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

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CHAPTER 2

The development of creative cognition across adolescence: distinct trajectories for insight and divergent thinking

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Abstract

We examined developmental trajectories of creative cognition across adolescence. Participants (*N* = 98), divided into four age groups (12/13 years, 15/16 years, 18/19 years, and 25-30 years), were subjected to a battery of tasks gauging creative insight (visual; verbal) and divergent thinking (verbal; visuo-spatial). The two older age groups outperformed the two younger age groups on insight tasks. The 25-30-year olds outperformed the two youngest age groups on the *originality* measure of verbal divergent thinking. No age-group differences were observed for verbal divergent thinking *fluency* and *flexibility*. On divergent thinking in the visuo-spatial domain, however, only 15/16-year-olds outperformed 12/13-year-olds; a model with peak performance for 15/16-year-olds showed the best fit. The results for the different creativity processes are discussed in relation to cognitive and related neurobiological models. We conclude that middle adolescence is a period of not only immaturities but also of creative potentials in the visuo-spatial domain, possibly related to developing control functions and explorative behavior.

Introduction

Creativity is considered a cornerstone of human society. Creativity is defined as the ability to generate ideas and problem solutions that are both novel and appropriate (Amabile, 1996; Sternberg & Lubart, 1996), and is a prerequisite for human survival and prosperity (Runco, 2004). For example, creative insights solve daily problems (Runco, 2004), artistic creativity promotes mate attraction (Griskevicius, Cialdini, & Kenrick, 2006; Miller, 2000), and creative strategizing allows one to win competition and conflicts (De Dreu & Nijstad, 2008). These and related insights suggest that creativity provides fitness and functionality, in that individuals with creative ability have higher probability of surviving and prospering than those lacking creative abilities.

Across human development, adolescence is an age period characterized by transformations toward life independency (Collins, Gleason, & Sesma, 1997; Hill & Holmbeck, 1986), and is a crucial phase for the development of many cognitive abilities (see e.g., Casey, Jones, & Hare, 2008; Steinberg, 2005). It has been argued that creative problem solving abilities are necessary and important skills facilitating the advancement toward mature adult functioning (Jaquish & Ripple, 1980). Hence, adolescence is expected to involve important changes in creative abilities. The aim of the current study was therefore to examine creative abilities across this transitional age period measuring two cognitive functions that represent creative potential: *insight* and *divergent thinking*.

Creative insight and divergent thinking

Insight tasks are commonly used to understand performance in creative problem solving situations (e.g., De Dreu, Baas, & Nijstad, 2008; Friedman & Förster, 2001; Harkins, 2006; Kounios & Beeman, 2009). Insight tasks typically require establishing associations among previously unrelated or weakly related information, and mental restructuring the problem space; processes which have a central role in creative cognition (Förster, Friedman, Liberman, 2004; Smith & Kounios, 1996). There is widespread agreement that insight solutions differ from non-insight solutions in that: 1) solvers experience their solutions as sudden and obviously correct; 2) prior to producing an insight solution solvers sometimes come to an impasse, no longer progressing toward a solution; 3) solvers usually cannot report the processing that enables them to overcome an impasse and reach a solution.

The second type of task, divergent thinking, is commonly used to verify creative potential and captures the extent to which individuals create novelty (Torrance, 1966). Divergent thinking tasks generally require participants to generate multiple solutions to an open ended problem (Guilford, 1967). The rationale behind these tasks is that creative success is assumed to be related to; a) one's ability to generate many responses (fluency), under the assumption that quantity breeds quality; b) the ability to generate responses in many different conceptual categories (flexibility); and c) the ability to generate unusual or infrequently generated responses (originality) (Guilford, 1950, 1967). Insight and divergent thinking are both associated with the ability to be creative, yet represent different aspects of the creative process.

It is important to distinguish divergent thinking from convergent thinking, as both have been associated with creative cognition (Cropley, 2006; Guilford 1950, 1967; DeYoung et al., 2008). As summarized above, divergent thinking refers to the ability to generate multiple associations to an idea in a random, unorganized way (Baas, De Dreu, & Nijstad, 2008; Friedman & Förster, 2000; Isen & Daubman, 1984; Martindale, Hines, Mitchell, & Covello, 1984). Convergent thinking, however, refers to an analytical and evaluative thinking mode, associated with discovering relations among information, and represents the capacity to quickly focus on the one best solution to a problem (Guilford, 1967; Gaborra, 2010; Runco, 2004). Consequently, convergent thinking has previously been related to cognitive control functioning and general intelligence (De Haan, 2009; Runco, 2004).

Prior research on creativity development mainly focused on divergent thinking but most authors documented divergent thinking only in elementary grades, and few have investigated development beyond age 12. For example Claxton, Pannels, and Rhoads (2005) performed a longitudinal study on figural divergent thinking, examining participant from 4th, 6th and 9th grade. Few age differences were apparent, although they observed a slump in originality for 6th graders. Jacquish and Ripple applied a verbal task in which participants had to respond to presented sounds. Comparisons between pre-adolescents (M_{age} = 10.8 years) and adolescents (M_{age} = 16.4 years) showed increased fluency and flexibility for the adolescents, but no changes in originality. Runco and Bachleda (1987) used a different and extensive set of divergent thinking tasks across 5th to 8th graders. Performance on the measures of verbal divergent thinking changed as a linear function of age. Lau and Cheung (2010) applied a similar set of tests to 4th to 9th graders, but showed that changes may be non-linear. They observed increased performances from 4th to 5th grade, a decrease to 7th graders, and then an increase in divergent thinking in 9th graders. Studies including comparisons between adolescents and adults are scarce. In one study, where participants had to come up with unusual uses for a common object, comparing 6th graders with university students revealed no age related changes for verbal divergent thinking (Wu, Cheng, Ip, McBride-Chang, 2010). This set of findings indicates that developmental changes differ between study methods, even within one type of creative cognition task such as divergent thinking. Moreover, this review of findings sets out the lack of research on development of creativity throughout the period of adolescence. In all, it leads to the question how creativity develops between late childhood, adolescence and adulthood for the broader domain of creativity, assessing divergent thinking and creative insight within the same individuals. The broader assessment in the same individuals is needed to unravel whether there are different developmental patterns for different aspects of creative cognition, and to understand how these aspects are related. To our knowledge the current study is the first to assess both insight and divergent thinking capacities from adolescence to adulthood.

The current study

A set of creativity tasks was administered to early (12/13 years), middle (15/16 years) and late adolescents (18/19 years) as well as adults (25-30 years). The battery included three creative insight tasks: the Gestalt Completion Test (GCT; De Dreu, Baas & Nijstad, 2008; Eckstrom, French, Harman, & Demen, 1976), the Snowy Picture Test (SPT; Baas, De Dreu, & Nijstad, 2011; Friedman & Förster, 2000, 2001; Eckstrom et al., 1976) and the Remote Associates Test (RAT; Mednick 1962), and two tasks gauging divergent thinking: the Alternate Uses Test (AUT; Torrance, 1966) and the Creative Ability Test (CAT, Van Dam & Van Wesel, 2006).

The three insight tasks all tap into insight but for different domains; visual or verbal. The GCT consists of fragments of pictures, the SPT consists of pictures blurred through complex patterns of visual noise, and the RAT consists of triads of words and requires participants to find a fourth related word. All insight tasks involve restructuring and unifying complex or remotely associated information to find a single optimum solution that is retrieved from memory. As such, these tasks require divergent but also convergent thinking (Guilford, 1950) as well as general knowledge, for which we expected to find age related increases.

The two divergent thinking tasks also focused on different domains, verbal and visuo-spatial. The Alternate Uses Test (AUT, Torrance, 1966) requires participants to specify as many original uses for a well-known object (e.g., brick) as they can; these are assessed in terms of fluency, flexibility and originality. Based on prior research using similar tests (Wu et al, 2010), we did not expect performance differences between the younger and older age groups. The second test, the CAT, is a visuo-spatial task in which participants are instructed to find as many matching figures as possible according prespecified rules. To find correct solutions to the CAT, relations among objects have to be retrieved based on corresponding features. The CAT requires some degree of convergent thinking as participants need to incorporate provided rules. It shows some similarities with relational reasoning tasks and tasks that test for frontal lobe functioning in terms of cognitive flexibility, e.g., the Wisconcin Card-Sorting Test (WCST; Myake et al., 2000). The nature of the CAT is, however, divergent rather than convergent, as rules are not provided about *where* solutions might be found or *what* solutions might look like. As such, the task differs from relational reasoning and cognitive flexibility tasks. We expected performance increases across the younger age groups, but we did not expect this task to be related to insight tasks.

Methods

Participants

Ninety-eight participants were divided into four age groups: 25 12/13-year-olds (M = 13.10 years, SD = .47, 13 male), 30 15/16-year-olds (*M* = 16.07 years, *SD* = .48, 13 male), 25 18/19-year-olds (*M* = 19.12 years, *SD* = .50, eight male), and 18 25-30-year-olds (M = 27.03, *SD* = 1.81, eight male). Gender distributions did not significantly differ across age groups (χ^2 (3, *N* = 98) = 2.13, *p* = .55). Participants were recruited from local schools (early and middle adolescents), from Leiden University (late adolescents and adults), and through local advertisements. All participants provided informed consent. In the case of minors, consent was also obtained from primary caregivers. To screen for behavioral problems participants from all age groups filled out the self-report version of the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997). Total scores for the two youngest age groups fell in the non-clinical range. No standard scores were available for ages >18 years, but scores from the older age groups did not differ significantly from the younger age groups. Depending on age and testing location, participants received a fixed payment, course credits, or a present.

Cognitive and behavioral assessment

Creativity has been associated with intelligence (Furnham & Bachtiar, 2008; Batey, Furnham, & Safiullina, 2010), working memory (De Dreu, Nijstad, Baas, Wolsink & Roskes, in press; Oberauer, Sü, Wilhelm & Wittmann, 2008; Vandervert, Schimpf & Hesheng, 2007), and verbal fluency (Gilhooly, Fioratou, Anthony & Wynn, 2007). To control for age-effects related to these concepts, standard scores were obtained from the WISC or WAIS subtests Similarities (verbal IQ) and Digit Span (DS; working memory)(Wechsler, 1991, 1997), and the Groninger Intelligence Test subtest Verbal Fluency (VF) (GIT; Luteijn & van der Ploeg, 1983). Eighty-four participants completed the Similarities subtest, 82 participants completed DS subtest, and 87 participants completed the VF subtest. One-way ANOVAs performed on these three measures revealed no significant age group effects (Similarities: $F(3,83) = 1.08$, $p = .36$; DS: $F(3,81) = 1.83$, $p = .15$; VF: $F(3,86) = .750$, $p = .53$). This renders alternative explanations for age-related differences in terms of verbal intelligence, working memory or verbal fluency unlikely.

Materials

<u>Insight tasks</u>

Three insight tasks were included: the *Gestalt Completion Test,* the *Snowy Picture Test* and the *Remote Associates Test*. Both the Gestalt Completion Test (GCT, Eckstrom et al., 1976) and the Snowy Picture Test (SPT, Eckstrom et al., 1976) measure visual insight (Förster et al., 2004; Eckstrom et al., 1976). In the GCT, participants view a series of fragmented pictures of familiar objects and indicate what they see. Successful identification of the objects requires processing relations among elements and integrating the fragments into a coherent 'Gestalt'. This process of *restructuring a stimulus set* is commonly considered a basic process of creative cognition (Schooler & Melcher, 1995). In the current study, we used a computerized version comprising 10 fragmented pictures (De Dreu, Baas, & Nijstad, 2008). The test items were preceded by two examples. Participants could type their answers or skip the question. By clicking a button the participants proceeded to the next picture. Response time was not restricted. Responses were coded as correct or incorrect (including skipped items).

In the SPT participants are presented with a series of images of familiar objects hidden within visual noise. To identify the hidden objects participants need to disregard misleading interpretations rendered by the context. The computerized version, used in this study, contained the first 12 pictures from the original SPT set (Baas, De Dreu, & Nijstad, 2011). Test items were presented in random order and were preceded by two examples. Answers could be typed during an unlimited response time, and responses were coded as correct or incorrect (including skipped items). The next picture was presented upon a button click.

The Remote Associates Test (RAT; Mednick, 1962) is a measure of verbal insight. Participants are presented with three words (e.g., envy, golf, beans) and are instructed to generate the one word that relates to all of these three words (i.e., green). To come up with the correct solution, participants need to identify relations among the three stimulus words. These relations are generally not the most obvious. In the current study, we used a computerized version of the RAT comprising 30 triads of Dutch words (De Dreu et al., 2011; Baas et al., 2011). Test items were presented in a random order, preceded by two example items. Participants were instructed to type their answers or skip if no solution was found and click a button to go to the next item. The response time was unlimited. Responses were coded as correct or incorrect (including skipped items).

<u>Divergent thinking tasks</u>

To gauge divergent thinking, we used the *Alternate Uses Test* (AUT, Guilford, 1967), and the *Creative Ability Test* (CAT, Van Dam & Van Wesel, 2006). The AUT measures divergent thinking in the verbal domain in terms of *fluency, flexibility,* and *originality.* Participants are given the name of an object and asked to generate as many alternative uses for the object as possible. In the current computerized version, participants were instructed to generate alternative uses for a *brick* (e.g., Baas et al., 2011; Friedman & Forster, 2001). Solutions can be unusual but must be appropriate. Answers could be typed for a fixed length of 4 minutes. Participants were instructed to press ENTER after each answer typed to submit the answer. Concurrently, the response field was cleared and the next answer could be given. *Fluency* scores were computed by counting the number of correct solutions provided. *Originality* was determined as follows. For each solution, frequency of occurrence across the total of solutions (provided by all participants) was determined. Since frequency distributions were positively skewed, frequency scores were log-transformed before averages were computed (similar effects were found with non-log-transformed frequency scores). Then, average frequency scores were computed for each participant. *Flexibility* was measured by the number of solution-categories. A trained rater assigned each solution to one of 35 solution-categories (e.g., building aspect; load; toy). Then, the number of applied solution-categories was counted for each participant individually.

The CAT measures *fluency* and *originality* of divergent thinking in the visuo-spatial domain. The test problem consists of nine squares including figures. Participants are asked to compose triads of squares based on the properties (e.g., number, position) of the figures included. These squares must be similar concerning a particular figure property (or properties) and therefore differ from the other six squares. Fluency sores were computed by counting participants' number of correct answers. Originality was computed by summing the uniqueness scores (1 = 'common' to 5 = 'very unique') of correct answers. Uniqueness scores were based on occurrence of solutions in previous validity studies (Van Dam & Van Wesel, 2006). Higher scores corresponded to lower frequency of occurrence. Participants were instructed to write down as many triads as they could. Response time was limited to 10 minutes. Prior to the test, participants were presented with an example emphasizing the variety of possible solutions (Van Wesel, 2006).

Procedure

Participants were invited to participate in a study about general problem solving. They were tested individually either in a classroom or in a separate room at Leiden University. Test administration was divided into three parts: 1) computerized versions of the GCT, SPT, RAT and AUT, for which participants were seated in front of a 15 inch laptop; 2) Similarities, DS and VF, which were administered orally; and 3) a paper and pencil version of the CAT. Duration of the three test parts was approximately 30, 15 and 15 minutes respectively including instructions. Participants were encouraged to ask for help if any ambiguity concerning a test remained after reading the instructions. In between tasks participants were given a break, and upon completion of the entire experiment, participants were debriefed and received their compensation.

Due to practical limitations, only 89 of the total of 98 participants completed all the computerized test ($N_{12/13\ yrs} = 25$; $N_{15/16\ yrs} = 23$; $N_{18/19\ yrs} = 25$; $N_{25\text{-}30\ yrs} = 16$), and 95 participants completed the CAT ($N_{12/13\ yrs} = 24$; $N_{15/16\ yrs} = 30$; $N_{18/19\ yrs} = 20$; $N_{25\text{-}30\ yrs} = 17$).

Results

First, we tested for age differences on insight and divergent thinking measures using analyses of variance (ANOVAs) with age as between-subjects factor. Significance thresholds were set to $p < .05$. All significant effects survived Greenhouse–Geisser correction. For all ANOVAs, Levene's test of homogeneity of variances was applied. Tukey HSD tests when variances were homogeneous, or Games–Howell tests when variances were non-homogeneous, were applied for post hoc analysis of between-group comparisons. Means and standard deviations of insight and divergent thinking measures are presented in Table 2-1. In addition, we conducted Principal Component Analyses (PCA) and correlations among task performances to identify relations between the different types of creativity measures.

Table 2-1. Means and standard deviations for performance parameter for insight and divergent thinking tasks by age group

		12/13 yrs		15/16 yrs		18/19 yrs		25-30 yrs	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Insight									
Visual	GCT[a]	5.36	1.87	5.65	1.43	6.92	1.04	7.44	1.36
	SPT[a]	5.89	1.83	6.00	2.20	7.56	2.04	7.82	1.74
Verbal	RAT[a]	7.32	3.24	9.57	3.26	12.44	3.49	13.06	2.95
Original Ideation									
verbal	AUTfluency[a]	10.76	5.72	9.70	4.88	11.12	5.92	10.13	4.59
	AUTflexibility[a]	6.80	3.08	5.96	2.44	7.36	2.69	7.19	3.06
	AUToriginality[a]	0.85	0.13	0.87	0.19	0.81	0.12	0.73	0.10
Visuo-spatial	CATfluency[b]	7.17	3.19	9.17	2.39	8.35	2.29	8.28	2.22
	CAToriginality[b]	10.58	6.79	13.53	5.26	11.48	4.71	12.22	4.80

Note. [a] 12/13 yrs, *n*=25; 15/16 yrs, *n*=23; 18/19 yrs, *n*=25; 25-30 yrs, *n*=16; [b] 12/13 yrs, *n*=24; 15/16 yrs, *n*=30; 18/19 yrs, *n*=20; 25-30 yrs, *n*=17; GCT = Gestalt Completion Test; SPT = Snowy Picture Test; RAT = Remote Association Test; AUT = Alternate Uses Test; CAT = Creative Ability Test.

Task performances

Insight tasks

Performances for the insight tests were examined in terms of accuracy (quantified as the number of correct solutions).

Visual insight: GCT and SPT

Participants' number of correct insights performances were submitted to a multivariate ANOVA with age group (12/13 yrs, 15/16 yrs, 18/19 yrs, 25-30 yrs) as between-subject variable. A multivariate main effect of age group ($F(6,170) = 5.36$; $p < .001$; $p\eta^2 = .25$) was found. Univariate ANOVAs were used to further examine the data. Both tasks revealed univariate main effects of age group. On the GCT, $F(3,85) = 9.58$; $p<.001$; $p\eta^2 = .25$, post hoc Games-Howell comparisons (Levene's test $F(3,85) = 3.17$; $p = .03$) showed that participants from the two older age groups out-performed participants from the two younger age groups (12/13 yrs < 18/19 yrs, $p = .001$; 15/16 yrs < 18/19 yrs, $p = .002$; 12/13 yrs < 25-30 yrs, $p = .004$ and 15/16 yrs < 25-30 yrs, *p* = .006; see Figure 2-1a). The univariate ANOVA for the SPT also resulted in a main effect of age, (F(3,85) =5.80; p=.002; pη^2 =.16), and again, the age group effect was driven by significant differences between participants of the two younger age groups on the one hand and participants from the two older age groups on the other hand; better performance was achieved by older participants. Post hoc Tukey HSD (Levene's test: p >.5) revealed significant effects for contrasts 12/13 yrs < 18/19 yrs, p = .02; 15/16 yrs < 18/19 yrs, p = .04; 12/13 yrs < 25-30 yrs, p = .02; and 15/16 yrs < 25-30 yrs, p = .04, see Figure 2-1b.

Verbal insight: RAT

Performance scores were entered into an ANOVA with age group (12/13 yrs, 15/16 yrs, 18/19 yrs, and 25-30 yrs) as between-subjects variable. Performance differed across age groups F(3,85) = 14.68; p < .001; pη^2 = .34. Tukey HSD post hoc analysis (Levene's test: p > .5) showed that accuracy for participants from the two older age groups was significantly better compared to participants from the two younger age groups; 12/13 yrs < 18/19 yrs, p < .001; 15/16 yrs < 18/19 yrs, p = .016; 12/13 yrs < 25-30 yrs, p <.001 and 15/16 yrs < 25-30 yrs, p = .008, see Figure 2-1c.

In all, the developmental trajectories of the creative insight tasks seemed to follow stepwise rather than linear or curvilinear patterns, generally observed for development of cognitive control (e.g., Huizenga et al., 2006). Post hoc model analyses using linear regression analyses confirmed that SPT and GCT results fitted stepwise patterns (contrast: -1, -1, 1, 1; for 12/13 yrs, 15/16 yrs, 18/19 yrs, 25-30 yrs age groups) better than linear (modeling results as a linear function of age) or curvilinear models (modeling results as log-transformed or quadratic functions of age), SPT: F(1, 87) = 16.56, R = .37, p < .001; GCT: F(1, 87) = 27.15, R = .49, p < .001. RAT results revealed best fit with the log-transformed curvilinear model: F(1, 87) = 39.30, R = .56, p < .001.

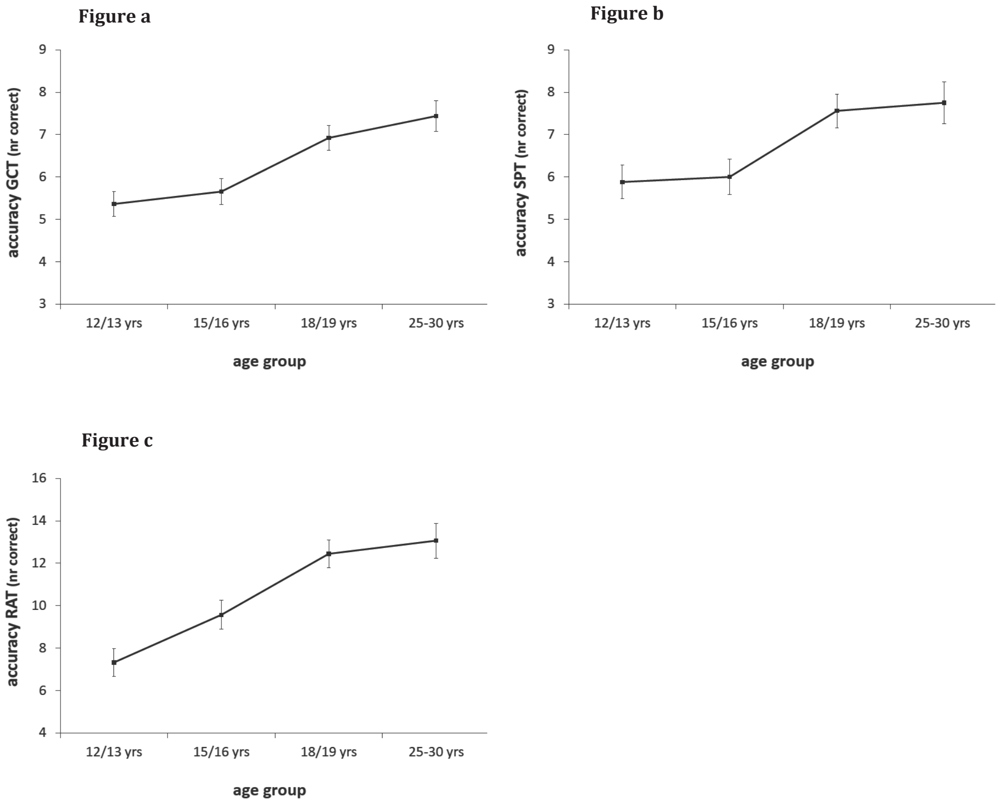

Figure 2-1. Insight performances
Mean ± 1 standard error (SEM) of the number of correct solutions for each group for the Gestalt Completion Test (a), Snowy Picture Test (b), and Remote Association Test (c).

<u>Divergent thinking</u>

Verbal divergent thinking: AUT

Performance was measured in terms of *fluency, flexibility and originality.* Univariate ANOVAs for the fluency and flexibility measures with age group (12/13 yrs, 15/16 yrs, 18/19 yrs, 25-30 yrs) as between subject variable showed no age group differences ($p > .05$). A univariate ANOVA on originality, represented by the mean frequency of solutions, yielded a significant age group effect (F (3,85) = 3.79, $p = .01$; $p\eta^2 = .12$). Post hoc Tukey HSD analyses (Levene's test: $p > .5$) showed that the two younger age groups had higher frequency scores (i.e., were *less* original) compared to the oldest age group (12/13 yrs < 25-30 yrs, $p = .03$ and 15/16 yrs < 25-30 yrs, p =.02). The 18/19 yrs group took an intermediate position and did not significantly differ from the other three groups. Accordingly, age group related changes of AUT originality, displayed in Figure 2-2, were best described by a linear model, $F(1, 87) = 11.37$, $R = .34$, $p = .001$.

Response times (time between entering consecutive solutions) showed large intra-subject variability, rendering it unlikely that participants typing speed, rather than the time for generating correct solutions was the main factor responsible for the observed inter-subject differences.

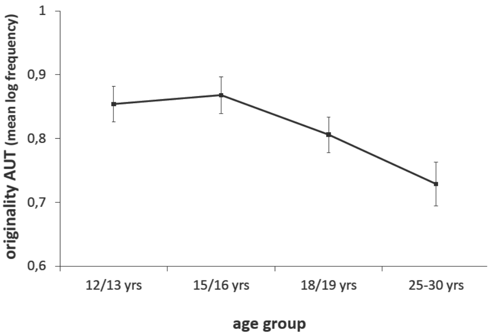

Figure 2-2. Verbal Divergent Thinking *originality*
Mean ± 1 standard error (SEM) of average log-transformed frequencies of ideas generated in the Alternate Uses Test for each age group.

Visuo-spatial divergent thinking: CAT

Performance was measured in terms of *fluency* and *originality*. Univariate ANOVAs with age group (12/13 yrs, 15/16 yrs, 18/19 yrs, 25-30 yrs) as between subject variable resulted in significant age group effects for fluency ($F(3,91) = 2.71$, $p < 0.05$; $p\eta^2 = .08$) but not for originality ($F(3,91) = 1.39$, $p = .25$; $p\eta^2 = .04$). Post hoc Tukey HSD analyses (Levene's test of equality: $p > .5$) showed that 15/16 years olds gave significantly more correct answers than 12/13 yrs olds ($p = .03$) . The two adult groups did not significantly differ from each other or from the two younger age groups (all p's >.05). As such, the results, presented in Figure 2-3, showed a complex pattern that did not fit significantly with linear, stepwise, or curvilinear models. Alternative model analyses regarding peak performance for middle adolescents (contrast: -1 3 -1 -1 ; for 12/13 yrs, 15/16 yrs, 18/9 yrs, and 25-30 yrs respectively) revealed significant fit ($F(3,91) = 5.01$, $p = .028$).

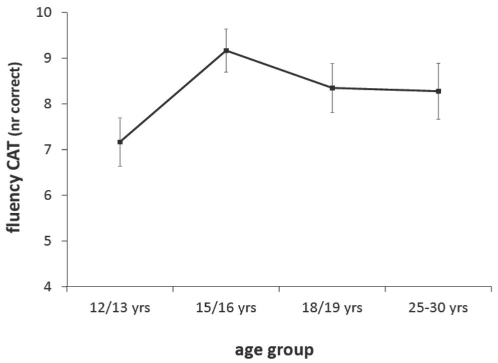

Figure 2-3. Visuo-Spatial Divergent Thinking *fluency*
Mean ± 1 standard error (SEM) of the number of correct solutions on the Creative Ability Test for each age group.

Principal Component Analyses

Principal Component analyses were performed on GCT, SPT and RAT performances, AUT fluency, AUT flexibility, AUT originality, CAT fluency and CAT originality scores ($N_{12/13\ yrs} = 25$; $N_{15/16\ yrs} = 23$; $N_{18/19\ yrs} = 25$; $N_{25\text{-}30\ yrs} = 16$) followed by Varimax Rotations. This approach was chosen to maximize the distinctions among aspects. The threshold for retained Eigenvalues was set to at 1.0 and only variables with loadings of at least .5 are interpreted as significant. The analysis revealed three factors, which accounted for 70% of the common variance. Table 2-2 shows that these factors reflect the trichotomy of developmental patterns observed with previous analyses. The first factor loaded with performances on the insight tasks and, marginally significantly, with AUT originality. The second factor loaded with AUT fluency, and AUT flexibility, and the third factor with CAT performances.

Table 2-2. Varimax rotated exporatory factor model

	Factor 1	Factor 2	Factor 3
GCT	**.77**	.08	-.01
SPT	**.68**	-.13	-.06
RAT	**.76**	-.10	-.01
AUTfluency	-.03	**.94**	-.00
AUTflexibility	.03	**.93**	.03
AUToriginality	-.49	-.26	-.10
CATfluency	.04	-.01	**.96**
CAToriginality	-.04	.04	**.97**

Note. *N* = 86; GCT = Gestalt Completion Test; SPT = Snowy Picture Test; RAT = Remote Association Test; AUT = Alternate Uses Test; CAT = Creative Ability Test. Loadings ≥.50 are in given in boldface.

Correlations

Bivariate correlations: Table 2-3 shows the correlations between creative task performances over all participants. As predicted, significant correlations are observed between measures of insight, between measures of verbal divergent thinking, and between measures of visuo-spatial divergent thinking. Additional correlations are observed between AU originality and insight performance, but only the correlation with GCT was statistically significant. Correlations between AU originality and SPT and RAT respectively were only marginally significant. Notice that AU originality scores are based on frequency scores, so that negative correlations indicate positive relations between originality and insight. In all, these correlations are in congruence with the extracted factors in the PCA.

Table 2-3. Bivariate correlations for performance parameters for Insight and Divergent Thinking tasks

	Insight		**Divergent Thinking**				
	SPT	RAT	AUT fluency	AUT flexibility	AUT originality	CAT fluency	CAT originality
GCT	.320 *	.453 **	.064	.078	-.275 *	-.002	-.003
SPT		.334 **	-.073	-.056	-.201	.019	-.099
RAT			-.115	.001	-.183	.063	-.072
AUTfluency				.791 **	-.152	-.002	.041
AUTflexibility					.142	.044	.046
AUToriginality						-.014	-.105
CATfluency							.870 **

Note. N = 89 except for following correlations: Insight-CPT (N = 86); AUT-CPT (N = 86); CPT-CPT (N = 95). GCT = Gestalt Completion Test; SPT = Snowy Picture Test; RAT = Remote Association Test; AUT = Alternate Uses Test; CAT = Creative Ability Test. *p < .01, two-tailed; **$p \leq$ .001, two-tailed.

Partial correlations: Only correlations between GCT and RAT (r = .24, p = .026), AU fluency and AU flexibility (r = .79, p < .001), and CAT fluency and CAT originality (r = .87, p < .001) remained significant after controlling for age group means. The disappearances and strong decreases of correlations between insight and divergent thinking after correction for age group effects indicate that the initial bivariate correlations between these constructs are likely driven by developmental differences.

Discussion

The aim of this study was to augment understanding of the development of creativity across adolescence. Using a range of creativity tests, we found distinct developmental patterns indicating that: 1) creative insight and the qualitative measure of verbal divergent thinking, originality, continue to develop into late adolescence; 2) the two quantitative measures of verbal divergent thinking, fluency and flexibility, reach adult level early in adolescence and; 3) visuo-spatial divergent thinking shows a non-linear developmental pattern with best performance at age 15-16. This trichotomy was supported by factor reduction and correlation analyses. In all, these data support the distinctiveness of creativity aspects. Mechanisms that may underlie these trajectories are discussed in the following paragraphs.

Creative insight

Creative insight showed increased performance with age continuing into late adolescence on both visual and verbal problems. Our results therefore indicate that the ability to successfully restructure and unify complex or remotely associated information is not fully developed until late adolescence.

A first factor that might have contributed to these developmental differences is the increasing amount of knowledge and experience gained with increasing age; both forms of insight require retrieval of stored knowledge and associations. Second, age related increases might be related to development of cognition control functioning. Creative insight performance has been shown to benefit from deliberate, focused, and structured exploration of cognitive categories or perspectives (De Dreu, Nijstad, & Baas, 2008; Finke, 1996; Schooler, Ohlsson, & Brooks, 1993; Simonton, 1999) and incremental search processes (Boden, 1998; Newell & Simon, 1972). In addition, neuroimaging studies indicate the importance of the prefrontal cortex for successful creative insight (Kounios et al., 2006; Razumnikova, 2007). It is now well documented that cognitive control functions, and associated prefrontal cortex areas, develop across childhood and adolescence (see e.g., Casey, Jones, & Hare, 2008; Crone, 2009). Specifically, cognitive control functions such as working memory, inhibition, monitoring, and mental switching, show protracted developmental trajectories throughout adolescence (Huizinga et al., 2006; Luna, Garver, Urban, Lazar & Sweeny, 2004). Accordingly, immature cognitive control functioning for the two youngest age groups in our study likely explains, at least to some degree, the observed age related differences.

Visual Insight

The developmental pattern for visual insight was best described by a model that tested for a performance-step between middle and late adolescence, rather than a linear age change. Non-linear developmental patterns with relative poor performance in middle adolescence are not uncommon in literature on visual cognition. For example, Uhlhaas and colleagues (2009) found sudden interruptions in Gestalt perception development during adolescence. Neurophysiologic measures indicate that these developmental interruptions are related to reorganizations of functional neural networks, which is compatible with functional and structural non-linear trajectories of cortical networks during this period as seen in imaging studies (Ashtari et al., 2007; Gogtay et al., 2004; Luna, 2010). Accordingly, we might expect functional changes toward more adult-like coordination of visual information processing to induce developmental stagnation of visual insight performance, as observed in our study.

Verbal divergent thinking

For verbal divergent thinking we found different developmental patterns for the three divergent thinking measures. Fluency and flexibility performances did not change throughout the age range. These results are in congruence with previous findings on verbal ideation for 6th graders and university students (Wu et al., 2010) and indicate that the capacity to generate numerous ideas from different categories is already fully developed in early adolescence. For the third measure of ideation, originality, which was not reported separately in the Wu et al (2010) study, marked increases were found after middle adolescence. Thus, although adolescents as young as 12 years old are able to produce adult-level numbers of solutions, the quality of solutions still develops.

Common to insight development, a first factor that might (partially) account for the developmental changes in originality performance concerns knowledge and experiences (Weisberg, 1999). Individual lifestyles of adults and late adolescents generally involve larger inter-individual variance of experiences and knowledge compared to younger groups. Consequently, older age-groups might create relatively infrequent associations and ideas. A second possible explanation for the age group differences concerns developmental changes in other cognitive processes. Successful creative thinking is associated with flexible coordination between analytic and associative processing (Christoff, Gordon & Smith, 2009a, 2009b; Martindale, 1999; Martindale & Hasenflus, 1978). Both associative and analytic processing is believed to lead to numerous ideas (De Dreu et al., 2012, Nijstad et al., 2010). However, the quality of generated ideas seems related to the coordination between them (e.g. Martindale, 1999), an ability that is associated with functioning of late developing prefrontal brain regions (Kerns, 2006; Kerns et al., 2004). Thus, for early and middle adolescents the ability to successfully shift between the two types of processing might not be fully developed (Smolucha & Smolucha, 1986; see also Runco, 2007). To test these hypotheses on the combined influence of associative, and analytical of processing, future research might relate creative thinking across age groups to activation in prefrontal cortex (e.g. see Fink et al., 2009).

Visuo-spatial divergent thinking

The participants' performance on the CAT showed marked increases from early to middle adolescence, whereas early adolescents' performance did not differ from late adolescents' or adults'. These results suggest an advantage for middle adolescents on this aspect of creativity. It should be noted that the middle adolescents did not differ significantly from the older age groups in performance, but the model which tested for a middle adolescent peak provided significant fit.

Success on this type of task is relatively independent of knowledge but requires shifting between representations of visual information provided, applying a set of rules, and monitoring behavior; cognitive functions that are still developing during young adolescence (Huizinga et al., 2006). It seems logical that the above-mentioned factors relate to the increase for middle compared to early adolescents. However, as mentioned, the youngest group did not differ significantly from the oldest two age groups, suggesting a relative advantage for the middle adolescents. The divergent character of the task introduces benefits for widely focused exploration of the externally presented information. Both animal and human studies indicate that explorative behavior is characteristic for adolescents (Dahl, 2011; Johnson & Wilbrecht, 2011), and that this behavior is likely associated with increased levels of dopamine in prefrontal cortex during this age period (see Casey et al, 2008; Spear, 2000). For middle adolescents, the required cognitive control functions are expected to be sufficiently developed. Combining these prerequisites with broadened attention toward externally presented stimuli (e.g.,Gray, Buhusi & Schmajuk, 1997), provides an explanation for the observed developmental pattern with advantages for middle adolescents. This hypothesis needs to be tested more elaborately in future research.

To summarize, several cognitive and related neurobiological aspects are likely to contribute to the distinct developmental patterns for insight and divergent thinking, including knowledge and experience, coordination between information processes, reorganizations of functional networks, and widely focused explorative behavior during adolescence. There are, however, some limitations of the current study that should be taken into account when drawing conclusions about developmental changes; a) the current study included a relatively small sample size (n=19 to n=30 per age group) and therefore future studies should replicate results to validate our findings; b) the study design was cross-sectional rather than longitudinal, which limits the reliability of the revealed age differences; c) the gaps between age groups may hide short-term changes in performance; and d) because of practical limitations, there were some differences were present between the younger and older participants in test administration (see Methods section). However, a lack of significant age group differences with regard to norm scores on measures of general cognitive abilities render it unlikely that the observed developmental patterns were merely the consequence of cohort effects. Thus, we believe the current study provides meaningful insights into the creative abilities and constraints across adolescent development and provides interesting hypotheses that need to be tested in future research.

Conclusions

To our knowledge the current study is the first to examine the development of diverse aspects of creativity across adolescent development. The findings demonstrated distinct developmental trajectories with marked discrepancies between divergent thinking and creative insight. These results could be related to age-related differences of knowledge and experiences only to some degree, and are likely related to the protracted development of cognitive control functioning and the relatively wide and explorative focusing style characteristic for middle adolescents. Similar conclusions have been suggested by animal research showing that adolescent mice show relatively greater flexibility for learning than more mature mice (Johnson & Wilbrecht, 2011). We hypothesize that these developmental changes are related to reorganizations of functional networks, which is in line with the developmental theory of interactive specialization (Johnson, 2011).

In future studies, it will be of interest to relate creative thinking to activation in the prefrontal cortex, to examine the combined influence of associative, automatic, and analytical, deliberate types of processing (e.g. see Fink et al., 2009). As individuals enter adolescence, this confronts them with multiple possibilities for learning and adaptation, possibly guided by increased capacity for widely focused processing, giving them opportunities for exploration. In sum, the current results indicate that adolescent development is not only a time of immaturity but also of flexibility and potential for creativity.

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