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# 6

## Creativity Development in Adolescence: Insight from Behavior, Brain, and Training Studies

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### **Abstract**

*Creativity is a multifaceted construct that recruits different cognitive processes. Here, we summarize studies that show that creativity develops considerably during adolescence with different developmental trajectories for insight, verbal divergent thinking, and visuospatial divergent thinking. Next, these developmental time courses are mapped to changes in brain activity when individuals perform divergent thinking tasks. The findings point to an important role of the prefrontal cortex for generating novelty and complexity. Finally, the potentials and limitations of training creativity in adolescence are described. The findings are interpreted vis-à-vis the dynamic changes that occur during adolescence in brain development and behavioral control processes. © 2016 Wiley Periodicals, Inc.*

**C**reative 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, and to generate and test multiple solutions to problems are valued more than ever before. Yet, whereas the importance of creative thinking in our society is undisputed, important gaps in our understanding of creativity remain. One key area that needs further investigation is the development of creative skills and competence. 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?

From studies in related research fields, there is evidence that adolescence is a crucial period for the development of cognitive abilities (Casey, Jones, & Hare, 2008; Steinberg, 2005), and indeed, adolescents’ brains demonstrate marked changes in structure and function (Luna, Padmanabhan, & O’Hearn, 2010; Shaw et al., 2008). Here we review recent studies on the development of creative thinking across adolescence to adulthood. We examine (a) the developmental trajectories of various aspects of creative thinking, (b) the development of underlying neural processes, and (c) the potential to improve creative thinking in adolescence through training.

## **The Development of 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 typically considered strange, whereas ideas that are feasible but not original are seen as mundane and, often, uninteresting. To understand the development of creative performance, this article builds upon the creative cognition approach, which identifies creative thinking as inherent to normal human cognitive functioning (Ward, Smith, & Finke, 1999) and emphasizes the dependence on fundamental cognitive functions, such as working memory and executive control (Nijstad, De Dreu, Rietzschel, & Baas, 2010).

Although the exact processes supporting creative outcomes are still under debate, there is growing consensus among scientists from social and cognitive (neuro)psychology that creative performance can be understood in terms of fast, implicit, and associative processing, and deliberate, effortful, and logical processing (Chaiken & Trope, 1999). This general notion has been further developed in the Dual Pathway to Creativity Model (De Dreu, Baas, & Nijstad, 2008), which describes creative outputs as the result of cognitive flexibility and cognitive persistence. Cognitive flexibility enables accessibility to multiple and broad cognitive categories, flexible

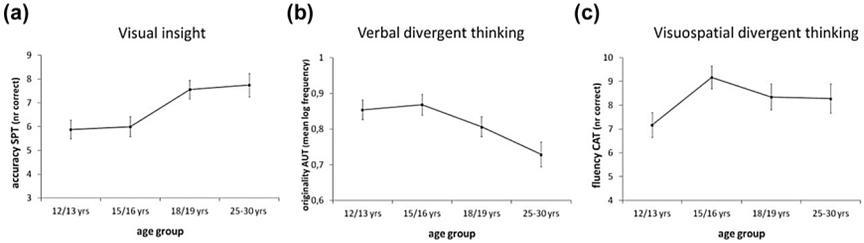
switching between these categories, and a global processing style or broad focus (Förster, Friedman, & Lieberman, 2004). Cognitive persistence, in contrast, is associated with focused and systematic effort, in-depth exploration of a relatively small number of cognitive categories, and a local processing style or narrow focus (De Dreu et al., 2008). Indeed, a vast body of research has shown that creative performance can be achieved through both a flexible and divergent way of thinking as well as a persistent and systematic way of thinking (for a review, see Dietrich & Kanso, 2010). It is commonly assumed, as with other dual-process models, that creative outcomes are the product of both processing types, with different contribution ratios depending on the type of task to complete and individual functioning.

In a comprehensive behavioral study (Kleibeuken, De Dreu, & Crone, 2013a), we examined the development of 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, being reflective of the cognitive flexibility pathway (Nijstad et al., 2010), divergent thinking has strong predictive value for creative success (Kim, 2008). Divergent thinking can be measured in different domains. We studied the Alternate Uses Task (AUT), which measures divergent thinking in the verbal domain, and the Creativity Ability Test (CAT), which measures divergent thinking in the visuospatial domain. The AUT explores a common task, which requires individuals to think of many unusual uses for a common object, for example, for a *brick*. The CAT involves predescribed rules that participants must adhere to when instructed to find as many matching figures as possible.

Participants in this study were in the age range 10–30 and creative performance on the divergent thinking tasks was expressed in terms of *fluency* (number of solutions), *flexibility* (generation of different conceptual categories), and *originality* (uniqueness or infrequency of solutions and ideas) (Guilford, 1967; Torrance, 1966). Thus, in terms of the Dual Pathway to Creativity Model (De Dreu et al., 2008), flexibility refers to a cognitive process including the ability to break, set, and use flat associative hierarchies of concepts, whereas fluency can be seen as an indicator of persistence (De Dreu et al., 2008).

The result of the developmental comparison study showed that on this version of the AUT, the capacity to generate multiple ideas (fluency) from different conceptual categories (flexibility) is already developed in adolescence but that the quality of solutions continues to develop (Figure 6.1). Possibly, with development adolescents gain knowledge from which associations can be made, and/or their better performance may reflect the development of cognitive processes that support the ability to flexibly coordinate between associative and analytic processing (Christoff, Gordon, & Smith,

**Figure 6.1. Developmental Trajectories from Early Adolescence (Ages 12–13 Years) to Adulthood (Ages 25–30 Years) for (a) Insight, (b) Verbal Divergent Thinking and (c) Visuospatial Divergent Thinking**



Source: Kleibeuker, S. W., De Dreu, C. K. W., & Crone, E. A. (2013a). The development of creative cognition across adolescence: Distinct trajectories for insight and divergent thinking. *Developmental Science*, 16(1), 2–12.

Note: (a) Mean  $\pm$  1 standard error (SEM) of the number of correct solutions for Snowy Picture Task. (b) Mean  $\pm$  1 standard error (SEM) of originality scores, represented by the mean frequency of solutions for Alternative Uses Task. Higher scores indicate less original solutions. (c) Mean  $\pm$  1 standard error (SEM) of the number of correct solutions for the Creative Ability Test. Reprinted with permission.

2009; Nijstad et al., 2010), an ability that develops only in late adolescence (Huizinga, Dolan, & van der Molen, 2006).

Some indirect support for the first explanation comes from the results for creative performance in the visuospatial CAT. Here we observed a relative advantage for middle adolescents for visuospatial divergent thinking compared to younger adolescent and young adults. Success is relatively independent of knowledge but requires generating and shifting between representations of the provided visual information, applying a set of rules, and monitoring behavior—cognitive functions that are commonly associated with prefrontal cortex (PFC) functioning and are still developing in adolescence (Huizinga et al., 2006). Possibly, middle adolescents have an advantage for explorative thinking (Johnson & Wilbrecht, 2011).

In addition to these divergent thinking tasks, participants completed insight tasks that, in contrast to divergent thinking tasks, have an established correct solution. This type of task generally requires establishing associations among unrelated or remotely related information and mentally restructuring the problem space (Förster et al., 2004). Insight solutions differ from noninsight solutions in that (a) solvers experience their solutions as sudden and have an “aha!” experience; (b) prior to producing an insight, solvers sometimes come to an impasse, a state of high uncertainty as to how to proceed; and (c) solvers usually cannot report the processing that led them to the solution. The tasks used in our study were the Gestalt Completion Task (GCT; Eckstrom, French, Harman, & Dermen, 1976), the Snowy Picture Task (SPT; Eckstrom et al., 1976), and the Remote Associates Task

(RAT; Mednick, 1962). The first two tasks (GCT and SPT) capture insight ability in the visual domain whereas the RAT focuses on insight ability in the verbal domain. We observed that creative insight (both visual and verbal) continued to develop into late adolescence. Noteworthy are the differential patterns of the developmental trajectories, which were best described by step-wise (visual) and curvilinear (verbal) models. In particular, results in the visual domain were indicative of qualitative changes in underlying cognitive processes (see also Uhlhaas et al., 2009).

In summary, these results supported the distinctiveness of creativity aspects and indicate both immaturities (insight, verbal divergent thinking originality) and creative potentials (visuospatial divergent thinking) during different stages of adolescence. These findings of different developmental time courses fit with prior studies indicating that creativity performances improve with age from childhood throughout adolescence (e.g., Lau & Cheung, 2010, Runco & Bahleda, 1986), but that performance slumps may occur at different stages in adolescence (Lau & Cheung, 2010; see also Wu, Cheng, Ip, & McBride-Chang, 2005 for a comparison between adolescents and adults).

### Neural Correlates of Creativity

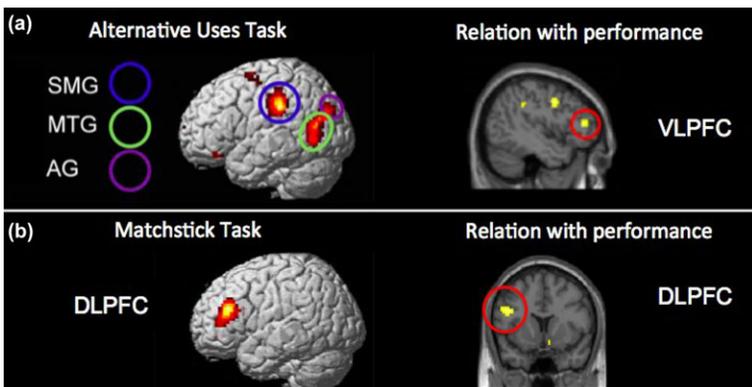
Neuroimaging is a useful method for gaining insight into the processes underlying creative success. In recent years, several researchers have investigated creative cognition using lesion studies and neuroimaging techniques, including functional magnetic resonance imaging (fMRI). Results are, however, 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 measures capturing different aspects of creative thinking. Despite this, there is consensus that the lateral parts of PFC play 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, for example, Arden et al., 2010; Dietrich & Kanso, 2010). Interestingly, this brain region still shows substantial changes over the course of adolescence (Mills & Tamnes, 2014). We therefore examined possible differences in neural activation between adolescence and adults when performing verbal and visuospatial insight tasks.

To tap into the underpinnings of creative cognition in the verbal divergent thinking domain, we adapted the AUT for use in an experimental imaging design. A relatively consistent finding across studies that have used the AUT in adults is the involvement of (left) temporoparietal regions, including the angular gyrus (AG) and the supramarginal gyrus (SMG) (Arden et al., 2010; Dietrich & Kanso, 2010). Notably, a substantial part of these studies revealed positive relations between PFC activations and

creative performance (e.g., Carlsson, Wendt, & Risberg, 2000; Chavez-Eakle, Graf-Guerrero, Garcia-Reyna, Vaugier, & Cruz-Fuentes, 2007; Gibson, Folley, & Park, 2009). We investigated the neurodevelopmental changes of verbal creative idea generation in adolescents and adults (Kleibeuker et al., 2013c). Based on the behavioral study described earlier, we predicted that adults (25–30 years) would outperform adolescents (15–17 years) on creative idea generation, and indeed, adults generated significantly more alternative uses than adolescents. Furthermore, the fMRI results indicated involvement of a temporoparietal network including the left angular gyrus (AG), the left supramarginal gyrus (SMG), and the bilateral middle temporal gyrus (MTG) in both adults and adolescents (Figure 6.2). Interestingly, trials with only *multiple* solutions, a hallmark of divergent thinking, resulted in additional left inferior frontal gyrus (IFG)/middle frontal gyrus (MFG) activation. Possibly, the ability to generate multiple ideas (*viz.* divergent thinking), involves cognitive control functioning, such as attentional inhibition and cognitive flexibility (see, for example, De Dreu et al., 2012). Notably, activations in these frontal regions were more pronounced in adults than adolescents.

To examine the processes underlying visuospatial creative problem solving we made use of the matchstick problem tasks (MPT; Guilford,

**Figure 6.2. (a) Brain Regions Involved in Verbal Divergent Thinking Based on the Alternative Uses Task and (b) Brain Regions Involved in Visuospatial Divergent Thinking Based on the Matchstick Task**



Sources: Kleibeuker, S. W., Koolschijn, P. C. M. P., Jolles, D. D., De Dreu, C. K. W., & Crone, E. A. (2013b). The neural coding of creative idea generation across adolescence and early adulthood. *Frontiers in Human Neuroscience*, 7, 905; Kleibeuker, S. W., Koolschijn, P. C. M. P., Jolles, D. D., Schel, M. A., De Dreu, C. K. W., & Crone, E. A. (2013c). Prefrontal cortex involvement in creative problem solving in middle adolescence and adulthood. *Developmental Cognitive Neuroscience*, 5, 197–206.

Note: SMG = supramarginal gyrus, MTG = middle temporal gyrus, AG = angular gyrus, DLPFC = dorsolateral prefrontal cortex, VLPFC = ventrolateral prefrontal cortex. Reprinted with permission.

1967), which presents the participants with classic divergent thinking problems. An MPT involves an arrangement of matches that must be reorganized to make other predescribed patterns by removing a number of matchsticks. To solve this kind of problem, one is required to overcome mental fixation of the initially presented formation of matchsticks (Guilford, 1967). Prior neuropsychological and brain imaging studies using MPT and related tasks revealed the involvement of the lateral PFC in creative problem solving (Goel & Vartanian, 2005).

In our study, adolescents (15–17 years) and adults (25–30 years) were subjected to both an MPT, while scanning neural activation with fMRI, and the previously used visuospatial divergent thinking task (creative ability task; CAT) outside the scanner (Kleibecker, Koolschijn, Jolles, De Dreu, & Crone, 2013b). Interestingly, adolescents outperformed adults on experimental problems (seeking alternative solutions for the MPT), indicating an advantage for this age group for problems that require exploration and shifting between representations. Solving the MPT problems was associated with increased activity in IFG and dorsolateral PFC (DLPFC) (Figure 6.2). A direct comparison between age groups revealed increased activation in left (IFG) and right (DLPFC) during successful creative problem solving for adolescents compared to adults. Individual difference analyses demonstrated a positive relation between creative problem-solving performance and activity in left IFG. Prior research suggests particular relevance of left IFG for switching between representations (Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006; Hirshorn & Thompson-Schill, 2006). Moreover, activation in right DLPFC was associated with better visuospatial divergent thinking capacities (CAT performance). Thus, individuals with greater visuospatial thinking abilities recruited right DLPFC during creative problem solving more than individuals with poor visuospatial thinking abilities. This study, therefore, supports the hypothesis that adolescence is not only a phase of immaturity but also a period of enhanced PFC activation for exploration and adaptive purposes (Crone & Dahl, 2012).

## **Creative Ideation Training in Adolescence**

Various studies have already demonstrated the effectiveness of training paradigms in improving creativity in both adults (Kienitz et al., 2014) and children (Cliatt, Shaw, & Sherwood, 1980). However, relatively little is known about how malleable creative thinking is in adolescence. Training studies in other higher cognitive skills include working memory (Jolles & Crone, 2012; Klingberg, 2010), executive control (Karbach & Kray, 2009; Zinke, Einert, Pfennig, & Kliegel, 2012), and algebraic equation solving (Qin et al., 2004), and emphasize the training susceptibility regarding performance and brain function during adolescence.

In a behavioral training study (Stevenson, Kleibeuker, De Dreu, & Crone, 2014), we applied a simple creative ideation training paradigm. The main aim of the study was to examine whether creative ideation could be improved by practicing alternative uses generation in adolescents (13–16 years) and adults (23–30 years). In this study, participants followed one of three training types, each composed of eight 20-minute practice sessions within 2 weeks: (a) alternative uses generation (creative ideation, experimental condition), (b) object characteristic naming (general ideation, control condition), or (c) global local rule switching (rule switching, control condition). Performance prior to training sessions resembled previous research and revealed that adolescents already performed at adult level on ideational fluency and flexibility and that adults outperformed adolescents on originality measures. Posttraining results demonstrated that participants in general (irrespective of age group and training condition) progressed on creative ideation originality and fluency. With regard to originality, adolescents progressed further after 2 weeks of training than adults, independent of the type of training. Possibly, this indicates greater practice susceptibility for adolescents than for adults, consistent with the hypothesis that adolescence is a period of enhanced flexibility in cognition and learning (Crone & Dahl, 2012; Johnson & Wilbrecht, 2011).

Important new questions triggered by these results are what (brain) mechanisms are underlying training success in adolescents and to what extent training effects are related to the reorganization of the PFC and associated regulatory systems during adolescence (Keating, 2004; Steinberg, 2005). To examine these issues, we asked participants aged 15–16 years to perform an adapted version of the AUT (similar to the task described in Kleibeuker et al., 2013c); fMRI images were acquired before and after the training program (Kleibeuker et al., 2015). Again, the core brain regions for creative ideation (SMG, AG, MTG) were consistently activated in adolescents and recruitment remained relatively stable after training. The results further demonstrated involvement of lateral PFC in creative ideation output, establishing that performance change, irrespective of training, was positively associated with activation change in IFG/MFG. This further indicates that lateral PFC activation is predictive of divergent thinking success. The exact functions of lateral PFC regions in divergent thinking still need to be deciphered. Future research should therefore distinguish between different aspects of the creative process and examine the relation between lateral PFC regions and the brain networks that support these divergent thinking aspects.

## Conclusion

This review highlights the distinctiveness of developmental trajectories for the different cognitive processes underlying creative performance, with a relative peak for middle adolescents' visuospatial divergent thinking

whereas adults outperformed adolescents on verbal idea generation. Interestingly, success for both types of creative tasks was related to lateral PFC activations so that, relative to adults, middle adolescents showed increased activity for visuospatial divergent thinking and decreased activity for verbal divergent thinking in these late developing brain regions.

It is important to recognize the complexity of creativity, which recruits distinct cognitive processes and takes on different meaning in different task domains. Although we captured creative performance in terms of its hallmarks—originality and insight—we also focused on a limited set of cognitive processes—divergent thinking in particular. Accordingly, and notwithstanding the fact that divergent thinking has been widely recognized as essential and predictive for creativity success (e.g., Kim, 2008; Nijstad et al., 2010), some reservations should be made regarding the generalizability of the results. For example, the Dual Pathway to Creativity Model (De Dreu et al., 2008) would predict that in addition to divergent thinking and cognitive flexibility, creativity can be achieved also through effortful and persistent processing. The work reviewed here did not focus on such effortful processing as a possible means toward creativity, and future studies are needed to uncover whether and how adolescents may differ from adults in this otherwise vital process. In addition, we used simple practice paradigms to gain insight into the trainability of creative thinking in adolescence. An interesting direction for future research is also to test in more detail the relation with executive functions such as working memory, inhibition, and relational reasoning. Nonetheless, the current findings provide important insights into the functionality of the adolescent brain when confronted with problems that require out-of-the-box thinking. Accordingly, the findings summarized here can serve as a useful starting point to model the relationship between neurocognitive development that recognizes the complexity of functional brain development during the transitional phase of adolescence and the vital cognitive processes underlying creativity in both verbal and visuospatial domains of performance. Such modeling could provide useful implications for educational purposes as a better understanding of how the adolescent brain processes information and generates opportunities to adjust educational programs to optimize successful processing of learning material.

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