



## The (b)link between creativity and dopamine: Spontaneous eye blink rates predict and dissociate divergent and convergent thinking

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### ARTICLE INFO

#### Article history:

Received 24 April 2009

Revised 23 February 2010

Accepted 2 March 2010

#### Keywords:

Creativity  
Divergent thinking  
Cognitive flexibility  
Dopamine

### ABSTRACT

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

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### 1. Introduction

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

of how this interplay is orchestrated, and there are reasons to believe that the neurotransmitter dopamine (DA) plays an important role in that.

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

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(2003) have reported differences in latent inhibition (an effect that is modulated by DA-targeting drugs) between more and less creative individuals.

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

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

## 2. Experiment 1

In Experiment 1, we considered two creativity tasks: the alternate uses task (AUT: Guilford, 1967) and the remote associates task (RAT: Mednick, 1962). The AUT has open-ended questions with multiple answers, and is thus diagnostic of divergent thinking. In contrast, the RAT has

questions with only one, if unconventional answer, and is thus diagnostic of convergent thinking. According to Guilford (1950), divergent and convergent thinking are the main ingredients of creativity, but in the light of the above caveats we do not claim that these are the only processes involved.

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

### 2.1. Method

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

#### 2.1.1. Alternate uses task (divergent thinking)

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

**2.1.1.1. Originality.** Each response is compared to the total amount of responses from all of the subjects. Responses

that were given by only 5% of the group count as unusual (1 point) and responses given by only 1% of them count as unique (2 points).

2.1.1.2. *Fluency*. The total of all responses.

2.1.1.3. *Flexibility*. The number of different categories used.

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

2.1.2. *Remote association task (convergent thinking)*

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

2.1.3. *Raven's Advanced Progressive Matrices (fluid intelligence)*

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

2.1.4. *Eye blink rate (dopamine marker)*

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

2.1.5. *Results and discussion*

From the four tasks or measurements, seven measures were extracted for each participant: originality, fluency, flexibility, and elaboration scores from the AUT, the num-

ber of correct items from the RAT, the number of correct items from Raven's APM, and the EBR (per min). Relationships between these measures were assessed by means of regressions (SPSS curve fitting procedure). We report the results (coefficients) for linear and quadratic fits (see Table 1); other types of relationships were also considered but did not provide better fits.

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

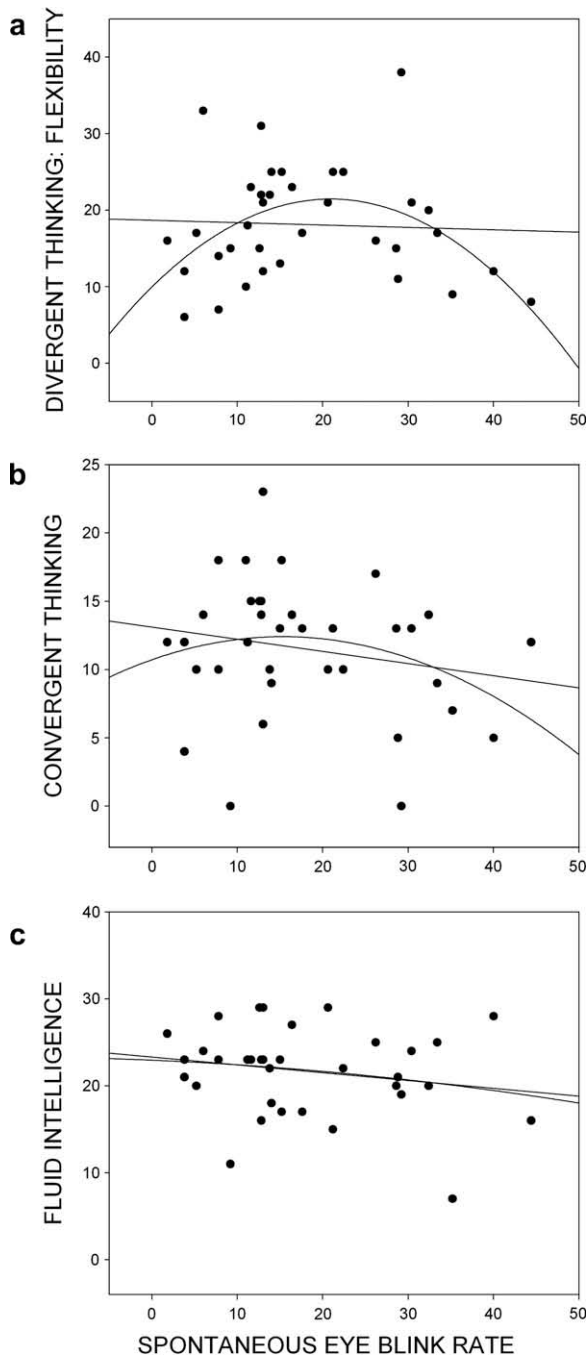
### 3. Experiment 2

Before considering the theoretical implications of our findings, it is important to know how stable and replicable they are. We assessed this issue by running a second study that sought to replicate the crucial correlation between EBR and flexibility. We also kept the convergent-thinking task to see whether EBR would still be uncorrelated with convergent thinking. Note that even though the association measures failed to pass the significance threshold in Experiment 1, they did reach a considerable numerical size and

**Table 1**

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

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



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

the outcome pattern (see Fig. 1b) looked not too different from that obtained for flexibility (Fig. 1a).

### 3.1. Method

Thirty-three new students of Leiden University volunteered in exchange for course credit or pay (21 females

and 12 males; mean age was 20.1 years). The method was as in Experiment 1 with the following exceptions: The APM was dropped and the AUT comprised of only one common household item (cup) with 5 min to list alternative uses. Only 22 of the participants performed the RAT.

### 3.2. Results and discussion

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

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

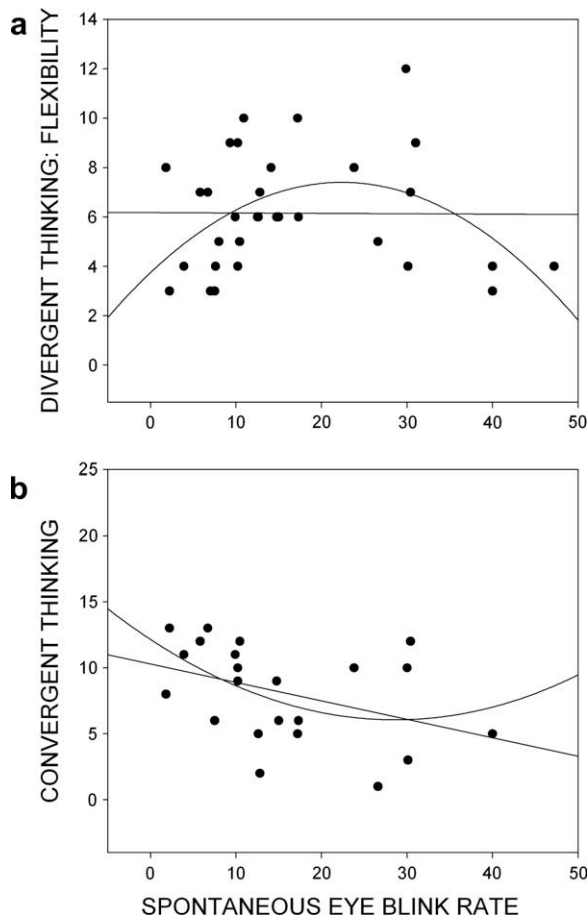
## 4. Experiment 3

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

**Table 2**

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

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



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

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

#### 4.1. Method

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

#### 4.2. Results and discussion

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

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

#### 5. Combined analysis

To increase the power of our analyses we combined the data from the three experiments by normalizing (z-transforming) AUT, RAT, and EBR measures. As obvious from Table 4, the increase in power rendered the association between EBR and flexibility highly significant and even the association between EBR and convergent thinking is reliable by now. However, whereas the relationship between EBR and flexibility is still decidedly quadratic and inverted U-shaped (see Fig. 4a), the relationship between EBR and convergent thinking is more or less linear (with a trend towards a slightly U-shaped function) and shows a negative relationship (see Fig. 4b), implying that convergent thinking is increasingly impaired by higher dopamine levels. As we tested unequal numbers of male and female participants, we reran these analyses separately for men and women. The outcome was the same: reliable quadratic (inverted U-shaped) relationships ( $ps < .01$ ), but no linear relationship ( $ps > .05$ ), between EBR and flexibility, and reliable linear relationships ( $ps < .05$ ), but no quadratic relationship ( $ps > 0.05$ ), between EBR and convergent thinking. Hence, our findings do not seem to depend on the particularities of our samples.

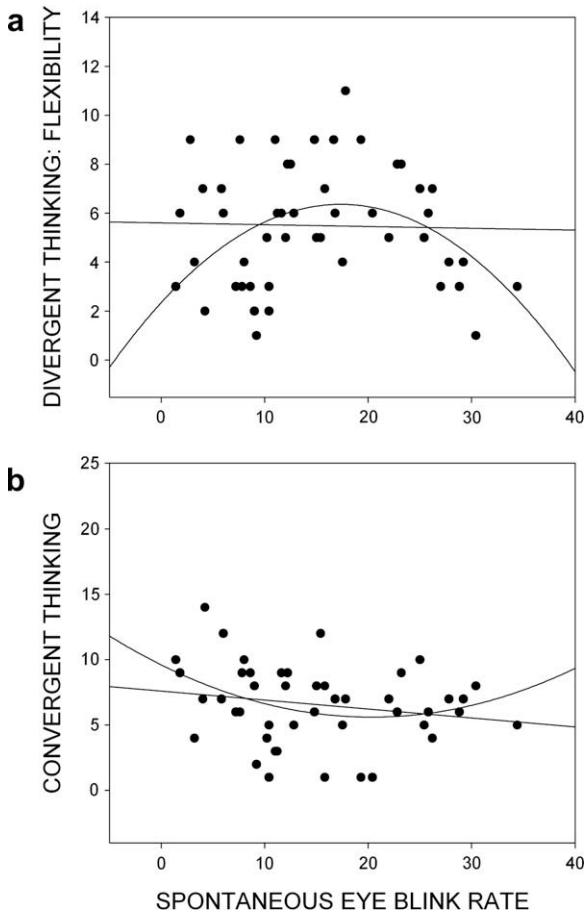
#### 6. General discussion

The major aim of our study was to investigate whether individual measures of creativity would covary with the individual EBR, which may point to a connection between

**Table 3**

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

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



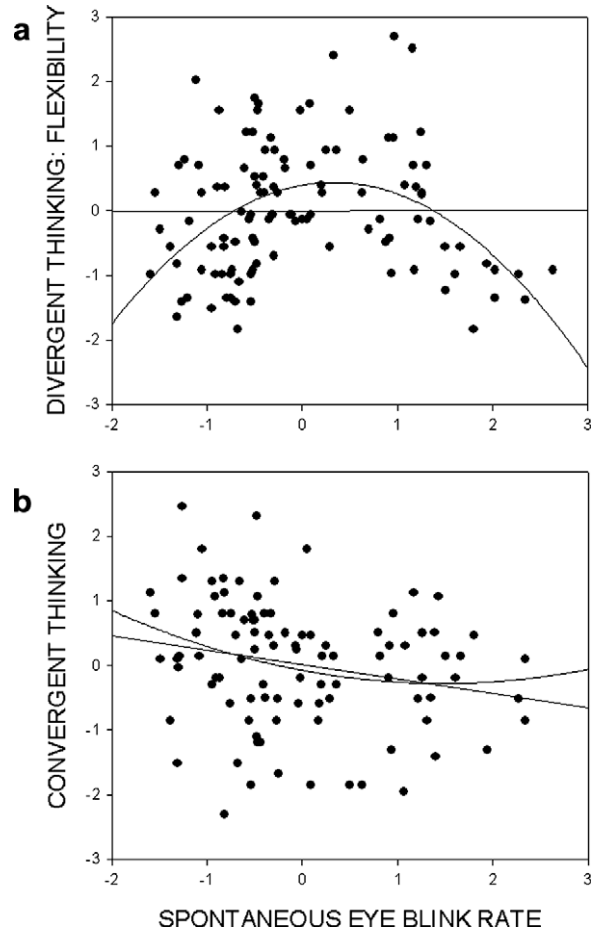
**Fig. 3.** Performance in (a) the divergent-thinking task (flexibility score), and (b) the convergent-thinking task in Experiment 3 as a function of spontaneous eye blink rate (EBR) per min. Regression lines for linear and quadratic fits are also given.

**Table 4**

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

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

creativity and dopamine. The answer is clear but a bit more complex than expected: EBR predicted both the quality of divergent thinking, and flexibility of switching between multiple categories in particular, and the quality of convergent thinking, but not fluid intelligence. However, the two



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

associations differed in type, pattern, and reliability: divergent thinking benefitted most from medium EBRs, while convergent thinking was best with low EBRs. If we take EBR as diagnostic of the individual level of dopaminergic functioning, this suggests that flexibility and convergent thinking are both related to dopamine, but to different degrees and in different ways. Our observations have a number of interesting theoretical implications.

First, they are consistent with the claim that creativity is not a homogeneous concept but reflects the interplay of separate, dissociable processes, such as convergent and divergent thinking (e.g., Guilford, 1950). Our findings do not fully fit with the idea that convergent and divergent thinking represent opposite poles of the same dimension (Eysenck, 1993), however. Even though Experiment 1 produced a negative correlation between convergent thinking and fluency in divergent thinking—suggesting that at least some aspects of divergent and convergent thinking are mutually incompatible—this association did not involve flexibility, the measure related to EBR, and could not be replicated in Experiments 2 and 3. The same holds for

the negative correlation between convergent thinking and elaboration in divergent thinking, which we observed in Experiment 3 only. Hence, convergent and divergent thinking are not necessarily opposites but they are not the same either. In fact, it makes sense to assume that convergent thinking draws on executive functions that keep the participant “on target” until the solution is found. Duncan et al. (2000) have considered that working memory (a system that is driven by dopamine: Williams & Goldman-Rakic, 2002) and other functions related to the frontal lobe are responsible for maintaining a high degree of activation of the task goal, which organizes and constrains other cognitive processes so to keep people focused on the task. As the findings of Duncan and colleagues show, the ability to keep such a focus is highly related to fluid intelligence. If we consider that our intelligence measure correlated positively with convergent thinking and that keeping a strictly limited focus is more functional for convergent thinking than it is for divergent thinking, a negative relation between convergent thinking and aspects of divergent thinking seems to fit into the bigger picture.

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

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

parts of convergent thinking may suggest that convergent thinking is related to the COMT gene. Indeed, working memory is mainly driven by mesocortical dopaminergic pathways, whereas receptors of the DA-D2 family dominate the nigrostriatal dopaminergic pathways, which raises the possibility that the former is more closely related to convergent thinking and the latter to divergent thinking.

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

### Acknowledgements

The research of Soghra Akbari Chermahini is supported by a post-graduate scholarship (PhD) of the Iranian Ministry of Science, Research and Technology. We are grateful to

Jeff Zacks and three anonymous reviewers for very constructive comments and advice.

## References

- Ashby, F. G., Isen, A. M., & Turken, A. U. (1999). A neuro-psychological theory of positive affect and its influence on cognition. *Psychological Review*, *106*, 529–550.
- Baas, M., De Dreu, C. K. W., & Nijstad, B. A. (2008). A meta-analysis of 25 years of mood-creativity research: Hedonic tone, activation, or regulatory focus? *Psychological Bulletin*, *134*, 779–806.
- Barbato, G., Ficca, G., Muscettola, G., Fichelle, M., Beatrice, M., & Rinaldi, F. (2000). Diurnal variation in spontaneous eye-blink rate. *Psychiatry Research*, *93*, 145–151.
- Bleuler, M. (1978). *The schizophrenic disorders: Long-term patient and family studies*. New Haven: Yale University Press.
- Blin, O., Masson, G., Azulay, J. P., Fondarai, J., & Serratrice, G. (1990). Apomorphine-induced blinking and yawning in healthy volunteers. *British Journal of Clinical Pharmacology*, *30*, 769–773.
- Brown, R. T. (1989). Creativity: What are we to measure? In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 3–32). New York: Plenum.
- Carson, S. H., Peterson, J. B., & Higgins, D. M. (2003). Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *Journal of Personality and Social Psychology*, *85*, 499–506.
- Cohen, J. D., & Servan-Schreiber, D. (1992). Context, cortex and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review*, *99*, 45–77.
- Colzato, L. S., & Hommel, B. (2009). Recreational use of cocaine eliminates inhibition of return. *Neuropsychology*, *23*, 125–129.
- Colzato, L. S., Kool, W., & Hommel, B. (2008). Stress modulation of visuomotor binding. *Neuropsychologia*, *46*, 1542–1548.
- Colzato, L. S., Slagter, H. A., van den Wildenberg, W., & Hommel, B. (2009). Closing one's eyes to reality: Evidence for a dopaminergic basis of psychotism from spontaneous eye blink rates. *Personality and Individual Differences*, *46*, 377–380.
- Colzato, L. S., van den Wildenberg, W., & Hommel, B. (2007). Impaired inhibitory control in recreational cocaine users. *PLoS ONE*, *2*(11), e1143.
- Colzato, L. S., van den Wildenberg, W., & Hommel, B. (2008). Reduced spontaneous eye blink rates in recreational cocaine users: Evidence for dopaminergic hypoactivity. *PLoS ONE*, *3*(10), e3461.
- Dauer, W., & Przedborski, S. (2003). Parkinson's disease: Mechanisms and models. *Neuron*, *39*, 889–909.
- Davis, M. A. (2009). Understanding the relationship between mood and creativity: A meta-analysis. *Organizational Behavior and Human Decision Processes*, *108*, 25–38.
- Davis, K., Kahn, R., Ko, G., & Davidson, M. (1991). Dopamine in schizophrenia: A review and reconceptualization. *American Journal of Psychiatry*, *148*, 1474–1486.
- Deuschel, G., & Goddemeier, C. (1998). Spontaneous and reflex activity of facial muscles in dystonia, Parkinson's disease, and in normal subjects. *Journal of Neurology and Neurosurgery Psychiatry*, *64*, 320–324.
- Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review*, *11*, 1011–1026.
- Dreisbach, G., Müller, J., Goschke, T., Strobel, A., Schulze, K., Lesch, K., et al. (2005). Dopamine and cognitive control: The influence of spontaneous eyeblink rate and dopamine gene polymorphisms on perseveration and distractibility. *Behavioral Neuroscience*, *119*, 483–490.
- Duncan, J., Seitz, R. J., Kolodny, J., Bor, D., Herzog, H., Ahmed, A., et al. (2000). A neural basis for general intelligence. *Science*, *289*, 457–460.
- Egan, M. F., Goldberg, T. E., Kolachana, B. S., Callicott, J. H., Mazzanti, C. M., Straub, R. E., et al. (2001). Effect of COMT Val108/158 Met genotype on frontal lobe function and risk for schizophrenia. *Proceedings of the National Academy of Science, USA*, *98*, 6917–6922.
- Eysenck, H. J. (1993). Creativity and personality: Suggestions for a theory. *Psychological Inquiry*, *4*, 147–178.
- Frank, M. J., Seeberger, L. C., & O'Reilly, R. C. (2004). By carrot or by stick: Cognitive reinforcement learning in Parkinsonism. *Science*, *306*, 1940–1943.
- Freed, W. (1980). Eye-blink rates and platelet monoamine oxidase activity in chronic schizophrenic patients. *Biological Psychiatry*, *15*, 329–332.
- Goldman-Rakic, P. S., Muly, E. C., III, & Williams, G. V. (2000). D1 receptors in prefrontal cells and circuits. *Brain Research Review*, *31*, 295–301.
- Guilford, J. P. (1950). Creativity. *American Psychologist*, *5*, 444–454.
- Guilford, J. P. (1967). *The nature of human intelligence*. New York: McGraw-Hill.
- Heilman, K. M. (2005). *Creativity and the brain*. New York: Psychology Press.
- Hietala, J., Syvälahti, E., Vilkmann, H., Vuorio, K., Rääkköläinen, V., Bergman, J., et al. (1999). Depressive symptoms and presynaptic dopamine function in neuroleptic-naïve schizophrenia. *Schizophrenia Research*, *35*, 41–50.
- Karson, C. N. (1983). Spontaneous eye-blink rates and dopaminergic systems. *Brain*, *106*, 643–653.
- Kleven, M. S., & Koek, W. (1996). Differential effects of direct and indirect dopamine agonists on eye blink rate in cynomolgus monkeys. *Journal of Pharmacology and Experimental Therapeutics*, *279*, 1211–1219.
- Lindström, L. H., Gefvert, O., Hagberg, G., Lundberg, T., Bergström, M., Hartvig, P., et al. (1999). Increased dopamine synthesis rate in medial prefrontal cortex and striatum in schizophrenia indicated by I-(beta-11C) DOPA and PET. *Biological Psychiatry*, *46*, 681–688.
- Mednick, S. (1962). The associative basis of creative problem solving process. *Psychological Review*, *69*, 200–232.
- Moghaddam, B., & Jackson, M. (2004). Effect of stress on prefrontal cortex function. *Neurotoxicity Research*, *6*, 73–78.
- Raven, J. C. (1965). *Advanced progressive matrices set I and II*. London: H.K. Lewis.
- Reuter, M., Roth, S., Holve, K., & Hennig, J. (2006). Identification of first candidate genes for creativity: A pilot study. *Brain Research*, *1069*, 190–197.
- Runco, M. (2007). *Creativity theories and themes: Research, development and practice*. Burlington, MA: Elsevier Academic Press.
- Shukla, D. (1985). Blink rate as clinical indicator. *Neurology*, *35*, 286.
- Sternberg, R. J., Kaufman, J. C., & Pretz, J. E. (2002). *The creativity conundrum: A propulsion model of kinds of creative contributions*. New York: Psychology Press.
- Taylor, J. R., Elsworth, J. D., Lawrence, M. S., Sladek, J. R., Jr., Roth, R. H., & Redmond, D. E. Jr., (1999). Spontaneous blink rates correlate with dopamine levels in the caudate nucleus of MPTP-treated monkeys. *Experimental Neurology*, *158*, 214–220.
- Volkow, N. D., Fowler, J. S., & Wang, G. J. (1999). Imaging studies on the role of dopamine in cocaine reinforcement and addiction in humans. *Journal of Psychopharmacology*, *13*, 337–345.
- Williams, G. V., & Goldman-Rakic, P. S. (2002). Modulation of memory fields by dopamine D1 receptors in prefrontal cortex. *Nature*, *376*, 572–575.