What Box?': behavioral, neuro-imaging, and training studies on the development of creative cognition in adolescence

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CHAPTER 1

General introduction

'The Ministry of Education, Science and Culture is working on a creative nation, and recognizes the importance of creative development in education'

Creative thinking has been indicated as 'the premier 21st century skill', and not without reason. In our current *knowledge society*, continuous innovation is critical, and information bases rapidly change and grow. Consequently, flexibility and the ability to think out of the box, to think divergently (or to generate and test multiple problem solutions instead of a single one) and to gain insight, are valued more than ever before.

These statements underscore the importance of creative thinking in our society and point toward the particular relevance of creativity development. They also raise important questions, including 'What does creative thinking mean? Does the ability to think creatively develop across childhood and adolescence, and how? Which neural mechanisms are involved during creative performance and, how (if possible) can creativity be improved?' Research on creative thinking development in adolescence to adulthood is severely lacking, yet this age group deserves close examination, as they are our future thought leaders.

From studies in related research fields, there is evidence that adolescence is a time period for crucial development of cognitive abilities (Casey, Jones, & Hare, 2008; Steinberg, 2005), and adolescents' brain demonstrates marked changes in structure and function (Luna, et al., 2010; Giedd and Rapoport, 2010; Shaw et al., 2008). This thesis therefore, focuses on this age group and transition period in order to address the above questions.

To study the mechanisms underlying creative thinking development, the research in this thesis combines behavioral measures with brain activation, as measured with functional magnetic resonance imaging (fMRI), across domains and ages, in both single test and longitudinal training designs. This allowed me to examine both age- and experience-related effects on creative thinking performance during functional brain development. Before describing the performed research and consequent results in Chapters 2 to 6, this chapter will provide an introduction to the theory of creative thinking, including the theoretical framework that has been incorporated to understand the processes underlying creative thinking. Subsequently, relevant prior research on the neural correlates of creative thinking is discussed. A short introduction of the adolescent period is then given, followed by an overview of prior research on creative thinking training. The introduction chapter finishes by providing the main goal of the thesis and a short overview of the upcoming chapters.

What is creative thinking?

Creativity is commonly referred to as the ability to generate ideas, insights and solutions that are both original and feasible (e.g. Amabile, 1996; Sternberg & Lubart, 1996). As such, creative outcomes should be new and uncommon, yet also potentially useful and relevant; original but infeasible ideas are commonly strange whereas ideas that are feasible but not original are mundane, and in a sense, boring. Creativity is believed to be one of humans' most important and complex behaviors. For example, creative insights solve daily problems, (e.g., use a broom to obtain a toy from under the couch); are requisite for scientific breakthroughs; and creative strategizing allows one to win competitions (De Dreu & Nijstad, 2008). To understand creative performance, the present dissertation builds upon the creative cognition approach which identifies creative success as inherent to normal human cognitive functioning (Ward, Smith, & Finke, 1999), and emphasizes the dependency on fundamental cognitive functions, such as working memory and executive control (Nijstad, De Dreu, Rietzschel, & Baas, 2010; Sowden, Pringle & Gabora, 2014). Accordingly, the development of creative capacities are considered to be related to the development of supporting cognitive functions, and, concurrently, creativity training success is considered to be depended on the trainability of its supporting functions.

Although the exact processes supporting creative outcomes are still under debate, it has become common to describe creative thinking through so called *dual-process models* of creative thinking. In cognitive and social psychology, dual-process models generally include two ways of achieving one's goal: 1) through fast, implicit and associative processing; and 2) through deliberate, effortful and logical processing (Chaiken & Trope, 1999). In the field of creative cognition, dual-process models commonly imply that both types of processing are involved to establish creative solutions that are both imaginative and useful.

A specific type of dual processing model, *The Dual Pathway to Creativity Model* (Baas, De Dreu & Nijstad, 2008; De Dreu, Baas, & Nijstad, 2008; Nijstad et al, 2010; Rietzschel, De

Dreu, & Nijstad, 2007), describes creative outputs as the result of 1) cognitive flexibility, and 2) cognitive persistence. According to the model, cognitive flexibility enables accessibility to multiple and broad cognitive categories; flexible switching between these categories; and a global processing style or broad focus. Cognitive persistence, on the other hand, is associated with focused and systematic effort, in-depth exploration of a relatively small number of cognitive categories, and a local processing style or narrow focus (De Dreu et al., 2008; 2012). Indeed, a vast body of research has shown that creative performance can be achieved through both a flexible and divergent way of thinking (e.g., Duncker, 1945; Oppenheimer, 2008; Simonton, 1997; Winkielman, Schwarz, Fazendeiro, & Reber, 2003), as well as a persistent and systematic way of thinking (Dietrich, 2004; Dietrich & Kanso, 2010; Finke, 1996; Rietzschel, Nijstad, & Stroebe, 2007; Sagiv, Arieli, Goldenberg, & Goldschmidt, 2009; Simonton, 1997). It is commonly assumed, as with other dual-process models, that creative outcomes are the product of both processing types, with different contribution ratios and, dependency on the type of task as well as individual functioning.

To date, creativity research has mainly focused on two types of cognitive functions that represent creative potential: *divergent thinking* and *insight.* Divergent thinking is the most commonly tested function in creativity research, and is considered an important component of the creative process as it captures one's capacity to create novelty (Torrance, 1966). Divergent thinking tasks require the generation of multiple solutions to an open-ended problem (Guilford, 1967) and have been shown to have significant predictive value for creative success (Kim, 2008). Divergent thinking can be measured in different domains. In this thesis, I studied the Alternate Uses Task (AUT) to test divergent thinking in the verbal domain, and the Creativity Ability Test (CAT) and the Matchstick Problem Task (MPT) to test divergent thinking in the visuo-spatial domain. The AUT requires individuals to think of as many unusual uses for a common object, for example, for a *brick*. The CAT and MPT involve pre-described rules that participants must adhere to when instructed to find as many solutions as possible. The CAT consists of squares including figures. Participants are asked to compose triads of squares based on the properties (e.g., number, position) of the figures included. The MPT involves an arrangement of matches that must be reorganized to make other pre-described patterns by removing a number of matchsticks. To solve these kinds of problems (CAT & MPT), one is required to overcome mental fixation. In case of the CAT, mental fixation is created due to one's own (prior) solution. In case of the MPT, fixation is the result of initially presented formation of matchsticks.

Creative performance in divergent thinking tasks is commonly expressed in terms of *fluency, flexibility* and *originality* (Guilford, 1967; Torrance, 1966). Fluency refers to the number of ideas, insights, problem solutions, or products that are generated. Larger numbers of ideas are associated with better creative performance under the assumption that quantity breeds quality. Flexibility refers to the generation of different conceptual categories or themes of ideas, and as such, requires overcoming mental fixedness; in case of the AUT *brick*, 'building' and 'weight' would be two different solution categories - the more different the categories, the more flexible a person is. The third measure of creative performance, originality, refers to the uniqueness or infrequency of solutions and ideas. The originality of an idea or solution is generally expressed in terms of a) 'uniqueness' which corresponds to a certain score assigned by an experienced scorer (or set of) , or b) 'infrequency' as calculated by taking into account the number of appearances of a certain solution across the total of solutions generated by the entire pool of participants. Fluency and originality may be correlated (under the assumption of 'quantity breeds quality'; Diehl & Stroebe, 1987), but it is not necessary, since one might generate a large number of solutions or ideas without uniqueness or originality (see De Dreu et al., 2008; Förster, Friedman, & Liberman, 2004). Fluency and flexibility are commonly related, at least to a certain degree; generating ideas or solutions in various categories will be associated with more ideas/solutions overall (Nijstad, Stroebe, & Lodewijkx, 2002). Flexibility may also be correlated to originality as larger numbers of conceptual categories increase the chance that uncommon categories are used and, consequently, relatively uncommon solutions are generated (Rietzschel et al., 2007). It should be noted that flexibility is not only a measure of creative performance, but refers to a cognitive process where it includes the ability to break set and use flat associative hierarchies of concepts (see above; *The Dual Pathway to Creativity Model*; Baas et al., 2008; De Dreu et al., 2008; Nijstad et al., 2010; Rietzschel et al., 2007).

Insight tasks, in contrast to divergent thinking tasks, have a demonstrable correct solution. This type of task generally requires establishing associations among previously unrelated or weakly related information, and mentally restructuring the problem space (Förster et al., 2004; Smith & Kounios, 1996). Insight solutions differ from non-insight solutions in that 1) solvers experience their solutions as sudden and have an 'aha!' experience; 2) prior to producing an insight, solution solvers sometimes come to a an impasse, a state of high uncertainty as to how to proceed; and 3) solvers usually cannot report the processing that led them to the solution. Common to divergent thinking tasks, insight tasks also have the pretension to measure creative potential; both types of tasks are associated with creative ability, but address different aspects of the creative process. Commonly used tasks used in the present thesis include the Gestalt Completion Task (GCT; Eckstrom et al., 1976), the Snowy Picture Task (SPT; Eckstrom et al., 1976) and the Remote Associates Task (RAT; Mednick, 1962). The first two tasks (GCT & SPT) capture insight ability in the visual domain whereas RAT focuses on insight ability in the verbal domain. The GCT consists of fragmented pictures and requires one to imaginatively complete them. In the SPT, participants are presented with a series of images of familiar objects hidden within visual noise. Participants need to disregard misleading interpretations that are rendered by the context to identify the objects. The RAT consists of triads of words and requires one to find a fourth, related word. As such, these insight tasks involve unifying complex or remotely associated information to find a single optimum solution that is retrieved from memory. To gain insight into the development of the complex construct of creative cognition, the current thesis includes a broad set of tasks capturing insight and divergent thinking in the verbal and visual domain.

Neural correlates of creativity

Neuroimaging is a useful method for gaining insight in the processes underlying creative success. In the current thesis, I have used fMRI for studying creative thinking in the visuospatial (Chapter 3) and verbal domain (Chapters 4 & 6). fMRI is a method that utilizes the Blood Oxygenation Level Dependent (BOLD) signal and examines which brain regions are activated during task performance. In recent years, several researchers have investigated creative cognition using lesion studies and neuroimaging techniques, including fMRI. Results are, however, not yet conclusive about the neural underpinnings of this complex construct (Arden, Chavez, Grazioplene, &Jung 2010; Dietrich & Kanso, 2010), and differences between study outcomes are likely related to the various designs capturing different aspects of creative thinking. Despite this, there is consensus that the (lateral parts of) the prefrontal cortex (PFC) plays a role in creative success. This brain region is generally associated with cognitive control functioning and coordinating lower level (associative) brain regions (e.g., Miller & Cohen, 2001), and is involved in both insight and divergent thinking tasks (see e.g., Arden et al., 2010; Dietrich & Kanso, 2010).

Matchstick Problem Tasks (MPT; Guilford, 1967) have previously been used to shed light on the processes underlying creative problem solving. Using MPT and related tasks, neuropsychological and brain imaging studies revealed the involvement of the lateral PFC in creative problem solving. For example, comparison of healthy controls to patients with lesions in different brain regions showed that patients with (right) frontal lesions were impaired in solving creative problems. Performances were most significantly impaired when strategy switches was required, indicating a role for lateral PFC regions particular in flexibility. Accordingly, an fMRI study in healthy adults demonstrated increased activation in bilateral ventral and dorsal PFC while solving matchstick problems, compared to brain activity while verifying a given solution to a matchstick problem (Goel & Vartanian, 2005). Furthermore, activation in the right dorsolateral PFC (DLPFC) correlated with the percentage of traced solutions, indicating that this region contributes to exploratory success.

The AUT and adapted versions of this verbal divergent thinking task are also commonly applied to gain insight into the underpinnings of creative cognition. Although there are differences between outcomes for these tasks, a relatively consistent finding is the involvement of (left) temporo-parietal regions, including the angular gyrus (AG) and the supramarginal gyrus (SMG) (Arden et al., 2010; Dietrich & Kanso, 2010). For example, Fink et al. (2009, 2010) compared brain activations for generating alternative uses (AU) with activations for retrieving ordinary characteristics (OC) to capture brain regions involved in creative idea generation Their results revealed increased activity in left angular gyrus (AG) and supramarginal gyrus (SMG). Other researchers utilizing (verbal) divergent thinking paradigms relatively consistently found activations of the PFC (e.g., Abraham et al., 2012; Carlsson, Wendt, & Risberg, 2000; Chavez-Eakle et al., 2007; Folley & Park, 2005; Howard-Jones, et al., 2005; Mashal, Faust, Hendler, & Jung-Beeman, 2007). Notably, a substantial part of these studies revealed positive relations between PFC activations and creative performances (e.g., Carlsson et al., 2000; Chavez et al., 2004; Chavez-Eakle et al., 2007; Gibson, Folley, & Park, 2009). Together, these findings indicate that temporo-parietal regions are involved in divergent thinking processes in general, whereas the ability to recruit PFC successfully might be discriminative for creative capacities. In the current thesis we applied adapted versions of the MPT (Chapter 3) and AUT (Chapter 4) while scanning to examine how creative thinking develops from adolescence to adulthood.

Adolescence

As described above, we focus on creative thinking in adolescence. The particular interest for in this period between childhood and adulthood is related to the characteristics of this period. The onset of adolescence is determined by biological processes as it is characterized by the start of pubertal maturation. The onset typically takes place between 9 and 12 years of age (usually 1 to 2 years later in boys than in girls). The end of adolescence is less explicitly determined as it is partly culturally defined. Adolescence typically extends into the early 20s when major physical changes have occured and individual independence in society attained (Crone en Dahl, 2012; Lerner & Steinberg, 2004).

Adolescence is a developmental stage characterized by transformations toward life independency, a period in which individuals come to terms with themselves and their environment. Successful development toward mature adult functioning is associated with creativity and related functions such as exploration and cognitive flexibility. Indeed explorative behavior is essential to develop one's identity, and adolescence has a natural time of learning and adjustment and requires flexibility in thought and action. Hence, adolescence is expected to involve important changes in creative capacities.

Research on creative thinking development throughout adolescence is scarce. Prior research mainly focused on divergent thinking in elementary grades, and only few have investigated development beyond age 12. These studies indicate that performances improve with age from childhood throughout adolescence (e.g., Runco and Bahleda, 1986; Lau and Cheung, 2010), but that performance slumps may occur at different stages in adolescence (Claxton, Pannels & Roads, 2005; Lau and Cheung, 2010). Studies including comparisons between adolescents and adults are also lacking. In one study where early adolescents were compared to adults on divergent thinking fluency and flexibility, no age effects were observed (Wu et al., 2005). The question of how creativity develops between late childhood and adulthood for the broader domain of creativity still remains.

Adolescence is also a time period with crucial development of many cognitive abilities (see e.g., Casey et al., 2008; Steinberg, 2005), especially of PFC functioning-related abilities including working memory and cognitive control. Since these functions are assumed to be related to creative cognition, an interesting question addressed in this thesis is how adolescent-specific changes in PFC functioning relate to creative success.

Previous studies demonstrate that adolescent brains are capable of changing, both structurally and functionally (Luna, et al., 2010; Giedd and Rapoport, 2010; Shaw et al., 2008). Early studies of post-mortem brain tissue reported that the PFC displays great changes well into the adolescent period and are revealed by marked reorganizations of synapses in this region (Huttenlocher, 1979). It is well known, today, that PFC regions are upon the last to mature. Additionally, large-scale longitudinal brain imaging studies identified significant changes during adolescence in gray matter volume. More specifically, these studies revealed that lateral PFC matures throughout adolescence, following an inverted U-shaped pattern with a peak in early adolescence (Gogtay et al., 2004); they also demonstrated varying developmental trajectories of gray matter for different regions within the PFC (Gogtay & Thompson, 2010). Moreover, functional neuroimaging studies indicate age-related changes of PFC activations for several cognitive functions including working memory, interference control and task-switching (for a review, see Bunge and Wright, 2007).

There is, however, inconsistency among reports of age-related changes in developmental trajectories. Functional neuroimaging studies have reported different developmental trajectories showing that prefrontal cortex is both *more* activated (e.g., Adleman et al., 2002; Crone et al., 2006c), and *less* activated with increasing age (e.g., Durston, et al., 2006; Morton et al., 2009). Age-related increases are commonly interpreted as an increase of the ability to recruit referred brain regions, whereas age-related decreases are often interpreted as increasing efficiency of referred brain regions. Intriguingly, some studies reported a specific peak in lateral PFC activation in middle adolescents (e.g., Crone, et al., 2006a; Dumontheil, et al., 2010). These studies, therefore, appear to challenge the above-mentioned relative simplistic maturational interpretations.

Adolescence is also associated with elevated levels of dopamine in the PFC (see Casey etal., 2008; Spear, 2000). These elevated levels have been shown to induce broadened attention toward externally presented stimuli and explorative behavior (Grey, Buhusi & Scmajuk, 1997). Taken together, PFC function during this transitional phase may not only be associated with limitations in cognitive control-related functions, but may also be tuned specifically toward exploration and adaptive flexibility (Crone & Dahl, 2012; Dahl, 2008; Johnsson & Willbrecht, 2012). Since both cognitive control and explorative behavior have been associated with creative success, the current thesis aims to gain insight into adolescent PFC functioning during different aspects of creative cognition, including creative problem solving and verbal divergent thinking.

Creative thinking training

To extend investigations into the development of creative ideation, this thesis includes creative thinking training effects on adolescents' performances and brain functions utilizing simple practice paradigms. Various studies have already demonstrated the effectiveness of training paradigms in improving creativity in both adults (Glover, 1980; Bott et al., 2014; Kienitz et al., 2014) and children (Torrance, 1972; Cliatt et al., 1980). However, relatively little is known about how malleable creative thinking is in adolescence. Training studies in other higher cognitive skills include working memory (Klingberg, 2010; Jolles et al., 2012), executive control (Karbach and Kray, 2009; Zinke et al., 2012), relational reasoning (Dumontheil et al., 2010), and algebraic equation solving (Qin et al., 2004), and emphasize the training susceptibility regarding performance and brain function during adolescence. In the current thesis we aim to gain insight into the malleability of the adolescent brain with regard to the development of creative thinking skills.

Numerous studies have examined creative thinking training effects on the behavioral level, yet relatively little research has focused on neuronal level. One AUT training study using EEG showed higher synchronization in frontal alpha activity after two weeks of AUT training (Fink et al., 2006), but it is not yet known how this relates to neural activation changes in the different brain regions involved in divergent thinking. A more commonly used approach to enhance creative performance in neuroimaging research involves cognitive stimulation by providing (moderately) creative ideas. Several studies have found this approach to be effective and training has been associated with functional changes of the (left) temporo-parietal, including the left MTG and PFC regions. An important question addressed in the current thesis concerns how activity in these regions changes through creative thinking training in adolescence. This will allow us to have a better understanding of how training-related changes in adolescents take place.

The current thesis

The main goal of this thesis is to gain insight into the development of creative thinking across adolescence and into adulthood. To this end, we utilized a range of creativity tasks, both with and without an fMRI scanner, and before and after training paradigms. This approach allowed me to examine 1) the differential developmental trajectories of various aspects of creative thinking; 2) the development of related neural processes; and 3) the potential toward creative thinking in adolescence.

In Chapter 2, I examined developmental trajectories of creative cognition across development. To this end, participants in four age groups (12-13 yrs, 14-15 yrs, 15-16 yrs, and 25-30 yrs) were subjected to a battery of tasks including the SPT, GCT and RAT to examine insight performance in the visual and verbal domains, and the CAT and the AUT to examine divergent thinking performance in the visuo-spatial and verbal domains, respectively.

The second empirical study, described in Chapter 3, examined behavioral and neural differences for creative problem solving in middle-adolescents (15-17 yrs) and adults (25-30 yrs). Performances and neural activations were measured while performing a matchstick problem Task (MPT) in the fMRI scanner. In addition, performances for the CAT were obtained outside the scanner and related to neural activations during the MPT. Chapter 4 examined the neural correlates of divergent thinking in adults (25-30 yrs) and adolescents (15-17 yrs). To this end, participants generated alternative uses (AU) or ordinary characteristics (OC) for common objects while brain activity was assessed using fMRI. Chapter 5 focused on whether performance could be improved by practicing alternative uses generation. The effectiveness of creative ideation training was examined in adolescents (13-16 yrs) and adults (23-30 yrs) measuring creative ideation performances on two versions of the AUT. Participants followed one of three training types, each comprising eight 20-minute sessions within 2 weeks time: 1) alternative uses generation (experimental condition); 2) object characteristic naming (control condition); or 3) rule-switching (control condition).

In Chapter 6, we tested the benefits of training creativity in adolescents. To this end, behavior and neural activity in 15-16-year-old adolescents performing an AUT task in the scanner were compared before and after two weeks of divergent thinking training, and we compared this to AUT activity in an active control group who performed a task-switching training program. Finally, Chapter 7 summarizes the main results of the empirical studies presented in this thesis. Here, implications of the results are discussed and suggestions for future research are presented.