in the example. As we have argued elsewhere(Hommel, in press; Hommel, Akbari Chermahini, van den Wildenberg &

Colzato, 2011), succeeding in this task is likely to require a task set that in some sense is opposite to that implied by divergent thinking. Indeed, recently we were able to demonstrate that mixing convergent and divergent thinking tasks with other laboratory tasks results in a double dissociation: while engaging in convergent thinking facilitates subsequent performance in tasks that require focusing on relevant and excluding irrelevant information, divergent thinking facilitates subsequent performance in tasks that require the distribution of processing resources (Hommel et al., 2011). If we assume that opposite control states are accompanied by opposite mood states (for reasons that we elaborate in the Discussion), the observation that divergent thinking is related to positive mood would imply that convergent thinking is associated with negative mood. Accordingly, the reciprocity hypothesis would suggest that the convergent-thinking task induces a more negative mood state.

A second factor we considered was whether participants were only expecting to carry out the thinking task or whether they actually carried it out. This manipulation was motivated by informal observations of ours that participants often show affective responses to the mere announcement of the tasks that we commonly use to assess creative thinking (the AUT and the RAT). A similar reaction can be observed when intelligence or mathematical tasks are being announced, irrespective of the eventual score of the participant. This suggests that such reactions are not reflecting the individual ability or performance on the task but some kind of stereotypical response that may or may not be related to particular task characteristics. To dissociate such stereotypical and/or expectation-driven mood changes from changes that result from the actual processes engaged by the task, we had two groups of participants carry out the divergent or convergent thinking task and two other groups just waiting to perform these tasks (for about the same duration) after having been instructed how to carry it out.

METHOD

Participants, Design, and Procedure

Eighty-four students from Leiden University volunteered in exchange for course credit or pay. Participants were informed that they were participating in a study on problem solving. They were randomly assigned to one of the four experimental groups (22 to each of the performance groups and 20 to each of the preparation groups). Participants underwent four tasks or measurements: an inventory assessing their general mood (PANAS), a mood inventory (MI1) assessing their current feeling state before working on the creativity task, (preparation for) a creativity task (either AUT or RAT), and another version of the MI (MI2) to assess their current feeling state after working on the creativity task. The order of the two versions was balanced across participants.

Table 1: Sequence of Events for the Four Experimental Groups.

Group	Pre-Test		Preparation	Execution	Post-Test
DT	PANAS	MI1	AUT	AUT	MI2
pDT	PANAS	MI1	AUT		MI2
CT	PANAS	MI1	RAT	RAT	MI2
pCT	PANAS	MI1	RAT		MI2

Note: PANAS=Positive and Negative Affect Scales; MI1=Mood Inventory (1st); AUT=Alternate Uses Task; RAT=Remote Association Task; MI2=Mood Inventory (2nd).

The members of the four experimental groups all worked through the PANAS, the MI1, and the final MI2, but they differed with respect to the creativity task (see Table 1). The first group (DT) worked on a divergent-thinking task (AUT), which calls for the broad association on a particular theme (object use). The second group (pDT) was instructed to prepare for working on the same task, but the task was never actually performed. Analogously, the third group (CT) worked on a convergent-thinking task (RAT), which calls for finding one single correct response, whereas the fourth group (pCT) was instructed to prepare for working on the convergent-thinking task without performing it. To keep the timing comparable across the four groups, the members of groups pDT and pCT were to talk about the experiment and the instruction of either DT or CT with the experimenter for 5 minutes instead of performing the creativity task. The items of the creativity tasks were not presented to them.

Positive and Negative Affect Scales (PANAS)

The Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) is a 20-item self-report mood scale that provides a general measure ("how do you feel generally?") of positive affect (PA) and negative affect (NA). The PANAS consists of 10 positive adjectives (such as "interested", "alert", "excited") and 10 negative adjectives (such as "disinterested", "upset", "guilty") rated on a Likert scale from 1 (very little or not at all) to 5 (very or extremely). Our Dutch version of the PANAS had high internal consistencies for both the PA (Cronbach's alpha=0.84) and the NA (Cronbach's alpha=0.80) subscale (cf., Hill et al., 2005).

Mood Inventory (MI)

Two Dutch versions of the mood inventory employed by Phillips, Bull, Adams, and Fraser (2002) and Oaksford, Morris, Grainger, and Williams (1996), and similar to the scale of Isen, Daubman, and Nowicki (1987), were used to assess current mood before and after preparing for and (in groups DT and CT) performing the creativity task. The items of this inventory assess three types of mood indicators (three hedonic, one physical arousal, and one worry measure; Phillips et al., 2002). One version (Cronbach's alpha=0.75) used the following adjective pairs (Dutch words are given in parentheses): happy–sad (blij-verdrietig), active–exhausted (actief-uitgeput), peaceful–anxious (verdig-angstig), carefree–serious (zorgeloos-serieus), and energetic–somber (energiek–sloom). The second version (Cronbach's alpha=0.85) used the pairs: positive–negative (positief-negatief), lively–tired (levendig-vermoeid), calm–uptight (kalm-opgewonden), bright–dispirited (helder-serieus), and cheerful–low (vrolijk-sloom). Positive and negative words were presented on the left and right side of a page, respectively. Nine-point Likert scales separated the words of each pair. Participants were asked to rate their current mood state (following Phillips et al., 2002). For further analyses, the mood scores were reversed for five items and then totaled for hedonic valence (items 1, 3, and 4), so that higher scores indicated more positive mood. Physical arousal (item 2), and worry (item 5) were scored separately.

Alternate Uses Task (divergent thinking)

In this task (based on Guilford, 1967, and translated into Dutch), participants were asked to list as many possible uses for a common household item (*cup*) as they can within 5 min. Responses can be scored with respect to four aspects (flexibility, originality, fluency, and elaboration), but given that flexibility seems to be the by far most reliable aspect (Akbari Chermahini & Hommel, 2010; Ashby, Valentin, & Turken, 2002), we considered flexibility scores only—which were derived from the number of different categories being used by the participant.

Remote Association Task (convergent thinking)

Mednick's Remote Associates Test (Mednick, Mednick, & Mednick, 1964), (considered as a convergent thinking test) was originally designed in accord with S.Mednick's (1962) associative theory of creativity. Based on this theory, the creative thinking process consists in the formation of associative elements into new combinations which either meet specified requirements or are in some way useful. The original test consists of 30 items (Mednick, 1968; Mednick & Mednick, 1967). Each item consists of three words that can be associated in one of several ways (e.g., *time, hair,* and *stretch*), such as forming a compound word or identifying a semantic associate (*long*). The items are constructed in such a way that only one solution is possible and that the first solution that comes to mind is commonly incorrect—which is why the test is taken to assess "remote" associations. Our Dutch version of the test comprised of 30 items and was found to be reasonably reliable (Cronbach's alpha=0.85). In our study, participants were given 5 min to complete the test.

RESULTS

Task performance

Performance in the AUT (flexibility score: M=5.5, SD=2.24) and the RAT (M=7.09, SD=3.25) was good and comparable to performance in other studies using these task versions (e.g., Akbari Chermahini & Hommel, 2010).

General mood

Table 2 provides an overview of the general mood states in the four experimental groups, as measured by the PANAS inventory. Two one-way ANOVAs with group as between-subjects factor did not reveal any hint to pre-experimental differences between the four groups with respect to either the positive or negative subscale of PANAS. The groups were thus comparable.

Table 2: Means and Standard Deviations for Pre-experimental General Mood States (positive and negative scales) in the Four Experimental Groups.

State Mood Index		Groups			
		DT	pDT	CT	pCT
		(n=22)	(n=20)	(n=22)	(n=20)
PANAS–P	M	3.4	3.4	3.5	3.5
	SD	.3	.5	.5	.5
PANAS-N	M	1.5	1.6	1.8	1.7
	SD	.5	.5	.5	.6

Note: PANAS-P=PANAS positive affect subscale; PANAS-N=PANAS negative affect subscale.

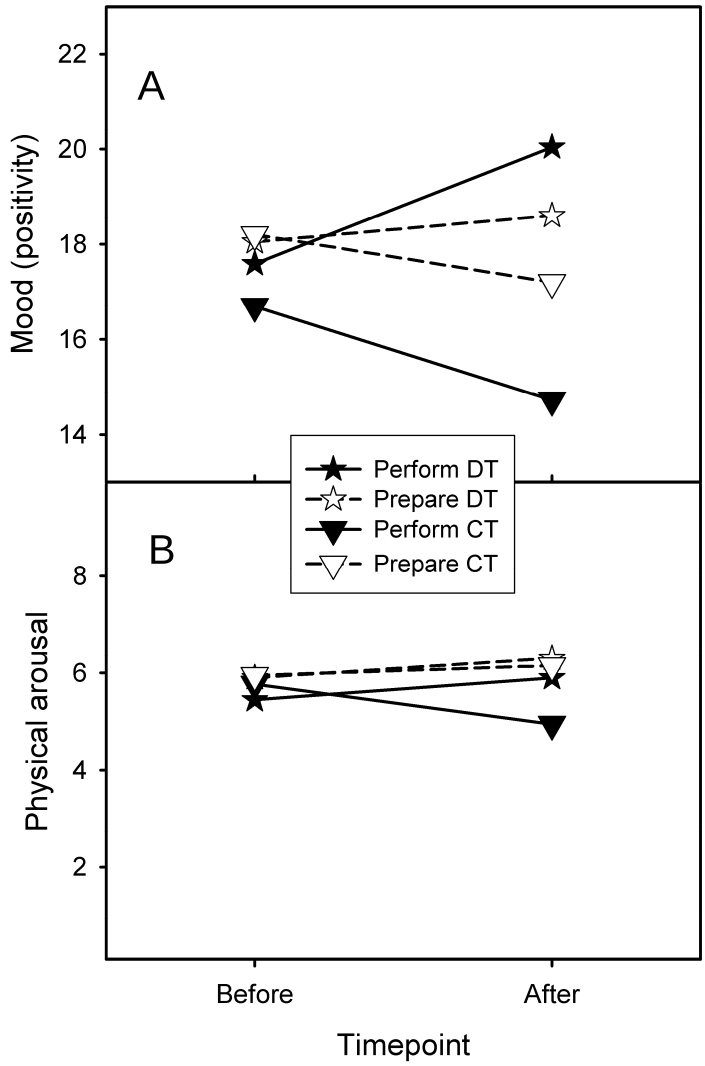

Figure 1: Mood (panel A) and subjective physical arousal (panel B) as a function of creativity task (divergent thinking=DT, convergent thinking-CT), activity (performing and preparing the creativity task), and timepoint (before vs. after preparation or performance of the creativity task)

Task-induced mood changes

Mood changes were analyzed by means of three sets of three-way ANOVAs on the MI1 and MI2, using the *hedonic valence* score, the *physical arousal* score, and the *worry* score as dependent variables. Creativity task (divergent thinking vs. convergent thinking) and activity (performing and preparing) served as between-subjects factors and timepoint (before vs. after the preparation or performance of the creativity task: MI1 vs. MI2) as within-subjects factor. The alpha level was 0.05.

Our actual hypotheses were tested by means of the hedonic valence ANOVA. There were only two reliable effects: an interaction between creativity task and timepoint, $F(1,80) = 17.95$, $p < 0.001$, $\eta^2 = 0.18$, that was modified by a three-way interaction with activity, $F(1,80) = 4.06$, $p < 0.05$, $\eta^2 = .05$. Separate ANOVAs showed that the task-by-timepoint interaction was reliable with performance, $F(1, 42) = 17.76$, $p < 0.01$, $\eta^2 = 0.30$, and but not with preparation, $F(1,38) = 2.85$, $p > 0.05$, $\eta^2 = 0.07$. As shown in Figure 1A, performing and, to a lesser degree, preparing for the DT task induced a more positive mood whereas performing and, to a lesser degree, preparing for the CT task induced a more negative mood. Interestingly, this pattern did not change when the individual performance in the creativity tasks was entered into the equation (as covariate) in the analyses of the performance groups (DT and CT), which rules out an account in terms of task difficulty and/or stress.

The analysis of the physical arousal score revealed only one reliable effect: an interaction between creativity task and timepoint, $F(1,80) = 6.11$, $p < 0.05$, $\eta^2 = 0.07$, even though the three-way interaction with activity approached significance, $F(1,80) = 3.24$, $p = 0.07$, $\eta^2 = 0.04$. Separate ANOVAs showed that the task-by-timepoint interaction was reliable with performance, $F(1,42) = 7.43$, $p < 0.01$, $\eta^2 = 0.15$, but not with preparation, $F(1,38) < 1$. As shown in Figure 1B, the outcome showed the same pattern as the hedonic valence data. The analysis of the worry score did not show any reliable effect, Fs<1.

DISCUSSION

The results are clear-cut. Most importantly, carrying out a task that requires creative thinking affects people's mood. This provides considerable support for the idea that mood and cognition are not only related, but that this relation is fully reciprocal (Bar, 2009; Gray, 2004; Gross, 2002; Salovey et al., 2002). Moreover, divergent and convergent thinking impact mood in opposite ways: divergent thinking is improving one's mood while convergent thinking is lowering it. This dissociation is consistent with Akbari Chermahini and

Hommel's (2010) observation that both types of thinking are related to one's dopamine level—the common currency that apparently mediates the interaction—but that these two relationships follow rather different functions. It also fits with the observation of Hommel et al. (2011) that convergent and divergent thinking support two different types of cognitive control. Finally, mood changes were particularly pronounced with actual task performance but mere preparation was also effective to some degree. The latter observation might suggest that divergent thinking and convergent thinking tasks evoke different, apparently even opposite stereotypical reactions which, as in intelligence tasks, do not seem to reflect individual performance and, thus, objective task characteristics. However, this effect might also indicate that preparing for divergent versus convergent thinking foreshadows the stronger performance-related effect, for instance because preparation involves the pre-activation of the very task-specific sets or states that are responsible for the mood swings that we observed. In any case, however, actually carrying out the task and, thus, the related thinking operations further boosts the task-specific mood changes to a degree that goes beyond possible stereotypical responses.

From a broader perspective, the outcome pattern of our study might be interpreted in three different ways. According to the first, the divergent-thinking task is just "more fun". However, even though this account seems particularly intuitive (and is shared by many colleagues to whom we reported our findings), closer consideration reveals that its logical structure and actual meaning is less clear. To render this "fun" explanation more than a theoretically meaningless re-description of the findings, it would be necessary to identify some sort of factor that is responsible for the resulting fun or perceived pleasantness. The task's physical or structural characteristics are unlikely candidates, as it would be difficult to argue that being presented with three target stimuli and/or producing one response per trial is depressing while encountering one stimulus and/or producing a number of responses per trial is pleasant (especially if one considers that participants in the two preparation groups produced even more output in the filler task). More plausible would be a factor that also considers how participants deal with the characteristics of the tasks. On the one hand, these might be motivational factors reflecting the type and degree of challenge the different tasks are posing, and the motivational state this challenge creates. On the other hand, it might be more cognitive factors that reflect the kind of task sets the different tasks require. We will discuss these two possibilities in turn.

According to a motivational account, the different emotional consequences of the two tasks might reflect differences in their demand characteristics. For instance, one may consider the convergent-thinking task more difficult than the divergent-thinking task (e.g., because it constrains responses more and/or because it takes longer to find a correct solution) and assume that easier tasks induce more positive, and more difficult tasks more negative mood. Even though this interpretation may seem intuitively plausible, closer consideration reveals that it runs into a number of theoretical and empirical problems. For one, people are known to be more motivated by tasks that are difficult but solvable than by easy tasks (for an overview, see Weiner, 1980). If we assume that combining high motivation and success is associated with positive mood, this suggests that, if anything, participants should show more positive mood after performing the convergent-thinking task. A similar prediction could be made based on reward-related brain processes. It is known that reward-induced brain responses are more pronounced the more unexpected success in a task is (Schultz, 1998). Given that reward is commonly assumed to lead to positive affect, this would suggest that identifying a correct response in a more difficult task is more rewarding and, thus, induces more positive mood than doing so in an easier task. Moreover, it makes sense to assume that the subjective difficulty is negatively correlated to the individual success. If so, participants that are performing more poorly in the convergent-thinking task should exhibit more negative-going mood than better-performing participants. However, we have seen that entering individual performance into the analysis did not explain the task-by-timepoint interaction, which does not seem to support an account in terms of subjective difficulty.

This motivational interpretation considers the observed changes in mood mere byproducts of task difficulty or related task characteristics without a particular functional role or meaning. However, it is also possible that the mood changes reflect the way the cognitive system is optimizing itself for the task at hand. The concept of mood refers to the personal level of analysis and implies a person having or being in the particular mood. At a systems level of analysis, this “being in a particular mood” implies the existence of a specific functional or neural state that corresponds to, and is correlated with this phenomenal experience. The probably most systematic correlate of mood changes are changes in the individual dopamine level (Ashby et al., 1999)—even though other neurotransmitter systems are also likely to be involved. Indeed, there is evidence from animal and human studies suggesting that the processing of positive and negative events is correlated with increases and decreases of the current dopamine level, respectively (Akbari Chermahini & Hommel, 2011; Schultz, 1998). This implies that being in good or bad mood can be considered the experiential reflection of a brain state that, among other things, comprises of an elevated or reduced dopamine level, respectively—mood and dopamine levels are thus two sides of the same coin. Interestingly, the current dopamine level is systematically related to performance in convergent- and divergent-thinking tasks: while convergent thinking benefits from a low level, divergent thinking is best with a medium-to-high level (Akbari Chermahini & Hommel, 2010). This implies that the optimal preparation for a convergent-thinking task would indeed consist in reducing the dopamine level—which would be accompanied by a more negative-going mood (Akbari Chermahini & Hommel, 2011)—while the optimal preparation for a divergent-thinking task would consists in elevating the dopamine level—which would be accompanied by positive-going mood. In other words, the task-related mood changes we observed might be the experiential reflection of adaptive neuromodular changes that make sure that the cognitive system is optimally prepared for the task at hand.

We admit these are only speculations that call for further investigation. But they suggest the interesting possibility that people might be able to self-regulate their current dopamine level by adapting mood-related brain states to the cognitive requirements of the present task. From a more functional perspective, this would fit the idea that mood and cognitive control are more tightly related than commonly thought (Bar, 2009). Mood may thus not necessarily, or not only, be considered a separable cause of particular control states but, rather, as the phenomenal expression of having such control states in place. In other words, different control states may feel differently. As our observations suggest, establishing and/or maintaining a focused, exclusive control state may come along with rather negative mood whereas a more distributed control state comes with rather positive mood.

If true, this has two interesting implications. Theoretically speaking, it would support approaches to human emotion that consider the phenomenal side effects of emotions—how an emotion makes one feel—less important than their functional implications—what an emotion does for our information processing. According to such approaches, different emotions go along with different types of readiness for particular types of actions (Frijda, 2007; James, 1884), such as fear and avoidance behavior (Le Doux, 1996). Our present findings suggest that this may not only hold for overt actions and action preparation but also for more general cognitive-control states. Practically speaking, the apparently close link between particular control states and particular mood states has the advantage of providing cues to assess the control state a given person is currently in. That is, someone's degree of positive or negative mood, and systematic changes therein, might provide important information about whether he or she is in a more focused or a more distributed control state. Given that mood states are commonly communicated through a broad range of perceivable cues, such as facial expression, body posture, or verbal style, this raises the exciting possibility that we might be able to directly perceive the control states of other people.

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CHAPTER 6

Cognitive control of convergent and divergent thinking: A control-state approach to human creativity

Hommel, B., Akbari Chermahini, S., van den Wildenberg, W.P.M., & Colzato, L.S. (submitted). Cognitive control of convergent and divergent thinking: A control-state approach to human creativity.

ABSTRACT

Five experiments sought to characterize the cognitive-control states driving convergent and divergent thinking. The creativity tasks served as primes that were expected to exert specific effects on cognitive control in other, unrelated probe tasks. Experiments 1-3 showed that convergent-thinking primes made conflict resolution in a global-local task, a semantic Stroop and a Simon task more efficient than divergent-thinking primes. Experiment 4 showed no relation between either prime task and stop-signal performance, thus ruling out contributions of inhibitory processes to the priming effect. Experiment 5 showed that divergent-thinking primes improved performance in an Attentional-Blink task. Findings suggest that convergent thinking induces a control state that emphasizes the top-down biasing of creative solutions and/or local competition between them, whereas divergent thinking is associated with reduced top-down control and/or local competition.

INTRODUCTION

Even though creativity is arguably the most important determinant of mankind's intellectual evolution, surprisingly little is known about how creativity actually works (Sternberg, Kaufman & Pretz, 2002). One important obstacle on the way to a systematic investigation of the mechanics of creativity results from disagreements regarding how to define the research question: should one aim to explain how creative products emerge, how more creative people differ from less creative ones, or which processes are involved in the creative act (see Brown, 1989; Runco, 2007)? These questions are further complicated by increasing evidence suggesting that creative acts rely on the interplay of multiple cognitive processes and neural networks (e.g., Dietrich, 2004; Eysenck, 1993; Heilman, 2005). To tackle some of these problems and avoid others, the present study considered creativity not as a *trait* that a given person may or may not have but, rather, as a particular type of behavior that emerges from a particular *state* (or a set of states) of the cognitive system that affects the way cognitive operations are run. Processes that are not directly involved in information processing but that target other processes are commonly thought of as control processes (Monsell, 1996), which renders our account a control-state approach to creativity.

According to Guilford (1950, 1967), the main ingredients of creativity are divergent and convergent thinking, even though we do not claim that these are the only processes involved in creative acts. Divergent thinking is taken to represent a style of thinking that allows many new ideas being generated, in a context where more than one solution is correct. The probably best example is a brainstorming session, which has the aim of generating as many ideas on a particular issue as possible. Guilford's (1967) Alternate Uses Task (AUT) to assess the productivity of divergent thinking follows the same scenario: participants are presented with a particular object, such as a pen, and they are to generate as many possible uses of this object as possible. In contrast, convergent thinking is considered a process of generating one possible solution to a particular problem. It emphasizes speed and relies on high accuracy and logic. Mednick's (1962) Remote Associates Task (RAT) that aims to assess convergent thinking fits with this profile: participants are presented with three unrelated words, such as "time", "hair", and "stretch", and are to identify the common associate ("long"). It makes sense to assume that divergent and convergent thinking are basic ingredients of many, if not all truly creative acts, which often comprise of a search for possibilities and options followed by the translation of the preferred option into reality (Hommel, in press).

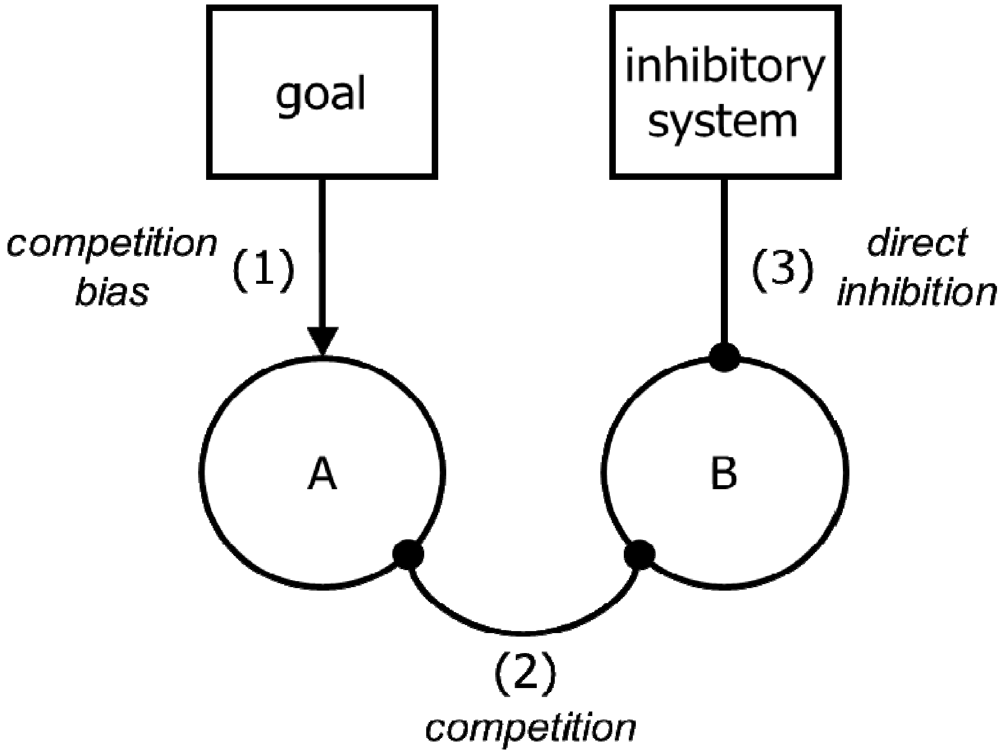

Figure 1: Possible mechanisms involved in selecting a goal-related target representation (of a perceptual or action event, or a thought) from a set of two competing alternatives. The target A might win the competition with an alternative B because: A is selectively supported by the goal representation through a facilitatory connection (Route 1: competition bias); A receives other types of associative support that suffices to outcompete B (Route 2: local competition); B is directly inhibited through some inhibitory control system (Route 3: direct inhibition).

Let us now consider the cognitive control states that would allow or be useful for divergent and convergent thinking. According to Colzato et al. (2008), the selection of stimulus or response representations (or thoughts, as in our case) can be controlled or biased in at least two different ways. Figure 1 sketches the situation where a decision needs to be made between alternative A (the "correct" or most appropriate alternative) and the competing alternative B. The competition between the two alternatives is represented by mutually inhibitory connections between their representations (Route 2), which captures the assumption that decision-making in biological systems is competitive (Bogacz, 2007). Competition is likely to yield winners and losers, so that it can be considered as a control mechanism that eventually will favor one alternative over others. Another, not necessarily exclusive way to facilitate the selection of the appropriate alternative is indicated in the figure as Route 1: The preferred alternative might receive top-down support from the representation of the action goal. This control strategy is underlying the biased-competition approach of Duncan, Humphreys, and Ward (1997), the conflict-resolution model of Cohen and colleagues (Botvinick, Braver, Barch, Carter & Cohen, 2001; Cohen, Dunbar & McClelland, 1990), the task-switching model of Gilbert and Shallice (2002), and many other control models.

As we assume that control states are affecting the way control is exerted, there are two major ways to modulate the processes captured in Figure 1. First, a control state might modulate the strength of top-down bias (Route 1) and, thus, increase or decrease the degree to which the goal representation supports one alternative in its competition with others. Second, a control state might modulate the strength of mutual local inhibition between alternatives (Route 2) and, thus, the degree to which competitors "suffer" from the support and selection of another alternative.[2]

Convergent thinking would seem to benefit from a strong degree of goal-directedness that is steering and efficiently constraining the search for the right concept or idea. This implies reliance on Route 1 and, hence, on a strong top-down bias of decision-making. Duncan, Emslie, Williams, Johnson, and Freer (1996) have suggested that individuals differ with respect to the degree to which they can provide or at least maintain such a top-down bias. In particular, they have claimed, and provided evidence that Spearman's g, a measure of fluid

[2] Some authors have pleaded for what in Figure 1 is indicated as Route 3: the inhibition of unwanted alternatives. We will introduce and further discuss this possibility in Experiment 4.

intelligence, is positively correlated with performance on a task that requires participants to maintain top-down biases over time. This fits with the observation that performance on convergent-thinking tasks is positively correlated with fluid intelligence (Akbari Chermahini & Hommel, 2010).

In contrast, divergent thinking would not seem to benefit from strong top-down control but, if anything, from rather weak and “allowing” top-down guidance. Moreover, efficient divergent thinking would seem to require jumping from one option to another, which suggests that the mutual inhibition between alternative thoughts should be weak. This kind of control state seems to be consistent with a number of previous assumptions and recent findings. For instance, Eysenck (1993) has related the divergent aspect of creativity to schizophrenia and suggested that schizophrenic patients and healthy creative individuals share a certain lack of constraints and inhibition in their thinking. Indeed, several authors since Bleuler (1978) have characterized schizophrenics as showing a kind of “widening of the associative horizon” (Eysenck, 1993). Along the same lines, Ashby, Isen, and Turken (1999) have associated higher dopamine levels (as to be found in schizophrenic patients) with greater cognitive flexibility and less inhibition between alternative thoughts (cf., Cohen & Servan-Schreiber, 1992). In healthy participants, carriers of the DRD2 TAQ IA polymorphism (which results in a 30-40% reduction in DA-D2 receptor density—a receptor that drives inhibitory processes) were shown to perform significantly better in a divergent-thinking task (Reuter, Roth, Holve, & Hennig, 2006).

These considerations suggest that the convergent- and divergent-thinking components of human creativity imply two different, to at least some degree opposite cognitive-control states that facilitate or even generate the respective thinking style. In particular, convergent thinking seems to require either strong top-down control or strong local competition, or both, whereas divergent thinking seems to call for weak top-down control and/or weak local competition. The aim of the present study was to seek for evidence, if possible, for the existence of these two types of control states and for their hypothesized relationship with particular thinking styles. Our general rationale was to characterize the hypothetical control states by studying the way they are affecting (supporting or interfering with) cognitive control in nominally and logically unrelated tasks that are known to require particular types of control.

The rationale underlying our empirical approach was based on the widely shared assumption that control states are inert and therefore changing slowly, especially in the absence of a pressing need for change. From a theoretical perspective, this is suggested by the assumption that control states (or meta-parameters: Doya, 2002) are globally represented and affecting the entire cognitive system (Baars, 1988; James, 1890; Monsell, 1996). Empirical support for this idea has been provided by Memelink and Hommel (2005, 2006), who showed that the attentional relevance of horizontal versus vertical spatial relationships in one task affects the relative weighting of horizontal and vertical stimulus and response codes in a logically unrelated but temporally overlapping stimulus-response compatibility task. In other words, the attentional set in one task automatically affects the attentional set in another. A similar observation has been made by Meiran, Hommel, Bibi, and Lev (2002). They had participants carry out sequences of "ready" responses (to signal that they were optimally prepared) and choice-reaction responses, and consistently found positive (rather than the expected negative) correlations between the latencies for these two types of responses. This suggests that participants' speed-accuracy settings fluctuate spontaneously during a task and they do so sufficiently slowly to impact temporally close responses in the same way.

If performing a convergent- or divergent-thinking task requires establishing a particular control state, and if this state is relatively inert—so the idea underlying our study—it is likely to spill over to and thus affect other, logically unrelated but temporally close tasks. If so, the characteristics of the control state adopted in the preceding thinking task (the *priming task*, as we will call it) should become visible through the way performance in the following task (the *probe task*) changes as a function of the type of the priming task. If the probe task can be expected to require strong top-down control and/or strong local competition—as many laboratory tasks do—performance thereon should be better if being primed by a convergent-thinking than a divergent-thinking task. In the first three experiments, we applied this reasoning to several tasks that can be assumed to tap different processes in the information-processing chain from perception to action. A fourth experiment tested whether the priming effects obtained in Experiments 1-3 are likely to reflect inhibitory processes. Finally, a fifth experiment included a probe task that is likely to benefit more from a weaker form of top-down control and/or local competition, so that performance thereon was expected to be better if being primed by a divergent-thinking than a convergent-thinking task.

EXPERIMENT 1 (GLOBAL-LOCAL TASK)

The first experiment considered the global-local task developed by Navon (1977) as a probe task. As Navon and others have shown, people can attend different levels of hierarchical stimuli, such as large letters made of smaller letters. Attending to the global aspect of such stimuli is commonly easier and perhaps more natural, as can be seen in faster reaction times and/or more accurate performance in response to global than to local stimulus features (the global-precedence effect; Navon, 1977). Nevertheless, people can be successfully instructed to attend to the local level as well, suggesting that the hierarchical level to which attention is being directed is under cognitive control. Indeed, the cognitive control model of Logan and Gordon (2001) foresees a particular control parameter that is assumed to regulate the currently attended stimulus level.

Maintaining a particular control parameter value or state in the face of stimuli that are open to multiple interpretations can be assumed to rely on, or at least encourage the adoption of a control strategy that relies on strong top-down support of decision-making (Route 1) and/or strong local competition (Route 2) to render the alternative interpretations mutually exclusive. If so, one would expect that a convergent-thinking task as a prime facilitates, or is at least more compatible with the natural mode of operation. In contrast, a divergent-thinking task as a prime would be incompatible with this natural mode and should therefore make it less efficient. If we assume that the difference in performance between responding to the global versus local stimulus level expresses the difficulty to overrule the natural tendency to attend to the global level, we would thus expect that this difference is smaller with a convergent-thinking prime than with a divergent-thinking prime.

Method

Participants

Nineteen young healthy adults served as subjects for partial fulfillment of course credit. Informed consent was obtained from all participants after the nature of the study were explained to them. The protocol was approved by the local ethical committee (Leiden University, Faculty of Social and Behavioral Sciences).

Apparatus and stimuli

The experiment was controlled by a Switch computer attached to a Philips 17" monitor. Responses were made by pressing the “Z” or “?” of the QWERTY computer keyboard with the left and right index finger, respectively. The target stimuli were adopted from Huizinga, Dolan, and van der Molen (2006), and consisted of geometric figures (see Figure 2) presented in red on a black screen. Larger (global) rectangles/squares consisted of smaller (local) rectangles or squares. Global stimuli (i.e., squares or rectangles; 93 x 93 pixels or 93 x 189 pixels respectively) were composed of many smaller “local” stimuli (i.e., squares or rectangles; 21 x 21 pixels or 8 x 46 pixels respectively). The space between the local elements of a stimulus was 3 pixels. A global square consisted of 16 small squares or 8 small rectangles; a global rectangle consisted of 32 small squares or 16 small rectangles. The experiment was composed by 3 practice and 3 experimental blocks. Convergent and divergent conditions were created by presenting participants with two paper and pencil creativity tasks (a convergent thinking task and a divergent thinking task).

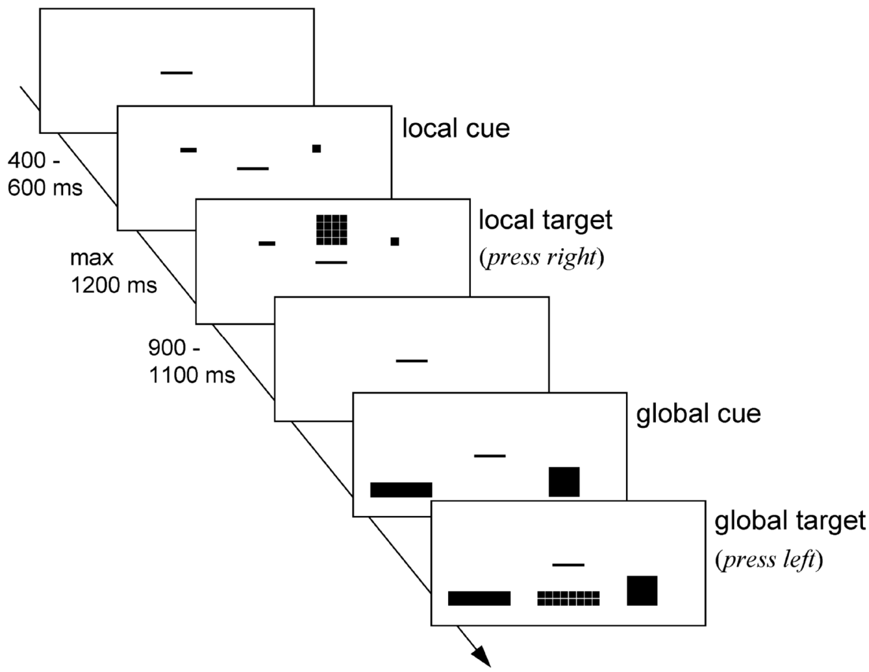

Figure 2: Sequence of events in Experiment 1.

Procedure and Design

Participants served in two 50-min sessions separated by one week. In one session they constantly switched between performing the Remote Association Task (based on Mednick, 1962, and translated into Dutch) for two minutes to induce convergent thinking (the prime task) and completing a block of the global-local taskadopted from Huizinga et al. (2006; see below) as probe task. In the other session they constantly switched between carrying out the Alternative Use Task (Guilford, 1967) for two minutes to induce divergent thinking (the prime task) and performing a block of the global-local probe task. Given that the experiment was composed by three practice and three experimental blocks, participants were to switch between the prime and the probe task six times per session.The order of these two types of sessions was counterbalanced across participants.

Remote Association Task (convergent thinking)

In this task, participants are presented with three unrelated words (such as time, hair, and stretch) and are asked to find a common associate (long). Our Dutch version comprised of 30 items (Cronbach's alpha = .85; see Akbari Chermahini & Hommel, 2011), which were to be responded to within 10 min.

Alternate Uses Task (divergent thinking)

In this task, participants were asked to list as many possible uses for six common household items (brick, shoe, newspaper, pen, towel, bottle) as they can within 10 min. The results can be scored in several ways with flexibility, the number of different categories used, being the most consistent and reliable (Akbari Chermahini & Hommel, 2010).

Global-Local Task

In this task, participants responded to randomly presented rectangles or squares by pressing a left or right response button, respectively. Three blocks of trials were administered, two training blocks in which the instruction (global or local) was constant across all trials followed by the experimental block in which participants switch between the global and the local task—a condition that increases the global-local effect. In one of the two training blocks, participants responded to the local figures and in the other block they responded to the global figure. The order of the training blocks was randomized across participants and each block consisted of 80 trials. In the third block participants alternated between predictable sequences of four "local" and four "global" trials (90 practice trials and 150 to-be-analyzed experimental trials). A cue indicated to which dimension (global or local) the participants should respond. Cues that related to the global (local) dimension consisted of a big (small) square, presented at one side of the target stimulus, and a big (small) rectangle, presented at the other side of the target stimulus. Cue and target remained on the screen until a response was given or 3500 ms had passed. The time interval between presentation of the cue and of the target stimulus was 500 ms and the interval between responses and the next presentation of the cue was 1000 ms. Participants were to respond as fast as possible while avoiding errors.

Results

Performance in the two priming tasks was good and comparable to performance in other studies (e.g., Akbari Chermahini & Hommel, 2010). Participants produced about 15 correct responses on average in the Remote Association Task (*M*=14.8 and *SD*=4.5) and used about 33 different categories in the Alternate Uses Task (*M*=33.3 and *SD*=10.0).

Mean RTs and proportions of errors from the global-local task were analyzed as a function of priming task (convergent vs. divergent thinking), target level (global vs. local), congruency between the stimuli on the two levels (congruent vs. incongruent), and task switch (i.e., same vs. different target level as in previous trial: task repetition vs. alternation). Four-way ANOVAs for dependent measures were run on RTs and error rates.

RTs revealed three reliable main effects: The effect of switch, $F(1,18)=91.56$, $p<.0001$, MSE = 1531.26, η^2p = 0.84, was due to that repeating the task allowed for faster responding than switching between target levels (346 vs. 389 ms); the effect of target level, $F(1,18)=85.15$, $p<.0001$, MSE = 1533.82, η^2p = 0.83, reflected the well-known global-precedence effect (Navon, 1977), that is, faster responses to globally than locally defined targets (347 vs. 388 ms); and the congruency effect, $F(1,18)=36.66$, $p<.0001$, MSE = 1301.12, η^2p = 0.67, indicated interference from the non-target level, that is, faster responses if the stimulus at the currently irrelevant level was congruent with the present target than if that stimulus was incongruent (355 vs. 380 ms).

More important for present purposes, priming task interacted with target level, $F(1,18)=7.54$, $p<.05$, MSE = 1301.12, η^2p = 0.30. As suggested by Figure 3, the effect of target level was reliable for both convergent and divergent conditions, $F(1,18)=42.58$, $p<.0001$, MSE = 962.00, η^2p = 0.70, and $F(1,18)=72.18$, $p<.0001$, MSE = 1320.33, η^2p = 0.80, respectively, but, as predicted, the global preference effect was reduced in the context of convergent thinking.

The error rates revealed no interactions but three main effects only: switch, $F(1,18)=9.00$, $p<.01$, MSE = 54.19, $\eta^2 p = 0.33$, indicating that repeating the task produced less errors than switching between target levels (8.5% vs. 11.1%); target level, $F(1,18)=25.30$, $p<.0001$, MSE = 89.32, $\eta^2 p = 0.53$, showing more errors to globally than locally defined targets (12.58% vs. 7.13%); and congruency, $F(1,18)=70.73$, $p<.0001$, MSE = 104.83, $\eta^2 p = 0.79$, reflecting the interference of the irrelevant target level, as indicated by a smaller proportion of errors on congruent as compared to incongruent trials (4.9% vs. 14.8%).

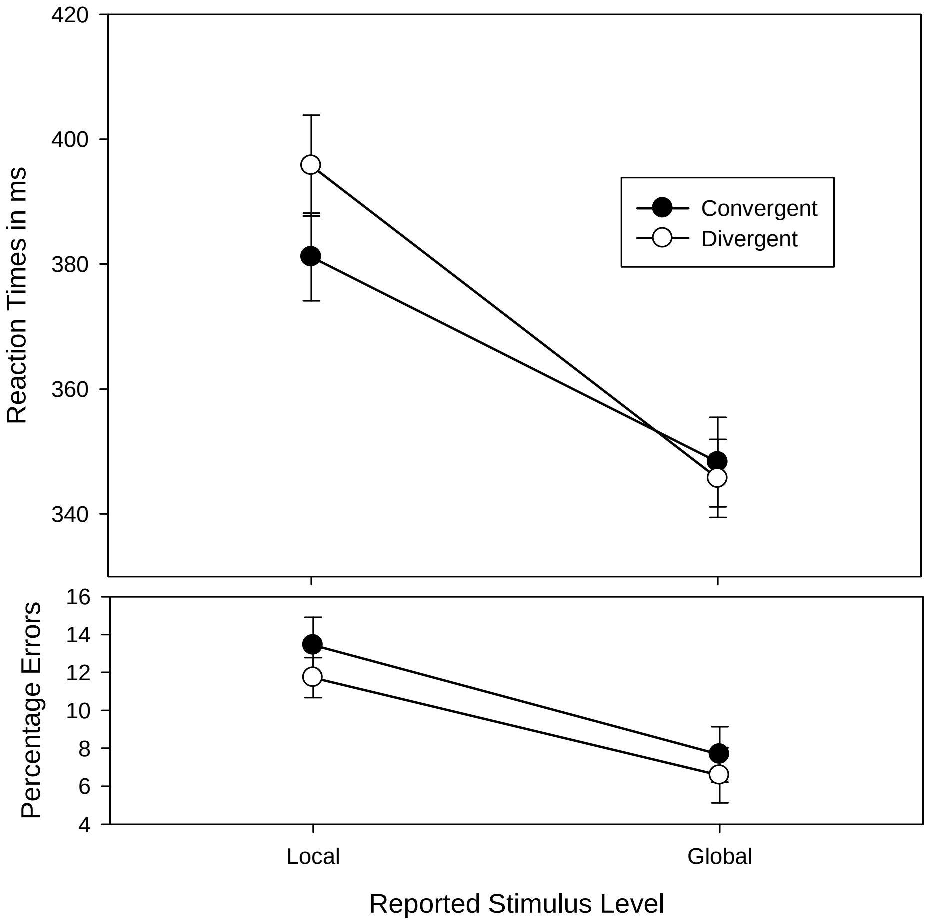

Figure 3: Mean reaction times and error percentages in Experiment 1, as a function of reported stimulus level (global vs. local) and priming task (convergent vs. divergent thinking).

Discussion

We expected that the cognitive-control state required for convergent thinking would be more consistent with maintaining a less dominant attentional set than the state required for divergent thinking. If so, one would expect that the global precedence effect (i.e., the performance benefit associated with responses to global as compared to local stimulus features) is less pronounced after having performed a convergent-thinking task than after a divergent-thinking task. This is exactly what the findings show. As one would expect, performance on the easier and more natural global task is unaffected by the priming task, whereas the more challenging local task, which is more likely to draw and depend on control processes, yields better performance if being primed by the convergent-thinking than by the divergent-thinking task.

A somewhat unexpected outcome is the inverted global-precedence effect in the error rates, suggesting better performance in the local task. Importantly, however, this is a mere main effect that cannot account for the crucial interaction observed in the RTs.

EXPERIMENT 2 (STROOP TASK)

Even though the global-local task draws on cognitive control, it is a task that taps into rather "early" attentional operations on (the outcomes of) perceptual organization processes. Our next step was to see whether interactions between creativity tasks and cognitive control can also be found for attentional control processes operating on somewhat more abstract stimulus representations. A perhaps obvious choice in this context is the Stroop task, which requires participants to respond to the color of colored color words—the less familiar and less overlearned response. Since the seminal study of Stroop (1935) it is known that people perform better in this task if they are presented with congruent stimuli, such as the word BLUE in blue ink, than with incongruent stimuli, such as the word GREEN in blue ink (for an overview, see MacLeod, 1991).

Researchers and available models agree that the Stroop effect is due to some sort of conflict between color- and word-related codes, which calls upon cognitive control to solve it (Cohen et al., 1990). Indeed, given that the stimulus affords different and conflicting types of responding, people need to rely on the representation and top-down impact of the instructed action goal to name the color of the stimuli. However, researchers and models do not agree on which kinds of codes are involved in, and responsible for the conflict: suggestions range from perceptual (e.g., Kornblum, 1994) and semantic codes (Seymour, 1977) to response representations (Dyer, 1973), often driven by the unrealistic assumption that phenomena as complex as the Stroop effect must have no more than one functional locus. To make sure that we are tapping conflict between codes that are fairly abstract, we therefore employed a semantic version of the Stroop task that was developed by Klein (1964).

As Klein demonstrated, color-naming responses are not only delayed if they refer to the ink of incongruent color words but also if they refer to color associates, such as the words "frog" (associated with green), "sun" (associated with yellow), or "fire" (associated with red). Even though this version has the disadvantage of producing a smaller congruency effect than the standard Stroop task, it rules out the possibility that the conflict takes place between perceptual codes—as was the case in Experiment 1. Hence, Experiment 2 was likely to target a different control domain than Experiment 1 did. Nevertheless, our predictions were similar. If successful performance in the Stroop task requires strong top-down guidance from the task goal, this control state should be more compatible with the control state established in a convergent-thinking task If so, the Stroop effect (i.e., the difference between performance on congruent and incongruent Stroop stimuli) should be smaller for convergent-thinking primes than for divergent-thinking primes.

Method

Twenty new young healthy adults served as subjects for partial fulfillment of course credit. They satisfied the same criteria as in Experiment 1. Convergent- and divergent-thinking prime conditions were created as in Experiment 1, the procedure was analogous (except that the global-local task was replaced by the Stroop task), and the apparatus was identical.

In the Stroop task, participants responded to yellow, blue, green, and red words by pressing the "Z", "X", ">" or "?" buttons of the QWERTY computer keyboard, respectively.

Eight Dutch color-associates served as (irrelevant) word stimuli: “boom” (tree), “zee” (sea), “zon” (sun), “citroen” (lemon), “gras” (grass), “lucht” (sky), “bloed” (blood), and “vuur” (fire), presented on the black background of the computer screen. The words appeared in either their semantically implied color (50% congruent trials; e.g., the word *bloed* in red ink) or in a semantically unrelated color (50% incongruent trials; e.g., the word *bloed* in green ink). The Stroop task took about 10 min, in which participants were asked to respond to the color of the 144 randomly presented color words while ignoring word meanings. The target remained on the screen until a response was given. During inter stimulus intervals a white fixation cross stayed on the black screen. The interval between presentation of the cue and of the target stimulus was 500 ms. The Stroop task was composed of two experimental blocks, so that participants were to switch between the prime and the probe task two times per session.

Results and Discussion

Performance in the Remote Association Task (M=7.4 and SD=3.5) and the Alternate Uses Task (M=13.2 and SD=4.2) was good; the lower absolute scores as compared to Experiment 1 reflected the fact that participants had only 2 instead of 6 2-minute intervals to complete the creativity tasks. Mean RTs and proportions of errors from the Stroop task were analyzed as a function of priming task (convergent vs. divergent thinking) and congruency (congruent vs. incongruent). Two-way ANOVAs were run on RTs and error rates. RTs revealed a reliable main effect for congruency, $F(1,19)=13.23$, $p<0.01$, $MSE = 3923.5$, $\eta^2p = 0.41$, that is, faster responses to congruent (588 ms) than incongruent stimuli (602 ms). Importantly, this Stroop-like effect was modified by priming task, $F(1,19)= 4.48$, $p<0.05$, $MSE = 1206.6$, $\eta^2p = 0.19$. As suggested by Figure 4, congruency was reliable for both convergent and divergent conditions but, as predicted, this Stroop-like effect was smaller for the convergent-thinking than for the divergent-thinking prime. The analysis of the error rates revealed no significant effect. This outcome supports our assumption that the control state implemented in the convergent-thinking task was more compatible with the control state that is functional for performing the Stroop task than the control state implemented in the divergent-thinking task was.

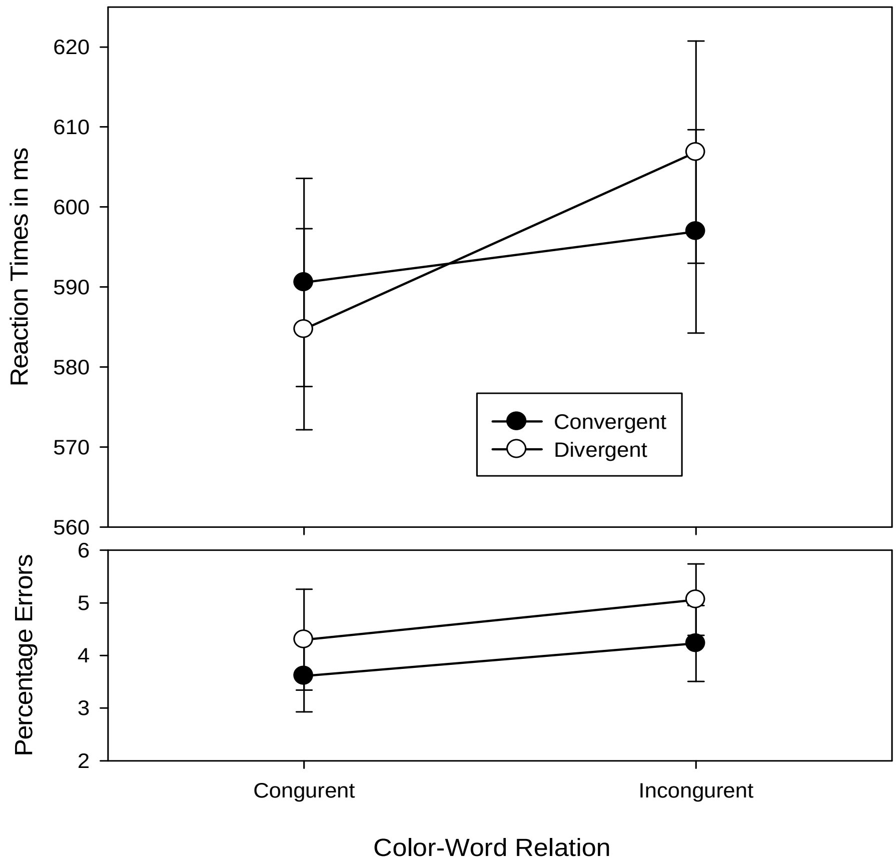

Figure 4: Mean reaction times and error percentages in Experiment 2, as a function of the relationship between named color and the meaning of the stimulus word (congruent vs. incongruent) and priming task (convergent vs. divergent thinking).

EXPERIMENT 3 (SIMON TASK)

The outcome of Experiment 2 suggests that the control-state-compatibility effect observed in a perceptual-conflict task in Experiment 1 generalizes to tasks that are likely to involve semantic conflicts. In Experiment 3 we went on by testing whether the same pattern of results can also be demonstrated in a task that taps into response conflict. The arguably purest assessment of response conflict is represented by the Simon task (cf., Hommel, 2011). In this task, participants respond to a non-spatial feature of commonly visual stimuli by pressing left and right response buttons. Importantly, the location of the stimulus varies randomly and is thus sometimes corresponding with the location of the correct response (the compatible condition) and sometimes not (the incompatible condition). As one might expect, performance is better with compatible than with incompatible relationships between stimulus location and response—the Simon effect (Simon & Small, 1969). Given that this task does not include any congruency or incongruency between the stimulus features (i.e., the non-spatial feature, such as color, and the spatial location), the Simon effect can be taken as a pure measure of response conflict (Hommel, 2011; Kornblum, Hasbroucq & Osman, 1990). Even though the type of conflict is likely to be different from the effects studied in Experiments 1 and 2, it makes sense to assume that the successfully performing the Simon task relies on a similar type of top-down support of the relevant stimulus feature as we have assumed for the global-local task and the Stroop task. Accordingly, we expected that the Simon effect would be smaller if being primed by a convergent-thinking task.

Method

Nineteen new young healthy adults served as subjects for partial fulfillment of course credit. The method was as in Experiment 1 except that the global-local task was replaced by the Simon task.

In the Simon task, a small (.5 x .5 cm) dark-grey fixation square stayed at the center of the screen. The target stimulus was either a green or a blue circle (1.5 cm in diameter) that appeared left or right of fixation. Circle color and location varied randomly but equiprobably. Responses were made by pressing the “Z” or “?” buttons on the computer keyboard with the left or right index finger, respectively.

Participants made speeded discriminative responses to the color of the circle, which stayed on screen until a response was given or 1500 ms had passed. Intervals between subsequent stimuli varied randomly but equiprobably, from 1750-2250 ms in steps of 100 ms. Participants were asked to ignore the location of the stimulus and to react as fast as possible while keeping error rates below 15% on average; feedback was provided at the end of a trial block. The task consisted of 60 practice trials (practice block) and 300 experimental trials (5 experimental blocks), and took about 25 min. to complete. Participants were thus to switch between the prime and the probe task six times per session.

Results and Discussion

Participants showed good performance in the Remote Association Task (*M*=7.7 and *SD*= 2.9) and the Alternate Uses Task (*M*=33 and *SD*=7.04). Mean RTs and proportions of errors from the Simon task were analyzed as a function of priming task (convergent vs. divergent thinking) and compatibility (compatible vs. incompatible). There was reliable main effect of compatibility in RTs, $F(1,18)=227.95$, $p<0.001$, MSE = 23207.49, $\eta^2p = 0.42$, showing faster responses in compatible than incompatible conditions (346 vs. 381 ms). Importantly, compatibility interacted with priming task, $F(1, 18)= 8.14$, $p=0.011$, MSE = 145.84, $\eta^2p = 0.31$. While the compatibility was reliable for both types of priming, the Simon effect was reduced by the convergent-thinking prime (see Figure 5). The analysis of the error rates revealed no significant effect. We can thus conclude that the control-state-compatibility effect obtained in Experiments 1 and 2 generalizes to a task tapping into response conflict.

EXPERIMENT 4 (STOP-SIGNAL TASK)

The results from Experiments 1-3 suggest that the control states that creativity tasks induce exert specific effects on logically unrelated laboratory tasks in which perceptual, semantic, or response conflicts are to be resolved. According to our theoretical reasoning, these conflicts reflect competition between the cognitive representations of stimulus events and/or actions, which needs to be resolved by biasing the interaction in such a way that goal-compatible representations are strengthened and therefore winning the competition. The role of a suitable control state in this scenario would be to provide a configuration of the cognitive system that maximizes this bias, be it through strengthening the competition bias or local competition or both.

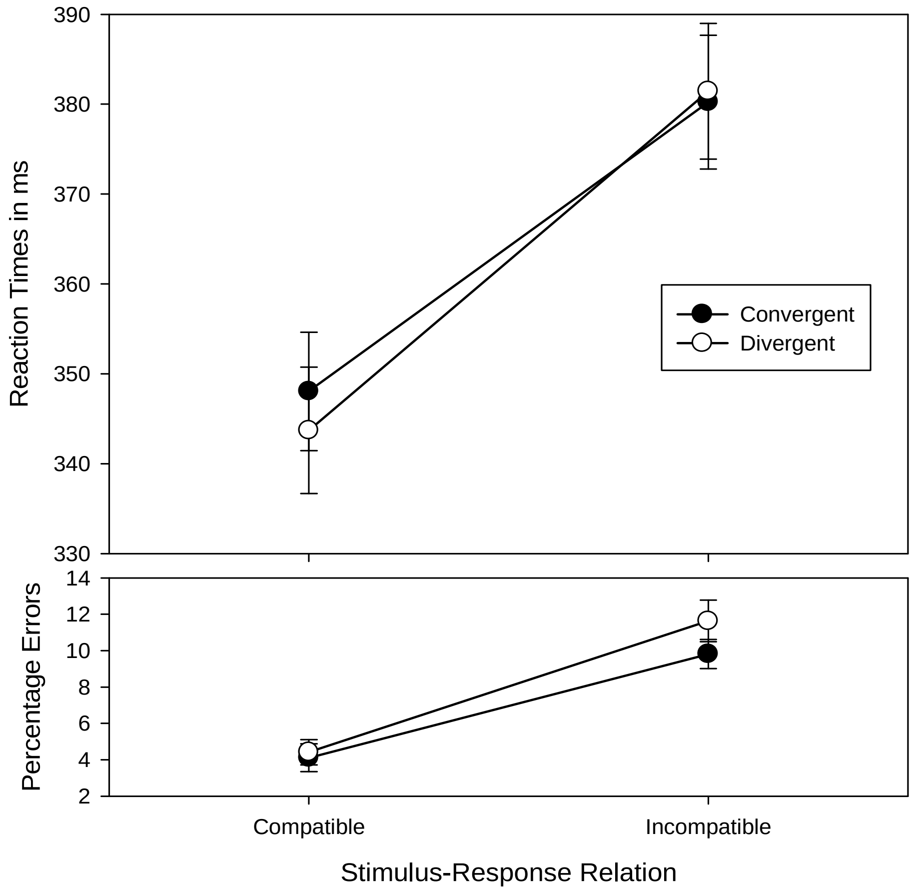

Figure 5: Mean reaction times and error percentages in Experiment 3, as a function of the relationship between stimulus location and response location (compatible vs. incompatible) and priming task (convergent vs. divergent thinking).

An alternative scenario is possible however. Various authors since Freud (1896) have emphasized the importance of inhibitory processes in regulating intentional behavior. In particular, researchers have considered the direct inhibition of response representations as a possible alternative or addition to competition biases (e.g., Harnishfeger, 1995; Ridderinkhof, 2002)—as indicated as Route 3 in Figure 1. With regard to the present Experiments 1-3, one might therefore argue that good performance in the global-local task, the Stroop task, and the

Simon task did not benefit from the convergent-thinking prime task because it had induced stronger competition bias or local competition but, rather, because it had strengthened some sort of inhibitory control. More inhibition might have selectively operated on and weakened global representations in the local task, word representations in the Stroop task, and location representations in the Simon task. It is often difficult to rule out such a possibility because direct inhibition on the one hand and the interplay between competition bias and local competition on the other can mimic each other's effects (Colzato et al., 2008): many effects related to the control of inter-representational conflict can be alternatively modeled by either increasing the impact of Route 3 or by increasing the strength of both Route 1 and Route 2.

In Experiment 4 we tackled this problem by using a probe task that is arguably the most reliable tool to tap into inhibitory control: the stop-signal task developed by Logan and Cowan (1984). In this task, participants are first prompted to execute a response but then, briefly before this response is executed, presented with a stop signal calling for the immediate abortion of that response. Systematically varying the time interval between the go signal and the following stop signal allows one to calculate the so-called stop-signal reaction time (SSRT), which represents an estimation of the processing time needed to stop execution just in time. Several observations have validated the assumption that this task taps into inhibitory control. For instance, SSRTs are elevated in various groups that are known to have difficulties inhibiting motor activity and/or unwanted actions, such as patients suffering from Parkinson's disease (Gauggel, Rieger & Feghoff, 2004) or diagnosed with ADHD (for a recent review see, Alderson, Rapport & Kofler, 2007), and cocaine users (Colzato, van den Wildenberg & Hommel, 2007). If the task-priming effects obtained in Experiments 1-3 would reflect inhibitory-control processes, we should find comparable priming effects on SSRT in the stop signal task. In particular, SSRTs should be faster (i.e., inhibition more efficient) if being primed by a convergent-thinking task than by a divergent-thinking task. In contrast, no such effect would be expected if the previous priming effects were due to the stronger competition bias and/or local competition induced by the convergent-thinking task.

Method

Twenty new young healthy adults served as subjects for partial fulfillment of course credit. The method was as in Experiment 1 except that the global-local task was replaced by the stop-signal task.In the stop-signal task (adopted from Colzato et al., 2007), responses were made by pressing the “Z” or “?” of the QWERTY computer keyboard with the left and right index finger, respectively. Participants were to react quickly and accurately by pressing the left and right key in response to the direction of a pseudo-randomly left- or right-pointing green arrow (go trials) of about 3.5 X 2.0 cm. Arrows appeared for 1500 ms or until a response was given. Intervals between subsequent go signals varied randomly but equiprobably, from 1250 to 1750 ms in steps of 125 ms. During these interstimulus intervals, a white fixation point (3 mm in diameter) stayed on the screen. The green arrow changed to red on 30 % of the trials, upon which the choice response had to be aborted (stop trials). A staircase-tracking procedure dynamically adjusted the delay between the onset of the go signal and the onset of the stop signal to control inhibition probability (Levitt, 1971). After a successfully inhibited stop trial, the next stop-signal delay increased by 50 ms, whereas the delay decreased by 50 ms after the participant was unable to stop. This algorithm ensured that motor actions were successfully inhibited in about half of the stop trials, which yielded accurate estimates of SSRT and compensates for differences in choice RT between participants (Band, van der Molen &Logan, 2003). The task consisted of five blocks of 104 trials each, the first of which served as a practice block to obtain stable performance, and it took about 30 min. to complete. Participants thus were to switch between the prime and the probe task five times per session.

Results and Discussion

Participants showed good performance in the Remote Association Task (*M*=11.8 and *SD*=2.7) and the Alternate Uses Task (*M*=23.8 and *SD*=6.2). T-tests of mean RTs to go-signals indicated almost identical levels of performance in convergent and divergent sessions (389 vs. 386 ms, respectively), $p>.66$. More importantly, the same was true for SSRTs (205 vs. 207 ms), $p>77$.

The outcome does not provide any support for the assumption that inhibitory processes were responsible for the beneficial impact of control states related to convergent thinking on performance in the global-local task, the Stroop task, and the Simon task—at least as far as these processes are captured by the stop-signal task. Even though this conclusion is based on a null effect and needs thus be treated with the necessary caution, it is consistent with the assumption that the task-priming effects observed in the present Experiments 1-3 reflect commonalities between prime and probe tasks in terms of Route-1 and/or Route-2 mechanisms but not Route-3 mechanisms.

EXPERIMEINT 5 (ATTENTIONAL BLINK)

Experiments 1-3 provided evidence that creativity tasks and, as we assume, the control states they require have a systematic impact on subsequent conflict tasks. However, all three demonstrations of such priming effects followed the same pattern in showing better performance after a convergent-thinking task. On the one hand, this makes sense given that most laboratory tasks targeting cognitive control processes were designed to study the impact of goals and intentions on cognitive processing under pressure, that is, under conditions that are challenging the maintenance of goals and intentions or their translation into overt behavior. Accordingly, it is not surprising that performance in these tasks benefits from control states that, as we argue in the case of convergent thinking, make the top-down biasing of cognitive processing and/or the exclusiveness of decision-making more efficient.

On the other hand, however, the observation that convergent thinking turned out to be the better prime in all the conflict tasks we investigated raises the possibility that other, less specific factors might have played a role. Fortunately, Experiment 4 provided evidence that the convergent-thinking task does not improve performance in every possible task or measure, which rules out general factors like motivation, task difficulty, and effort consumption. The same conclusion is suggested by the observation that the priming task failed to produce a main effect on performance in any of the other probe tasks as well. However, it is possible that conflict-related measures, such as the global-local effect, the Stroop and the Simon effect, are more sensitive than is the general performance level, so that it is difficult to rule out that the positive impact of convergent thinking on subsequent performance is less specific than we suggest. This suggestion would gain credibility it the opposite pattern could also be demonstrated, that is, if it could be shown that task performance can also benefit from divergent thinking in principle. Experiment 5 was designed to provide such a demonstration, if possible.

As we have alluded to already, most tasks that are assumed to tap into cognitive control processes follow the strategy suggested by Ach (1905)—presumably the first to investigate the human will experimentally—to put the task goal in opposition to one's habits, such as the tendency to respond to the global shape or locations of visual objects, or to read words rather than naming their color. Only if our will to execute the task goal can overcome these opposing habits, so the idea, can we be sure that performance measures are actually reflecting the operation of the will—or of cognitive control, as we now call it. Accordingly, the degree to which opposing habits can be overcome provides a direct measure of willpower (Ach, 1910) or, in more modern terms, of the efficiency of cognitive control. From this perspective, any increase of top-down control would be expected to improve performance, which makes many laboratory tasks less promising candidates for demonstrating a beneficial priming effect of divergent thinking. And yet, there is one widely used task that has been suspected to suffer from too much cognitive control: the Attentional Blink (AB) task (Raymond, Shapiro & Arnell, 1992).

The AB is observed if two difficult to identify target stimuli appear in close temporal proximity, such as in tasks using rapid serial visual presentation techniques. Whereas the first target (T1) is commonly easy to report accurately, performance on the second target (T2) is often dramatically impaired if it follows T1 within 200-500 ms. Most researchers agree that the AB reflects some sort of attentional bottleneck that prevents the consolidation of T2 while T1 is being processed, so that T2 is registered but forgotten before it can be reported (cf. Hommel et al., 2006; Martens & Wyble, 2010).

The nature of the underlying bottleneck is less well understood, however. There is increasing evidence that the presence and size of the AB depends on the task context (e.g., Di Lollo, Kawahara, Ghorashi & Enns, 2005) and the instructions participants are receiving. For instance, the size of the AB is considerably reduced, and the effect sometimes disappears altogether, if participants are encouraged to assume a more relaxed attitude towards the task (Olivers & Nieuwenhuis, 2005) or are otherwise distracted (Olivers & Nieuwenhuis, 2006).

According to Olivers and Nieuwenhuis (2006), this pattern suggests that the AB is due to an overinvestment of attentional resources into the processing and consolidation of T1, which leaves too little for T2 to perform accurately. This possibility fits well with findings of Shapiro, Schmitz, Martens, Hommel, and Schnitzler (2006), who studied electromagnetic markers of attentional resource allocation in the AB task. As it turned out, participants who showed more evidence of attention-related brain activity while processing T1 were more likely to miss T2 in the blink interval. In other words, people are showing a smaller AB the less they monopolize attentional resources for T1 processing.

Considering the characteristics that we hypothesize to underlie convergent and divergent thinking, it makes sense to assume that the control state driving divergent thinking might be more beneficial for good performance in the AB task than the control state implied by convergent thinking. If divergent thinking weakens the impact of top-down control on the activation of target representations and/or the local competition between them, this would seem to be a good strategy for reducing the size of the AB. Two recent observations support this idea. For one, bilinguals have been shown to produce a larger AB than monolinguals (Colzato et al., 2008). Learning and mastering a second language is often assumed to increase cognitive conflict because it inflates the possibilities to express almost any given concept. To deal with this challenge, bilinguals have been claimed to develop special control strategies to better focus on words from one language to the expense of words from the other (Green, 1998), and there is evidence that these strategies generalize to non-lingual conflict tasks (for an overview, see Bialystok & Craik, 2010). If we thus assume that bilinguals exert more top-down control (i.e., have developed a stronger Route-1 mechanism), the finding that they produce a more pronounced AB suggests that convergent thinking may indeed be associated with a less AB-suitable control state than divergent thinking is.

For another, Calvinists have been shown to produce a larger AB than atheists (Colzato, Hommel & Shapiro, 2010). Following Colzato, Hommel, and colleagues (Colzato, van Beest et al., 2010; Hommel & Colzato, 2010), Calvinists are trained to focus on individual goals and to adopt a particularly “exclusive” control profile, which translates into an emphasis of Route-1 and Route-2 mechanisms. As this emphasis is apparently associated with a larger AB, it makes sense to assume that a divergent-thinking priming task leads to a smaller AB than a convergent-thinking prime.

Method

Twenty new young healthy adults served as subjects for partial fulfillment of course credit. The method was as in Experiment 1 except that the global-local task was replaced by the AB task.

The AB task was adopted from Colzato, Hommel, and Shapiro (2010). Participants were seated at a viewing distance of about 50 cm. The fixation mark ("+") and all target (digit) and distractor (letter) stimuli (16-point Times New Roman font) were presented centrally in black on a gray background. Letters were drawn randomly without replacement from the complete alphabet. Digits were drawn randomly from the set 1-9.

Participants were to identify and report two digits (T1 and T2) presented in a rapid stream of letter distractors. After having read the instructions, which included a slow demonstration of the RSVP, and indicating to have fully understood the task, participants went through 24 training trials, which we re-run if participants made more than 50% errors. The fixation mark was shown for 2000 ms and, after a blank interval of another 250 ms, the presentation of the letter-digit stream commenced. Twenty 20 items appeared with a duration of 70 ms each and an inter-stimulus interval of 30 ms.

The position of T1 in the stimulus stream varied randomly between positions 7, 8, and 9, so to reduce predictability. T2 was presented directly after T1 (lag 1), or after another 2, 4, or 7 distracters (lag 3, 5, and 8 respectively). Both targets were to be reported directly (order of report was not considered) after the last item of the stream was presented by pressing the corresponding digit keys. The task was composed by three blocks (144 experimental trials: 3 temporal locations of T1 x 4 lags x 12 repetitions) and took about 15 min. to complete. Participants werethus to switch between the prime and the probe task three times per session.

Results

Participants showed good performance in the Remote Association Task (M=8.8 and SD=2.8) and the Alternate Uses Task (M=18.4 and SD=4.6). T1 and conditional T2 (T2|T1) accuracy data were submitted to separate ANOVAs with lag (1, 3, 5, and 8) as a within-participants factor and prime task as between-participant factor. The T1 analysis produced a main effect of lag, $F(3,57)=35.57$, $p<0.001$, MSE = .001, $\eta^2p = 0.65$, due to a dip of performance with the shortest lag (accuracy: 89.2%, 96.5%, 95.8%, and 95.0%, for lags 1, 3, 5, and 8, respectively). This pattern is typical for AB tasks in which presentation rate is fast and the two targets belong to the same category and, thus, satisfy the same selection criteria (Colzato, Hommel & Shapiro, 2010; Hommel & Akyürek, 2005; Potter, Staub & O'Connor, 2002).

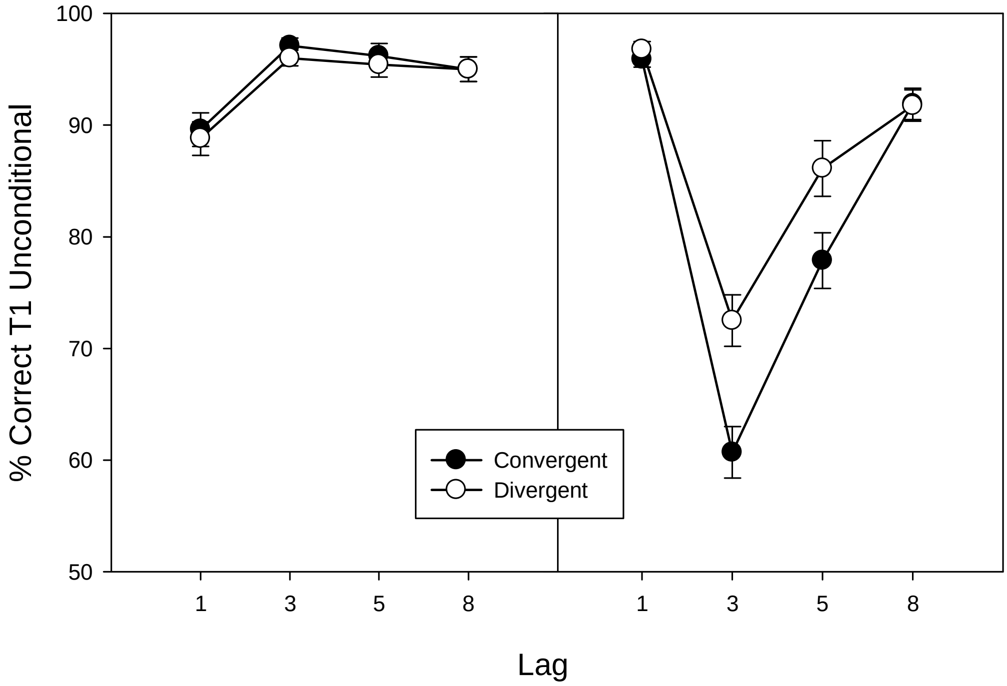

Figure 6: Report accuracy in Experiment 5 for T1 (unconditional) and T2 (given T1correct), as a function of the priming task (convergent vs. divergent thinking).

More importantly, the analysis of conditional T2 accuracy rendered all three effects significant: the main effects of lag, $F(3,57)=173.88$, $p<0.001$, MSE = .004, $\eta^2p = 0.90$, and prime task, $F(1,19)=5.51$, $p<0.03$, MSE = .02, $\eta^2p = 0.22$, and the interaction, $F(3,57)=5.42$, $p<0.002$, MSE = .006, $\eta^2p = 0.22$. The underlying pattern is shown in Figure 6: Whereas the two prime tasks yielded comparable performance at the shortest and longest lag,$F < 1$, a divergent-thinking prime produced better performance than the convergent-thinking prime at lag 3, $F(1,19)=9.30$, $p<0.01$, MSE = .015, $\eta^2p = 0.33$, and tended to do so at lag 5,

$F(1,19)=3.95$, $p=0.062$, MSE = .017, $\eta^2p = 0.17$. In other words, divergent thinking reduced the AB.

The outcome of Experiment 5 was as expected, which suggests that the cognitive control states induced by convergent thinking are beneficial for many but apparently not for all cognitive tasks. Even though it seems clear that some degree of top-down processing must take place in performing an AB task (so to keep the target templates sufficiently active to detect a matching target), this task is likely to suffer from overinvestment of attentional resources (Olivers & Nieuwenhuis, 2006; Shapiro et al., 2006). Our observations confirm that such overinvestment is counteracted to some degree at least by the cognitive set people establish when engaging in brainstorming-like activities. This fits nicely with the previous observations that the AB is reduced if participants assume a more relaxed attitude towards the task (Olivers & Nieuwenhuis, 2005).

GENERAL DISCUSSION

The aim of the present study was to characterize the cognitive-control states that participants establish when carrying out a creativity task by seeking for after-effects of divergent-thinking and convergent-thinking tasks on common, reasonably well understood cognitive tasks. A systematic pattern emerged: convergent thinking benefited performance in the global-local task (Experiment 1), the semantic-Stroop task (Experiment 2), and the Simon task (Experiment 3) more than divergent thinking did. These tasks are suspected to induce conflict between perceptual interpretations, semantic representation, and response codes, respectively, which suggests that the cognitive-control state underlying convergent thinking is well-suited to reduce various sorts of cognitive conflict. As we have suggested, this might be because this control state is characterized by a relatively strong top-down support of task-relevant information and/or by relatively strong local competition between representations of relevant and irrelevant information (Routes 1 and 2). In contrast, the two prime tasks had no specific impact on the ability of participants to inhibit strong response tendencies (Experiment 4). This is inconsistent with any role of inhibitory processes in regulating convergent and divergent thinking (Route 3), at least as far as they are needed for and assessed by the stop-signal task. Finally, we were able to show that the control state induced by convergent thinking is not advantageous for all cognitive tasks. In particular, tasks that can be assumed to benefit from a relaxation of top-down control, such as the AB task, gain more from the control state induced by divergent thinking (Experiment 5).

Taken together, our findings suggest a relatively clear-cut picture, according to which convergent and divergent thinking are associated with specific control states that people can apparently establish on-the-fly. On the one hand, this does not rule out the possibility that some individuals are more able, proficient, or practiced in establishing one or another of these states. In that sense, our findings do not rule out the possibility that some individuals are, or at least can be more creative than others—the trait account of creativity. On the other hand, however, our findings do suggest that creativity is also a matter of inter-individual variability. In other words, the same person can be more or less creative—the state account of creativity.

One important aspect of the pattern we obtained is that human creativity is not a unitary concept. Even though creativity studies have been using versions of our divergent-thinking and convergent-thinking tasks for decades, our findings provide strong evidence that these two types of tasks do not measure the same thing. This also fits with Akbari Chermahini and Hommel's (2010) observation that both types of tasks are related to dopamine but in very different ways and with the conclusion of Baas, De Dreu, and Nijstad (2008) that creativity tasks differ substantially in their sensitivity for particular aspects of creative performance. It may very well be that both convergent and divergent thinking is needed for truly creative activities: divergent thinking presumably more in the leading brainstorming phase that considers all possible options and convergent thinking more in the following phase in which the preferred option is further thought through and worked out. Nevertheless, it seems to make little sense of speaking about creativity as such without referring to specific cognitive or computational functions. Only if these functions can be properly isolated, a realistic functional and neural model of creative performance can be developed.

One limitation of our experimental approach is that it did not provide a neutral baseline, so that it is impossible to say whether better performance after one type of thinking was due to a benefit associated with this thinking style or interference associated with the other style or both. However, this consideration is based on the questionable assumption that a given participant's control state is neutral before entering a psychological laboratory. Note that our experimental rationale could only work because control states are apparently inert and tend to outlive the task for which they were created (Allport et al., 1994; Memelink & Hommel, 2006). This implies that every experimental subject brings mixtures of various control states to the lab—states that were originally created to master the exam the subject was coming from, to overcomethe participant's tendency to smoke after lunch, to avoid distractions on his or her way to the testing room, and so forth. Research on the so-called resting-state activity (Smith et al., 2010) provides strong evidence that even having a participant to do nothing at all creates very specific types of interactions within and between neural networks—control states that is. All we could thus hope for was that our experimental manipulations were pushing the control states of our participants in one or another direction without getting even near to any perfect experimental control. Even though this does not allow addressing all the questions that may remain, it was sufficient to demonstrate that the control states induced by the two types of creativity tasks are different and more compatible with some tasks but not with others.

Considering that convergent and divergent thinking apparently induce different control states and, thus, are supporting performance in different types of tasks, it might be tempting to assume that these control states are opposites, mirror images of each other. In fact, the scenarios we developed in the introduction might suggest that the two critical control routes (1 and 2) are correlated in such a way that cognitive control may alternatively engage in either a strict control style involving strong top-down bias and local competition or in a loose control style involving weak top-down guidance and local competition. Even though such an approach would certainly be attractive in its parsimony, we at this point hesitate to adopt it for at least three reasons implied by the observations of Akbari Chermahini and Hommel (2010). One is that individual performance in convergent thinking and divergent thinking was not correlated, which does not fit with the negative correlation that the unidimensional account would suggest. Second, convergent thinking was more reliably correlated with fluid intelligence than divergent thinking was but, if anything, the two correlations tended to go into the same direction with better convergent and divergent thinking performance with individuals higher in intelligence. Again, a unidimensional account would rather seem to suggest correlations of different signs. And, as mentioned already, both convergent and divergent thinking performance was related to a physiological marker of dopamine production but the two functions obtained cannot be described as the opposites of each other: whereas convergent thinking was linearly related to dopamine (better performance the lower the dopamine level), divergent thinking related to dopamine in an inverted-U shape (best performance with medium levels). Even though it is true that psychological functions might be related to neurochemistry in complicated ways, these different profiles do not provide support for the idea that the control states underlying convergent and divergent thinking are mere mirror images of each other. In any case, more research on this issue is urgently needed.

Our study aimed at characterizing the two arguably most relevant and most often investigated types of creative activity. However, we do not mean to imply that convergent and divergent thinking cover the whole range of human creativity, nor do we think that the two types of control states that we focused on are the only aspects of controlling creative behavior. For instance, Dietrich (2004) made a distinction between deliberate and spontaneous creative processes and between cognitive and emotional knowledge domains within which these processes operate. Considering the nature of our tasks, the present study could thus be characterized as targeting deliberate creative processes operating in a mainly cognitive knowledge domain. Even though Dietrich's framework is post hoc and has not yet been empirically tested, it is thus possible that our conclusions do not, or not fully, generalize to spontaneous creativity and/or knowledge with a stronger emotional flavor.

Another interesting distinction that has been made with respect to creative processes is that between solutions that are associated with a conscious "Aha!" or insight experience and those that are not (for an overview, see Kounios & Jung-Beeman, in press). Jung-Beeman and colleagues have provided evidence that insight-associated solutions are mediated by different brain areas and that these areas are differentially sensitive to experimental manipulations, such as solution priming (e.g., Bowden & Jung-Beeman, 2003; Jung-Beeman et al., 2004). Given the relatively long-lasting after-effects of creativity tasks in the present study, it makes sense to assume that participants in such insight studies do not switch between different control configurations on a trial-to-trial basis. This suggests that the same control configuration can generate different types of experience and, presumably, allow for different ways to find a creative solution. Which way is chosen in a given trial might be the result of competition between alternative solutions and the differential top-down support they receive. Note that providing strong Route-1 support for one alternative only biases, but does not determine, the ultimate decision, so that sometimes a non-supported alternative might win the competition. If one considers top-down support a kind of expectation, a winning non-supported alternative might be more surprising and more likely to trigger an “Aha!” experience. In any case, it seems clear that future research does not only need to differentiate between different types of processes underlying creative behavior and different types of control states driving these processes, but it also needs to study the manner in which control states exert their control and constrain cognitive competition for the most creative solution.

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ACKNOWLEDGEMENTS

The research of S. Akbari Chermahini is supported by a post-graduate scholarship (PhD) of the Iranian Ministry of Science, Research and Technology. The research of W.P.M. van den Wildenberg and of L.S. Colzato is supported by Veni grants of the NWO (Netherlands Organization for Scientific Research).

CHAPTER 7

Summary and Discussion

Summary of results

In this thesis, five empirical chapters investigated the functional and neuromodulatory basis of creativity, and tried to identify optimal conditions for divergent and convergent thinking. Since there is not a consensus in the scientific community on the definition of creativity, it is important to define the processes under study and the kind of task or test being applied to measure the concept of interest. In this thesis, two different thinking styles were considered as two different types of creativity: divergent and convergent thinking. The Alternative Uses Task (AUT) (Guilford, 1967) was employed to measure divergent thinking, and the Remote Associate Task (RAT) (Mednick, 1962) to measure convergent thinking.

Participants in this research were native Dutch speakers, so Dutch versions of creativity tests were needed. The AUT was easy to adapt and participants could easily be asked to write down as many possible uses for a common house hold item in their own language. However the RAT is different and its nature necessitated the development and validation of a Dutch version. In chapter 2, we have reported the development and validation of a 30-item Dutch version of the RAT, and Item Response Theory (IRT) was applied to generate a short, qualified, and valid 22-item out of 30-item test. The 30-item test was used in this thesis. The 22-item is reliable and very useful test to measure convergent thinking in research with time restrictions. The IRT approach was used to identify difficulty and discrimination parameters for each item as well, so one can choose items that fit the sample (for example: a group of people with low or high ability) and purpose of the research.

In chapter 3 we addressed whether individual measures of creativity would co-vary with the individual eye-blink rate (EBR), which may point to a connection between creativity and dopamine. The relationship between creativity, intelligence, and EBR—a clinical marker of brain dopamine function—was investigated. Results of three experiments with separate groups of subjects revealed that performance on an intelligence test (fluid intelligence) does not depend on brain dopamine function while creative performance does: results showed a negative correlation between convergent thinking and dopamine level and performance on divergent thinking test followed an invert U-shaped relation with the individual dopamine level.

The results of the experiments reported in chapter 3 were considered as the basic idea to run a mood induction experiment, which is reported in chapter 4. Results of a (positive or negative) mood induction experiment show that positive mood, when compared to negative mood, increased EBR and enhanced creative performance on a divergent thinking test. These results are consistent with previous research showing that positive mood enhances creative performance (Isen et al., 1987) and with the idea that the influence of positive mood on cognitive performance is due to increased dopamine levels (Ashby et at., 1999). Positive mood significantly increases EBR and improved flexibility in a divergent thinking task in people with low dopamine level. But there is a different scenario for people with medium (or high) level of dopamine, as the benefit of positive mood was very small and not significant. We conclude that the impact of positive mood on the performance in divergent thinking depends on an individual's dopamine level.

Chapter 5 presents the results of an experiment that investigated influence of performing a creativity test (divergent vs. convergent thinking) on mood state. Results revealed that performing divergent and convergent thinking tasks improved and impaired current mood, respectively. These results support the idea that mood and cognition are not just related, but that this relation is fully reciprocal (Bar, 2009; Gray, 2004; Gross, 2002; Salovey et al., 2002).

Performing divergent and convergent thinking tests establishes different cognitive control states. This idea was investigated in chapter 6 by seeking for after-effects of performing two creativity tests on five well-known cognitive tasks (1-Global-Local, 2-Stroop, 3-Simon, 4-Stop-Signal, 5-Attentional Blink). Results show that the control state induced by convergent thinking benefited performance in cognitive tasks that require top-down control and strong local competition between representations of relevant and irrelevant information (tasks 1-3); in contrast, divergent thinking induced a cognitive control state that enhances performance on tasks that benefit from less top-down control, such as the Attentional Blink task.

DISCUSSION

Brain dopamine function and performance on divergent and convergent thinking tasks

The studies of this thesis provide empirical evidence that creativity is not a homogeneous concept; rather it reflects the interplay of separate, dissociable processes such as convergent and divergent thinking (e.g., Guilford, 1967). The cognitive mechanism of these two processes is different, but not opposite as assumed by Eysenck (1993). Taken together, results of four studies presented in this thesis (chapters 3-6) show that convergent and divergent thinking are not necessarily opposite but they are not the same either, and optimal performance in different types of creativity tasks requires different conditions.

In chapter 3 we concluded that performance on divergent-thinking tasks varies as a function of individual dopamine level, where medium levels produce the best performance, while convergent thinking was best with low dopamine levels. This suggests that divergent and convergent thinking are both related to dopamine, but to different degrees and in different ways. It was observed that eye-blink rate was predicting creative performance, which provides strong support for approaches that relate creativity to dopamine (Ashby et al., 1999; Eysenck, 1993; Reuter et al., 2006). At the same time, however, the obtained dissociation calls for a more differentiated approach that distinguishes between convergent and divergent processes and allows for tapping different creativity-dopamine functions.

If positive mood increases the dopamine level, which also works as a mechanism to improve performance, as suggested by Ashby et al. (1999), then it seems difficult to account for the impact of mood-enhancing manipulations on performance. As we report in chapter 4, participants with a relatively low level of dopaminergic functioning are likely to benefit from better mood, whereas people with a relatively high level of dopaminergic functioning, such as individuals scoring high in psychoticism (Colzato, Slagter, van den Wildenberg & Hommel, 2009), may actually do not benefit of better mood. Depending on which part of the distribution happens to be more strongly represented in a given sample, the corresponding study may find a positive, negative, or no relationship between mood and the given performance measure. This may explain the seemingly confusing and contradictory relationship between mood and performance (Baas, De Dreu & Nijstad, 2008; Davis, 2009), especially if one considers that divergent and convergent thinking, often treated equivalent indicators of creativity, seem to relate to dopaminergic functioning in different ways. In fact, this thesis' observations (negative correlation between eye blink rate and performance in convergent thinking, chapter 3) suggest that increasing dopaminergic supply can be expected to actually hamper convergent thinking irrespective of the current level. If so, then mood is unlikely to affect convergent and divergent thinking in the same fashion, which is yet another reason as to make a distinction between the different aspects of human creativity.

Optimal brain dopamine function for cognition and creativity

Evidence from both physiological and behavioral studies suggests that normal cognitive performance occurs only within a limited range of dopamine receptor activation. Researchers have shown that cognitive functions are impaired when there is a decrease in dopamine functioning in the brain, as in Parkinson's disease, or with dopaminergic hyperproduction, as in case of schizophrenia (Gotham et al., 1988; Knable & Weinberger, 1997). Too little or too much dopamine receptor activation leads to deficient operation of the neural mechanisms that are required for optimum performance in divergent-thinking creativity tasks (due to a lack of facilitation or excessive inhibition, respectively) thus resulting in diminished cognitive performance. This suggests that optimal functioning of the prefrontal cortex needs an optimal level of dopamine as described by an inverted U-shape curve (Cools et al., 2001; Vijayraghavan et al., 2007).

It has been shown by a large number of studies that positive affect systematically influences performance on many cognitive tasks. The dopamine theory of positive affect (Ashby, 1999) accounts for many of these effects by assuming that positive affect is associated with increased brain dopamine levels. The theory accounts for influences of positive affect on olfaction, the consolidation of long-term (i.e., episodic) memories, working memory, and creative problem solving. It assumes that creative problem solving is improved, in part, because increased dopamine release in the anterior cingulate improves cognitive flexibility and facilitates the selection of cognitive perspective. This theory, along with research on the impact of positive affect on creative performance, helps us to better understand the mechanisms underlying the impact of dopamine on human creative performance.

It has been shown that during the course of normal aging, dopamine levels in the human brain decrease by 7% or 8% during each decade of life (e.g, Gabrieli, 1995; van Domburg & ten Donkelaar, 1991). Considering the relation between dopamine and cognitive performance, this raises the question whether cognitive flexibility and creative problem-solving also diminish with age. It is generally assumed that people become less flexible and more rigid as they get older. A large amount of research revealed that cognitive flexibility does decrease during normal aging (e.g., Collins & Tellier, 1994; Stankov, 1988), but we are not aware of any study that examined the effect of age on performance on creative problem solving specifically on divergent thinking (Alternative Uses Task) and convergent thinking (Remote Associate Task). If we consider flexibility as the main component of divergent thinking, we can assume that performance on this type of creativity task decreases with aging.

But at the individual level the actual picture might be more complex. Consider the results from chapter 3, where we demonstrated that optimal performance in divergent and convergent thinking is associated with medium and low levels of dopamine respectively. If we accept that aging is associated with a decrease of dopamine, we can assume that people with a high level of dopamine might be more creative as they get older in both divergent and convergent thinking (Figure 1, black-arrows). It is possible that a similar scenario applies to other cognitive tasks that relate to brain dopamine function in an inverted U-shaped fashion, such as working memory tasks. In contrast to high-level dopamine individuals, it is likely that aging has no advantage or is even harmful for creative performance for people with low dopamine levels. More research is needed to examine this possibility in order to fully understand the role of interaction of aging and dopamine on creative performance.

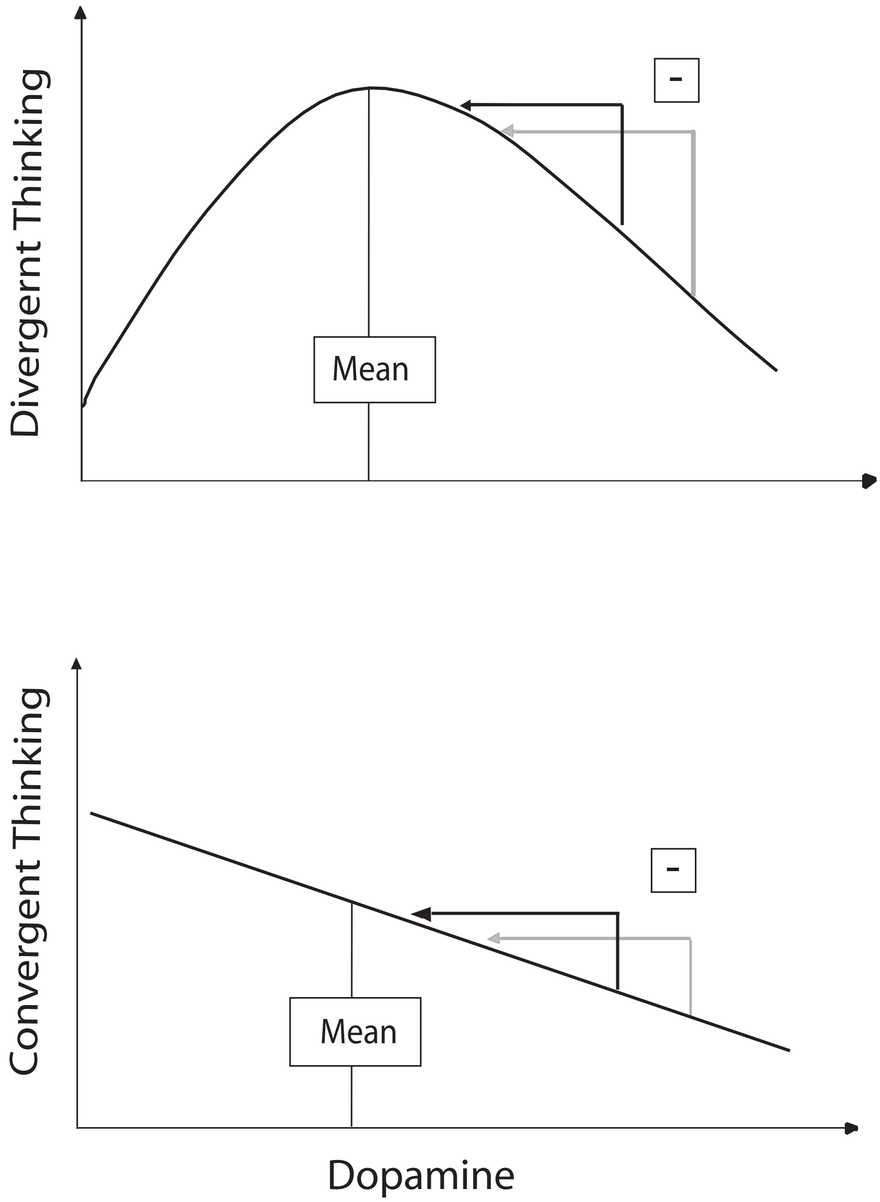

Figure 1: Hypothetical functions relating performance in divergent and convergent thinking to the individual dopamine level. Estimates of group means are taken from Akbari Chermahini & Hommel (2010). Note that, depending on the base level of dopamine, an age-related decrease in dopamine might be beneficial for divergent and convergent thinking tasks for some clinical populations (e.g., schizophrenic; gray-arrows) and in non-clinical population for individuals with high level of dopamine (black-arrows).

Moving to clinical populations, our approach raises interesting questions regarding the impact of aging on performance. For instance, it predicts that people who suffer from too high levels of dopamine (such as in schizophrenia) should actually benefit from aging—due to the aging-induced decease in dopamine levels (Figure 1, gray-arrows). These and related considerations encourage novel questions and lines of research, which we believe can further increase our understanding of creative performance and the cognitive mechanism involved in an optimum level of creativity.

Implications of the results of this thesis might also be important for education and business. If we consider creativity the fountainhead of human civilization, all progress and innovation depends on our ability to change existing thinking patterns, break with the present, and build something new. So, it is no surprise if we see managers seeking to boost creativity in their employees, school-teachers desiring to elevate creative problem solving among their pupils, and parents trying to bring out the artistic talent in their children. Based on the results of our research, we assume they can get better results if their training practice and interventions consider individual differences in dopaminergic functioning as well as the type of creativity that is intended to be enhanced. This certainly holds for the relationship between the effect of mood and individual dopamine levels in the context of performance in divergent thinking—as investigated in this thesis. Whether it also holds for the effect of mood on convergent thinking remains to be investigated.

Creativity and mood: reciprocal effects

In chapter 5 it was found that carrying out a task that requires creative thinking affects people's mood. Moreover, divergent and convergent thinking impact mood in opposite ways: while divergent thinking improves one's mood convergent thinking lowers it. This provides considerable support for the idea that mood and cognition are not just related, but that the relation is fully reciprocal (Bar, 2009; Gray, 2004; Gross, 2002; Salovey et al., 2002). This dissociation is consistent with Akbari Chermahini and Hommel’s (2010) observation that divergent and convergent thinking are related to one's dopamine level—the common currency that apparently mediates the interaction—and that these two relationships follow rather different functions. Performing divergent thinking and convergent thinking tasks evoke different, apparently even opposite stereotypical reactions which do not seem to reflect individual performance and, thus, objective task difficulty. However, actually carrying out the task and the related thinking operations further boosts the task-specific mood changes to a degree that goes beyond possible stereotypical responses. In a broader perspective, this research's findings demonstrate uncertainty principle (Heisenberg, 1927), according to which the act of measurement can change what is being measured. As it seems, engaging in a creativity task creates a mood swing in the direction that facilitates performance in that particular task. It can be conclude that mood and cognition are not just related, but that this relation is fully reciprocal.

This fits with the theoretical considerations of Bar (2009) that there is a direct reciprocal relation between the cortical activation of associations and mood regulation, whereby positive mood promotes associative processing, and associative processing promotes positive mood. The activation of associations might be beneficial for improving mood because associations afford the generation of predictions, and prediction minimize uncertainty, thus reducing anxiety and stress, which are both concomitants of mood disorder. The second mood-related benefit of broad associative activation is that associations prevent persistent rumination, another hallmark of mood disorder, by distracting the thought process away from dwelling on a narrow, negative theme. Broad associative activation helps gain a broader perspective. This calls for a distinction between narrow and broad associative activations. Narrow associative thinking, or rumination, refers to associations that surround a narrow focus (Figure 2a). Broad associative activations, by contrast, active association that make thought processes advance from one context to another smoothly (Figure 2b).

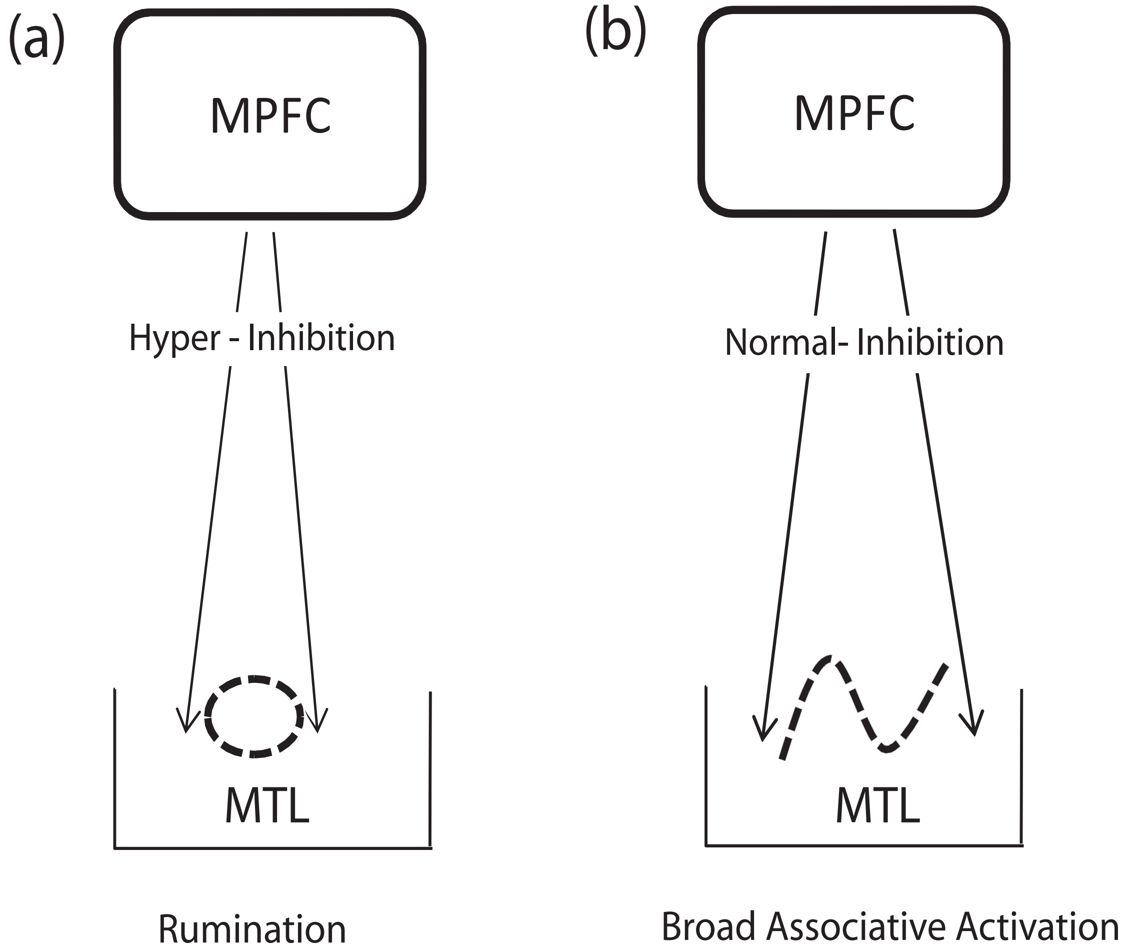

Figure 2: Rumination versus broadly associative thinking. (a) The thought pattern typical of mood disorder involves rumination around a narrow focus. Even if this thought pattern is associative, it is limited in scope. Such constrained thought is proposed here to stem from hyper-inhibition from the MPFC (medial prefrontal cortex) to the MTL (medial temporal lobe). (b) The thought pattern in the brain of individuals without mood disorders is characterized by a broadly associative activation that, although still affected by inhibition signals (for functional guidance), can seamlessly disengage from one focus and advance to another. (Reproduced from Bar, 2009; *Trends in Cognitive Science*. 13)

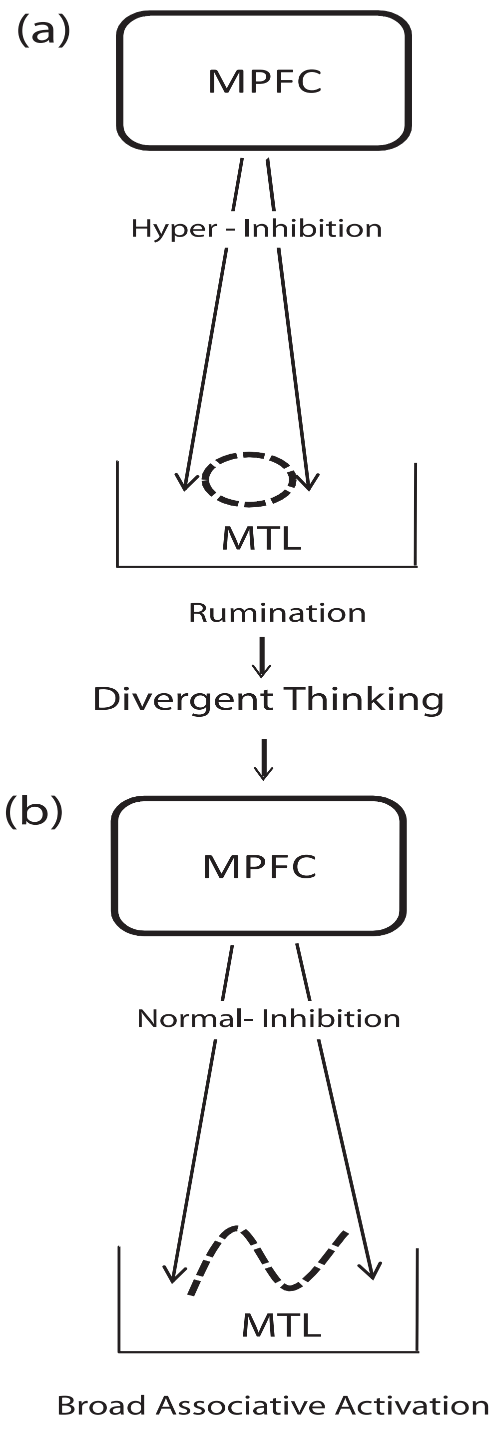

Figure 3: Performing a divergent thinking task might improve mood and change the associative activation from narrow representation (a) to broad representation (b).

As we mentioned earlier, results from chapter 5 show that performing a divergent thinking task elevates mood. This result can be explained by the assumption that broad associative activation improves mood. This finding has the practical implication that performing a divergent thinking task might be a non-invasive method for treating mood disorders, especially in people who suffer from rumination (negative narrow scope of attention) that is associated with depression. The training and restructuring of the ability for broad associative thinking can elicit improvements that range from structure modification to mood and behavior (Figure 3). Future research needs to investigate whether performing a divergent thinking task can be useful to change the narrow focus and rumination in individuals with depression to broad associative activation to at least some degree, and improve their mood.

Creativity and cognitive control

Convergent and divergent thinking apparently induce different cognitive control states in individuals and support performance of individuals in different cognitive tasks in different ways. The after-effect of performing divergent and convergent thinking tasks on 5 cognitive tasks (Global-Local, Stroop, Simon, Stop-Signal, Attentional Blink) was investigated and reported in chapter 6. Results from five experiments revealed that convergent thinking benefited performance in the tasks that are suspected to induce conflict between perceptual interpretations (Global-Local task), semantic (semantic-Stroop task), and response codes (Simon task) by establishing a relatively strong top-down cognitive-control state and also reduce various sorts of cognitive conflict. Cognitive control induced by convergent thinking was not beneficial for all cognitive tasks. In contrast divergent thinking induces cognitive control state and benefits tasks that apply less top-down control (such as Attentional Blink task).

The findings suggest a scenario according to which convergent and divergent thinking are associated with specific control states that people can apparently establish when needed. Nevertheless, this does not rule out the possibility that some individuals are more able, proficient, or practiced in establishing one or another of these states. In that sense, the findings do not rule out the possibility that some individuals are, or at least can be more creative than others—the trait account of creativity. Thereby it is suggested that creativity is a matter of intra-individual variability where the same person can be more or less creative.

The five studies presented in chapters 2-6 illuminate that human creativity is not a unitary concept and is consistent with conclusions from earlier research that creativity tasks differ substantially in their sensitivity for particular aspects of creative performance (Baas, De Dreu, & Nijstad, 2008). The findings provide strong evidence that divergent-thinking and convergent-thinking tasks are two different types of tasks to measure two types of creativity and that they do not measure the same thing. It can be said that divergent and convergent thinking are ideal types, and not mutually exclusive. Both convergent and divergent thinking are needed for any truly creative activity; latter presumably more in leading brainstorming phase that considers all possible options and former more in the following phase in which the preferred option is further thought through and worked out.

Taken together, the results of the five empirical chapter of this thesis indicate that creativity, an important skill that is often thought of as a stable characteristic of people, can be facilitated by a transient pleasant affective state. Moreover, the affective state sufficient to do this can be induced subtly, by small everyday events. This suggests that creativity can be fostered by appropriate modification of the physical or interpersonal environment. But one should be aware that not everybody benefited from good mood.

The most important implication of the results in this thesis is for future research on individual differences and creative performance as well as on mood and creativity research. Furthermore, by identifying cognitive mechanism and the basic principles of creativity, researchers might be able to enhance this process better in the future, with potentially enormous benefits for society.

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Samenvatting

In dit proefschrift wordt in vijf empirische hoofdstukken de functionele en neuromodulatorische basis van creativiteit onderzocht. Aangezien er in de wetenschappelijke gemeenschap geen consensus is over de definitie van creativiteit is het belangrijk om, zowel het proces dat bestudeerd wordt en het soort taken of testen die worden gebruikt om het concept van interesse te meten te definiëren. In dit proefschrift worden twee denkstijlen verondersteld als twee verschillende vormen van creativiteit: divergent denken en convergent denken. De 'Alternatieve gebruiken taak' (Alternative Uses Task' of AUT, Guilford, 1967) werd gebruikt om divergent denken te meten, de 'Verre associaten taak' (Remote Associate Task of RAT, Mednick, 1962) werd gebruikt om convergent denken te meten.

De proefpersonen in dit onderzoek hadden Nederlands als moedertaal, dus werden Nederlandse versies van de creativiteitstesten gemaakt. De AUT was eenvoudig aan te passen en de participanten konden makkelijk gevraagd worden om zo veel mogelijk manieren te bedenken om een veelvoorkomend huishoudelijk artikel te gebruiken in hun eigen taal. De RAT is anders van aard, waardoor het noodzakelijk was om een Nederlandse versie te ontwikkelen en te valideren.

In hoofdstuk 2 wordt de ontwikkeling van validatie van een Nederlandse versie van de RAT gerapporteerd bestaande uit 30 items. Item-respons theorie is toegepast om een korte, gevalideerde 22- items test te maken uit de 30 item test. The 22-item test is betrouwbaar en erg nuttig om convergent denken te meten in onderzoek met tijdsrestricties. De IRT benadering is ook gebruikt om moeilijkheid- en onderscheidingsparameters voor ieder item te bepalen, zodat men items kan kiezen die passen bij de steekproef (bijvoorbeeld: een groep mensen met lage of hoge capaciteit) en het doel van het onderzoek.

In hoofdstuk 3 wordt onderzocht of individuele maten van creativiteit zouden correleren met individuele oog knippersnelheid (eye-blink rate of EBR), hetgeen kan wijzen op een relatie tussen creativiteit en dopamine. De relatie tussen creativiteit, intelligentie, en EBR - een klinische marker van de brein dopamine functie - is onderzocht. Het resultaat van drie experimenten met drie aparte groepen van participanten liet zien dat de prestatie op een intelligentietest (fluid intelligence) niet afhangt van brein dopamine functie terwijl creatieve prestatie dat wel doet: resultaten lieten een negatieve correlatie zien tussen convergent denken en dopamine level en prestatie op de divergent denken test volgende een inverse U-vorm relatie met individuele dopamine level.

De resultaten van de experimenten, die in hoofdstuk 3 zijn gerapporteerd zijn gebruikt als het basis idee voor een experiment waarin stemming wordt geïnduceerd (mood induction), en is gerapporteerd in hoofdstuk 4. De resultaten van een (positieve of negatieve) stemmingsinductie experiment laten zien dat positieve stemming vergeleken met negatieve stemming voor een toename van EBR en een toegenomen creatieve prestatie leidde op een divergent denken test. Deze resultaten zijn consistent met eerder onderzoek dat laat zien dat positieve stemming creatieve prestatie kan doen toenemen (Isen et al., 1987) én dat de invloed van positieve stemming op cognitieve prestatie veroorzaakt wordt door toegenomen dopamine niveaus (Ashby et al, 1999). Positieve stemming zorgt voor een significante toename van EBR en toegenomen flexibiliteit in een divergent denken taak bij mensen met een laag dopamine niveau. Maar er is een ander scenario voor mensen met een gemiddeld of hoog niveau van dopamine, omdat de winst van positieve stemming klein was en niet significant. Men kan concluderen dat de impact van positieve stemming op de prestatie van divergent denken afhangt van de dopamine niveaus van een individu.

Hoofdstuk 5 presenteert de resultaten van een experiment, waarin werd onderzocht wat de invloed is van het maken van een creativiteitstest (divergent vs. convergent denken) op stemming. Resultaten ondersteunen het idee dat stemming en cognitie niet alleen gerelateerd zijn maar dat deze relatie volledig wederkerig is (Bar, 2009; Gray, 2004; Gross, 2002; Salovey et al., 2002).

Het uitvoeren van divergente en convergente denktaken leidt tot verschillende modi van cognitieve controle. Dit idee is onderzocht in hoofdstuk 6 door middel van het zoeken naar na effecten van het maken van de twee creativiteittesten op vijf bekende cognitieve taken (1-Global-Local, 2-Stroop, 3-Simon, 4-Stop-Signal, 5-Attentional Blink). De resultaten laten zien dat de controlemodus die geïnduceerd wordt door convergent denken de prestatie verbeterde op cognitieve taken waarvoor top-down controle nodig is, en een sterke lokale competitie tussen representaties van relevante en irrelevante informatie (zoals de Stroop taak); divergente denktaken daarentegen, induceerden een cognitieve controlemodus die de prestatie verbeterde op taken die voordeel hebben van minder top-down controle, zoals de Attentional Blink taak.

Acknowledgements

This dissertation could not have been written without the support of my supervisor Professor Bernhard Hommel, who greatly enriched my knowledge with his exceptional insight into psychology, and who provided me with direction in creativity research.

I wish to thank Lorenza Colzato, Guido Band and all my Cognitive Psychology colleagues, who inspired me during my PhD research. I also owe Albertien Olthoff, Atie Breugem and Marianne van der Stel for their care and devotion in supporting me in many aspects.

And I wish to express my gratitude to my high school teacher B. Mehmandoust, who inspired my interest in psychology.

Most of all I would like to thank my parents for the support they provided me through my entire life and last but not least, many thanks to Mohammed and Anis for their understanding and endless love through the duration of my studies.

Curriculum Vitae

Soghra Akbari Chermahini was born on May 22nd, 1973, in Chermahin, a village of Isfahan, Iran. After finishing high school in Chermahin in 1991, she moved to Isfahan University, where she completed a Bachelor of Arts in the field of “The psychology of exceptional children”. After graduating at Isfahan University in 1995, she moved to Tehran to begin her Master of Arts in “General Psychology” at Tarbiyat Moddaress University, Iran. During her studies, she worked at a research institute dedicated to the study of exceptional children in Tehran, where she developed the idea to write her thesis on gifted children with cognitive and behavioral problems. She received her Master’s degree with distinction in 1999. In 2001, she began working as a part time lecturer at a private university of Dmaghan, Iran. During this period, she collaborated with other researchers working at counseling centers in Isfahan and Damghan. In 2006 she received a highly prestigious scholarship, which included support for her family, from the Iranian Ministry of Science, Research and Technology to do her PhD in Cognitive Psychology abroad. She decided to work on her PhD project under the supervision of Prof. Bernhard Hommel at Leiden University and moved to the Netherlands, along with her family, in September 2006.