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Eye Blink Rate Predicts and Dissociates the Effective Execution of Early and Late Stage Creative Idea Generation

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Abstract

In the present study, the correlations of eye blink rate (EBR) with the effective execution of early and late creative idea generation were explored. Participants engaged in a real-world idea generation task. Resting state EBR (before the task) and task-evoked EBR (during the task) were measured using eye-tracking. The results showed that resting state EBR negatively correlated with the amount of generated ideas during early stage, but not late stage idea generation. Task-evoked EBR did not correlate with the amount of generated ideas during early nor late stage idea generation. However, the change in EBR (from resting state to during early or late stage idea generation) positively correlated with the amount of ideas generated during early, but not during late stage idea generation. The contribution of this study is that it shows that EBR predicts and dissociates the effective execution of early and late stage creative idea generation.

Keywords: Creativity; Eye Blink Rate; Idea Generation.

Introduction

Eye behaviours such as fixations, eye blink rate (EBR), and pupil size are increasingly used to study creativity (See Salvi & Bowden, 2016 for a review) – the creation of ideas, solutions, or products that are both original and appropriate (Abraham, 2018). One important result of such studies is that eye blink rate, the average number of blinks per minute (de Rooij & Vromans, 2018), predicts and dissociates performance on different types of psychometric tests of creative potential (e.g., Akbari Chermahini & Hommel, 2010). Moreover, EBR has been used as a proxy for measuring fronto-striatal dopamine (Jongkees & Colzato, 2016), cognitive control (Akbari Chermahini & Hommel, 2010; 2012), motivation and affect (de Rooij & Vromans, 2018), and internal cognition (Salvi et al., 2015; Walcher, Körner, & Benedek, 2017). Studies of EBR and creative potential therefore inform theory about the involvement of these neuro-psychological factors in creativity. Psychometric tests of creative potential, however, often suffer from poor ecological validity, casting doubt over their explanatory power for actual real-world creative idea generation (Zeng, Proctor, & Salvendy, 2011). The present study therefore explores the correlations of EBR with the effective execution of the creative idea generation process, using a task that resembles real-world creative tasks more closely than psychometric tests of creative potential.

To enable creativity, people execute a creative process, which entails the execution of a set of cognitive processes and actions that enable a person to understand the problem that needs to be solved, generate ideas, and plan for further action (see Lubart, 2001 for a review). Idea generation is characterized by moving back and forth between generation and evaluation and is executed iteratively (Isaksen, Dorval, & Treffinger, 2010). In *early stages of idea generation* people typically retrieve concepts, which are synthesized into loosely formulated ideas, which process can involve remote association, conceptual combination, idea transformation, and analogical transfer (Finke, Ward, & Smith, 1992). The idea generation process evolves recursively, guided by the evaluation and selection of ideas for further development. Over iterations, and thus in *late stages of idea generation*, initially loosely formulated ideas are developed into more elaborately formulated ideas (Finke et al., 1992), and which process can be extended with combining previous ideas, filling in missing details, and simulating and testing implications and the validity of the ideas (Isaksen et al., 2010).

Previous research suggested that EBR predicts and dissociates performance on different types of psychometric tests of *creative potential*. *Resting state EBR* (i.e., EBR measured while a person is relaxed and not engaged in a thinking task) predicted the amount of different concepts (flexibility) used during the alternative uses task (AUT) (Akbari Chermahini & Hommel, 2010), a test where people are asked to list as many creative uses for a common object as they can (e.g., presented stimulus: *"Brick"*, possible response: *"Paper weight"*) (Guilford, 1957). This relationship was best described with a quadratic (inverted U-shaped) function. In the studies by Akbari Chermahini and Hommel no correlations, linear or otherwise, were found between resting state EBR and the amount of listed uses (fluency) or the statistical infrequency of the listed uses (originality). The results of a study by Ueda and colleagues, however, suggested that resting state EBR predicted the amount of listed uses during the AUT, which was also best described by a curvilinear (inverted U-shape) function (Ueda, Tominaga, Kajimura, & Nomura, 2016). Moreover, resting state EBR negatively correlated with the amount of correctly solved items during the remote associates task (RAT) (Akbari Chermahini & Hommel, 2010; Ueda et al., 2016), a test where people are asked multiple times to find the word that forms a compound word with each of the three given words (e.g., presented stimulus: *"Fox, Man, Peep"*, correct response: *"Hole"*) (Mednick & Mednick, 1971). In addition, Ueda and colleagues found that resting state EBR positively correlated with reaction time during the RAT.

Previous studies also suggested that *task-evoked EBR* (i.e., EBR measured while actively engaged in a task), predicts and dissociates performance on psychometric tests of creative potential. That is, task-evoked EBR positively correlated with the amount of uses listed during the AUT (Ueda et al., 2016). In the same study, *task-evoked EBR* did not significantly correlate with the amount of correctly solved items during the RAT, but did positively correlate with reaction time during the RAT.

Studies on the *change from resting state to task-evoked EBR* add to these findings. That is, a study by Akbari & Hommel (2012) showed that the effects of stimulus induced increases in EBR on the amount of concepts used during the AUT differed significantly between people with low and high resting state EBR. That is, stimulus-induced increases in EBR led people with low resting state EBR to use more diverse concepts during the AUT than people with high resting state EBR. However, de Rooij & Vromans (2018) found no correlation or curvilinear relationship between the changes in EBR and the amount of uses, the amount of different concepts used, or the statistical infrequency of the responses during the AUT. Contrastingly, the same study showed that the change in EBR negatively correlated with the amount of correct responses to the RAT. However, when individual differences in positive and negative affect were taken into account, the interaction between a disposition to experience anxiety during creative tasks and the change in EBR positively correlated with the amount of correct responses to the RAT.

The main limitation of the currently available research though, is that psychometric tests of creative potential, such as the AUT and RAT, suffer from poor ecological validity (Zeng et al., 2011). Tests such as the AUT, for example, rarely correlate stronger than .30 with questionnaires and with performance on creative tasks with high ecological validity. Specifically relevant for creative idea generation, is that there is no clear necessity for iteration in such tests (Zeng et al., 2011), which is an essential aspects of idea generation process execution, that leads to differences in performance during early and late stage creative idea generation (Lubart, 2001). It is therefore not known if and how the processes that underlie performance during the AUT and RAT, are also involved in early and late stage idea generation. Moreover, the AUT and RAT are rather abstract tasks and lack goals with personal relevance that typically characterize real-world creative tasks (Kilgour, 2006). This ignores the essential role of domain-specific knowledge, and is likely to engage motivation differently than in real-world creative idea generation tasks (e.g., de Rooij & Jones, 2013). Thus, EBR may correlate differently, if at all, with performance during early and late stage idea generation in tasks that resemble real-world creative tasks more closely, than with performance during the AUT and RAT.

What is clear from these psychometric tests of creative potential, is that there is no indication of a correlation between EBR and qualitative aspects of idea generation (Akbari Chermahini & Hommel, 2010; 2012; de Rooij & Vromans, 2018; Ueda et al., 2016). That is, none of the studies showed correlations between EBR and the originality of the responses during these tests. Rather, results of these studies showed correlations between EBR and the quantity of responses (e.g., the amount of ideas during the AUT, the amount of solved items during the RAT). These studies therefore contribute that the correlations, if any, between EBR and performance during early and late stage idea generation is likely quantitative, and thus indicative of effective execution of the idea generation process, rather than directly of creativity.

Therefore, in *the present study* the correlations of EBR with the effective execution of the idea generation process (as measured by the amount of generated ideas) during early and late idea generation were explored, using a task that resembles real-world creative tasks more closely than psychometric tests of creative potential.

Method

To explore the correlation of EBR with the amount of ideas generated during early and late stage idea generation, an experiment was conducted.[1]

Participants

Seventy-eight people participated in this study (M_{age} = 23.34, SD_{age} = 3.46, 55 female, 23 male). They had normal or corrected-to-normal vision. Most (n = 76) were recruited via the participant recruitment system of a communication science department at a Dutch university. Participants received course credit as compensation for their time spent on the study. Two additional participants, recent graduates, requested to participate out of interest and did not receive compensation. On average, the participants self-reported to be moderately experienced with marketing (M = 3.79, SD = 1.11) (1 = *No experience*, 5 = *Very experienced*).

Idea generation task

The participants engaged in an idea generation task, were they were asked to generate creative marketing ideas aimed at helping a web shop that sells bicycles to attract more visitors to their website. Their idea generation process was split up into two separate tasks, both of which each participant completed, to capture early and late stage idea generation.

Task 1: Early stage idea generation

To capture early stage idea generation, participants were asked to generate as many creative marketing ideas as they could (Figure 1b). This, to elicit a range of pre-inventive structures that participants could then combine and elaborate upon in the subsequent late stage idea generation task. To enable the measurement of EBR, the early stage idea generation task was cued. Each trial started with a fixation dot (5 seconds), after which participants were asked

[1] Note that the data for this paper was collected as part of a larger experiment on eye behaviour and idea generation. Although the EBR data is used only in the study presented here, the participants, tasks, and procedure is the same as in other studies based on the same data set.

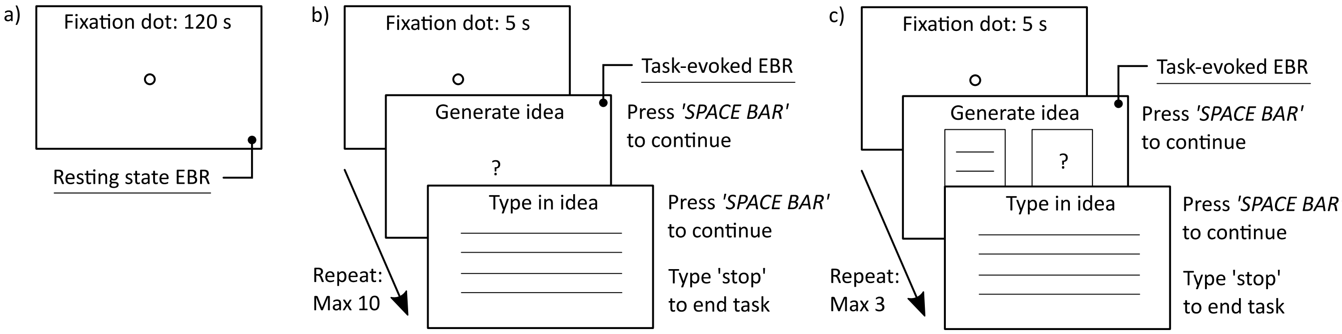

Figure 1: Trial structure of the a) resting state, b) early stage, and c) late stage idea generation tasks, including measurement points for resting state and task-evoked EBR.

to generate a creative marketing idea that was relevant to the provided problem description. There was no time limit. When a participant had generated an idea, the space bar could be pressed after which a text input field was presented on the screen where the participant could type in the idea they generated. This trial sequence was repeated a maximum of ten times. If the participants believed they could not generate any more ideas before the limit of ten trials was reached, they could type in 'stop' to end the early stage idea generation task, and start the late stage idea generation task.

Task 2: Late stage idea generation

To capture late stage idea generation, participants were asked to select two or more of their previously generated ideas to develop a more elaborate and detailed idea (Figure 1c). For example, if a participant generated the ideas to use an *"Instagram page"* and *"hire influencers to promote your Instagram posts"* during early stage idea generation, these could then be combined and developed into a more detailed elaborate solution, (e.g., *"where content developed for the Instagram page is suitable for hired influencers, with a follower demographic suitable for the web shop, which they can then share with their followers"*). Their previously generated ideas were available to the participants during this task (they were listed on the computer screen). The same trial structure was used as during the early stage idea generation task. That is, participants were instructed to look at a fixation dot for 5 seconds, after which they had time to combine previously generated ideas into more elaborate ideas. After generating an idea, they pressed the space bar on the keyboard, and a text input field emerged where they could type in their idea. There was no time limit. However, there was a maximum of 3 trials. If they believed that they could not generate any more ideas before they reached the limit of three trials, they typed in "stop" to stop the task, and with that end the experiment.

Assessment of the effective execution of the idea generation process

To gain insight into how effective the idea generation process was executed idea generation *fluency* was assessed (i.e., the amount of ideas generated). Fluency is a commonly used performance indicator used in studies of idea generation (Guilford, 1957). In the present study, participants generated on average 6.25 ideas during early stage idea generation (SD = 2.33), and on average 2.28 ideas during late stage idea generation (SD = .78).

Eye blink rate

Eye blinks were recorded with a head mounted eye-tracker, and were defined as eye-tracker signal loss with a duration of 40-400 milliseconds (de Rooij & Vromans, 2018). EBR was defined as the average amount of blinks per minute, and was calculated based on the amount of recorded eye blinks and the amount time during which these were recorded. The following measurements of EBR were used: (I) *Resting state EBR* - EBR recorded in resting state before the creative idea generation task, where participants were asked to relax and watch a fixation dot for 120 seconds (Figure 1a); (II) *Task-evoked EBR* - EBR recorded during early stage and during late stage idea generation. EBR was recorded only in the parts of the trials where participants were thinking about their ideas (Figure 1b and 1c); (III) *Change in EBR (task-evoked – resting state EBR)* - The change in EBR from resting state to early stage and to late stage idea generation.

To reduce measurement error, only data from eye blinks recordings after 2 seconds of the start, and before 2 seconds of the end of each measurement, were used to calculate EBR. This helped prevent blinks due to changing screens at the start of a task, and pressing ENTER when an idea was generated, to confound the EBR measurements (de Rooij & Vromans, 2018). Three participants did not blink during resting state. This may indicate that participants simply did not blink for 120 seconds, but may also indicate measurement error. Since the latter cannot be ruled out resting state EBR of these three participants was not used in the analysis. Finally, as EBR is only stable in the morning, midday, and afternoon (Barbato et al., 2000), the experiment was organised only between 9 am to 5 pm.

Apparatus

Materials were presented using dark letters against a grey background on a 22” Dell P2210 monitor (1680×1050 resolution). EBR was recorded using the EyeLink II head-mounted eye-tracker (SR Research Ltd.) at 250Hz. The cable that connected the eye-tracker to the computer was attached to the ceiling to reduce perceived weight and pull that may negatively affect comfort. LED lighting was used to diffuse environmental lighting as evenly as possible. The experiment was in OpenSesame with the PyGaze library (Dalmaijer et al. 2014).

Procedure

Participants received a written introduction to the experiment, signed informed consent, and filled in a short questionnaire about their socio-demographics and marketing experience. Information about the true purpose of the experiment was withheld at this stage. Participants were seated behind a computer screen in a sound proof booth. The head-mounted eye-tracker was installed and calibrated using a 5-point validation. The distance to the screen was approximately 70 cm. Then, participants could practice with the experiment software. After this, participants were asked to relax and look at a fixation dot for 120 seconds. Next, participants read the provided problem statement, and started with the idea generation task. Finally, the participants were debriefed in full, and after being asked whether they could guess the purpose of the experiment.

Analysis

The data obtained in the present study were analysed using generalized linear mixed models. The models were calculated using Satterthwaite approximation to account for the relatively small sample size. Robust covariances were used for the tested of fixed coefficients to handle violations of model assumptions. For models with the amount of generated ideas as the target, a negative binomial distribution was used with a log link. For the model with EBR as the target, a normal distribution with an identity link was used. Model terms and targets are presented in Table 2.

Results

Table 1: Descriptive statistics of EBR during resting state, early stage (task evoked), and late stage (task evoked) idea generation.

	EBR		
	M	*SE*	*n*
Resting state	13.23	1.21	75
Early stage	7.18	.60	78
Late stage	3.91	.40	78

Note. M = mean, *SE* = standard error, *n* = count.

The descriptive statistics are presented in Table 1. The results showed a significant main difference between the tasks for EBR, $F(2, 228) = 32.07$, $p < .001$ (Figure 2a).[2] The pairwise comparisons (not corrected) showed a significant difference in EBR between resting state and early stage, estimated difference = -6.06, $t = 4.48$, $p < .001$, 95% CI[-8.72, -3.39], and late stage idea generation, estimated difference = -9.32, $t = 7.30$, $p < .001$, 95% CI[-11.84, -6.81]; and between early and late stage idea generation, estimated difference = -3.27, $t = 4.52$, $p < .001$, 95% CI[-4.69, -1.84]. These findings suggest that in the present study, EBR decreased from resting state, to early stage idea generation, to late stage idea generation.

Table 2: Correlations and effects (GLMM) of resting state EBR, task-evoked EBR, and their difference with fluency during late and early stage idea generation.

Model terms	Correlations of Fluency with EBR		
	Resting state	Task-evoked	Change EBR
Intercept	.83** (.06)	.86** (.08)	.81** (.06)
Early stage	1.12** (.08)	.92** (.10)	1.08**(.06)
Late stage	.[a]	.[a]	.[a]
EBR	>-.01 (<.01)	-.01 (.02)	>-.01 (<.01)
Early stage x EBR	-.01* (<.01)	.02 (.02)	.01 (<.01)**
Late stage x EBR	.[a]	.[a]	.[a]

Note. Data are unstandardized coefficients and standard errors (between parentheses). [a] Reference variable. * p < .05, ** p < .01.

The results showed a significant and negative interaction between idea generation stage and resting state EBR for the overall amount of generated ideas, $b = -.01$ $t = 2.00$, $p = .049$, 95% CI[-.02, -.01] (Table 2). Pearson correlations showed that this interaction effect could be explained by a significant and negative correlation between resting state EBR and the amount of generated ideas during early stage idea generation, $r = -.170$, $p = .043$, and a negative but not significant correlation between resting state EBR and the amount of generated ideas during late stage idea generation, $r = -.039$, $p = .675$ (Figure 2c). These findings indicate that resting state EBR negatively correlates with the effective execution of early but not late stage idea generation.

The results showed no significant correlations between task-evoked EBR and the amount of generated ideas; and no significant interaction between idea generation stage and task-evoked EBR for the amount of generated ideas (Table 2, Figure 2b). These findings indicate no relationship between task-evoked EBR and the effective execution of the creative idea generation process.

Furthermore, the results showed a significant and positive interaction between idea generation stage and the change in EBR from resting state to each task, for the overall amount of generated ideas, $b = .01$, $t = 3.04$, $p = .003$, 95% CI[.01, .02] (Table 2). Pearson correlations showed that this interaction effect could be explained by a significant and

[2] Quadratic models were also tested by adding the squared EBR terms to the models presented in Table 2. No significant coefficients were found that add to the results obtained with the linear models. We also refer to Figures 2b-2d for visual inspection.

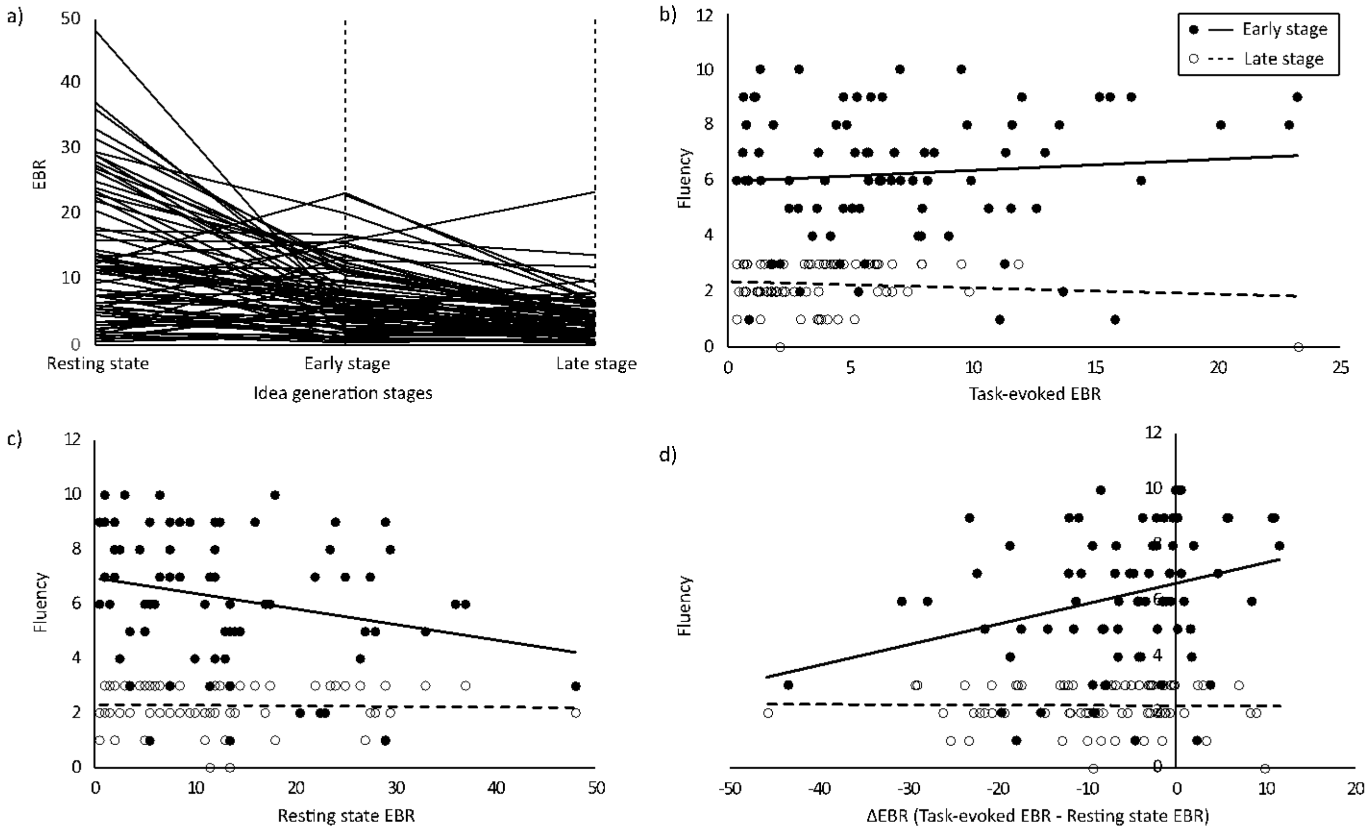

Figure 2: a) Spaghetti plot showing EBR measured at resting state, early stage, and late stage idea generation for each participant; b) Scatter plot of fluency and task-evoked EBR for early and late stage idea generation; c) Scatter plot of fluency and resting state EBR for early and late stage idea generation; and d) Scatter plot of fluency and the difference between task-evoked and resting state EBR for early and late stage idea generation.

positive correlation between the change in EBR and the amount of generated ideas during early stage idea generation, r = .298, p = .010, and a negative but not significant correlation between the change in EBR and the amount of generated ideas during late stage idea generation, r = -.014, p = .904 (Figure 2d). These findings indicate that the change in EBR positively correlates with the effective execution of early but not late stage idea generation.

Discussion

In the present study, the correlations of EBR with the effective execution of the idea generation process (as measured by the amount of generated ideas) during early and late idea generation were explored, using a task that was designed to closely resemble real-world creative tasks.

The results showed that resting state EBR negatively correlated with the amount of generated ideas during the early stage, but not during the late stage of creative idea generation (Figure 2c). This finding contrasts with previous research that suggested that the relationship between resting state EBR and the amount of generated ideas during the AUT best described with an inverted U-shape function[2] (Ueda et al., 2016), or that no significant correlation between the amount of ideas generated during the AUT and resting state EBR exists (Akbari Chermahini & Hommel, 2010). Possibly, this finding is more in line with previous research that indicates that the amount of solved items during the RAT negatively correlates with resting state EBR (Akbari Chermahini & Hommel, 2010), but this finding has been inconsistent across studies, cf. (Ueda et al., 2016).

The results also suggested that task-evoked EBR does not correlate with the amount of generated ideas during early nor during late stage idea generation (Figure 2b). This differs from previous research, which indicated task-evoked EBR positively correlated with the amount of uses listed during the AUT (Ueda et al., 2016); but is in line with results from the same study, which suggested that task-evoked EBR did not significantly correlate with the amount of correctly solved items during the RAT. In addition, differences between early and late stage idea generation could also be explained by previous findings that suggest that EBR quickly increases right before generating problem solutions via spontaneous insight (Salvi et al., 2015). Speculatively, moments of insight could appear more frequently in early than in late stage idea generation, as in the latter people focus more on recombining existing ideas. The results of the present study, however, also suggested that the change in EBR (from resting state to during the tasks) positively correlated with the amount of ideas generated during early, but not during late stage idea generation (Figure 2d). This is in line with previous research that suggests that there are circumstances in which the change in EBR positively correlates with the amount of solved items, but not with related findings that suggest a negative correlation between the change in EBR and the amount of solved items during the RAT (de Rooij & Vromans, 2018).

There are, of course, also limitations that threaten the validity of the results. Although the present study purports to use a task with high ecological validity, no claims can be made on specific aspects of its validity. That is, due to the novelty of the task no tests of validity have been done (cf. de Rooij, Vromans, & Dekker, 2018). Furthermore, to enable measurement of EBR, idea generation was cued and split up into two tasks, representing early and late stage idea generation. In reality, such an artificial separation does not typically happen, and may hamper the often free flowing nature of creative idea generation (Lubart, 2001), which threatens the ecological validity of the used creative idea generation task, (cf. de Rooij & Vromans, 2018). Furthermore, to accommodate eye-tracking measurements responses were cued and limited to 10 responses during early, and 3 responses during late stage idea generation, limiting variance. The limited variance of late stage idea generation could therefore alternatively explain why no correlation between EBR and the amount of ideas generated in late stage idea generation was found. Decisions made to support ecological validity also came at the cost of introducing potential confounding factors. That is, no counterbalancing between early and late stage idea generation is possible, so any found differences could be confounded by adaptation to light conditions. Finally, due to the use of a novel task, it is difficult to compare the results obtained in the present study to results from previous related work. This limits the degree to which the results of this study can be grounded in such previous work. Limitations such as these should be taken into account when interpreting and building upon the present study.

The contribution of the present study is therefore that it shows for the first time that EBR predicts and dissociates the effective execution of early and late stage creative idea generation, using a creative task that resembles real-world creative tasks more closely than psychometric tasks of creative potential. Differences in the results between the present and previous studies using these psychometric tasks, show the importance of using tasks with higher face validity, as indeed, the results differ. This has implications for the development of theory on how the neuro-psychological correlates of EBR relate to creative idea generation.

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