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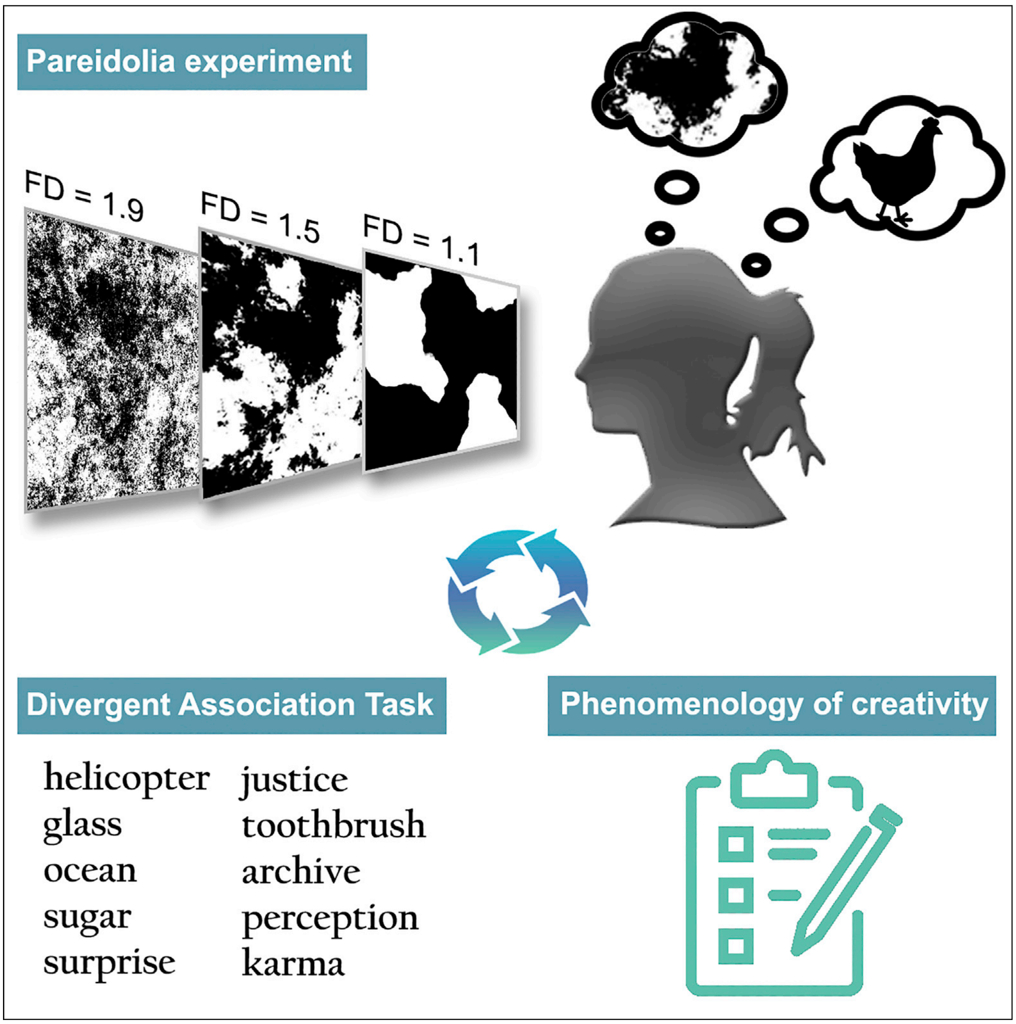

Antoine Bellemare Pepin, Yann Harel, Jordan O'Byrne, Geneviève Mageau, Arne Dietrich, Karim Jerbi

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Highlights

Creativity has been linked to divergent thinking

Creativity is associated with enhanced pareidolia (i.e., divergent perception)

High-creatives report pareidolia across a broader range of image fractal dimensions

Divergent perception constitutes a promising phenomenon for the study of creativity

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Processing visual ambiguity in fractal patterns: Pareidolia as a sign of creativity

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SUMMARY

Creativity is a highly valued and beneficial skill that empirical research typically probes using "divergent thinking" (DT) tasks such as problem solving and novel idea generation. Here, in contrast, we examine the perceptual aspect of creativity by asking whether creative individuals are more likely to perceive recognizable forms in ambiguous stimuli –a phenomenon known as pareidolia. To this end, we designed a visual task in which participants were asked to identify as many recognizable forms as possible in cloud-like fractal images. We found that pareidolic perceptions arise more often and more rapidly in highly creative individuals. Furthermore, high-creatives report pareidolia across a broader range of image contrasts and fractal dimensions than do low creatives. These results extend the established body of work on DT by introducing divergent perception as a complementary manifestation of the creative mind, thus clarifying the perception-creation link while opening new paths for studying creative behavior in humans.

INTRODUCTION

Creativity is a cornerstone of human evolution. It allows us to adapt to our environment and transform it. A widely accepted definition of creativity is the ability to produce work that is both novel (i.e., original, unexpected) and useful (i.e., adaptive given task constraints) (Sternberg and Lubart, 1999), though it has been argued that this definition does not capture the full breadth and multiple facets of creativity (Barbot et al., 2015; Dietrich, 2007; Fryer, 2012; Glăveanu, 2014). Moreover, although there have been many attempts to characterize the neural mechanisms underlying creativity (Dietrich, 2004; Jung et al., 2009; Simonton, 2010; Wiggins and Bhattacharya, 2014), no consensus has yet emerged (Dietrich and Kanso, 2010; Sawyer, 2012). To date, most of the empirical research on creativity has focused on the concept of divergent thinking (DT; Guilford, 1950; Weisberg, 2006), defined as the ability to generate multiple solutions to an open-ended problem (Guilford, 1950, 1967). The most widely used measure of creativity, the Torrance Tests of Creative Thinking (TTCT), consists mostly of DT tests (Kim, 2006). Two major problems arise when claiming that DT tests measure creativity *per se* (Dietrich, 2018, 2019b). First, it has been argued that the opposite – convergent thinking – can also produce creative ideas (Simonton, 2015). Second, DT is a compound construct, which gathers multiple facets and mental processes within a single measure (Ward et al., 1999). These problems invite caution when approaching creativity as a monolithic entity (Dietrich, 2019a) and beckon for complementary ways of operationalizing this multifaceted concept. Many accounts of creativity focus on cognitive processes, i.e., thinking differently. In this paper, we instead examine whether highly creative individuals differ in their perceptual processes, i.e., seeing differently.

It has recently been proposed that our ability to create depends heavily on our ability to perceive and model the external world (Heath and Ventura, 2016). Indeed, creative individuals seem to process external sensory stimuli differently (Flowers and Garbin, 1989; Berns, 2008), in that they will tend to more easily connect unrelated elements. Accordingly, researchers have begun to investigate creativity through the lens of embodied cognition (Malinin, 2019), which views action and perception as complementary. This approach emphasizes exploration and interactions with the physical environment as essential prerequisites for the emergence of cognition and therefore creativity, attributing to attention the creative role of diversifying the field of experience and perceptual contents (D'Angelo, 2020). A study on creative experience under the effect of psychedelics also distinguishes between creative performances, which can be recorded, and creative experiences, which are subjective and anchored in perception (Fischer and Scheib, 1971). This distinction between creative action (performance) and creative perception (experience) points to

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the importance of studying the phenomenology of creativity (Nelson, 2005) complementarily to classical measures involving the production of creative artifacts. Finally, it has been suggested that creativity might emerge through *confused perception* (such as Beethoven's deafness), *malfunctioning perception* (such as psychotic symptoms), and *intentional perception* (expertise and use of analogical thinking) (Pereira and Tschimmel, 2012). These cases of altered perception result from an increase in noise/uncertainty in the sensory signal whether through degradation of receptors, in the case of deafness or blindness, or through increased prediction errors and reduced latent inhibition, as is the case in psychotic symptoms or psychedelic experiences. Together, these studies suggest that high-creative individuals have perceptual abilities that differ from low-creative individuals, and more specifically, that they might process ambiguous stimuli differently. However, to our knowledge, this has not yet been systematically investigated.

A natural approach to exploring inter-individual variability in processing ambiguous images is to exploit pareidolia, which is the experience of seeing meaningful patterns or connections in random stimuli (Petchkovsky, 2008), a fundamental aspect of human perception (Fyfe et al., 2008). Interestingly, pareidolia is thought to be an adaptive skill, as it may have helped early hominids to detect threats in complex sensory environments (Barrett, 2000; Meschiari, 2009). At the root of pareidolia is a concept called aberrant salience, which corresponds to an altered attentional state leading to a failed suppression of irrelevant or familiar information (Kapur, 2003; Kapur et al., 2005). This decrease in latent inhibition may facilitate the emergence of pareidolic perceptions through concomitant complexification of sensory data and increases in top-down modulations. Pareidolia proneness is associated with schizophrenia symptoms, such as delusional thinking, paranoia, and hallucinations (Belayachi et al., 2015; Vercammen et al., 2008; Yokoi et al., 2014). In a non-clinical population, a common example of pareidolia is the perception of meaningful objects in clouds. Clouds are complex visual stimuli that exhibit inherently unpredictable structures, making them ambiguous by nature. This ambiguity can be perceived in one of two ways. First, the brain can perceive it as noise with no relevant information and attribute the label *cloud* to the perceived image. In the second pareidolic instance, the brain makes an association between random features of the cloud and a known object, resulting in the perception of a meaningful object in noise such as a cat or a heart. However, it is important to note that this perceived cat or heart does not perfectly match any one previously perceived exemplar, but rather, it creatively emerges from the interaction of the semantic concept with the details of the fractal image. In short, "Pareidolia is a creative act because it is not about seeing things for what they are but seeing things for what they could be" (Heath and Ventura, 2016).

Pareidolia has mostly been studied in the context of face detection (Hong et al., 2013; Lee, 2016; Liu et al., 2014), although more recent studies have also examined natural scenery images (Diana et al., 2021) and generative stimuli (Bies et al., 2016; Rogowitz and Voss, 1990; Taylor et al., 2017). Crucially, the empirical relation between creativity and pareidolia has received very little attention. A rare exception is an interesting study by Diana et al. (2021), which suggests that fluency on a DT task significantly predicts fluency and originality in a Divergent Pareidolia Task. Pareidolia can be seen as a perceptual counterpart of DT, in that it relies on the possibility of finding multiple solutions within a single problem space. The problem to be solved emerges from the ambiguity in the stimulus, and pareidolic perceptions are the multiple solutions to that problem. Whereas DT probes creative thinking in the context of semantic problems resolved through conceptual expansion, divergent perception probes creative perception in the context of sensory problems resolved through pattern recognition. Pareidolia and creative thinking thus share the common fundamental process of relying on divergent processes to generate new ideas or percepts. In the context of DT, idea generation is measured in terms of fluency, flexibility, and originality (Almeida et al., 2008; Guilford, 1950). In divergent perception, percept generation can likewise be measured in terms of pareidolic fluency (finding multiple percepts in a unique stimulus) and flexibility (finding at least one percept in a wide range of stimuli).

Previous research indicates that the emergence of pareidolia depends on image properties including contrast and fractality. These properties are therefore likely to moderate the proposed relation between the observer's creativity and their tendency to experience pareidolia. Image fractality can be quantified by its fractal dimension (*FD*), a measure of the signal's self-similarity when observed at different magnifications. One of the first studies to assess the effect of *FD* on pareidolia reported a relation between the *FD* of generative cloud images and the prevalence of pareidolia (Rogowitz and Voss, 1990). The authors presented four images simultaneously to participants and asked them to indicate the image in which a recognizable object was first detected. Although this method is useful to determine the *FD* that preferably elicits spontaneous pareidolia, it does not speak to the systematic relations between fractality and pareidolia.

Moreover, no statistical analysis was conducted on this dataset. A second study (Taylor et al., 2017) investigated the relation between pareidolia and *FD* by exposing 23 participants to a set of 24 images with *FD* ranging from 1.05 to 1.95. Participants were asked to report the number of percepts elicited by each stimulus. Results indicated that lower *FD* stimuli elicited significantly more pareidolic percepts. Whereas this study has the advantage of systematically investigating the relation between *FD* and pareidolia, it is limited by a small sample size and a small number of stimuli. In the same vein, (Bies et al., 2016) demonstrated that object pareidolia is more diverse and occurs faster for *FD* values close to 1.3. However, the number of stimuli used in the experiment was limited to 4 per *FD*, for a total of 16, which may limit statistical inferences. Interestingly, the *FD* that tends to facilitate pareidolia ($FD = 1.3$) has also been associated with the perception of beauty and esthetic preference (Aks and Sprott, 1996; Hagerhall et al., 2004; Taylor et al., 2005), both in synthetic noise images and works of art (Viengkham and Spehar, 2018), suggesting that a stimulus with a higher chance of triggering pareidolia might also be judged as more esthetically appealing. Coherently, Taylor and Spehar (2016) developed a fluency model suggesting that mid-*FD*s (1.3–1.5) optimize both the observer's capacities of pattern recognition and the emergence of esthetic experience. Individual differences between preferred patterns in a range of *FD* have been systematically investigated by (Spehar et al., 2016), who report that 90% of individuals can be classified as either preferring low (20%), intermediate (50%), or high (20%) *FD*s, whereas no specific link between these profiles and creativity has been investigated. These individual differences in susceptibility to pareidolia across different FDs suggest that the modulation of image *FD* offers a means to experimentally manipulate pareidolia in a laboratory setting.

Here, we set out to investigate the link between pareidolic perception and creative experience, as well as the moderating role of situational factors. To this end, we developed a pareidolia paradigm where 50 participants with various levels of creativity viewed a wide range of synthetic cloud-like images. Importantly, we generated the stimuli by manipulation of fractal dimension and contrast and predicted that pareidolia would occur preferentially at intermediate *FD* levels (close to 1.3) consistently with previous research (Bies et al., 2016) and that higher contrast would facilitate pareidolia. In the first step, we sought to validate the presence of a relation between pareidolia and two key properties of the generated stimuli (*FD* and contrast). We then proceeded with our main objectives and hypothesized that creativity would be positively correlated with pareidolia. In terms of moderation, we expected that *FD* and contrast level would moderate the relation between creativity and pareidolia. Specifically, we predicted that differences between low and high creatives would be amplified for optimal settings of *FD* and contrast.

Creativity was primarily measured using the Experience of Creativity Questionnaire (ECQ; Nelson and Rawlings, 2009), which focuses on the phenomenological dimension of creativity and is designed to measure individual differences in the intensity of the creative experience as well as the depth of immersion when engaging in creative processes. This approach to assessing creativity is appealing for two main reasons: First, by being non-domain-specific, the ECQ can capture creativity irrespective of whether individuals engage in the production of creative artifacts or other classical artistic practices. Second, by focusing on the phenomenological aspect of the creative process, the ECQ captures the perceptual components of the creative experience, which according to our hypothesis, would correlate with pareidolia. This said, because the use of self-reported creativity measures has its limitations, we also administered a complementary creativity test that measures DY. For this, we used the recently proposed Divergent Association Task (DAT; Olson et al., 2021), which requires the participant to find words that are the most semantically distant from one another. The associated creativity score is then computed automatically by estimating the mean semantic distance between the proposed words. Importantly, this study (Olson et al., 2021) has shown that DAT correlates with performance on two widely used creativity measures (the Alternative Uses Task and the Bridge-the-Associative-Gap Task). This was confirmed in two different datasets, and a high test-retest reliability was observed ($r = 0.73$; see their table 4 for a list of correlations between DAT and different dimensions of DT). Although DAT does not measure exactly DT in its standard definition, it is thought to assess the efficiency/flexibility of the associative network (Olson et al., 2021). As a result, the use of the ECQ and DAT in the present study allows us to probe the relation between self-reported creativity, DT, and pareidolia.

RESULTS

All participants viewed 360 visual fractal stimuli and were instructed to identify as many percepts as possible in each image during the 8-s presentation. The stimuli consisted of 3 levels of contrast and 12 levels of fractal dimensions ranging from 0.8 to 1.9 (Figure 1). Reaction times were measured as the latency of the button press indicating the emergence of the first pareidolic percept. We conducted an image-based analysis of reported

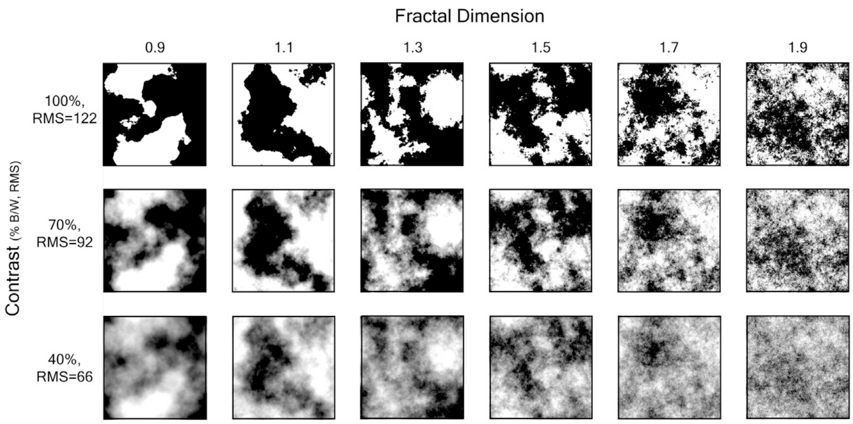

Figure 1. Stimuli generated with 1/f spatial noise

The *x*-axis represents the fractal dimension of stimuli, ranging from 0.9 to 1.9. The *y*-axis represents the three levels of contrast, ranging from full black and white (top), to 20% of black and 20% of white (bottom).

pareidolia to address the potential issue of response bias. If the responses of the participants (i.e., pareidolia occurrence and number of percepts) were random and unrelated to pareidolia occurrence, we'd expect the mean pareidolia responses for the stimuli to be similar across all stimuli. Both for pareidolia occurrences and the number of objects variables, we found that the response distributions across subjects were significantly different from the distributions of random behavioral responses (Figure S2). These results indicate that the distribution of the original data significantly differs from that of randomly generated behavioral responses.

Effect of stimulus fractal dimension on pareidolia

Considering the hypothesis that intermediate *FD*s (around 1.3) might facilitate pareidolia and given that the scatterplots showed clear inverted U-shapes, regressions were computed to model both the linear and the quadratic effect of *FD* on each of the four dependent variables (see Figure 2). We found significant

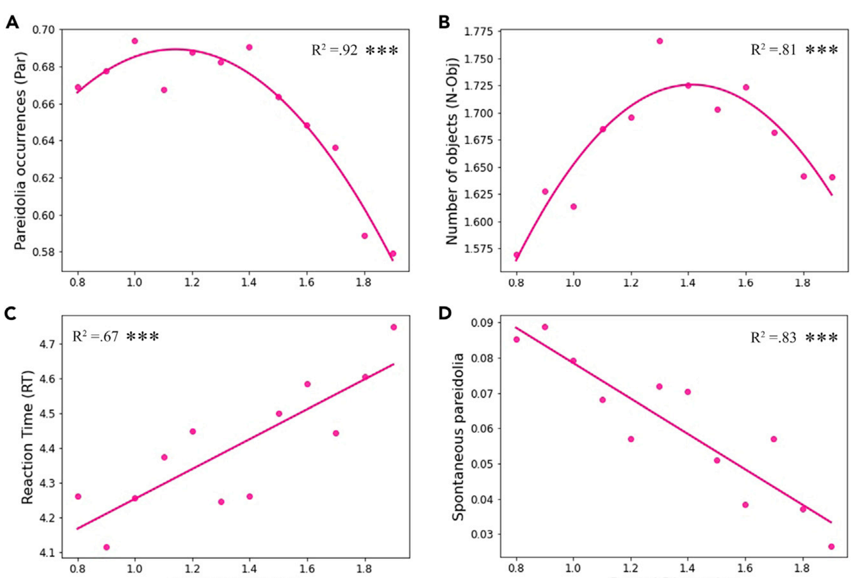

Figure 2. Pareidolia as a function of fractal dimension (*FD*)

(A) Pareidolia occurrences (*Par*) as a function of *FD*.

(B) Number of perceived objects for pareidolia trials as a function of *FD*.

(C) Time before first pareidolic percept as a function of *FD*.

(D) Proportion of pareidolia trials with reaction time shorter than 2 s. R^2 corresponds to the adjusted coefficient of determination in the corresponding regression model. ***$p < 0.001$. See also Figures S2 and S3.

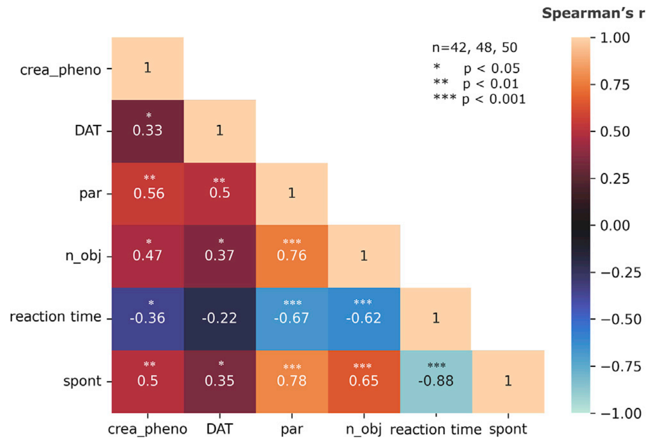

Figure 3. Correlation matrix of creativity measures and pareidolia

Par: pareidolia occurrences, N_obj: number of objects, reaction time: reaction time, spont: spontaneous pareidolia, crea_pheno: creative phenomenology, DAT: Divergent Association Task. All Spearman correlations were performed using the maximum sample size ($n = 42$ for DAT, $n = 48$ for RT and Spont_par, and $n = 50$ for the rest). Significance levels were $*p < 0.05$; $**p < 0.01$; $***p < 0.001$. See also Figure S4 for normality tests on these variables.

quadratic relations between *FD* and pareidolia occurrences (*Par*), $R^2 = 0.91$, $F(2,9) = 43.51$, $p < 0.001$, and number of objects (*N_obj*), $R^2 = 0.86$, $F(2,9) = 28.25$, $p < 0.001$, whereas the linear trend explained more variance than the quadratic trend for reaction time (*RT*) and spontaneous pareidolia (*Spont_par*). These results indicate that low to mid-*FD*s are associated with increased pareidolia, mid-*FD*s yield a higher number of pareidolic percepts, and low FDs facilitate rapid and spontaneous pareidolia.

Effect of image contrast on pareidolia

To investigate the effect of contrast on pareidolia, we ran a repeated-measure ANOVA with a Greenhouse-Geisser correction on each of the four DVs. We found a statistically significant effect of contrast on the occurrence of pareidolia (*Par*), $F(1.65, 74.03) = 49.5$, $p < 0.001$, the number of pareidolic percepts (*N_obj*), $F(1.5, 67.67) = 81.94$, $p < 0.001$, reaction time (*RT*), $F(1.8, 75.51) = 11.46$, $p < 0.001$) and spontaneous pareidolia (*Spont_par*) $F(1.61, 72.63) = 8.78$, $p < 0.001$. Post-hoc tests using the Bonferroni correction revealed that all contrast levels differed significantly ($p < 0.001$) for *Par* and *N_obj*, whereas for *RT* and *Spont_par,* only high-contrast images differed significantly from mid-contrast (RT: $p < 0.01$, *Spont_par:* $p < 0.05$) and low contrast (both $p < 0.01$). These results indicate that high-contrast images facilitate both the flexibility and the fluency of pareidolia, as well as the speed of its emergence.

Relation between creativity measures and pareidolia

To test our main hypothesis that high-creatives experience increased pareidolia we computed the Spearman correlations between creativity (both self-reported and based on DT) and properties of pareidolic experience across participants. Spearman correlations were used because our measures of the number of objects and spontaneous pareidolia were not normally distributed. More specifically, we assessed pairwise correlations between two measures of creativity (*DAT and Crea_pheno*) and four measures of pareidolia (*Par*, *N_obj*, *Reaction Time, and Spont_par*), and controlled for multiple correlations using the false discovery rate (FDR). Sample sizes for this correlational analysis ranged from 42 to 50. Figure 3 shows that *Crea_pheno was* significantly correlated with the four measures of pareidolia: *Par* ($r(49) = 0.55$, $p < 0.01$), *N_obj* ($r(49) = 0.47$, $p < 0.05$), *RT* ($r(49) = -0.36$, $p < 0.05$), *spont_par* ($r(49) = 0.5$, $p < 0.01$), whereas DAT scores were correlated with *par* ($r(41) = 0.5$, $p < 0.01$), *N_obj* ($r(41) = 0.37$, $p < 0.05$), *RT* ($r(41) = 0.35$, $p < 0.05$) and with *Crea_pheno* ($r(41) = 0.33$, $p < 0.05$).

To get a better understanding of the correlation between DAT (our measure of DT) and *Crea_pheno* (self-reported metric of creativity), we performed further correlation analysis between DAT scores and each of the two sub-dimensions of the *Crea_pheno* test: the first is related to one specific creative experience the participant identifies with (*Crea pheno specific*), and the second reflects the assessment of creative processes in a broader sense (*Crea pheno general*). The results are shown in Figures 4A and 4B. Interestingly, this analysis revealed

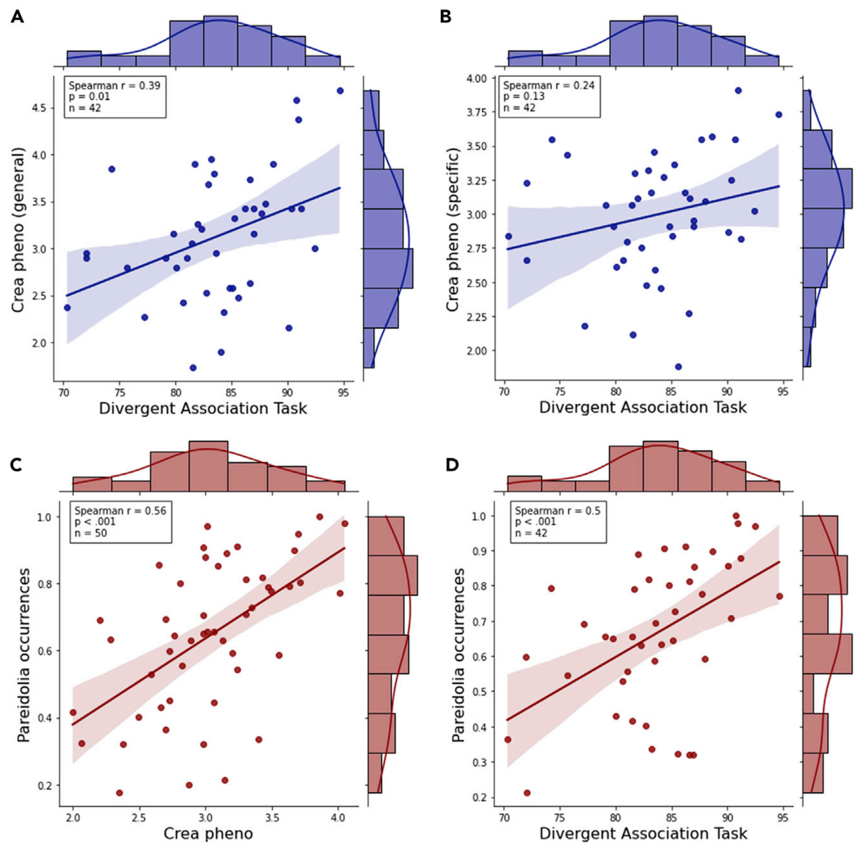

Figure 4. Spearman correlations between self-reported creativity, divergent association, and pareidolia occurrences (*Par*)

(A) Significant correlation between the general dimension of *Crea_pheno* and DAT.

(B) Non-significant correlation between the specific dimension of *Crea_pheno* and DAT.

(C) Significant correlation between *Crea_pheno* and pareidolia occurrences.

(D) Significant correlation between DAT and pareidolia occurrences. Pareidolia scores are averaged across all trials. See also Table S1.

that DT (i.e., DAT) was significantly correlated with the general dimension of *Crea_pheno* ($r(41) = 0.39$, $p < 0.05$) but not with the sub-component that assesses a specific creative experience ($r(41) = 0.24$, $p = 0.13$).

Together, these results support the hypothesis that creative individuals are more prone to experience pareidolia. The main statistical models presented in the subsequent sections are built using *Crea_pheno* because this measure exhibited the strongest correlation with pareidolia and was available for all 50 participants (the DAT scores were only available in the 42 participants who were able to participate in the follow-up data collection). This said, the observed correlations between both types of creativity metrics and pareidolia will be useful for our interpretation and discussion. Results of the GLMM using DAT as a dependent variable are provided in supplementary material; Table S1.

Interaction effects of creativity, fractal dimension, and contrast on pareidolia

We ran generalized linear mixed-effect models (GLMMs) that modeled the moderation effects of contrast and *FD* on creativity in predicting pareidolia occurrences (*Par*), number of objects (*N_obj*), and reaction time (*RT*). A quadratic term (FD^2) for both fixed and random effects of *FD* was included in the model in order to account for its nonlinear relation with pareidolia. Contrast was only considered in the fixed effect structure, as it has been recommended that random variables must have more than 12 levels (Clark and Linzer, 2015). The final model included all possible two-way interactions between creativity, *FD*, and contrast, as well as their three-way interaction. We ran the GLMMs with all the subjects, as well as without subjects with scores higher than 3 SDs above the mean. We report the former case, whereas both cases result in the same significant effects.

Table 1. **Moderation effect of *FD* and Contrast on Creativity in predicting Pareidolia (*Par*)**

Fixed effects	Estimate	Std. Error	*z*-value	*p*-value
(Intercept)	1.57	0.19	8.50	<0.001***
FD	0.35	0.40	0.87	0.38
FD^2	−1.2	0.35	−3.44	<0.001***
Contrast	−0.98	0.11	−8.97	<0.001***
Creativity	1.11	0.19	5.92	<0.001***
FD × Creativity	−1.21	0.42	−2.88	0.004**
FD^2 × Creativity	0.94	0.36	2.6	0.009**
FD × Contrast	0.45	0.44	1.43	0.31
FD^2 × Contrast	0.29	0.38	0.77	0.44
Contrast × Creativity	−0.33	0.12	−2.86	0.004*
FD × Creativity × Contrast	1.22	0.46	2.63	0.009**
FD^2 × Creativity × Contrast	−1.02	0.40	−2.57	0.01*

Number of participants = 50, number of trials = 360, total *n* = 18,000. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

The GLMM results in Table 1 and Figure 5 show that both *FD* (p = 0.004) and contrast (p = 0.004) interact significantly with creativity in predicting pareidolia occurrence, whereas the three-way interaction between *FD*, contrast and creativity was also significant. The two-way interactions validate the hypothesis that both *FD* and *contrast* moderate the effect of creativity on pareidolia, whereas the significant effect of *Crea_pheno* alone reveals that creativity predicts pareidolia at an average level of *FD* and at high *contrast*. The three-way interaction demonstrates that for high-contrast images, differences between low and high creatives are smaller for mid-*FD*s and larger for images of low and high *FD*s in predicting pareidolia.

For the GLMM predicting *N_obj*, the moderation of stimulus properties on the relation between creativity and *N_obj* was not significant. Thus, a model only containing the main effects was adopted. We found significant fixed effects for the two moderator variables, *FD* ($p < 0.001$), FD^2 ($p < 0.001$), and *contrast* ($p < 0.001$), as well as for *Crea_pheno* ($p < 0.001$) (see Table 2).

We conducted a third GLMM that predicts reaction time (*RT*). This revealed significant fixed effects of *Crea_pheno, FD*, and *Contrast,* and two-way interactions between *contrast* and *FD* ($p < 0.001$) and between *contrast* and *Crea_pheno* (see Table 3). The two interactions revealed that differences in *RTs* between high vs low-mid-contrast were enhanced for low FDs (FD × Contrast) and high-creatives (Contrast × Creativity), indicating that high-contrast images increase the probability of shorter reaction time especially for images with lower fractal dimension and individuals with high creativity scores. Note that no GLMM was built to predict spontaneous pareidolia (*Spont_par*), as this variable was on the participant's level rather than on the observation's level.

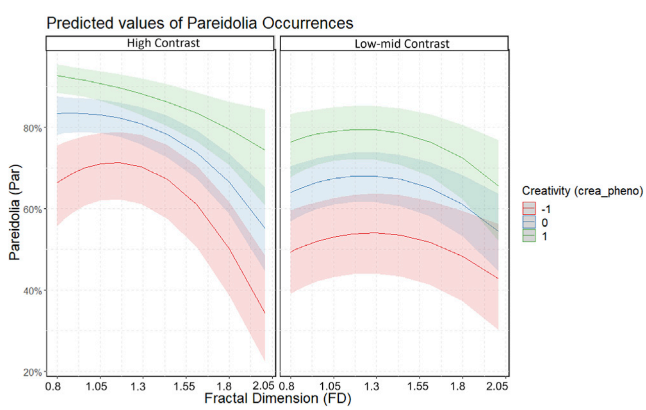

Figure 5. Predicted probabilities of the interaction between *FD*, Contrast, and Creativity on pareidolia occurrences

Statistical values are in Table 1. See also Figure S1.

Table 2. Main effects of *FD*, Contrast, and Creativity in predicting the number of objects (N_obj)

Fixed effects	Estimate	Std. Error	*z*-value	*p*-value
(Intercept)	−0.07	0.09	−0.81	0.42
FD	0.90	0.18	5.04	<0.001***
FD^2	−0.82	0.16	−4.99	<0.001***
Contrast	−0.33	0.02	−16.92	<0.001***
Creativity	0.35	0.07	4.75	<0.001***

Number of participants = 50, number of trials = 360, total n = 11,618. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

We also conducted post-hoc Spearman correlation analyses to predict pareidolia occurrence *(Par)* from creativity scores at each level of *FD* and for the two categories of *contrast*. FDR correction for multiple correlations was applied. As shown in Table 4, for high-contrast images, our results show a larger effect size (Spearman Rho values) of *crea_pheno* for low and high *FD* in predicting pareidolia occurrence, indicating that the difference between low- and high-creatives is smaller for mid-*FD*s. For low- to mid-contrast images, the trend is less clearly defined.

DISCUSSION

In this study, we investigated the relation between creativity and divergent perception. To do so, we implemented a pareidolia task in which participants were asked to identify recognizable forms in cloud-like images with different levels of fractality and contrast.

Typically, creativity is investigated by estimating the potential for creative problem solving and novel idea generation, a process known as DT. Here, in an important departure from previous work, we introduce divergent perception as a suggested cognitive marker and predictor of creativity. Our results show that the perception of objects in ambiguous fractal stimuli (i.e., pareidolia) occurs more often and more rapidly in creative individuals. More specifically, linear mixed-effect modeling revealed that high-creative individuals are more flexible (wider range of optimal *FD*s), fluent (higher number of percepts), and faster in experiencing pareidolia. We also found that the association between creativity and pareidolia is stronger for high-contrast images with either low or high FD. Taken together, these results suggest that divergent perception captures a key cognitive feature of creativity, complementing established findings on DT. These results may have several future applications, in which pareidolic performance may be considered as a practical and easy-to-implement index of creativity or possibly a metric to monitor in the context of creativity training. In the following, we discuss our main observations reported in light of previous work.

Pareidolia depends on image contrast and fractal dimension

Quadratic regression analyses revealed that low to mid *FD*s maximize occurrences of pareidolia across trials, whereas mid-range *FD*s promote higher numbers of percepts during trials of pareidolia. This last result is congruent with Bies et al. (2016), who reported enhanced pareidolia in images with *FD* around 1.3. Consistently, quadratic regression analysis on reaction time indicates that pareidolia arises faster in low *FD*s. Hence, pareidolia seems to be generally facilitated by stimuli of lower levels of inherent complexity,

Table 3. Moderation of FD and Contrast on Creativity in predicting the reaction time (RT)

Fixed effects	Estimate	Std. Error	*t*-value	*p*-value
(Intercept)	1.38	0.03	53.67	<0.001***
FD	0.15	0.23	6.55	<0.001***
Contrast	0.10	0.02	6.14	<0.001***
Creativity	−0.1	0.03	−3.72	<0.001***
FD × Creativity	0.02	0.02	0.89	0.37
FD × Contrast	−0.08	0.03	−3.21	0.001**
Contrast × Creativity	0.04	0.02	2.05	0.04*
FD^2 × Creativity × Contrast	−0.01	0.03	−0.45	0.65

Number of participants = 48, number of trials = 360, total n = 9,557. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 4. Spearman correlations for each fractal dimension (*FD*) to predict pareidolia from creativity scores

Par/*FD*	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
High contrast	0.58***	0.53***	0.51***	0.50***	0.43**	0.41**	0.35*	0.47***	0.44**	0.46**	0.50***	0.56***
Low- t-mid-contrast	0.50***	0.50***	0.56***	0.53***	0.45**	0.55***	0.42**	0.50***	0.51***	0.49***	0.45**	0.31*

Corrected *p*-values: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. $n = 50$ for each regression.

consistently with the findings of (Rogowitz and Voss, 1990; Taylor et al., 2017), whereas mid-*FD* images facilitate the experience of multiple pareidolic percepts. Our results showed that higher levels of contrast are associated with increased pareidolia occurrence and number of perceived objects, as well as shorter reaction time. This effect is consistent with the figure-ground segregation principle of Gestalt theory, which explains that as contrast increases, so does the perceptual saliency of what is perceived as the object compared with what is identified as the background (Wagemans et al., 2012). In the case of the pareidolia task, high-contrast images seem to facilitate dissociation between black and white structures, leading to increased figure-ground segregation.

Creativity is associated with a higher propensity to pareidolia

Our findings support the hypothesis that creativity is correlated with the propensity to pareidolia. In particular, the correlation analysis (Figure 3) revealed that pareidolia occurrence is correlated both with phenomenological creativity and with DT abilities, measured via the Experience of Creativity Questionnaire (ECQ) and DAT, respectively. These results support the view that creativity, measured with two complementary tools, is predictive of pareidolia during the perception of fractal visual noise. Because of Its complex and multifaceted nature, the breadth of human creativity cannot be fully captured in a single measure. Indeed, none of the available tests and assessment tools is optimal, and using a combination of metrics, each sensitive to distinct aspects of creativity, is recommended.

The GLMM results further demonstrated the significant fixed effect of creativity on the occurrence of pareidolia, the number of pareidolic percepts, and reaction time, indicating with more confidence that creative individuals experience pareidolia more often (for different stimuli), more rapidly, and that they perceive a higher number of percepts when pareidolia occurs. These findings are in line with studies on bistable perception demonstrating that self-reported creative individuals are able to reverse the percept significantly more often (Bergum and Bergum, 1979; Klintman, 1984; Wernery, 2013), which requires the capacity to inhibit one percept over another. The role of (dis)inhibitory processes in creativity is not well established, and conflicting results indicate that both inhibitory (Benedek et al., 2012) and disinhibitory (Radel et al., 2015) processes might participate in the emergence of creative behavior. Other studies point to the role of cognitive flexibility in creative ideation (de Dreu et al., 2011; Nijstad et al., 2010), whereas future studies are still required to investigate the relation between these processes and pareidolia.

Only very few studies have investigated the connections between pareidolia and creativity. One recent study (Wu et al., 2019) measured the impact of perceiving ambiguous stimuli on subsequent creative outcomes. Their results show that participants who passively looked at ambiguous figures, compared with non-ambiguous figures, scored higher on fluency, flexibility, and originality in a subsequent Alternative Uses Task, and on creativity in a story generation task, thereby suggesting that processing ambiguous stimuli could have a beneficial priming effect on creative processes. Another recent study demonstrated that performances on both free association and DT tasks were predictive of pareidolic fluency and originality (Diana et al., 2021), also pointing to a functional role of pareidolia in creativity. With the present study, we incorporated a parametric manipulation of image complexity and showed that pareidolia relates to creativity, whereas this relation varies in function of the stimulus properties.

Higher creatives experience pareidolia across a larger repertoire of stimuli

Correlation analyses revealed specific patterns of the relation between creativity and pareidolia depending on the contrast level and the fractal dimension of the images. Analyzing high-contrast images, which previous analyses have shown to generally facilitate pareidolia more than low-mid-contrast images, we found that creativity predicts pareidolia specifically for low- and high-*FD* images. Two conclusions emerge from this result. First, it indicates that high-creatives seem to be more flexible in the way they integrate ambiguous information, as reflected by their ability to experience pareidolia in a wider range of *FD*s. As divergent perception skills of high-creatives are less dependent on the physical properties of the stimulus, this would probably reflect a greater capacity to voluntarily produce the pareidolic effect, even under less favorable stimulation conditions. Their ease to experience pareidolia in high-*FD* images is coherent with preliminary results showing that self-reported high-creative individuals prefer looking at images with higher FD (Richards, 2001), which seems to have been the case for Jackson Pollock, whose paintings show increasing FD throughout his lifetime (Schiestl et al., 1999). The ability of creative individuals to detect multiple percepts more easily in ambiguous visual stimuli might result from a tendency to depart from the propensity to automatize perception toward a single, most predictable percept. Even though the automatization of perception might facilitate behavioral efficiency in most of our daily tasks, the present findings suggest that creative individuals might rely on defusing these perceptual habits to maximize novelty seeking and idea generation.

Second, our results suggest that mid-*FD*s (around 1.3) may facilitate pareidolia, especially for low-creative individuals. This effect is further illustrated by the significant quadratic relationship between *FD* and pareidolia only for the low-creative group (see Figure S1). These findings complement the studies of Taylor et al. (2017) and Rogowitz and Voss, 1990, which showed a facilitation of pareidolia for images of *FD* 1.3, by indicating that this effect may be more predominant for low-creative individuals. Given that images of *FD* 1.3 have also been associated with the perception of beauty (Spehar et al., 2003), the present results suggest that stimuli perceived as esthetic concomitantly facilitate the emergence of pareidolic percepts. This view is in line with theories of embodied cognition that posit that esthetic quality is not a property of the stimulus, but an emergent phenomenon derived from the interaction between the brain and stimulus (Roddy and Furlong, 2014).

Spontaneous and deliberate pareidolia

The difference in reaction times favoring high-creatives leads to the hypothesis that low and high creatives may rely on different perceptual strategies. One neuroscientific framework that may help to understand the mechanisms involved in pareidolia is the model proposed by Dietrich (2019), which suggests a distinction between deliberate and spontaneous modes of creativity. The deliberate mode implies a conscious process of trial-and-error, which recruits a large amount of cognitive and attentional resources, possibly involving top-down brain mechanisms. The spontaneous mode, on the other hand, implies an unconscious process leading to what is reported as insights and results from effortless attention and possibly bottom-up brain processes. This duality of intentional and spontaneous modes in creative behavior may also be linked to the concept of "flipflop thinking", i.e. alternating between greater focus and greater mind wandering (Dobson and Christoff, 2020; Zamani et al., 2022).

We specifically tested the hypothesis that creative individuals are more prone to experience spontaneous pareidolia, which we defined as the ratio of the number of trials with *RTs* below 2 s to the total number of trials where pareidolia was reported. Our findings revealed a significant positive correlation between this metric of spontaneous pareidolia and creativity. Applied to the perspective of divergent perception, spontaneous pareidolia would correspond to the emergence of percepts in a context of low cognitive load, possibly as the result of an implicit resolution of confusion (Shen et al., 2016). This particularity of effortlessness associated with spontaneous creativity suggests that participants with higher spontaneous pareidolia might engage in the task with an effortless mode of attention. On the contrary, low-creative individuals may have more heavily relied on a deliberate mode of pareidolia, which implies a trial-and-error search process and higher cognitive load.

Divergent perception

Aside from proposing a functional link between creativity and perception of ambiguous stimuli, this study introduced a newly designed pareidolia task as a measure of divergent perception. We may think of the idea of divergent perception as the perceptual counterpart of DT. Hence, without having a direct "productive" outcome, pareidolia enables to account for a phenomenon of multiple coexisting solutions within the same problem space, as is the case with classical DT tasks such as the Alternative Uses Task (AUT). The present study showed that creative individuals, as measured by two different metrics of creativity, have higher levels of fluency (number of objects) and flexibility (range of fractal dimensions) when performing a visual pareidolia task.

One might ask whether the perceptual processes investigated with a pareidolia task could merely be interpreted as imagination? A pareidolia task allows for divergent perception, which may overlap with processes generally involved in imagination, but is more specific to the case of finding multiple alternative solutions (here constructing multiple percepts) to a problem, as in DT. Arguably, creativity and imagination are intrinsically related and different types of imagination might not promote equally the emergence of creative idea generation. Several authors have drawn distinctions between categories of imagination, such as distinguishing between bottom-up and top-down imagination (Vyshedskiy, 2019), or between mental imagery, novel-combinatorial (counterfactual), altered state, and phenomenology-based imagination (Abraham, 2016). Interestingly, pareidolia seems to encompass different categories of imagination, in that it relies both on the phenomenology associated with sensory experience and on the counterfactual process involved in "seeing" what is not objectively there based on earlier experiences. Hence, we argue that a divergent perception is a form of imagination that leads to idea generation through a balance between bottom-up and top-down processes.

Pareidolia as a source of creative ideation

The role of remote associations in creative processes has periodically appeared in the neuroscientific literature on creativity (Mednick, 1962; 1968; Sassenberg et al., 2017). Creative individuals, who are characterized by a propensity to perform remote associations, may use this skill at a perceptual level in order to more easily identify internal representations in ambiguous sensory information. Ambiguous stimuli would therefore constitute opportunities for a creative mind to apply top-down modulations that may result in conceptual expansion. By enriching sensory experience through a search for visual complexity, interactions with ambiguous stimuli afford the opportunity to resolve sensory dissonance with active top-down modulation. These top-down modulations allow the integration of sensory information into new conceptions and refined models. Hence, this adaptive strategy of making sense of (cognitively integrating) ambiguous sensory information gives rise to opportunities for constructing new models of the external world, based on the inherent complexity of stimuli. These new models are the very soil in which creativity plants its root and where new ideas can grow. Top-down modulations of ambiguous information enable internal representations to interact with each other within emergent perceptual content. Moreover, we might speculate that the inherent complexity of the stimuli enables the addition of uncertainty (natural noise) in the interaction between these internal representations. The malleability of internal representations, coupled with the inherent noise of sensory information, facilitates novel combinations of remote concepts, and the conjuration of seemingly non-familiar percepts. Hence, we suggest that pareidolia could be both a marker and a source of creative ideation.

Numerous artists anecdotally reported experiencing pareidolia as a source of inspiration in their creative work. As exposed in Gamboni (2002) work *Potential Images*, Piero di Cosimo inspired his painting by looking at the sky, Novalis wrote about figures he saw in the clouds, and Chinese painter Sung Ti used the technique of looking at a dilapidated wall covered by a thin piece of white silk: "*You gaze at it until you can see the ruins through the silk, its prominences, its levels, its zig-zags and its cleavages, storing them up in your mind, and fixing them in your eyes. Soon you will see men, birds, plants and trees, flying and moving among them. You may then ply your brush according to your fancy*" (Gamboni, 2002).

Leonardo Da Vinci recommended in his *Treatise on Painting* to look at rock formations, stained surfaces, ashes, and clouds, to get inspiration: "*Moreover, you can see various battles, and rapid actions of figures, strange expressions on faces, costumes, and an infinite number of things, which you can reduce to good, integrated form*" (Da Vinci, 1956).' By looking at these natural sceneries, Da Vinci (1956) demonstrates how prototypic internal representations can coexist within ambiguous sensory information and give rise to new modes of interactions, pointing to the natural role of fractal noise in the generation of new ideas. All these reports point to a functional link between pareidolia and creative inspiration, a link that is substantiated by the present study.

Conclusion

The present study is a first attempt to empirically link creativity and perceptual processes, using a pareidolia task. We showed that levels of creativity, whether measured by a questionnaire on phenomenological aspects of creative experience or through assessment of DT, significantly predict the occurrence of pareidolic experiences. We further identified systematic relations between pareidolia, creativity, and the fractal dimension of the perceived visual stimuli. For high-contrast images, the propensity to experience pareidolia was higher in creative individuals specifically for low and high fractal dimensions. Taken together, these results indicate that (1) high levels of creativity are associated with enhanced pareidolia and (2) both fractal dimension and image contrast are key stimulus properties to manipulate when investigating pareidolic perception. These results also suggest that pareidolia could be a marker of idea generation and a predictor of creativity as it involves the perceptual ability of creating new ideas from the integration of ambiguous stimuli. Our findings call for future research to expand our understanding of the neuro-cognitive mechanisms associated with multiple dimensions of creativity, as well as the efficient encoding of image statistics (Simoncelli and Olshausen, 2001). Future work might also benefit from integrating measures of visual imagery vividness (Salge et al., 2021) and content of the pareidolic percepts. The present results point toward the promise of probing creativity through the exploration of the neural dynamics associated with pareidolia. Whereas a few studies have examined face pareidolia detection (Liu et al., 2014; Rekow et al., 2022; Wardle et al., 2020), none have used fractal visual stimuli with open-ended designs. Another promising avenue for further research is designing methods to measure the properties of pareidolic percepts (e.g., richness, diversity) in order to strengthen the theoretical link between creativity and pareidolia.

Limitations of the study

Creativity is a highly multifaceted ability that cannot be captured by any one metric. By complementing conventional DT measures with a pareidolia task that probes the perceptual aspect of creativity, the present work has sought a fuller characterization of creativity's many dimensions. That being said, some aspects of creativity still may not be accounted for by the measures used here, and so we limit the interpretation of our results to a characterization of the link between pareidolia, DT (as measured by DAT), and phenomenological components of creativity (as measured by ECQ).

Secondly, the distinction between spontaneous and deliberate pareidolia was made based on a threshold on reaction time—a simple metric that, however, limits our inference about cognitive processes subtending the emergence of pareidolia. Hence, new experimental designs specifically targeting this distinction between these two modes of pareidolia would help get a better understanding of the cognitive underpinning of pareidolia.

As a final point, the data gathered during the pareidolia task allowed the derivation of quantitative measures of fluency (number of percepts) and flexibility (pareidolia occurrences), whereas the qualitative content of the pareidolic percepts was ignored. By recording the content of percepts, additional semantic metrics could be computed to complement our understanding of the relation between creativity and pareidolia. For example, a metric of originality could be obtained by computing the average pairwise semantic distance between reported words, as an indicator of remote associations.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2022.105103.

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AUTHOR CONTRIBUTIONS

A.B.P: conceptualization, methodology, formal analysis, data curation and writing. Y.H.: data curation, conceptualization, writing – review and editing. J.O.: writing – review and editing. G.M.: formal analysis, writing – review and editing. A.D.: validation. K.J.: writing – reviewing and editing, conceptualization, supervision.

DECLARATION OF INTERESTS

The authors declare no competing interests.

INCLUSION AND DIVERSITY

We worked to ensure sex balance in the selection of non-human subjects. One or more of the authors of this paper self-identifies as an underrepresented ethnic minority in science.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Python script of the pareidolia experiment	this study	https://doi.org/10.6084/m9.figshare.19950371.v2
R script for running the Generalized Linear Mixed Effect Model	this study	https://doi.org/10.6084/m9.figshare.19469957.v2
Software and algorithms		
R version 4.1.3.	R core team 2020 R: The R Project for Statistical Computing (r-project.org)	N/A
Python version 3.7.4.	Python Software Foundation (www.python.org)	N/A

RESOURCE AVAILABILITY

Lead contact

Inquiries should be addressed to the lead contact, Antoine Bellemare Pepin (antoine.bellemare9@gmail.com).

Materials availability

This study did not generate new unique reagents.

Data and code availability

- The behavioral data reported in this study cannot be deposited in a public repository due to partial restrictions stipulated by the ethical approval committee. Upon reasonable request to the authors, an institutional data sharing agreement will allow for access to the data.
- Original code has been deposited at Figshare repository and is publicly available as of the date of publication. DOIs of the Python script of the pareidolia experiment as well as of the R script for running the Generalized Linear Mixed Effect Models are listed in the key resources table.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

EXPERIMENTAL MODEL AND SUBJECT DETAILS

Human participants

50 neurotypical individuals (19 females) between the ages of 19 and 35 ($M = 27.4$, $SD = 3.24$) took part in the experiment. This study has been approved by the Neuroimaging Aging Research Ethics Committee (CER-VN) and all participants signed an informed consent form. Reaction time was not collected for two participants, leaving 48 participants for the analyses that required reaction times. The research project received ethics committee approval before all participants provided written informed consent to participate in this study.

METHOD DETAILS

Experimental protocol

In the first part of the experiment, 360 stimuli (3 levels of contrast and 12 levels of fractal dimension ranging from 0.8 to 1.9) were presented to each participant in a pseudo-random order. The participants faced the screen for the duration of the task and gave their answers using a standard keyboard. The images were of a size covering approximately 10 degrees of visual angle. The task of the participants was to detect the maximum number of percepts during the 8-s presentation of each stimulus. The participants had to press the spacebar when they perceived a first figurative object in the stimulus. After each stimulus, they reported the total number of perceived objects (scale from 0 to 5-and-above). A block of 10 trials preceded the experiment so that the participants could get used to the task. Participants were told before the task that at the end of the experiment, images for which they report the highest number of objects will be presented to them again to assess the reported content. This procedure was deliberately implemented to reduce the chances that participants provide false responses during the test. During the experimental procedure, there was no mention of the term "creativity," as we wanted to avoid putting any pressure on the participants to perform well on a ''creativity test''. The participants were told that it was a study on perception, and that it could be seen as a game, similar to finding objects in the clouds and that there were no good or bad answers. The experimenter stayed with the participants during this test block in order to answer any questions. The experiment lasted about 60 min, divided into three blocks of 20 min, between which it was proposed to the participants to take a short break if desired.

Creativity assessment

The participants completed the Experience of Creativity Questionnaire (ECQ), a phenomenological measure of creativity, which is divided into two parts. The first part, which refers to a specific creative activity, comprises five subscales: power/pleasure, absorption, distinct experience, anxiety and clarity of preparation. The second part, reflecting the engagement with creative activities in general, is divided in three subscales: transformation, centrality of the experience, and transpersonal. The five subscales of the first part closely relate to flow-type experiences, which have been identified as a specific form of creativity (Dietrich, 2004). As a complementary measure to the ECQ, we chose a recently introduced behavioral measure of creativity, the Divergent Association Task (DAT), for which the data was collected in a follow-up study in 41 out of the 50 participants. Participants had to provide the ten most semantically distant words. Semantic distance between each pair of words was computed with GloVe (Pennington et al., 2014) a freely available model which was pre-trained on the Common Crawl corpus, containing text from billions of web pages. Since the participants were French speakers, the data were collected in French. We tried using GloVe with a French database but found that a significant proportion of words were not recognized by the algorithm. Hence, the words were translated to English before computing the score. One of these participants was treated as an outlier as their score exceeded 3 SDs above the mean. The creativity tests were always administered after the pareidolia task, alongside a series of other tests (meditation, personality, flow state).

Stimulus design

Fractal dimension (*FD*) describes the fractal scaling relation between the patterns observed at different magnifications (Spehar et al., 2003). Many algorithms allow for the computation of fractal dimension (Lopes and Betrouni, 2009). Images of lower *FD* can be considered less detailed, while images of higher *FD* are more detailed and inherently complex (Pentland, 1984; Cutting and Garvin, 1987; Gilden et al., 1993). Fractals themselves are characterized as either *exact* or *statistical*. Exact fractals exhibit a geometry that repeats itself exactly at different levels of magnification, while statistical fractals contain a certain degree of randomness within their structure, leading to partial similarities between different magnifications.

Statistical fractal images were generated using a 1/f spatial noise (Lennon, 2000) based on the inverse discrete Fourier Transform (Figure 1), allowing control over the *FD* of each image. The fractal dimension was derived from the spectral slope (Beta) of the distribution with the formula $FD = (\text{Beta} * 2–6)/2$. Beta values ranged from -2.2 ($\approx$ brown noise) to -1.1 ($\approx$ pink noise) and corresponding *FD* values from 0.8 to 1.9. Variability in spectral slope between different images has also been demonstrated using natural images (Tolhurst et al., 1992). This algorithm allowed to generate images with autocorrelated structure and values following a Gaussian distribution.

We generated a set of 360 images of size 512 by 512 pixels. The images were manipulated to create three distinct levels of contrast. At high contrast, half of all image pixels were set to black and the other half to white by thresholding the grayscale image at the mean luminance level, as in (Spehar et al., 2016). Two other contrast levels were generated by thresholding at 35% from each extreme of the spectrum for medium contrast (leaving 30% of pixels as grayscale), and at 20% from each extreme for low contrast (leaving 60% grayscale). The averaged root mean squared (RMS) values, which correspond to the SD of the pixel intensities (Peli, 1990), were computed for each contrast level. RMS scores were 122.2 (SD = 4.7), 92.35 (SD = 8.5), and 65.7 (SD = 10.5) for high, mid and low contrast respectively. According to (50), the *FD* is not affected by changing the contrast of the image. We validated that the *FD* did not differ between contrast levels by applying the differential box-counting method (Kolekar et al., 2000), which allows us to compute *FD* on grayscale images. In the end, we have a set of 1080 images (360 images X 3 contrast levels) that was divided into three new sets of 360 images with distinct patterns for each contrast level. The images from the three sets were randomly assigned to the 50 participants. This procedure allows us to have the same images with different contrast levels in our full dataset, without the drawback of presenting images with the same structures and varying contrast levels to the same participant.

Pareidolia measures

Pareidolia was assessed based on three indicators: reaction time (*RT*), pareidolia occurrence (*Par*) and number of objects perceived (*N_obj*). *RT* corresponds to the time between stimulus onset and first pareidolic perception. Pareidolia (*Par*) is a value between 0 and 1 representing the proportion of trials in which one or more pareidolic perceptions occurred. *Par* thus aims to capture participants' flexibility, defined as the capacity to experience pareidolia in a wide range of stimuli. Number of objects (*N_obj*) represents the average number of pareidolic percepts on trials during which pareidolia occurred, and aims to capture the fluency aspect of pareidolia, i.e. the capacity to fluently modulate perceptions within the same stimulus. Finally, a measure of spontaneous pareidolia (*Spont_par)* was derived by computing the proportion of trials where pareidolia was reported within the first 2 s, compared to the total number of trials where pareidolia was reported. Several threshold values (1.5/2/2.5s) were tested to ensure that our results are consistent (see Figure S3 for more details). Spontaneous pareidolia serves as a complementary measure of reaction time designed to target the trials that are likely to reflect the spontaneous emergence of pareidolic percepts.

QUANTIFICATION AND STATISTICAL ANALYSIS

Initial analyses

To confirm that stimulus properties are related to pareidolia, we examined the linear and quadratic relation between *FD* and pareidolia with regression models and performed a repeated-measure ANOVA to investigate the effect of contrast on pareidolia. We also ran image-based analyses to check whether there was some evidence for consistency across participants in their responses to identical stimuli. First, we computed the mean value of pareidolia occurrence and number of percepts reported for each single image. We then computed new means for the same variable but this time after randomly shuffling the provided responses across all stimuli (as a realization of a mean of random responses for each stimulus). Most importantly, we tested the differences between the distribution of the original pareidolia response data and 1000 randomized sets of responses using two-sample Kolmogorov-Smirnov tests. Spearman correlations were used for the computation of the correlation matrix, while Shapiro-Wilk test of normality were conducted on each of our variables.

Generalized linear mixed effect model

Generalized Linear Mixed Effects Models (GLMM) are regression models that allow using non-normally distributed dependent variables and including random effects to model variables from different nested levels (Bates et al., 2015). By incorporating the variability inherent to nested variables, GLMM is a family of statistical models that allows the modeling of cross-level interactions. In the present case, the first level corresponds to the trial level, comprising pareidolia variables, *FD* and contrast, while the second level corresponds to the participant level, comprising questionnaire variables (creative phenomenology, *Crea_pheno*). Hence, the use of GLMM enables us to include all the inherent variance in the data and investigate first- and second-level variabilities simultaneously within a single model.

Two predictors (*Crea_pheno, FD)* were centered around the grand mean, while *contrast* was transformed into a binary variable based on preliminary analyses. To do so, medium and low contrast images were treated together as opposed to high-contrast images. Random slopes were also included for *FD* terms following the guideline from (Barr, 2013) that suggests including random slope for any within-unit factor. When the predicted variable was *Par,* a binomial distribution with a logit link function was specified to best fit the binary outcome, while when the predicted variable was *N_obj*, a zero-truncated negative binomial distribution was specified. For our third dependent variable, RT, a logarithmic link function was specified. To achieve a good fit to the data with a GLMM, successive models were constructed and compared with each other while the level of complexity was increased at each iteration. To quantify the superiority of one model over another, ANOVAs comparing the Akaike Information Criterion (AIC) of two models were computed (Royle, 2013).

Principal analyses

We first tested whether creativity measures were correlated with pareidolia (averaged across all trials for each participant) using Spearman correlation. We then ran a Generalized Linear Mixed-effect Model (GLMM) that models the moderation effects of contrast and *FD* (both linear and quadratic terms) on creativity. To explore further the moderator effect of *FD* on the relation between creativity and pareidolia, we (1) ran regression analyses to predict pareidolia from creativity scores for each *FD* (Bonferroni corrected), (2) examined the quadratic relation between *FD* and pareidolia for high- and low-creatives and (3) ran the GLMM replacing *Crea_pheno* by the measure of divergent thinking (see supplementary materials).