Neural and cognitive mechanisms of creativity
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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.
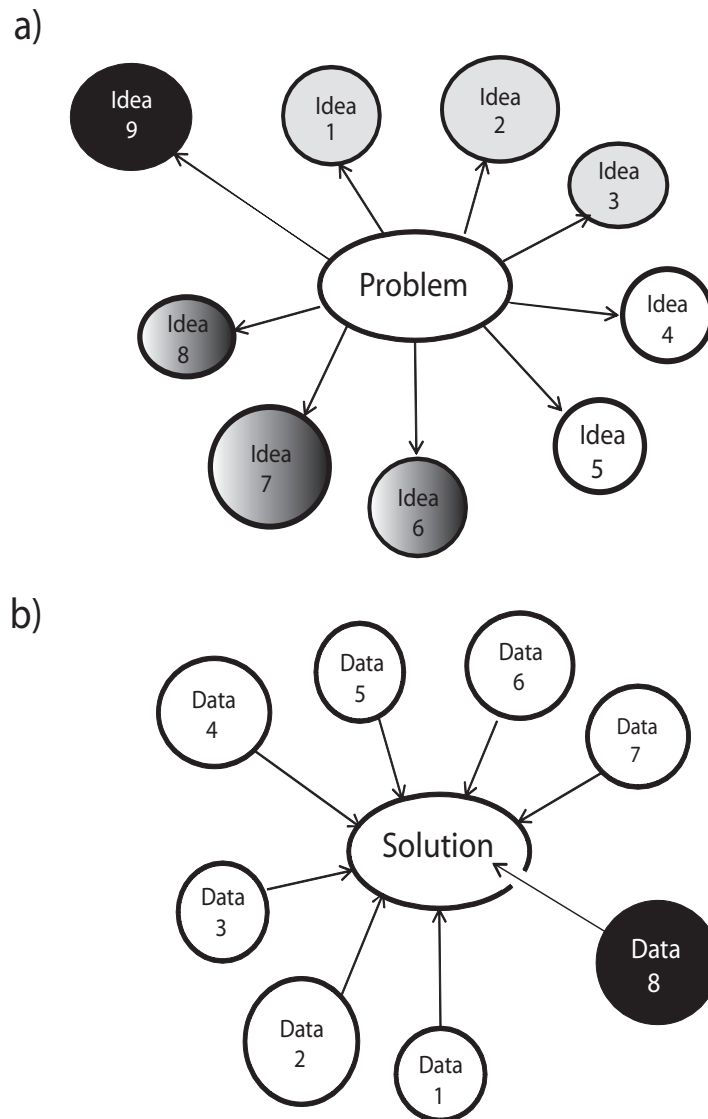
Figure 1: Hypothetical charts of divergent and convergent thinking. In the chart of divergent thinking (a), fluency, flexibility, originality, and elaboration are represented by number of circles, circles with same color, black circle with longest arrow, and size of the circles respectively. In the chart 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).
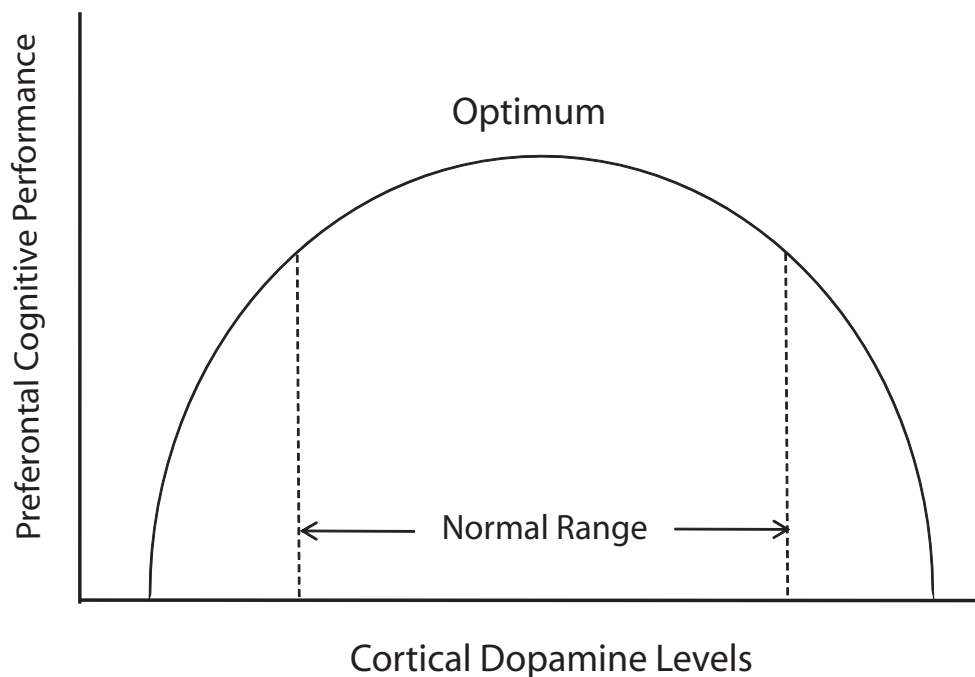
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Figure 2: An inverted U-shaped relationship between cortical dopamine and cognitive performance. When either cortical dopamine levels activity are below the optimal range, as may occur in Parkinson's disease, or above the optimal range, as may occur 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

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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 θ1 (Theta1) and β2 (Beta2) bands (Razoumnikova, 2000): In the θ1 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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