Studying Creative Psychedelic Perception through the lens of Pareidolia

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TABLE OF CONTENTS

1. Abstract

Background
Understanding how psilocybin alters visual perception is crucial for understanding its complex effects on human cognition and creativity. While its influence is recognized, specific alterations of creative perception remain unspecified. Our research quantifies psilocybin's effects on visual creative perception through pareidolia, where familiar patterns are perceived in ambiguous stimuli. This reflects divergent perception, akin to divergent thinking in creativity.

Objective
Our study aims to quantify perceptual changes induced by psilocybin and train a machine learning model to predict psilocybin influence based on pareidolia characteristics.

Design/Methods
In this within-subject study, participants experience both an active condition (3 grams of psilocybin mushroom) and a placebo condition (0.5 grams of active mushroom supplemented with non-active mushroom), spaced one month apart. Participants drew perceived pareidolia on see-through stencils laid over pareidolia-invoking images in four consecutive 5-minute sessions, with verbal descriptions recorded after each session. Descriptions were analyzed using the Alternative Uses Test (AUT) scoring system for originality, fluency, flexibility, and elaboration. Drawings underwent a visuospatial analysis, quantifying size, and distance between drawings. Fractal dimension and contrast level of regions corresponding to pareidolia events were calculated. All characteristics were tested between conditions across all pareidolia using linear mixed models (LMMs) and per pareidolia using (non-)parametric tests. A Random Forest classifier was trained using these features to predict psilocybin influence.

Results
Psilocybin selectively enhanced elaboration without significantly impacting other creativity domains across pareidolia images. A trend towards larger average size was found across pareidolia, but only reached significance in Pareidolia 3. Significant differences were found in average fractal dimension and contrast in Pareidolia 1, indicating stimulus-dependent effects. The Random Forest classifier demonstrated robust predictive power, with an AUC of around 0.8 in 3 out of 4 pareidolia images.

Conclusion
Psilocybin significantly influences elaboration of perceived pareidolia, suggesting increased richness of visual perception, without changing other creativity domains, showing a selective effect on creative perception. Significant differences in pareidolia-specific tests indicate complex stimulus-dependent effects of psilocybin. Despite subtle effects, the Random Forest classifier effectively classified psilocybin influence, highlighting the potential of computational methods in studying altered states of consciousness.

2. Introduction

It is widely recognized that psilocybin induces profound, transient alterations in consciousness, also known as the psychedelic state (Nichols, 2016; Bayne & Carter, 2018). However, the specifics of the perceptual changes in this psychedelic state remain largely unspecified. Understanding how psilocybin alters visual perception is crucial for understanding its complex effects on human cognition and creativity. Our research investigates these alterations of visual perception through the lens of pareidolia.

Classic psychedelics like psilocybin, N-N dimethyltryptamine (DMT), lysergic acid diethylamide (LSD), and mescaline have been the target of a large amount of neuroscientific and clinical studies over the last years (Sessa, 2018). This continuation of psychedelic research has illuminated the mechanisms and applications of altered states of consciousness, revealing their potential for treating various mental health disorders and promoting sustained well-being (Carhart-Harris & Goodwin, 2017; Barrett & Griffiths, 2018; Nichols & Walter, 2020).

Psilocybin, which is metabolized into psilocin (4-hydroxy-dimethyltryptamine), is the main hallucinogenic compound found in *psilocybe* (“magic”) mushrooms and is classified as a classic serotonergic psychedelic, mainly acting on the serotonin (5HT-2A) receptors (Mastinu et al., 2023). The word psychedelic is derived from the Greek psykhē (see psyche), meaning "mind", and dēloun, meaning "make visible, reveal" (Rosen, 2012) and is attributed to these substances for their “mind-manifesting" abilities (Nichols, 2016). Historically, psilocybin has been used in various healing rituals and is renowned for inducing deep existential experiences that can leave long-lasting psychological impacts (Carhart-Harris et al., 2012).

2.1. History

First described by Wasson (1957) during his explorations of indigenous ceremonies in Mexico, the use of psilocybin mushrooms dates back centuries. The oldest undisputable evidence of ritualistic consumption of psilocybin mushrooms is depicted in the Codex "Yuta Tnoho" or "Vindobonensis Mexicanus I," created in the early 1500s CE. This Mixtec culture codex illustrates a sacred ceremony where deities consume mushrooms before the first dawn. However, other historical references, such as the "mushroom stones" in Guatemala (Lowy, 1971) and murals in Spain (Akers et al., 2011), suggest that the ceremonial use of psilocybin mushrooms may date back much further than the early 1500s CE (Van Court et al., 2022). Additionally, the ceremonial use of psilocybin mushrooms appears to be a recurring phenomenon across various cultures worldwide. Tribes in Siberia, Borneo, New Guinea, China, and Japan have all been noted to partake in similar rituals worshipping these hallucinogenic fungi (Wasson, 1957).

2.2. Mechanisms

Although stigmatized and restricted for many years, in recent years, psilocybin has regained attention for its therapeutic potential in psychotherapy, leading to an exponential growth in psychedelic research and contributing to what is now known as the 'psychedelic renaissance' (Griffiths et al., 2016; Sessa, 2018). The observation of cross-tolerance and a series of empirical studies in humans and animal models support (partial) agonism at the serotonin (5-HT)2A receptor as a common mechanism for the action of psychedelics (Nichols, 2016; Mastinu et al., 2023).

The dominant theory on how psilocybin alters brain perception involves its impact on functional connectivity of brain networks. Psilocybin significantly decreases the positive coupling between the medial prefrontal cortex (mPFC) and the posterior cingulate cortex (PCC), suggesting that its subjective effects are due to disinhibition of the Default Mode Network (DMN) and the subsequent increase in connectivity and communication between neural networks (see Figure 1), decreasing brain hierarchy and enabling a state of "unconstrained cognition" (Carhart-Harris et al., 2012; Carhart-Harris et al., 2014; Girn et al., 2020). This theory, known as "relaxed beliefs under psychedelics" (REBUS) posits that psychedelics relax the precision of high-level priors or beliefs, flattening the hierarchy of the brain, and liberating bottom-up information flow, particularly from intrinsic sources like the limbic and sensory system. This process increases the sensitivity of high-level systems to bottom-up signaling, allowing for the potential revision and deweighting of rigid priors (Carhart-Harris & Friston, 2019). Additionally, Bâlâet (2022) notes the importance of the serotonergic system on visual cognition due to a high expression of serotonin (5HT2A) receptors.

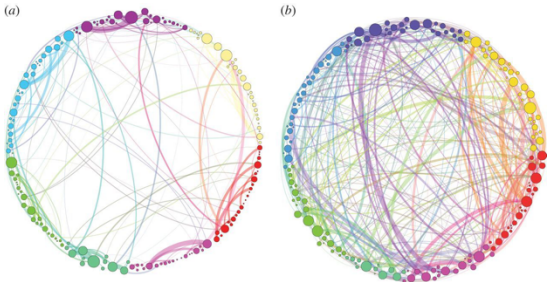


Figure 1. ***Simplified visualization of brain network connectivity in placebo condition (a) and under the influence of psilocybin (b).*** *Colors represent brain networks, the width of links is proportional to their weight, and the size of nodes is proportional to their strength. Disinhibition of the mPFC and DMN in the placebo condition allow for intercommunication between brain regions that are usually less functionally connected. Image from Petri et al., 2014*

2.3. Psychedelics and Perception

Ingestion of a high dose of psilocybin mushrooms (0.3–0.6 mg/kg) induces a range of sensory perception changes, from mild to profound, including trance-like experiences with hallucinogenic properties and a (positive) mood change (Mastinu et al., 2023; Bâlâet, 2022), synesthesia, sensory illusions, and auditory and visual hallucinations (Reiff et al., 2020). Descriptions of these experiences include phenomena such as "walls breathing" (Nichols, 2016), more intense colors and textures, geometric shapes, rhythmic movements, micropsia and macropsia (perception of objects as smaller or larger than they are), afterimages, and hallucinations of objects, animals, or beings not

present (Díaz, 2010; Preller & Vollenweider, 2016). Additionally, the increased connectivity between brain regions following psychedelic administration can cause a temporary loss of the sense of personal identity, also known as ego-dissolution, and a deep sense of connectedness to others, nature, and the universe (Tagliazucchi et al., 2016; Letheby & Gerrans, 2017). These experiences are often described as profoundly mystical and spiritual (Barrett & Griffiths, 2018).

There has been considerable research on psilocybin's effects on visual perception. However, none of these studies have linked these effects to divergent perception. Hill et al. (1969) observed significant distortions in sensory thresholds, where participants struggled to 'correct' visual distortions, indicating a strong alteration in visual perception. Fisher et al. (1969) reported a significant reduction in brightness preference under the influence of psilocybin, suggesting increased sensitivity to visual stimuli. Silverman (1971) noted hypersensitivity to low-to-moderate stimuli but decreased sensitivity to high-intensity stimuli. In a more recent article on the effects of psilocybin on gaze fixation during visual perception, Muller et al. (2023) report a shift to more local visual exploration under the influence of psilocybin. Despite this research, there remains a significant gap in our understanding of the specific, quantifiable changes in visual perception and creativity caused by psilocybin. The present study aims to take a novel approach by quantifying changes in visual perception and creativity using pareidolia perception as a study system.

2.4. Pareidolia

Pareidolia is the phenomenon of illusory perception of familiar patterns like faces, animals or other objects in ambiguous visual stimuli where they do not really exist, such as clouds, trees, or ice formations (Liu et al., 2014; Heath & Ventura, 2016; Smailes et al., 2019). The word is derived from the Greek words ‘pará’ (παρά, "beside, alongside, instead [of]") and ‘eídōlon’ (εἴδωλον, "image, form, shape").

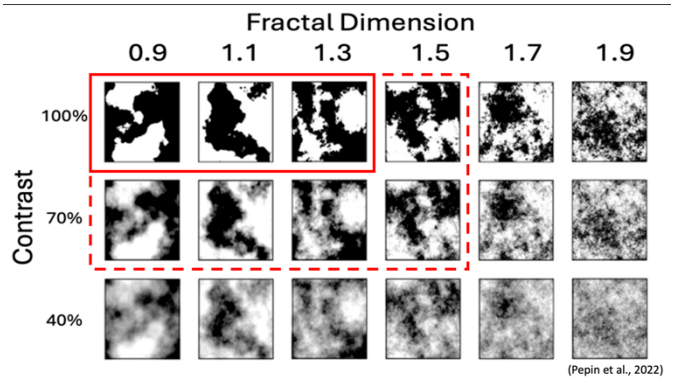


Figure 2. ***Overview of low fractal dimension and high contrast (solid red box) facilitating pareidolia perception.*** *However, creative individuals tend to perceive pareidolia in a wider range of fractal dimensions and contrasts (dashed red box; Figure from Pepin et al., 2022a).*

Pareidolia perception is influenced by the fractality and contrast level of an image. Image fractality can be quantified by its fractal dimension (FD), a measure of a signal’s self-similarity at different magnifications, typically ranging between 1 and 2 (see Figure 2; Pepin et al., 2022a). Bies et al. (2016) suggest that pareidolia perception is optimal in stimuli with lower levels of inherent complexity. Additionally, Pepin et al. (2022a) report that the contrast level of an

image influences the perception of pareidolia, with higher contrast increasing both fluency and flexibility (quantity and categorical variation, respectively) of perceived pareidolia.

Pareidolia are all around us, and their perception is a fundamental part of human cognition. Probably the most common form of the phenomenon is face pareidolia, where individuals perceive face-like patterns in objects, such as the smiley-face :-) produced by a colon, a dash, and a bracket. Similarly, the front of a car or the bark of a tree could trigger a pareidolia event. An eye-tracking study by Kato and Mugitani (2015) demonstrated that infants aged 8 to 10 months begin to perceive face pareidolia in face-like configurations of dots, underscoring that this inherent tendency to recognize faces in patterns is present early in human development.

Studies have shown that face-specific neural mechanisms, like the Fusiform Face Area (FFA), are triggered by face-like configurations in objects (Hadjikhani et al., 2009) and even in pure-noise images (Liu et al., 2014). The thalamus also plays a crucial role in this process, acting as a gate for sensory and cognitive information (Kuypers, 2018). This phenomenon occurs due to a mismatch between internal representations and sensory inputs, involving both bottom-up integration and top-down modulation of stimuli (Smailes et al., 2019). Decreased inhibition of the mPFC and DMN, and increased connectivity of other brain regions under the influence of psilocybin may increasing the likelihood of a pareidolia event (see Fig. 1).

2.5. Psychedelics and Creativity

Creativity and creative problem-solving are complex, multilayered constructs rooted in human perception and evolution (Jung et al., 2013; Pepin et al., 2022b; Bâlâet, 2022). Despite widespread disagreement on the topic and research of creativity, a generally accepted definition is the production of novel, uncommon, and useful ideas (Runco & Jaeger, 2012; Stein, 1953). Creativity is critically linked to divergent thinking—a measure of cognitive processes that involve generating multiple solutions to an open-ended problem (Runco & Acar, 2012).

The research on psilocybin's effect on creativity reflects this broader debate. Psilocybin has been reported to enhance creative ideation and overall creativity (Kuypers, 2018). It is also suggested that the decreased functional connectivity of the default mode network (DMN) potentially enhances cognitive flexibility and creative thinking through increased communication between usually less-connected brain regions (Carhart-Harris et al., 2012; Petri et al., 2014; Kuypers, 2018).

The 'facilitatory theory' proposes that the positive mood states induced by psychedelics activate a rich and complex set of thoughts and memories, thereby facilitating mental flexibility and the generation of new ideas (Baas et al., 2011; Kuypers, 2018). However, Mason et al. (2021) nuance this finding, reporting that while

psilocybin increases spontaneous insights, it may decrease deliberate task-based creativity under acute influence. Furthermore, Bonnieux et al. (2023) in their scoping review noted that macrodoses tend to acutely impair cognitive performance and creativity, whereas microdoses lean towards enhancing creativity.

2.6. Pareidolia and divergent perception

While divergent thinking (DT) involves generating multiple solutions to a problem through conceptual expansion, divergent perception involves recognizing patterns within sensory inputs. Pareidolia can be viewed as a perceptual counterpart of divergent thinking, where the ambiguity in a stimulus can lead to multiple possible perceptions. As Heath and Ventura (2016) put it, "Pareidolia is a creative act because it is not about seeing things for what they are, but seeing things for what they could be."

In our study, we used a modified version of the Alternate Uses Test (AUT; Guilford, 1968), a widely utilized task to assess divergent thinking (Diana et al., 2021). In the original AUT, participants are tasked to think of as many uses as possible for everyday objects like a brick or a pencil. Their level of DT is scored across four domains of creativity: originality of ideas, fluency of idea production, flexibility among ideas, and elaboration of ideas. In our alternative version, we test divergent perception. Participants are asked to draw all the pareidolia they perceived in pareidolia-suggestive images on an overlaid paper stencil. Verbal descriptions of pareidolia were recorded and analyzed using the creative ideation domains of originality, fluency, flexibility, and elaboration of ideas (Guilford, 1957; Torrance, 1966).

The drawings produced by participants undergo a separate spatial-physical analysis, which includes examining the size and distance between drawings to identify any changes in the perceptual domain. Additionally, the fractal dimension and contrast of the areas where subjects identified pareidolia were analyzed and compared between conditions to look for changes in the threshold of pareidolia perception under the influence of psilocybin.

2.7. General Goal

A key objective of this research is to develop metrics that can distinguish pareidolia reports produced under the influence of psilocybin from those produced under a placebo. Ultimately, we aim to produce a machine learning classifier based on the combined features of the Alternative Uses Test (AUT) domains, spatial information of the pareidolia drawings, and fractal dimension (FD) & contrast data of the original images to predict whether a pareidolia report was produced either in placebo or active (psilocybin) condition. This will be achieved by training and evaluating binary random forest classifiers.

3. Research questions

1. How does psilocybin alter the perception of pareidolia compared to a non-active dose?
2. Can the changes in pareidolia perception under the influence of psilocybin be quantified using measures of originality, fluency, flexibility, and elaboration from the Alternative Uses Test (AUT)?
3. Are there any changes in the spatial characteristics, such as size and distance between pareidolia, under the influence of psilocybin?
4. Do the fractal dimension and contrast of areas corresponding to reported pareidolia differ between active and non-active doses of psilocybin?
5. Can the quantified differences in pareidolia perception be utilized to train a machine learning classifier to distinguish between active and non-active psilocybin conditions?

3.1. Hypotheses

Building on the theories of pareidolia perception and the effects of psilocybin on brain networks, we hypothesize that psilocybin will enhance several aspects of creative cognition in pareidolia perception. Firstly, we anticipate that psilocybin will enhance the generation of novel and unique interpretations of ambiguous stimuli, leading to higher originality scores. This expectation is based on the "unconstrained cognition" state facilitated by psilocybin, which makes the brain more receptive to novel bottom-up information. This hypothesis is supported by research linking pareidolia perception to internal representations and sensory inputs, involving both bottom-up integration and top-down modulation of stimuli (Smailes et al., 2019) allowing “unconstrained cognition” (Carhart-Harris et al., 2012) and relaxation of brain rigidity (REBUS) (Carhart-Harris & Friston, 2019).

Additionally, we predict that the reduction in cognitive rigidity due to psilocybin will lead to an increased number of pareidolia events perceived, indicating higher fluency in visual divergent perception. This aligns with the theory that psilocybin's liberation of cognitive processes enhances the fluency of creative thinking. Furthermore, we hypothesize that psilocybin will facilitate cognitive flexibility, enabling a broader range of interpretations and a more effortless switch between different categories of pareidolia. We expect this higher flexibility score due to increased associative thinking under the influence of psilocybin (Figure 1 by Petri et al., 2014; Girn et al., 2020).

Moreover, we hypothesize that the increased fluidity of cognitive processes under psilocybin will result in more detailed and intricate interpretations of stimuli, reflected in higher elaboration scores. This would demonstrate an enhanced ability to follow associative pathways and add details to perceived pareidolia.

Research by Muller et al. (2023) indicates that psilocybin promotes a more localized visual exploration. We hypothesize that pareidolia perceived under psilocybin will be smaller and more closely spaced than those perceived under the placebo condition.

Psilocybin's influence on visual sensitivity suggests that participants will perceive pareidolia across a broader range of fractal dimensions and contrast levels in the psilocybin condition compared to the placebo condition, aligning with findings by Pepin et al. (2022a) and Fischer et al. (1969).

Considering the subjective nature of visual perception, we hypothesize significant individual differences in the size and number of pareidolia perceived. This inter-individual variability underscores the importance of accounting for personal differences in studies of creativity and perception (Li et al., 2014; Kuypers, 2018).

4. Methods and materials

The data used in this thesis was collected during an experiment conducted prior to my arrival at the Consciousness, Culture, and Complexity Lab in Buenos Aires, Argentina. Below, I give a brief overview of the data collection process. For a more detailed description of the data collection methods and experimental specifics, please refer to Muller et al., 2023.

4.1. Participants and Experimental Design

This study involved 23 participants (four females, average age 31 ± 4 years, average weight 72 ± 15 kg) recruited through word of mouth and social media. Eligibility was determined via a phone interview and a psychiatric screening. Participants were required to have at least two prior experiences with a significant dose of psilocybin mushrooms. Detailed inclusion and exclusion criteria ensured the selection of appropriate participants, with exclusions based on recent use of psychoactive substances, psychiatric disorders, and other health conditions (Muller et al., 2023). All participants had normal or corrected-to-normal vision. One subject (S04) could not perform the pareidolia task during the active condition due to drug effects, one paper with descriptions was lost (S09), and another subject (S17) did not complete the 4th pareidolia in the active condition.

The study was conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee at the Universidad Abierta Interamericana (Buenos Aires, Argentina), protocol number 0-1068. Participants provided written informed consent and received no financial compensation.

The research followed a randomized, double-blind, placebo-controlled, within-subject design. Participants underwent two conditions: a high-dose psilocybin condition (3 g of psilocybin mushroom) and an active placebo condition (0.5 g psilocybin mushroom mixed with 2.5 g inactive edible mushrooms), with a one-month interval between conditions to reduce potential tolerance and memory effects. The experiment was conducted in a comfortable house setting with the participant and a team of researchers present.

4.2. Acute Effects Measurement

Participants used a Visual Analog Scale (VAS) to rate the subjective intensity of various perceptual experiences such as distorted size and space, unusual bodily sensations, and geometric patterns. The VAS was administered four times, starting one hour after dose ingestion and again every hour until the drug effects subsided. The pareidolia experiment was conducted approximately 4 hours after the dosing, it was the last of a string of experiments conducted during the psilocybin drug effects. For acute drug effects see Figure 3 below (Muller et al., 2023).

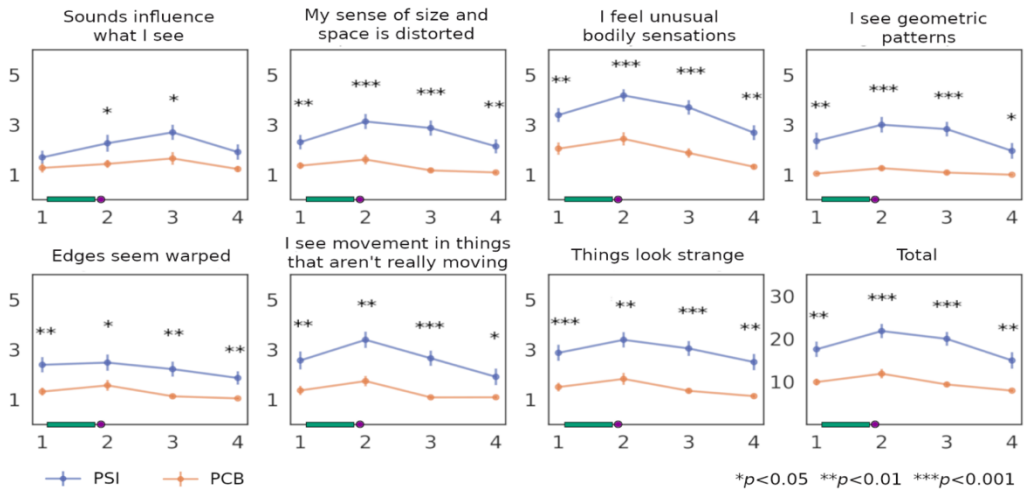


Figure 3. ***Acute effects measured using individual VAS items and overall intensity of the experience given by the sum of all items.*** *Results are shown for each measurement time point, with consecutive measurements separated by one hour. The points indicate the mean across participants and the vertical lines the standard error of the mean. The Pareidolia experiment took place around hour 4. Statistical significance is indicated using asterisks (Wilcoxon signed-rank test). Figure taken from Muller et al., 2023.*

4.3. Pareidolia experiment

For the experiment, a selection of 4 pareidolia-invoking natural formation images was made to study the visual perception changes (see Figures 4-7).
The subjects were presented with these images one at a time. A transparent film was attached in front of the picture and markers were provided.
Subjects were given 5 minutes alone with the image to draw all pareidolia (shapes, faces, animals, objects, etc.) that they perceived on the drawing sheet. After 5 minutes the researcher entered the room and recorded the verbal descriptions of the pareidolia images portrayed on the drawing sheet. These sheets were later photographed with a digital camera and saved in a Google Drive folder for analysis, together with the verbal descriptions.

The analysis of the pareidolia data was conducted in three distinct dimensions:

Figure 4. ***Pareidolia image 1 (P1):*** *Tree formation 1, fractal dimension: 1.82, contrast level: 66.77*

Figure 5. ***Pareidolia image 2 (P2):*** *Ice formation, fractal dimension: 1.86, contrast level: 50.71*

The verbal descriptions of pareidolia were scored on originality, fluency, flexibility, and elaboration to quantify creative perception and allow comparison between conditions. This method has been previously applied to study pareidolia data (Diana et al., 2021).

Figure 6. ***Pareidolia image 3 (P3):*** *Cloud formation, fractal dimension: 1.78, contrast level: 42.75*

Next, the drawing sheets were digitized, binarized, and the topographical characteristics of individual pareidolia events, and average distance between pareidolia events on the same drawing sheet were examined to explore spatial perception influences of psilocybin.

Figure 7. ***Pareidolia image 4 (P4):*** *Tree formation 2, fractal dimension: 1.82, contrast level: 55.22*

Finally, areas of the pareidolia images corresponding to pareidolia events on the drawing sheets were identified. Fractal dimension and contrast of these areas was calculated and compared between conditions.

All data gathered from the different analyses was gathered to train random forest classifiers, aiming to distinguish between pareidolia perceived under the effects of psilocybin and those perceived in the placebo condition. This approach aimed to test whether the quantification of psilocybin's effects on perception and creativity, as captured in the earlier analyses, allowed the classifier to accurately identify and classify pareidolia events based on the condition (psilocybin or placebo).

4.4. Pareidolia description analysis

We analyzed the reported verbal descriptions dataset using the 'Alternative Uses Test' (AUT) scoring system, developed by Guilford in 1968, to quantify the subjects' divergent perceptions. While fluency, flexibility, and originality have traditionally been more frequently used in scoring approaches, Torrance (1966) and Guilford (1967) recognized that elaboration significantly contributes to creativity by aiding the development and refinement of ideas. Elaboration was included here as it complements novelty-generating processes by refining and developing ideas, leading to response generation (Vartanian et al., 2020). Thus, we scored divergent perception of pareidolia through four components and their summed total:

- Originality (uniqueness of pareidolia)
- Fluency (number of pareidolia described)

- Flexibility (variety of ideas/number of different categories)
- Elaboration (level of detail used to describe pareidolia)
- Total (sum of all domains above)

See Figure 8 below for examples of pareidolia events recorded and their corresponding (translated) verbal descriptions. The following sections will further elaborate on scoring of the divergent perception component.

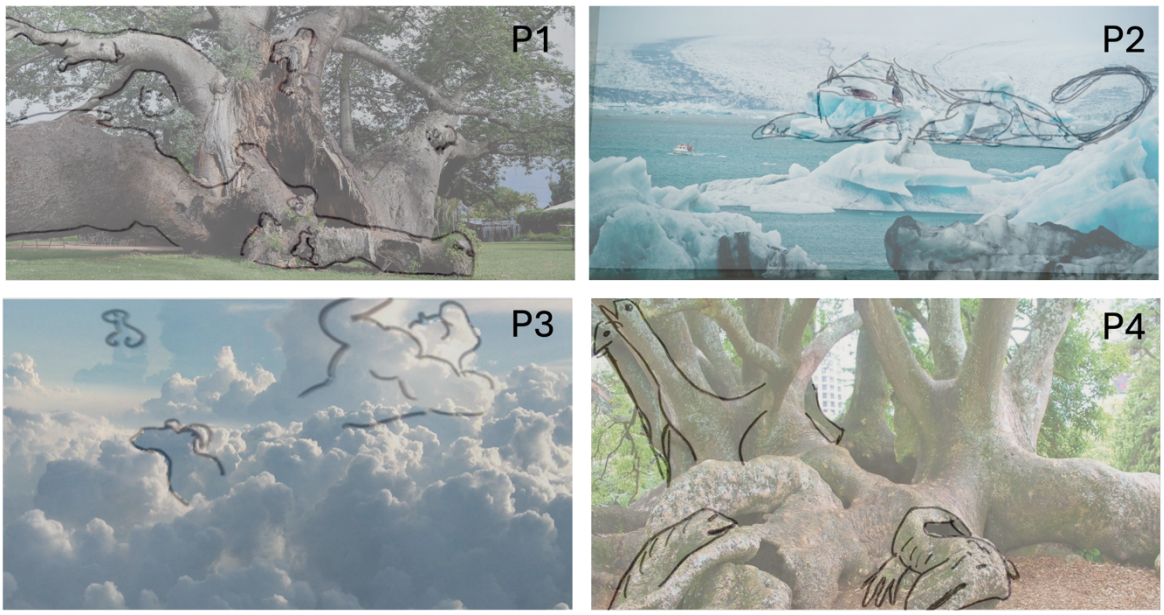


Figure 8. ***Examples of pareidolia events perceived in the pareidolia images and their descriptions.***
P1: S13, active; A dead elephant – lizard – a squirrel – a bizarre thing, fantasy-like – a face
P2: S02, active: A cat
P3: S23, placebo: A goat – mythological figure contorting his back - Caricature
P4: S05, placebo: Reptiles in general, a snake – Komodo Dragon – Dinosaurs with long necks

4.4.1. Originality Scoring System

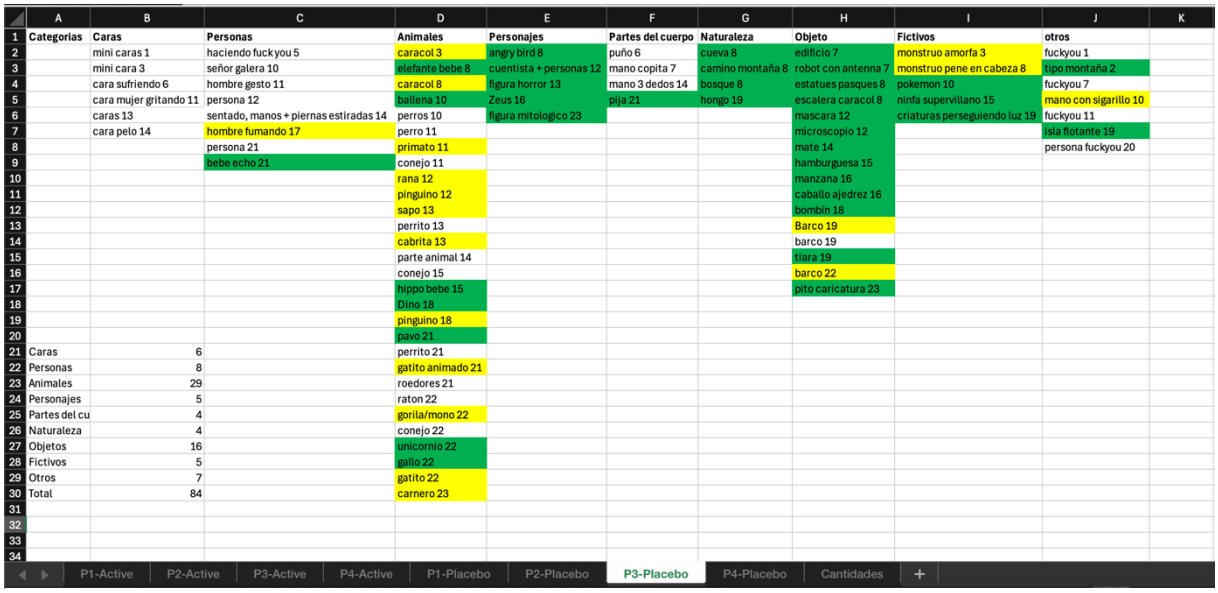
The originality of pareidolia events was analyzed per pareidolia image, per condition, resulting in eight (4 pareidolia images * 2 conditions) originality assessments (see Figure 9). All descriptions were categorized and scored based on the statistical (in)frequency within the total pool of descriptions in the respective pareidolia x condition originality assessment sheet (e.g. P2-Active or P4-Placebo; Runco et al., 1987; Diana et al., 2021).

A unique drawing description within an assessment sheet received 2 points for originality. Descriptions occurring in less than 3% of the cases within the condition received 1 point (e.g. if 2 snails were perceived over a total of 84 pareidolia its occurrence is (2 / 84) * 100 = 2.38% < 3% = 1 originality point). Pareidolia occurrence of more than 3% received 0 points. Traditionally, 1 originality point is awarded to ideas

occurring in less than 5% of the total ideas (Runco et al., 1987). However, we decided to adopt a ‘less than 3%’ approach as this better fit our data, preventing excessive leniency in originality point attribution.

Common pareidolia like faces typically did not receive originality points unless described as a specific character or person. Specifically named animal species received originality points based on specificity. For example, an eagle and an ostrich mentioned only once received 2 originality points each, as they are described as specific species. Similarly, a Komodo Dragon received 2 originality points, whereas “reptile”, “snake”, and “lizard” were determined to be too general and were categorized under the same umbrella. Consequently, their originality score, based on the total number of pareidolia in the respective assessment sheet resulted in (3 / 92) * 100 = 3.26% > 3% = 0 originality points.

All scoring was performed by the author (Toon Brilman). In cases of ambiguity or uncertainty, the final decision was made through consensus among all researchers involved (Toon Brilman, Stephani Muller, and Carla Pallavicini). See Figure 9 for the originality assessment sheet for P3-Placebo.



	Categorias	Caras	Personas	Animales	Personajes	Partes del cuerpo	Naturaleza	Objeto	Fictivos	otros
2		mini caras 1	haciendo fuck you 5	caracol 3	angry bird 8	puño 6	cueva 8	edificio 7	monstruo amorfa 3	fuckyou 1
3		mini cara 3	señor galera 10	elefante bebe 8	cuentista + personas 12	mano copita 7	camino montaña 8	robot con antenna 7	monstruo pene en cabeza 8	tipo montaña 2
4		cara sufriendo 6	hombre gesto 11	caracol 8	figura horror 13	mano 3 dedos 14	bosque 8	estatues pasques 8	pokemon 10	fuckyou 7
5		cara mujer gritando 11	persona 12	ballena 10	Zeus 16	pija 21	hongo 19	escalera caracol 8	ninfa supervillano 15	mano con sigarillo 10
6		caras 13	sentado, manos + piernas estiradas 14	perros 10	figura mitologico 23			mascara 12	criaturas perseguiendo luz 19	fuckyou 11
7		cara pelo 14	hombre fumando 17	perro 11				microscopio 12		isla flotante 19
8			persona 21	primato 11				mate 14		persona fuckyou 20
9			bebe echo 21	conejo 11				hamburguesa 15		
10				rana 12				manzana 16		
11				pinguino 12				caballo ajedrez 16		
12				sapo 13				bombín 18		
13				perrito 13				Barco 19		
14				cabrita 13				barco 19		
15				parte animal 14				tiara 19		
16				conejo 15				barco 22		
17				hippo bebe 15				pito caricatura 23		
18				Dino 18						
19				pinguino 18						
20				pavo 21						
21	Caras	6		perrito 21						
22	Personas	8		gatito animado 21						
23	Animales	29		roedores 21						
24	Personajes	5		raton 22						
25	Partes del cu	4		gorila/mono 22						
26	Naturaleza	4		conejo 22						
27	Objetos	16		unicornio 22						
28	Fictivos	5		gallo 22						
29	Otros	7		gatito 22						
30	Total	84		carnero 23						
31										
32										
33										
34										

P1-Active | P2-Active | P3-Active | P4-Active | P1-Placebo | P2-Placebo | P3-Placebo | P4-Placebo | Cantidades | +

Figure 9. ***Originality assessment sheet, per pareidolia (P3), per condition (Placebo).*** *Green cells contain unique pareidolia (2 points), yellow cells contain pareidolia with <3% occurrence (1 point), white cells contain pareidolia with >3% occurrence (0 points). The categories (from left to right) read: Faces, Persons, Animals, Characters, Body parts, Nature, Objects, Fictive creatures, Others. The number behind each pareidolia is the subject-number, used to link the total (summed) originality score to the respective subject. Bottom-left shows number of pareidolia per category and their summed total, used to calculate percentage of occurrence.*

4.4.2. Fluency Scoring System

Fluency is the numerical quantity of individual pareidolia described. Plural descriptions like "faces" or "3 penguins" are scored as a single pareidolia description, as they are recognized as a group/entity.

4.4.3. Flexibility Scoring System

Flexibility reflects the variety of described drawings across categories. Categories include faces, persons (e.g., someone sitting down, someone looking up), characters (e.g., Angry Bird, the Penguin from Batman), animals, objects, fictive creatures (e.g., monsters, ghosts), nature (e.g., a cave, a forest), and 'other' (see Figure 9). Categories were defined throughout the categorization process, defining a new category when a description did not fit any of the yet defined categories.

4.4.4. Elaboration Scoring System

Elaboration points were awarded based on the level of detail added to each description, with a maximum of 2 points per drawing. For example, "elephant" received 0 points, "elephant with a hat" received 1 point, and "elephant with a hat holding a cup" received 2 points. Descriptions like "person seen from the side" did not receive an elaboration point, as they did not add detail beyond the base drawing of "person."

While acknowledging a certain level of subjectivity in scoring decisions, we applied the rules as consistently and objectively as possible throughout the assessment to minimize potential biases and ensure that the results are not skewed.

To account for potential confounds between originality and fluency scores, summed originality scores were normalized by dividing them by fluency (i.e., the total number of drawings), resulting in the originality2 score (hereafter ‘originality’ represents this normalized value). This approach addresses the issue that a high fluency score could artificially inflate the originality score, thereby leading to misleading conclusions about creative performance. By normalizing the originality score, we provide a more accurate originality score that reflects the quality of creative output, ranging between 0 and 2, as recommended by Clark and Mirels (1970) and Cavanna et al. (2022). This allows for a more precise comparison of originality across conditions and participants.

Although the AUT scoring system provides a valuable assessment of creativity and divergent perception, it has its limitations. The final scores from the AUT may not perfectly represent creativity, as the system tends to award higher scores to subjects who draw many small items, while fewer points are given for a single, large, elaborate, and creative drawing. To address this limitation and gain a more comprehensive understanding of pareidolia perception, we supplemented the pareidolia description assessment with a visuospatial analysis of the drawings, as well as fractal dimension and contrast assessments.

4.5. Pareidolia event drawing analysis

To analyze the visuospatial effects of psilocybin on pareidolia perception, we adopted a topographical approach, focusing on the spatial organization of pareidolia events on

the drawing sheets. This involved standardizing orientation and size, binarizing the images, and processing them in Python to obtain information on their position and size.

First, the images of the drawing sheets were standardized using Microsoft PowerPoint. This process involved overlaying each drawing sheet onto its respective pareidolia image to match the drawn pareidolia events to their respective areas. The images were then resized, rotated, and cropped to match the dimensions of their respective pareidolia image, as the pareidolia images have different dimensions.

Next, to utilize the contour detection function in Python, the drawing sheet images needed to be binarized. However, variations in marker shades, room brightness, image contrast, and other factors posed challenges for standardized binarization in Python. To address this, the images were manually binarized using Microsoft PowerPoint. Each image was opened in PowerPoint, and the 'Image Format' tab was accessed. Under the 'Recolor' options, the 'Black and White: 50%' preset was selected to binarize the image. To reduce noise, the sharpness was set to 100% to enhance the drawing lines, and brightness and contrast were adjusted based on the individual image characteristics (see Figure 10). The binarized images, with minimized noise, were saved for subsequent processing.

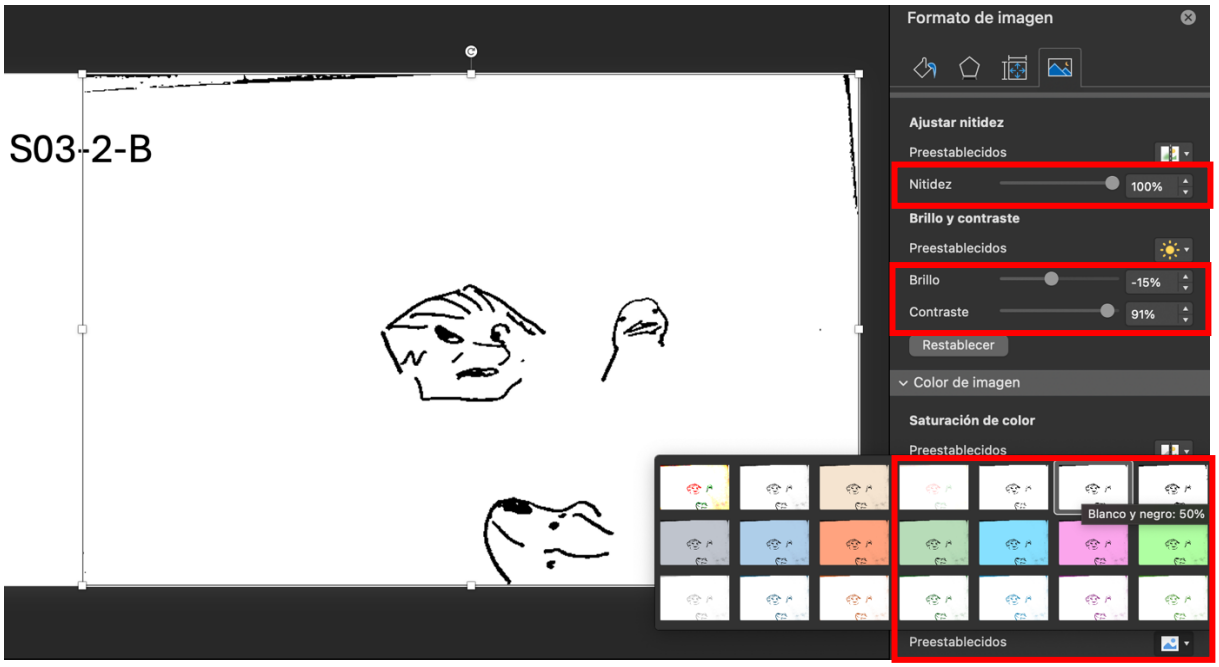


Figure 10. ***Screenshot of the manual binarization process****. The 'Image format' (Formato de imagen) tab on the side allow for manipulations of the image. Note the Blanco y negro: 50% option selected in the preset options (within the red box below). Sharpness (Nitidez): 100%; 'Brightness' (Brillo) and 'Contrast' (Contrast) levels varied depending on image. In some cases, noise remained at edges of the image (upper-left and upper-right corner) after this binarization process. This noise was manually removed later using white-outs.*

The contour detection function and grouping methods were employed in Python to group individual pareidolia events in the binarized drawing sheets. A grouping algorithm was developed to cluster contours based on proximity, assuming contours within a

certain distance (e.g. 250 pixels) belonged to the same drawing. However, noise in the binarized images significantly hindered the grouping process and required further manual intervention. Using PowerPoint, we manually removed noise from the binarized images, which substantially improved grouping accuracy. Despite this, variations in drawing size, style, and composition meant that no single proximity clustering parameter could consistently group all drawings correctly. Adjustments to minimal contour size and inter-contour distance were tested, but inconsistencies remained.

To address these issues, we implemented manual grouping. A custom Python script was developed to display images one by one, with an interactive sliding bar to adjust the inter-contour proximity clustering parameter. Despite improvements, some drawings could not be grouped correctly (see Figure 11). Consequently, full-manual grouping was performed. Each image was assessed individually, and rectangles were manually drawn to group individual pareidolia events. The coordinates and sizes of these rectangles, which encompassed the entire drawing, were saved in a JSON log file and compiled into a data frame for further analysis. The statistical analyses will be elaborated upon later.

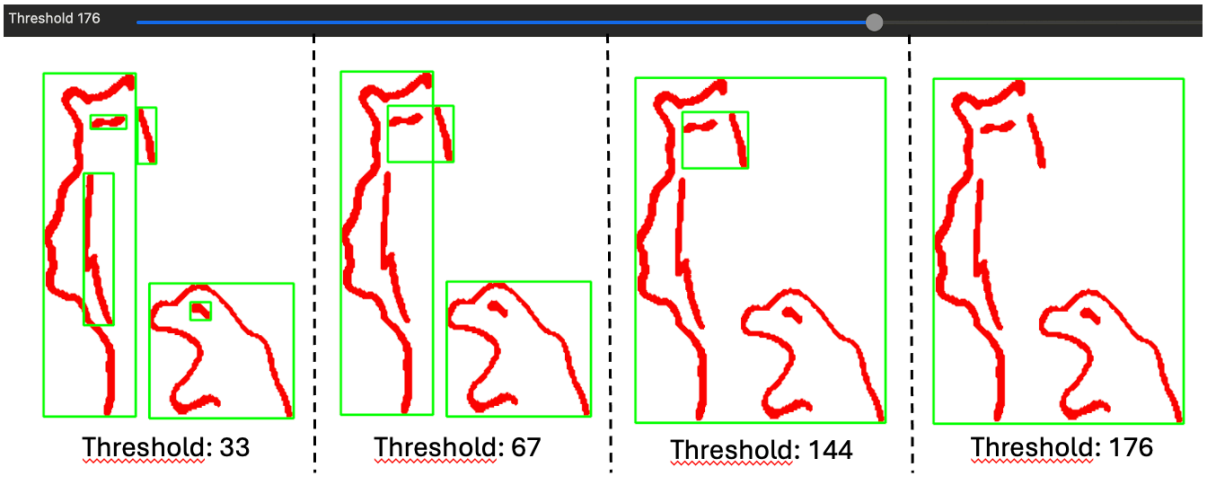


Figure 11. ***Example of inability to correctly group drawings using the inter-contour proximity clustering slide-bar*** *shown at the top of the image. Drawings are in red as recognized contours. Clustering at different proximity thresholds visualized by green rectangles. Verbal descriptions were used to help identify individual drawings.*

4.6. Artificial Neural Network Analysis

In the next phase, we intended to employ an Artificial Neural Network (ANN) to assess the probability of pareidolia perception in the regions of the background image where pareidolia were perceived. The correct grouping rectangles obtained in the previous processing step represent the size and location of each pareidolia event. When these rectangle coordinates are plotted on the original pareidolia images, they define the Regions of Interest (ROIs) where pareidolia events occurred (see Figure 12). Individual ROIs were cropped from the background images using the rectangle coordinates from the JSON files and saved for the ANN analysis. Filenames of the ROIs were parsed to extract relevant details such as subject number, pareidolia number, condition, and

drawing number. These details ensured the accurate linking of computed features to the corresponding pareidolia event.

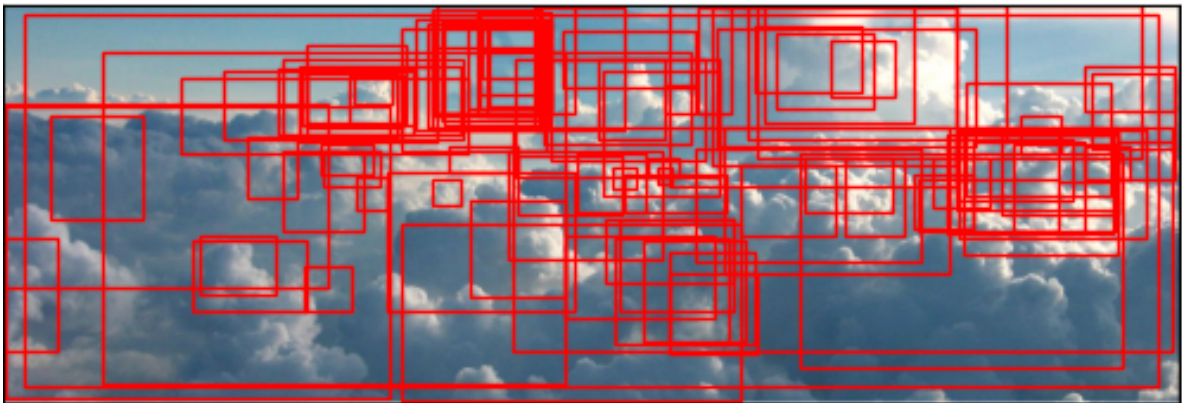


Figure 12. ***Overview of all ROIs of P3 in the active condition****. Each rectangle represents the size and location of a pareidolia event.*

Initially, the VGG-16 model, a Convolutional Neural Network (CNN), was utilized due to its recognized accuracy in image recognition and classification. The VGG-16 model consists of 16 layers that detect features, reduce image size, and make final classification decisions.

We aimed to feed the ROIs into the ANN to obtain an 'objective' assessment of each ROI, assessing what pareidolia the ANN perceived (if any) and what probability the ANN would assign to perceiving the specific pareidolia identified by the subject in the respective ROI. However, VGG-16's specificity and inconsistency in responses to similar images rendered it unsuitable for our purposes (see Figure 13). Additionally, VGG-16 could not offer probabilistic assessments of perceiving specific pareidolia, which was a crucial aspect we aimed to evaluate.

Figure 13. Left image: (S15, monkey from Madagascar) + VGG-16 output. Right image (S18, monkey with glasses) + VGG-16 output

To address the limitations encountered with the VGG-16 network, ChatGPT-4.0 (hereafter ChatGPT) was considered for its flexibility, interactive capabilities, and the possibility to upload and evaluate images (ROIs). A one-month membership was purchased to explore this avenue. Through trial-and-error, standardized prompts were

developed, aimed to minimize artificial bias and maximize consistency in responses. The assessment was divided into three distinct prompts:

In the first prompt, we provided an ROI and asked ChatGPT to provide 10 independent observations of whole image pareidolia, each with assigned probability scores. This aimed to create a form of repeated measures that could be generalized in later analyses.

Prompt 1: "Please provide 10 independent (viewing the image for the first time, without prior influence) observations of whole image pareidolia. Consider only whole-image pareidolia, not, for example, in the top-left corner..., only large-scale pareidolia. Assign a probability score representing the likelihood that someone perceives that particular pareidolia to each observation. Avoid introducing artificial variability and provide genuine perceptions only. The pareidolia can be of faces, body parts, animals, objects, fictive entities, or any other recognizable shapes. Please ensure consistent assessment by adhering to these guidelines."

In the second prompt, we provided ChatGPT with the pareidolia perceived by the participant in the ROI. We then asked ChatGPT to compare its own pareidolia identified in the previous response with those identified by the subject.

Prompt 2: "The pareidolia identified by the subject was a _____. Please compare your perceived pareidolia from Prompt 1 to the pareidolia identified by the subject. For each observation indicate whether they match. If they match, provide 1. If they do not match, provide 0."

In the final prompt, we reversed the question from the first prompt. ChatGPT was asked to assign a probability of the perception of the particular pareidolia perceived by the participant in the ROI. This prompt also asked for 10 independent assessments, and ChatGPT was requested to aggregate the results into a table.

Prompt 3: "Again, please provide 10 independent observations, this time assigning a probability score (0-1) representing the likelihood that an objective observer perceives a _____ in the provided image the first time they see it. Do this completely independently from prompt 1. Ensure that each observation is genuine and follows the given guidelines for consistency and independence. Please provide your reasoning for this answer. Please put the output you generated from prompts 1, 2, and 3 in an output table with the following columns: Image name, subject's pareidolia, Chat's pareidolia prompt 1, Chat's probability score prompt 1, Chat match with subject?, probability observing subject's pareidolia."

Despite explicitly requesting independent assessments and avoiding artificial probability assignments, ChatGPT's responses exhibited artificial variance, bias, and arbitrary probability scores. Observations were not truly independent, and probability scores often decreased systematically (see example analysis in figures 14 and 15). Consequently, ChatGPT was deemed unsuitable for reliable pareidolia analysis due to these inconsistencies. As a result, alternative methods for analyzing pareidolia in images had to be considered.

Figure 14. ***Example pareidolia used in Figure 15 for ChatGPT analysis.*** *This subject (S14, active condition) perceived a 'person'. The image on the left is the ROI used in the ChatGPT analysis. The image on the right shows the pareidolia event perceived by subject 14, and the middle image shows the drawing laid over the image.*

	Image Name	Subject's Pareidolia	Chat's Pareidolia Prompt 1	Chat's Probability Score Prompt 1	Chat Match with Subject?	Probability Observing Subject's Pareidolia
2	Copia de S14-1-Act-1	Person	Giant Elephant Head	70%	0	0.8
3	Copia de S14-1-Act-1	Person	Dragon	65%	0	0.6
4	Copia de S14-1-Act-1	Person	Ancient Tree Spirit	60%	1	0.7
5	Copia de S14-1-Act-1	Person	Dinosaur Skeleton	55%	0	0.5
6	Copia de S14-1-Act-1	Person	Giant Snake	50%	0	0.4
7	Copia de S14-1-Act-1	Person	Gorilla	45%	1	0.3
8	Copia de S14-1-Act-1	Person	Wizard with Staff	40%	1	0.5
9	Copia de S14-1-Act-1	Person	Horse Head	35%	0	0.4
10	Copia de S14-1-Act-1	Person	Fallen Giant	30%	1	0.5
11	Copia de S14-1-Act-1	Person	Mermaid	25%	1	0.6

Figure 15. ***The table generated by ChatGPT after executing the three separate prompts.*** *Note the constant probability decrease of 5% and the 'Probability Observing Subject's Pareidolia' ranging from 0.3 to 0.8*

4.7. ROI Analysis

As an alternative to ANN analysis for the ROI data, we explored the differences in pareidolia perception threshold by comparing the fractal dimension and contrast of ROIs between conditions. The fractal dimension of the ROIs was calculated using the box-counting method in Python. First, ROIs were converted to grayscale and binarized to distinguish between background and foreground pixels, setting pixels with intensities above 127 to white (255) and those below to black (0). This binary image was normalized to contain only 0s (black) and 1s (white). Then, grids of varying box sizes were overlaid on the binary images, and the number of boxes containing at least one pixel with a non-zero value was counted. Finally, the logarithm of the box sizes was plotted against the logarithm of the box counts, and the slope of this log-log plot was used to calculate the fractal dimension. This measure quantifies the image's complexity, with values typically ranging between 1 and 2. Additionally, the standard deviation of the fractal dimension was calculated to compare the variation between conditions.

ROI contrast was determined by calculating the standard deviation of pixel intensities in grayscale images. This involved converting the ROIs to grayscale and then measuring the variation in pixel intensity values. Higher standard deviation values indicate greater contrast, reflecting more pronounced differences between light and dark areas within the ROI, with values ranging between 0 and 100.

To ensure accurate linking of computed features to the corresponding ROIs, filenames were parsed to extract relevant details such as subject number, pareidolia number, condition, and drawing number. This detailed parsing ensured the accurate linking of computed features to the corresponding pareidolia event.

4.8. Data Aggregation

Data from the Pareidolia description analysis, the Pareidolia event drawing analysis, and the ROI analysis were compiled into two main data frames:

- Individual Pareidolia Event Dataset: This data frame contains the fractal dimension, its standard deviation, contrast, and size on all individual pareidolia events recorded. However, this dataset may be skewed as some individuals perceived many more pareidolia than others.

- Aggregated Dataset: This data frame contains a single value per subject, per pareidolia, per condition (20 subjects * 4 images * 2 conditions = 160 rows). It includes both the AUT data and the averaged data from the individual pareidolia event data frame. By averaging the values of all drawings per subject, per pareidolia, per condition, we ensured a consistent structure across all data points. For instance, the format includes subject number, condition, pareidolia number, AUT scores (originality, fluency, flexibility, elaboration, and total), and averaged measures of size, distance, fractal dimension, standard deviation of fractal dimension, and contrast. This approach helps mitigate the skewness caused by varying numbers of perceived pareidolia across subjects.

These structured datasets allowed for a comprehensive analysis of the pareidolia perception data, facilitating the identification of patterns and effects of psilocybin on visual perception and creativity. For descriptive statistics see Tables 2 and 3 in the results section.

5. Statistics

5.1. Normality testing

Prior to comparing means of variables between conditions, the distributions of the variables were tested for normality, a key assumption of the paired sample t-test. This was done using the Shapiro-Wilk test. If the Shapiro-Wilk test returned a p-value less than 0.05, it indicated a violation of the normality assumption. Consequently, for those variables, the non-parametric alternative, the Wilcoxon signed-rank test, was used to compare the means (see Table 1).

Variable	Pareidolia 1	Pareidolia 2	Pareidolia 3	Pareidolia 4
Originality	Parametric	Parametric	Parametric	Non-Parametric
Fluency	Non-Parametric	Non-Parametric	Non-Parametric	Non-Parametric
Flexibility	Non-Parametric	Non-Parametric	Non-Parametric	Non-Parametric
Elaboration	Non-Parametric	Non-Parametric	Non-Parametric	Non-Parametric
Total	Non-Parametric	Non-Parametric	Non-Parametric	Non-Parametric
Avg size	Non-Parametric	Non-Parametric	Non-Parametric	Non-Parametric
Avg distance	Non-Parametric	Parametric	Non-Parametric	Parametric
Avg FD	Parametric	Parametric	Non-Parametric	Non-Parametric
Avg FD SD	Non-Parametric	Non-Parametric	Non-Parametric	Non-Parametric
Avg contrast	Parametric	Parametric	Non-Parametric	Parametric

Table 1. ***Shapiro-Wilk normality tests for each variable across all pareidolia images*** *before performing the mean comparisons. Variables that met the normality assumption were analyzed using the parametric paired sample t-test. For variables that violated the normality assumption (Shapiro-Wilk test $p < 0.05$), the non-parametric Wilcoxon signed-rank test was applied. The table above summarizes which test was used for each variable within each pareidolia image.*

5.2. Pareidolia Description Analysis

The pareidolia descriptions were analyzed using linear mixed models to assess the effects of the condition on the creativity domains (originality, fluency, flexibility, elaboration, and total scores), accounting for variance between individuals and pareidolia images. Additionally, we compared the means for each creativity domain across pareidolia images to identify any pareidolia-specific differences between conditions.

5.3. Pareidolia Event Analysis

The individual pareidolia event data frame, containing size, fractal dimension (standard deviation), and contrast level of pareidolia events and their ROIs, was analyzed to compare these variables between conditions. Linear mixed models were used, incorporating all individual pareidolia events and considering variance between subjects and pareidolia images. For the aggregated data frame, the means of these variables were compared for each pareidolia image separately. Depending on the normality of the data distribution, a paired sample t-test was used where applicable, and the non-parametric Wilcoxon signed-rank test was employed when necessary (see Table 1).

5.4. Random Forest Model Statistics

We trained random forest classifiers (Breiman, 2001) to differentiate pareidolia events produced under active psilocybin or placebo conditions. The classifiers were built using the scikit-learn library (Abraham et al. 2014). For each pareidolia image, we trained 1,000 random forest models, each containing 1,000 decision trees. To ensure diverse feature selection, each tree used a random subset of features, with the subset size approximately equal to the square root of the total number of features.

The quality of each decision tree split was measured using Gini impurity, a metric that helps determine the best feature for splitting the data at each node. Each tree was allowed to grow until all leaf nodes were pure, meaning each leaf node contained only one class (either psilocybin or placebo). We did not set a minimum threshold for the decrease in impurity needed to make a split, nor did we require a minimum number of samples at the leaf nodes. Detailed classifier hyperparameters can be found at scikit-learn.org.

To assess the statistical significance of the classifier accuracy, we performed a permutation test. This involved training and evaluating an additional 1,000 random forest classifiers with the class labels randomly shuffled. We compared the accuracy of these classifiers to the accuracy of the original classifiers. An empirical p-value was calculated by counting how many times the accuracy of the classifiers with shuffled labels exceeded that of the original classifiers. Accuracy was measured as the area under the receiver operating characteristic curve (AUC), with significance set at $p<0.05$.

6. Results

This study aimed to investigate the effects of psilocybin on visual perception and creativity through the lens of pareidolia. We worked with three categories of data: pareidolia descriptions, pareidolia event drawings, and Regions of Interest (ROIs). Descriptions of pareidolia were scored based on the Alternative Uses Test (AUT) creativity domain metrics: originality, fluency, flexibility, and elaboration. We examined pareidolia event size and average distance between events to assess visuospatial differences between conditions. Additionally, the ROIs were analyzed by calculating the fractal dimension and contrast levels corresponding to pareidolia events. Depending on the normality of variable distributions, we used parametric or non-parametric tests and employed linear mixed models (LMMs) to analyze the data.

Ultimately, we aggregated the averaged results per subject, pareidolia, and condition for all studied dimensions. This comprehensive dataset was used to train and evaluate a random forest binary classifier, providing insights into psilocybin's effects on visual perception and creativity. Figure 16 shows heatmaps of the combined-condition distributions of pareidolia events. These heatmaps indicate 'pareidolia hotspots' where many subjects perceived pareidolia in both conditions in violet. Areas more red or more blue highlight regions where subjects found more pareidolia in the active or placebo condition, respectively.

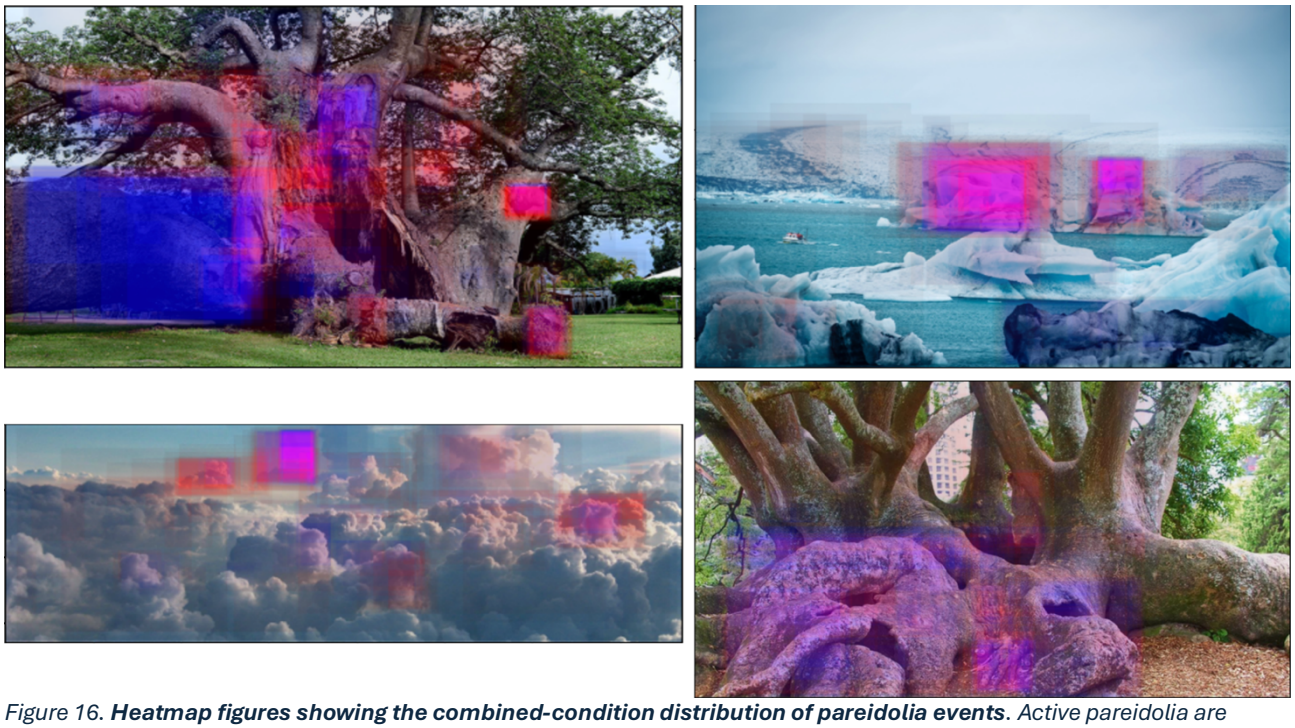


Figure 16. ***Heatmap figures showing the combined-condition distribution of pareidolia events****. Active pareidolia are plotted in red, Placebo-pareidolia are plotted in blue. Violet areas represent 'pareidolia hotspots' where subjects in both conditions found pareidolia. Areas that are redder represent areas where more pareidolia are perceived in the active condition compared to the placebo condition and vice versa.*

6.1. *Descriptive statistics*

In this study, we utilized two main datasets for analysis.

Individual pareidolia event dataset: This dataset contains data on the fractal dimension (FD), FD standard deviation, contrast, and size of all individual pareidolia events. We initially recruited 23 subjects; however, one subject (S04) was unable to perform the pareidolia task during the active condition due to the drug's effects and is therefore excluded from all datasets. Additionally, data for the 4th pareidolia in the active condition (P4-Active) of subject S17 was lost. Despite this, we included the remaining data from S17 to increase statistical power, given the low number of participants. Finally, the paper with verbal descriptions of pareidolia content for subject S09 was also lost, making description assessment impossible for this subject. However, this did not affect the drawn pareidolia data in this dataset.

Thus, a total of 22 subjects perceived 844 pareidolia events, equally distributed between conditions (N = 422 for both psilocybin and placebo). Detailed descriptive statistics for this dataset can be found in Table 2.

	Active dose condition			Placebo condition		
Feature	mean	std	min-max	mean	std	min-max
Size	96,325	203,566	600 - 1,631,150	91,997	181,725	416 - 1,509,112
Fractal Dimension	1.74	0.16	0.62 - 1.91	1.72	0.17	0.77 - 1.9
FD std. dev.	0.1	0.02	0.05 - 0.2	0.1	0.02	0.02 - 0.23
Contast	43.9	17.22	9.02 - 89.79	43.5	16.45	9.12 - 93.93

Table 2. ***Descriptive statistics table of the individual pareidolia event dataset*** *presenting the mean, standard deviation, and min-max values of size, FD (std dev), and contrast for individual drawings per condition. For both the active and placebo condition N = 422. Size is measured in pixels.*

Aggregated dataset: The second dataset aggregates data collected from all analyses. This dataset contains a single value per subject, per pareidolia, per condition, resulting in a total of 160 rows (20 subjects * 4 images * 2 conditions). It includes both the AUT data and the averaged data from the individual pareidolia event dataset. By averaging the values of all drawings per subject, per pareidolia, per condition, we ensured a consistent structure across all data points. Subjects S17 and S09 are excluded from the aggregated dataset to ensure only complete subject-data is included.

Descriptive statistics for the aggregated dataset are presented in Table 3. These tables provide a comprehensive overview of the collected data. The following sections present the results of the different statistical analyses, concluding with the random forest classifier results.

	Active dose condition			Placebo condition		
Feature	mean	std	min-max	mean	std	min-max
AUT originality	0.92	0.55	0.0 - 2.0	0.83	0.55	0.0 - 2.0
AUT fluency	4.42	3.55	1.0 - 16.0	4.6	2.65	1.0 - 15.0
AUT flexibility	2.6	1.51	1.0 - 8.0	2.62	1.33	1.0 - 7.0
AUT elaboration	4.14	4.16	0.0 - 20.0	3.05	2.54	0.0 - 14.0
AUT total	12.08	8.81	3.0 - 43.38	11.11	5.8	3.0 - 28.27
Avg. size (px)	158,046	218,109	12,047 - 1,248,561	117,120	153,480	9,893 - 715,170
Avg distance (px)	599	136	283 - 1021	595	170	233 - 1196
Avg. fractal dim.	1.75	0.11	1.36 - 1.9	1.74	0.1	1.43 - 1.88
Std. fractal dim.	0.1	0.01	0.06 - 0.14	0.1	0.01	0.07 - 0.14
Avg. contrast	43.4	15.28	9.55 - 71.61	42.49	13.59	14.5 - 68.99

Table 3. ***Descriptive statistics table of the aggregated dataset*** *containing the mean, standard deviation, and min-max values of all creativity domains and results of the pareidolia event analyses per condition. For both conditions N = 20 subjects * 4 pareidolia = 80*

6.2. Pareidolia descriptions dimension

6.2.1. Linear Mixed Model analysis

The results from the AUT linear mixed models (LMMs) indicated a significant effect of the condition on elaboration scores, with higher scores observed in the active condition compared to the placebo condition (Coef. = -1.088, p = 0.005).

In contrast, LMMs analyzing other creativity domains, such as fluency and originality, did not show a significant effect of the condition (Originality: Coef. = -0.089, p = 0.277; Fluency: Coef. = 0.175, p = 0.563; Flexibility: Coef. = 0.025, p = 0.879). These results indicate that psilocybin had a notable impact on participants' elaboration in their descriptions of pareidolia while not significantly altering originality, fluency, or flexibility of pareidolia events.

Additionally, the LMMs revealed substantial variability in creative perception scores between individuals. For instance, the variability in fluency (Group Var = 10.419) and elaboration (Group Var = 5.320) domains indicates that significant variation in creative perception exist among subjects that are not solely attributable to the condition. This individual variation suggests that there are inherent differences in how subjects perceive and describe pareidolia.

6.2.2. *Non-Parametric analysis*

In most cases, the non-parametric Wilcoxon signed-rank test was used to test the pareidolia-specific means of creativity domains (only originality P1-3 were distributed normally and thus tested using a paired sample t-test). There were no significant differences between active and placebo conditions across all domains and pareidolia. However, in Pareidolia 4, the comparison of originality approached significance (p = 0.053), potentially indicating a tendency towards the active condition having a higher originality score (Fig. 17). Additionally, while not significantly different, elaboration scores were higher consistently across pareidolia (Fig. 18).

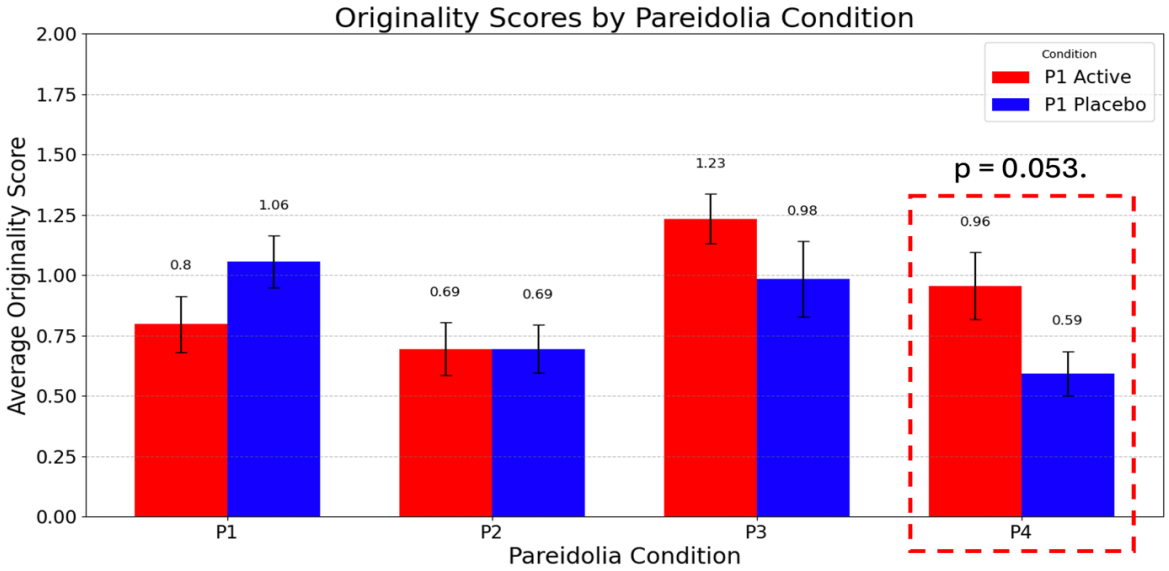


Figure 17. ***Bar graphs of average originality scores, between conditions, across pareidolia.*** *The Wilcoxon signed-rank test (p = 0.053) shows a near-significant difference between conditions in P4.*

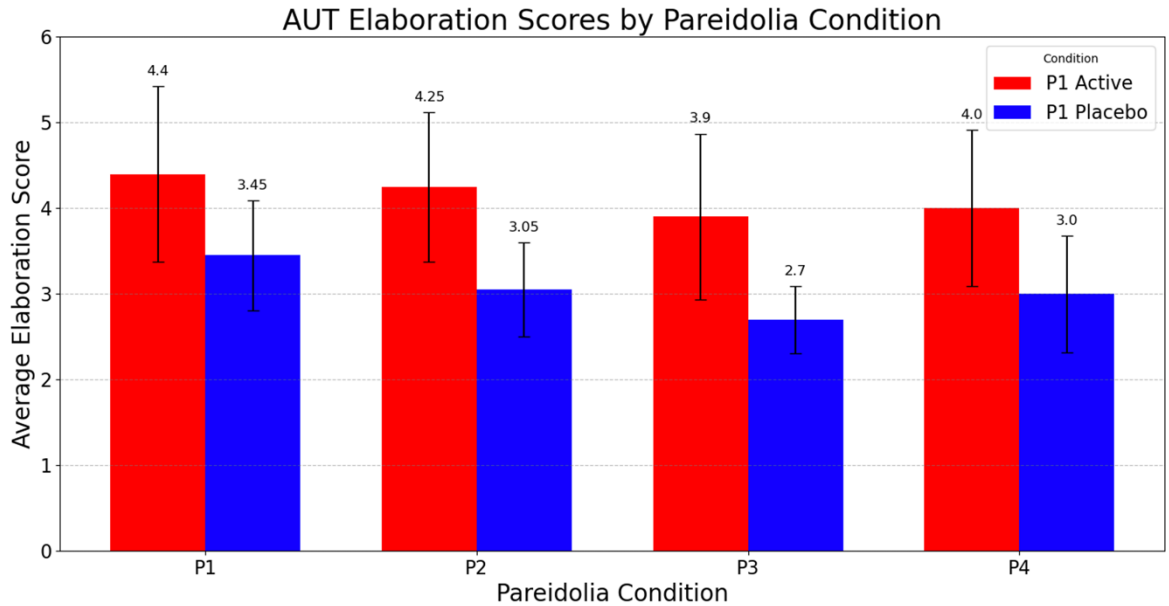


Figure 18. ***Bar graphs of average elaboration scores, between conditions, across pareidolia.*** *The Wilcoxon signed-rank test does not show any (near-)significant results, but the trend is consistent.*

6.3. *Pareidolia drawing dimension*

6.3.1. *Pareidolia linear mixed model analyses*

Linear mixed models analyzing fractal dimension (FD), FD standard deviation (FD std dev), size, and contrast did not show a significant effect between the active and placebo conditions (Fractal Dimension: Coef. = -0.020, p = 0.083; FD std dev: Coef. = 0.000, p = 0.799; Size: Coef. = 122,506.18, p = 0.132; Contrast: Coef. = -0.802, p = 0.448). This lack of significant difference suggests the condition did not have a notable impact on these measures across pareidolia.

Like the creativity domain LMMs, there was substantial variability between individuals in some variables (e.g. Contrast: Group Var = 19.270), indicating significant individual differences in visual perception.

6.3.2. *Average size of pareidolia drawings*

In Figure 19, we present bar graphs comparing the average size of pareidolia events per pareidolia image. Each bar displays the average pareidolia size for a specific condition (active or placebo) and pareidolia image (P1, P2, P3, P4). A significant difference was observed in Pareidolia 3. The average size of pareidolia events was significantly larger in the active condition compared to the placebo (p = 0.048), with a mean difference (M_diff) of 37,681.45 pixels and a standard deviation (SD) of 94,467.57 pixels. The non-parametric Wilcoxon signed-rank tests did not reach significance for Pareidolia 1, 2, and 4. However, there is a consistent trend of larger pareidolia perceived in the active condition compared to the placebo condition.

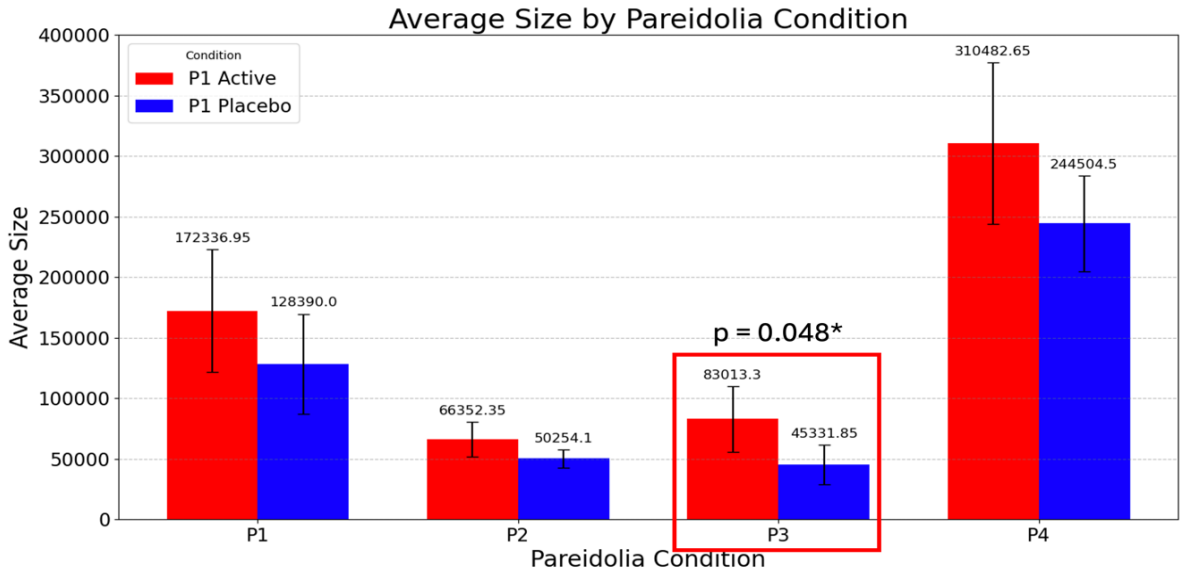


Figure 19. ***Bar graphs of the average size of pareidolia events perceived, between conditions, across pareidolia****. The Wilcoxon signed-rank test revealed a significant difference in average pareidolia size for P3 between the active and placebo conditions (p = 0.048). Additionally, mean size of pareidolia perceived in the active condition are consistently larger compared to the placebo condition.*

6.3.3. *Average distance between pareidolia drawings*

See Figure 20 for an overview of the average distance between pareidolia events. After the removal of NaN-values present in the 'average distance between pareidolia events' variable (as the distance between 0 or 1 drawing cannot be calculated), no significant differences were found for Pareidolia 1, 3, and 4. A paired sample t-test for Pareidolia 2 showed a near-significant difference (p = 0.059) with a mean difference of 61.89 pixels (SD = 129.74), hinting towards a larger average distance between pareidolia events in the active condition compared to placebo in P2.

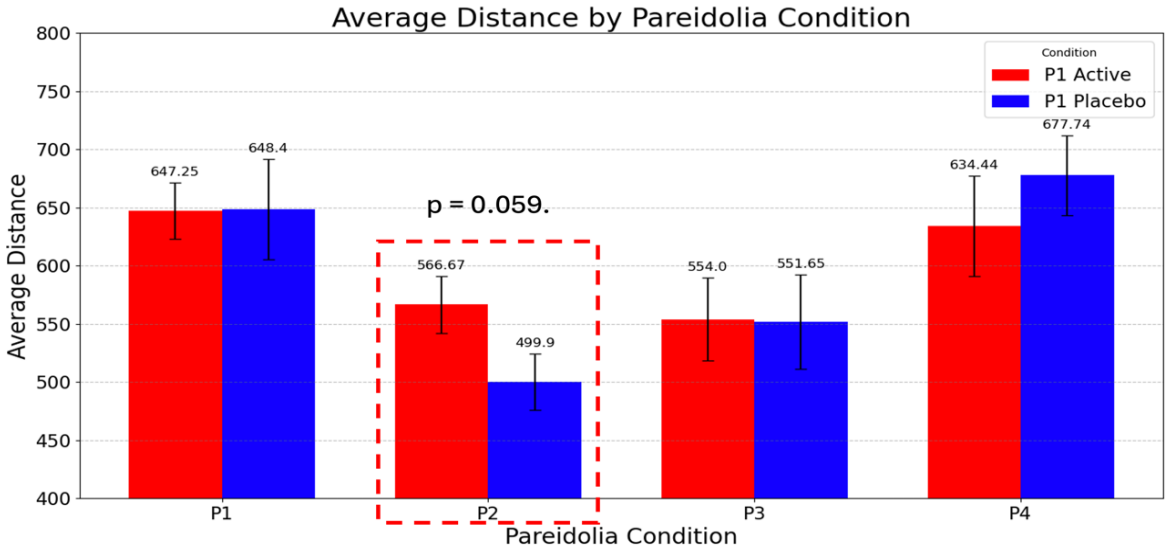


Figure 20. ***Bar graphs of the average distance between pareidolia events, between conditions, across pareidolia.*** *The paired sample t-test performed on P2 and P4 shows a near-significant difference in the average distance between pareidolia events of P2 Active and P2 Placebo (p = 0.059). The Wilcoxon signed-rank test was performed on P1 and P3, yielding insignificant results.*

6.4. *Pareidolia Region of Interest analysis*

6.4.1. *Average fractal dimension of ROIs*

See Figure 21 for an overview of the average fractal dimension per pareidolia between conditions. A paired sample t-test for average FD in P1 found a significant difference in Pareidolia 1 (p = 0.017), with a higher average FD in the active condition (M_diff = 0.038, SD = 0.065). No significant differences were found for Pareidolia 2, 3, and 4. An overview of the average fractal dimension standard deviation (FD SD) per pareidolia between conditions is shown in Figure 22. No significant differences were found for average FD SD in Pareidolia 1, 2, and 4. However, the Wilcoxon signed-rank test performed on Pareidolia 3 shows a near-significant difference in FD SD between conditions (p = 0.051), with a mean difference of -0.008 (SD = 0.014).

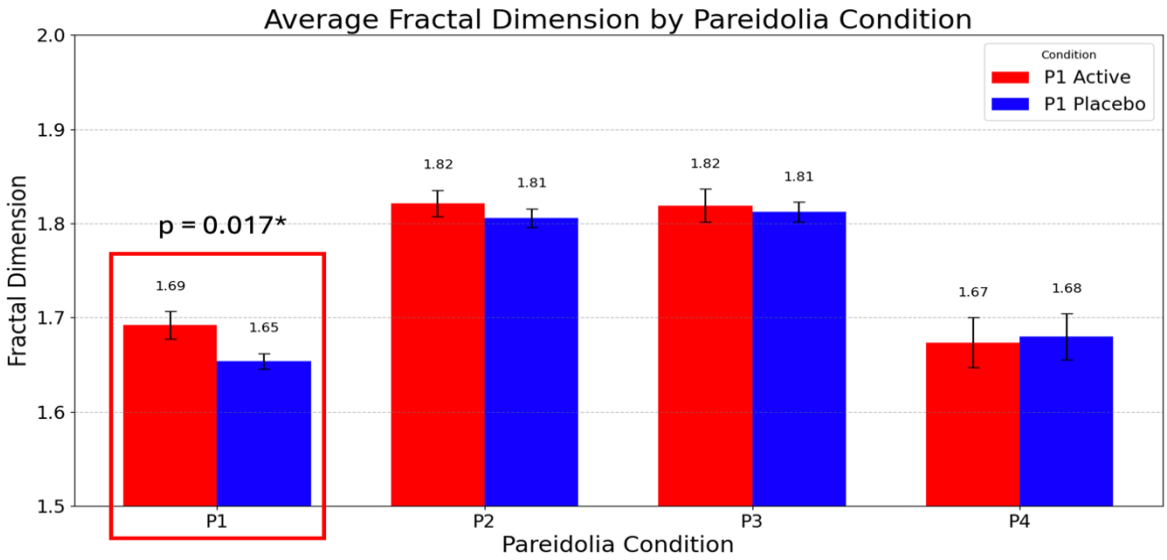


Figure 21. ***Bar graphs of the average fractal dimension, between conditions, across pareidolia.*** *The paired sample t-test on P1 returns a significant difference between the P1 Active and P1 Placebo conditions (p = 0.017). Wilcoxon signed-rank tests on P3 and P4 yield insignificant results.*

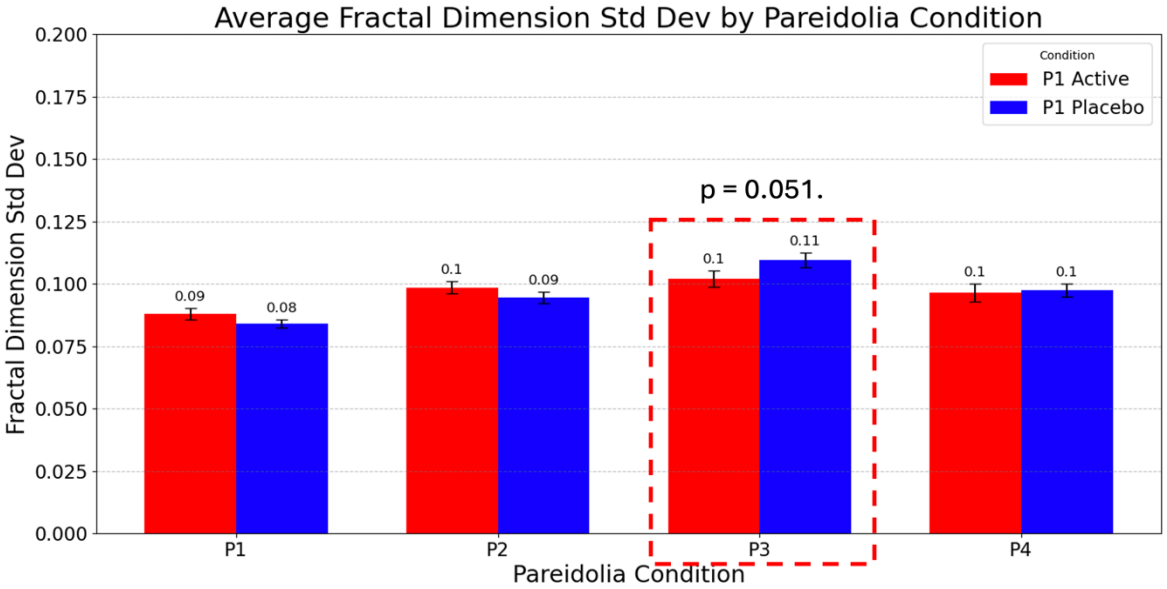


Figure 22. ***Bar graphs of the average standard deviation of fractal dimension, between conditions, across pareidolia.*** *The Wilcoxon signed-rank test performed on all pareidolia returns a near-significant difference between the P3 Active and P3 Placebo conditions (p = 0.051). The other tests showed no significant differences of FD SD between conditions.*

6.4.2. *Average contrast levels of ROI's*

See Figure 23 for an overview of the average contrast of the ROIs for both conditions per pareidolia. A paired sample t-test for Pareidolia 1 revealed a significant difference between conditions (p = 0.008), with higher average contrast in the active condition (M_diff = 3.762, SD = 5.654). No significant differences were found for Pareidolia 2, 3, and 4.

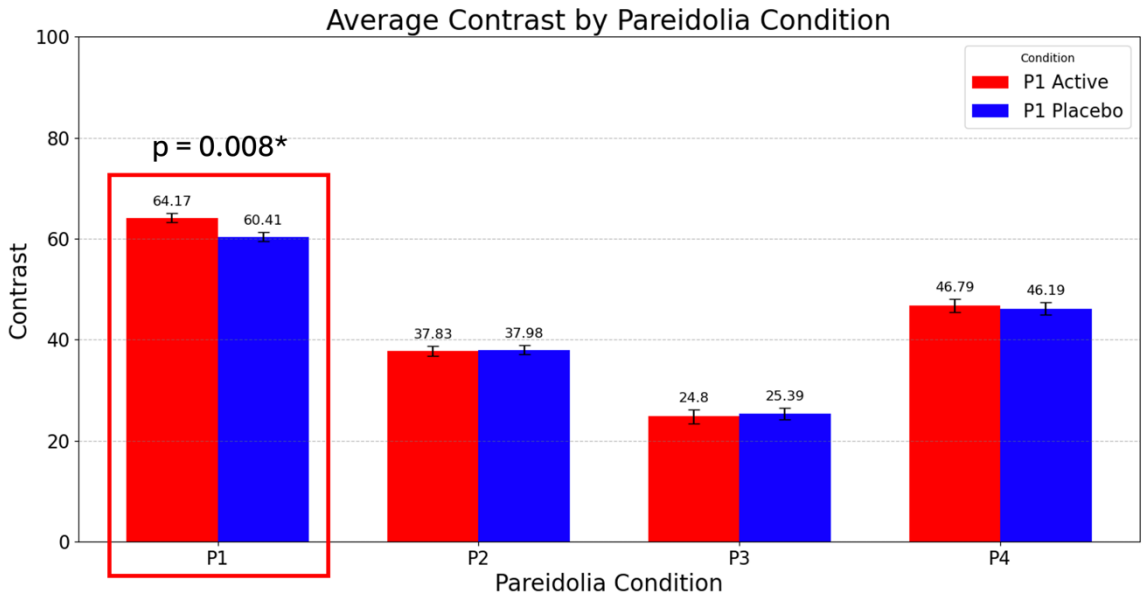


Figure 23. ***Bar graphs of the average contrast level between conditions, across pareidolia.*** *The paired sample t-test returns a significant difference between the P1 Active and P1 Placebo conditions (p = 0.008).*

In summary, the LMM analysis of elaboration showed a significantly higher score in the active condition compared to the placebo condition, this trend was consistent across pareidolia. Similarly, the average size of pareidolia was shown to be consistently larger in the active condition, reaching significance in Pareidolia 3.

Average fractal dimension (FD) and average contrast were significantly higher in the active condition compared to placebo in Pareidolia 1, indicating that these measures were influenced by the condition. Near-significant differences were identified for the average distance between drawings in Pareidolia 2, and for AUT originality and average standard deviation (SD) of FD in Pareidolia 3. Other tests did not reveal significant differences, suggesting that the condition did not affect these measures. For a visual overview of these findings, see Figure 24, which presents radar plots for each pareidolia showing the variable means and 95% confidence interval per condition.

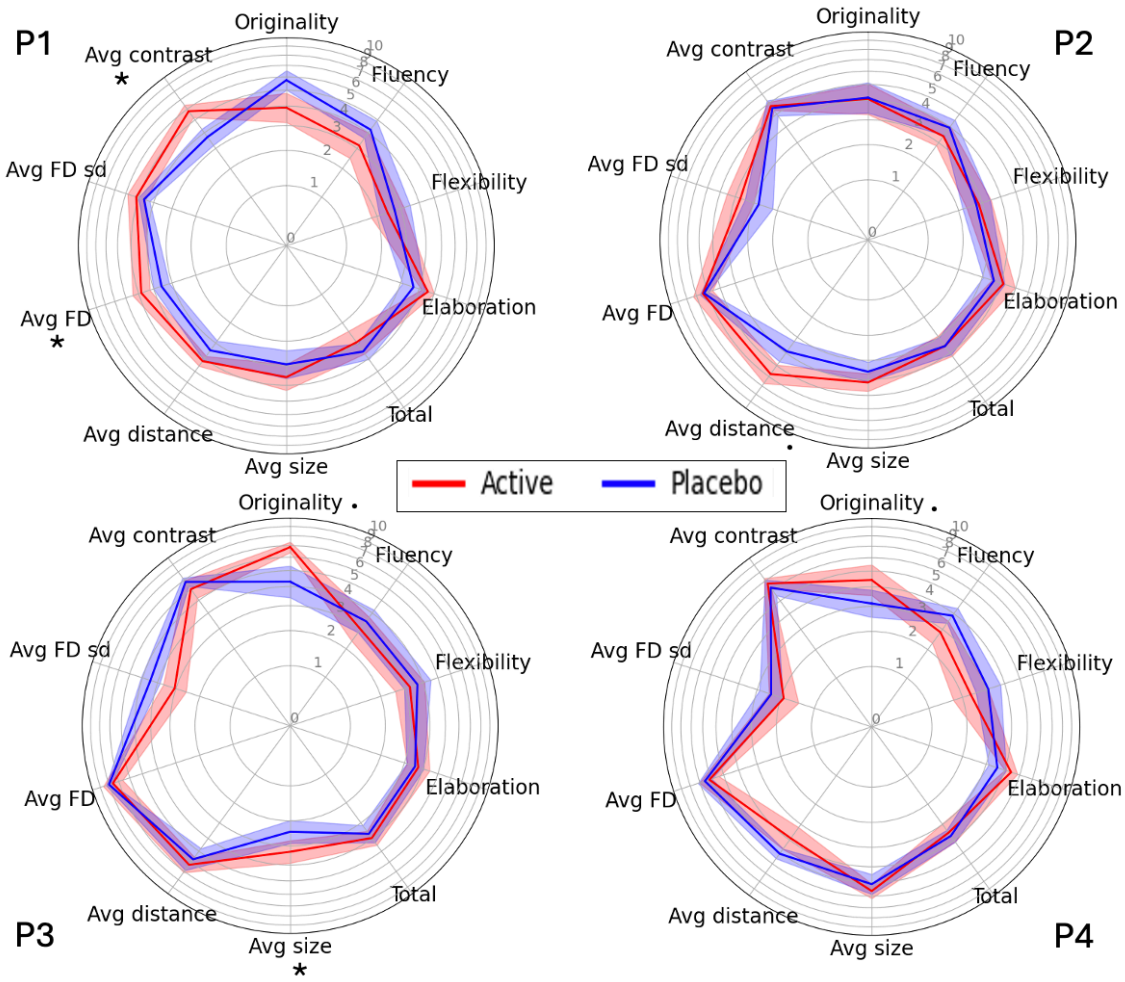


Figure 24. ***Radar plot overview of variable means (solid line) and standard deviations (shade) per pareidolia image.*** *Stars (*) indicate a significant difference between conditions, while dots (•) indicate a near-significant difference.*

6.5. *Machine learning implementation for all-feature classification*

Random forest classifiers were trained for each pareidolia image to determine whether the condition associated with a pareidolia event could be accurately classified based on the characteristics present in the collected data. This algorithm enables the combination of features of distinct nature while retaining information on feature importance. We used nine features in our analysis: five creativity domain scores (fluency, elaboration, originality, flexibility, and total), drawing size, average distance, fractal dimension, and contrast levels.

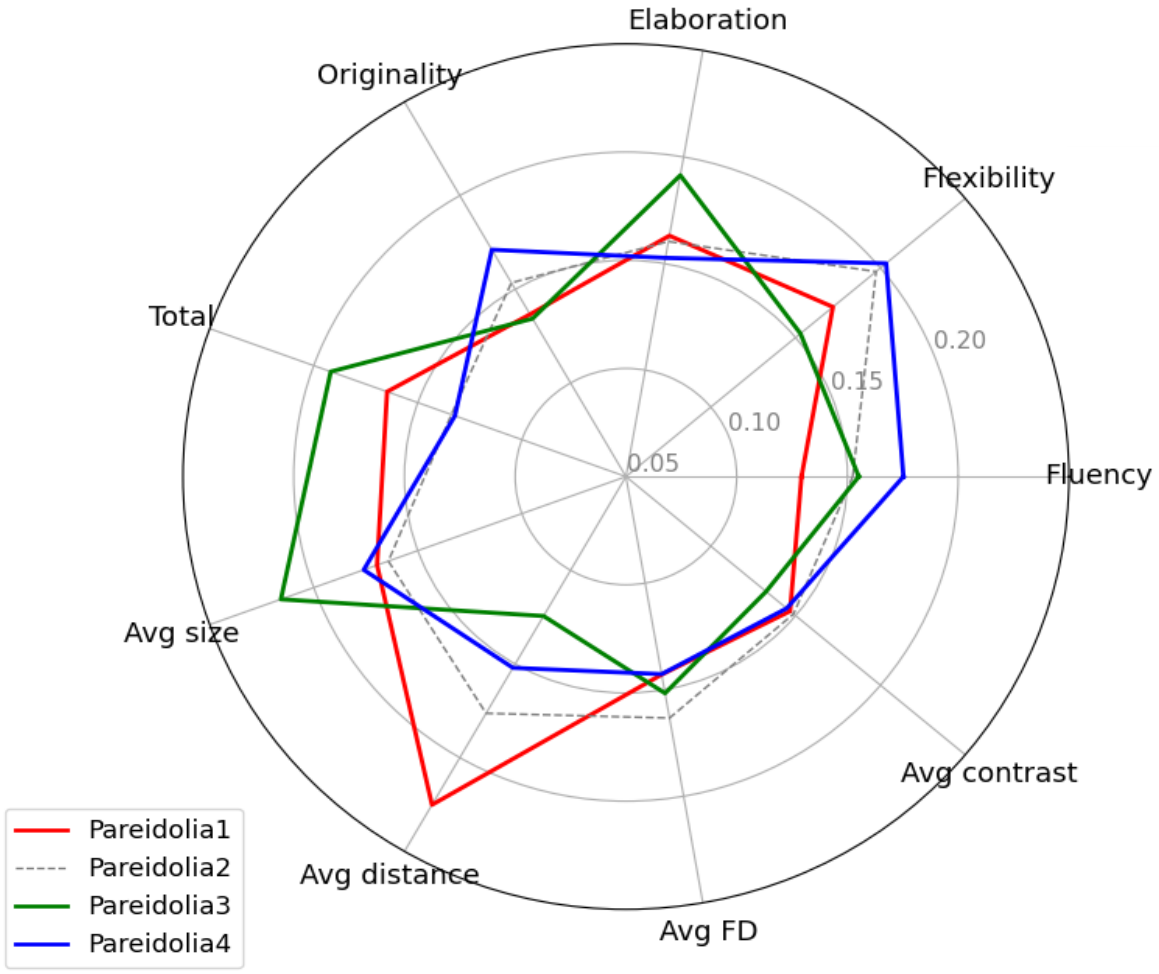


Figure 25. ***Radar plot with relative importance of each variable to Random Forest classifier per Pareidolia****. Pareidolia 2 is shown in grey as succesful classification was not achieved. Note that there is considerable variation in which features are determined as relatively important for succesful classification between pareidolia.*

The relative importance of features across subjects is illustrated in Figure 25 above. The classification model performance is evaluated using the area under the curve (AUC) metric. In Figure 26, the orange histograms and diagonals correspond to shuffled data, expected to average around a 0.5 classification success (chance), while the blue histograms represent the AUC distributions for the real data. Notably, in Pareidolia 1, 3, and 4, the AUC distributions for the real data were significantly higher than those for the shuffled data, indicating better model performance. This is further supported by the ROC curves in Figure 26b, where the curves for real data (blue) show improved learning compared to the 0.5 slope of the shuffled data, which indicates random guessing.

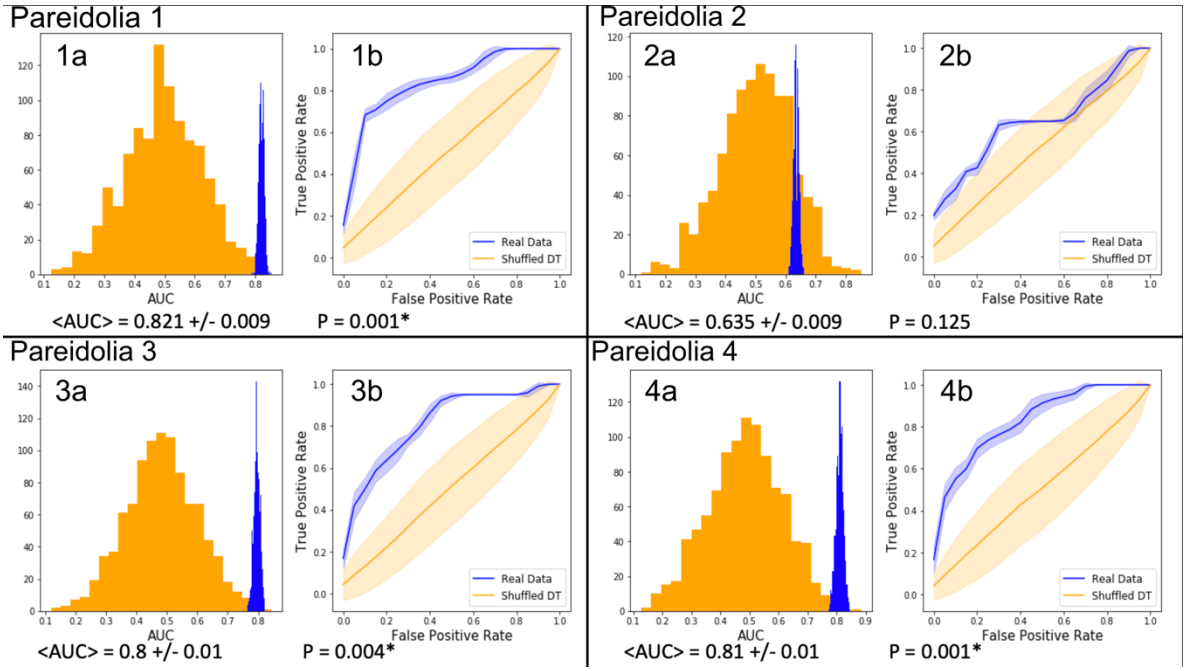


Figure 26. ***Overview of random forest classifier model performance.*** *The histograms ('a') show the distribution of AUC values obtained from the shuffled datasets (orange bars) and the AUC value from the real dataset (blue bar). The receiver operating characteristic (ROC) curves illustrate the classifier's performance (b), with the blue line representing the real data and the shaded area indicating the 95% confidence interval. The orange line represents the chance ROC curve for the shuffled decision trees, with the shaded area indicating the 95% confidence interval for the shuffled datasets. The clear separation between the blue and orange lines demonstrates the classifier's ability to distinguish between the two conditions effectively.*

The performance of the random forest classifier varied across the different pareidolia images, showing significant results in three out of four cases. For Pareidolia 1, the classifier achieved a mean AUC of 0.821 (SD = 0.009; p = 0.001). Pareidolia 2 yielded a mean AUC of 0.635 (SD = 0.009; p = 0.125), indicating no significant classification ability. For Pareidolia 3, the classifier achieved a mean AUC of 0.800 (SD = 0.010; p = 0.004). The highest performance was observed for Pareidolia 4, with a mean AUC of 0.810 (SD = 0.010; $p < 0.001$). These results suggest that the combination of AUT metrics, drawing size, average distance, fractal dimension, and contrast levels can effectively capture the influence of psilocybin on visual perception and creativity.

7. Discussion

This study aimed to investigate the effects of psilocybin on visual perception and creative cognition through the pareidolia phenomenon, and to develop metrics that could distinguish between pareidolia events occurring under the influence of psilocybin versus a placebo. Our key findings provide valuable insights into how psilocybin influences visual perception and creative cognition.

7.1. Pareidolia event elaboration

When analyzing the descriptions dataset, the AUT scoring system was indeed effective and allowed us to translate the raw data into objective scores, as implemented in previous works (Diana et al., 2021). In this domain, we found significant results in the elaboration metric, which refers to the ability to follow an associative pathway for a while and add details to an idea (Runco & Acar, 2012). We observed a significant increase in the elaboration score of descriptions in the active condition compared to the non-active condition, indicating that subjects provided more details when describing the pareidolia events they experienced under the influence of psilocybin. This result suggests that psilocybin selectively enhances the elaboration aspect of divergent visual perception, facilitating the generation of more detailed and intricate interpretations of ambiguous visual stimuli. Although the non-parametric tests comparing mean elaboration scores between conditions for each pareidolia did not show significant differences, there is a consistent trend of increased elaboration scores in the active condition compared to the placebo condition across pareidolia (Fig. 18).

The absence of significant differences in the other creativity domains (originality, fluency, and flexibility), along with the definition of creativity as “the production of novel, uncommon, and useful ideas” (Runco & Jaeger, 2012; Stein, 1953), does not necessarily support a clear-cut increase in creativity under the influence of psilocybin. Instead, it suggests that the effect of psilocybin on creative visual perception is specifically influencing the elaboration of perception. This selective enhancement of elaboration is consistent with previous research indicating that psilocybin can increase the richness and vividness of sensory experiences (Preller & Vollenweider, 2016). However, these findings diverge from studies reporting increased generation of spontaneous creative insights (Mason et al., 2021) and heightened associative thinking (Girn et al., 2020). Based on such studies, one might anticipate that psilocybin-induced changes in creativity would manifest, besides increases in elaboration, as increased originality, fluency, and/or flexibility in pareidolia tasks. The absence of significant effects in these domains suggests that while psilocybin may enrich the content and detail of creative perception, it does not necessarily enhance the diversity or uniqueness of creative perception. This

highlights the nuanced and specific ways in which psilocybin influences different aspects of creative cognition.

These results can also be related to the findings by Sanz et al. (2020) on language use under the influence of psychedelics. Sanz's study found increased entropy and verbosity and reduced semantic coherence in language produced under LSD. Our findings on the increased elaboration of pareidolia event descriptions in the active condition might hint towards a more fragmented and less structured use of language under the influence of psilocybin, requiring more words to express a similar pareidolia experience. Elaboration is scored based on the number of details added to the description of the pareidolia event, therefore, the use of more words to describe a detail should not influence this score, but results need to be interpreted with caution. Thus, our results may reflect either an overall enhancement in the richness of pareidolia perception or the effects of psilocybin on language, leading to more elaborate descriptions.

Because the elaboration score applies to the verbal descriptions of pareidolia it may not translate directly to paper (drawn pareidolia). However, we also found an increase in pareidolia size. This difference only reached significance in P3, but the increased average size in the active condition was consistent across pareidolia, indicating that the elaboration also manifested itself in more elaborate drawings. This connection between verbal and drawn elaboration will be discussed in further detail in the visuospatial section, but it is worth noting here as it suggests a broader impact of psilocybin on elaborative processes.

7.2. Other creativity domains

In the other creativity domains, the linear mixed models (LMMs) and (non-)parametric tests found no significant differences in the creativity domains of originality, fluency, and flexibility between the active and placebo conditions. Although the originality scores for Pareidolia 4 approached significance in the Wilcoxon signed-rank test ($p = 0.053$), the overall analysis of originality scores across all pareidolia conditions (P2 showing no differences and P1 and P3 showing minimal variations, Fig. 17) suggests that these fluctuations are likely within the normal range of variability rather than indicative of a systematic effect of psilocybin.

These findings suggest that psilocybin may selectively enhance depth of creativity, such as elaboration of ideas or perception, while not significantly impacting breadth of creativity, like originality, fluency, and flexibility, as previously discussed.

However, the methodology used to score creativity could also impact the observed results. In a similar study by Diana et al. (2021), researchers complemented frequency-based scoring of a divergent pareidolia task with a subjective, rater-based scoring

method, adapting the snapshot method by Silvia et al. (2009). This approach offers several advantages over frequency-based procedures, including controlling for inappropriate, random, or too vague ideas and considering important facets of creative thinking not captured by the AUT creativity domains, such as remoteness and cleverness (Silvia et al., 2008; Silvia et al., 2009).

Our findings partially supported these hypotheses. The significant increase in elaboration scores under psilocybin suggests that subjects provided more detailed descriptions of the pareidolia events they experienced, aligning with our hypothesis about elaboration. However, the absence of significant differences in originality, fluency, and flexibility scores between conditions suggests that psilocybin's effects on creativity are more selective and nuanced than initially hypothesized. This highlights the importance of considering both aggregate and item-specific analyses to fully understand psilocybin's impact on creative cognition.

7.3. Visuospatial pareidolia analysis

Reports on psilocybin-induced visual phenomena captured in the VAS throughout the experiment show that participants in the active condition experienced significant distortions in visual perception during hour 4 when the pareidolia experiment was conducted. Notably, participants reported that "my sense of size and space is distorted" and "edges seem warped" (Fig. 3).

The analysis of spatial characteristics using linear mixed models showed no significant differences in the sizes or average distances between pareidolia events. However, non-parametric analysis revealed a significant difference in the average size of pareidolia events in P3, with larger pareidolia observed in the active psilocybin condition (Fig. 19). The other pareidolia also exhibited a trend towards larger sizes in the active condition, although the results were not statistically significant. This result, along with the previous description elaboration enhancement, could be interpreted as an enhancement in drawing elaboration, where participants include more details, hence covering a larger area with their drawings.

Additionally, a near-significant difference in the average distance between drawings was found in Pareidolia 2 (P2), indicating a tendency for larger distances between pareidolia in the active condition. However, this difference was not present in the other pareidolia images.

These findings do not support our hypothesis that psilocybin would lead to smaller and more closely spaced pareidolia, which is inconsistent with the findings of Muller et al. (2023), who reported a more detail-oriented, local gaze induced by psilocybin.

It is essential to consider that the size and distance between pareidolia are strongly influenced by the fixed 'pareidolia hotspots' within each image. These hotspots guide participants to perceive pareidolia in specific locations (as seen on the heatmaps in Figure 16). This inherent structure may bias the spatial characteristics measured, potentially masking any effects of psilocybin on visuospatial perception. The consistent locations and sizes of these hotspots could obscure the underlying influence of psilocybin on spatial characteristics.

7.4. Stimulus-dependent effects of pareidolia perception

The linear mixed model analysis comparing the fractal dimension of ROIs between conditions did not present significant differences between conditions, however, there was a tendency towards a higher fractal dimension of pareidolia events in the active condition ($p = 0.083$), suggesting a potential influence of psilocybin on the range of fractal dimensions in which pareidolia are perceived. Additionally, a significant difference in average fractal dimension between conditions was found in P1, while comparisons in other pareidolia images returned insignificant effects, as shown in Fig. 20.

The linear mixed model analysis comparing the contrast of ROIs between conditions showed no significant result. However, the non-parametric test comparing average contrast levels of ROIs in Pareidolia 1 revealed a significant difference between the active and placebo conditions, with the active condition showing higher average contrast levels (Fig. 22). This suggests that psilocybin may enhance the perception of visual contrast, although this effect is not consistent across all pareidolia images.

The higher average fractal dimension and contrast in ROIs of Pareidolia 1 could indicate that an increased contrast sensitivity might enable the perception of pareidolia in areas with greater fractal complexity. This finding aligns with reports of psilocybin-induced visual phenomena, such as altered visual processing, increased sensitivity to visual patterns and contrast, and enhanced associative thinking (Preller & Vollenweider, 2016; Díaz, 2010; Girn et al., 2020). Additionally, Pepin et al. (2022a) indicated that creatives perceive pareidolia across a broader spectrum of fractal dimensions and contrast. This suggests that psilocybin might similarly broaden the range of fractal dimensions in which individuals perceive pareidolia.

Higher average contrast levels in the active condition would support the hypothesis that psilocybin increases sensitivity to visual patterns and color contrasts. Participants under the influence of psilocybin perceived pareidolia in a slightly wider range of contrasts, hinting towards enhanced sensitivity to visual stimuli. Although significant only in Pareidolia 1, this finding aligns with previous research showing that psilocybin can alter visual processing, making subtle visual details more pronounced (Pepin et al., 2022a; Fischer et al., 1969). Additionally, Fisher et al. (1969) found that some

individuals had reduced sensitivity to brightness under psilocybin, while others experienced increased sensitivity, highlighting the variability in visual perception among individuals. This individual variation in contrast perception is indicative of broader differences observed across various measures in our study.

7.5. Individual Differences in Pareidolia Perception

Throughout our investigation, significant individual differences were observed in the perception of pareidolia. This variability was evident across many variables, including the size and distance of perceived pareidolia, fluency, elaboration, and contrast levels. The random effects in our linear mixed models (e.g., Contrast: Group Var = 19.270, Average distance: Group Var = 1129.868), highlight that significant differences in creative perception exist among subjects, which are not solely attributable to the condition. This individual variation suggests inherent differences in how subjects perceive and describe pareidolia, emphasizing the importance of considering baseline creative perception differences in studies assessing the effects of psilocybin.

To comprehensively discuss the obtained results, it is important to examine the possibility that psilocybin's effects on creative perception are highly dependent on the stimuli characteristics of the images used in the pareidolia task. Our pareidolia images had relatively high whole-image fractal dimensions (FDs), ranging from 1.78 (P3) to 1.86 (P2). However, within these images, the FD range of pareidolia events in ROIs spanned from 0.62 to 1.91. Additionally, whole-image contrast levels varied between 42.75 (P3) and 66.77 (P1), with regions where pareidolia were perceived spanning a contrast range from 9.02 to 93.93.

Bies et al. (2016) and Pepin et al. (2022a) report that high contrast facilitates flexibility and fluency of pareidolia perception, which aligns with our data. For example, P1, which has higher contrast, showed a higher number of pareidolia in both conditions (N-active = 123, N-placebo = 114) compared to P3, which had the lowest whole-image contrast (N-active = 105, N-placebo = 98). The inherent characteristics of the pareidolia images likely influenced the observed differences in pareidolia perception, with this effect being more pronounced in high-contrast images.

7.6. Random Forest binary classification

The random forest binary classifiers successfully distinguished pareidolia events between the active and placebo condition, achieving an accuracy of around 0.8, as measured by the area under the receiver operating characteristic curve (AUC), for three of the four pareidolia images (Fig. 26). Features such as ‘Flexibility’, ‘AUT Total score’, ‘Average size’, and ‘Average distance’ consistently showed higher importance across

multiple pareidolia images (Fig. 25). This suggests that these features significantly influence the perception of pareidolia under psilocybin.

Interestingly, the features, identified as important by the classifier, are not necessarily those that showed significant differences in our previous analyses. Additionally, the importance of specific features varied between the different pareidolia images, reinforcing the notion that the visual and cognitive effects of psilocybin are influenced by the characteristics of the stimuli. These findings are consistent with our previous results, which indicated that both the inherent properties of the pareidolia images and the individual variability among subjects play critical roles in shaping the effects of psilocybin.

The discrepancy between the significant results in LMMs and (non-)parametric analyses, and the features important in the random forest model, can be attributed to the different objectives and capabilities of these methods. Traditional analyses identify significant differences, while random forests capture complex interactions and non-linear relationships, providing a more nuanced understanding of factor contributions to classification (Strobl et al., 2009; Boulesteix et al., 2012).

The classifier's lower performance for Pareidolia 2 might be linked to the relatively high importance of ‘Flexibility’ (0.147430) and ‘Average distance’ (0.126312), which may not be reflective of clear changes under psilocybin for this specific image. These features, while important in the overall dataset, might not sufficiently capture the unique characteristics of Pareidolia 2 under the influence of psilocybin. The high importance of the Flexibility and Total features is particularly surprising, as their distributions between conditions are practically the same. This lack of variability could make classification more difficult, reducing the classifier's performance for Pareidolia 2.

Overall, the high classification accuracy in distinguishing between the active and non-active conditions indicates that psilocybin induces changes in pareidolia perception that are robust and detectable using machine learning techniques. This provides an objective and quantitative method for assessing psilocybin's effects on creative visual perception, complementing findings from linear mixed models and pareidolia-specific (non-)parametric analyses.

7.7. Implications

This study contributes to the growing body of research on the cognitive and perceptual effects of psilocybin, offering valuable insights into its selective enhancement of creative visual perception. The findings could have important implications for both therapeutic and scientific applications.

Firstly, the selective enhancement of elaboration under psilocybin underscores its potential as a therapeutic tool, particularly for treating conditions characterized by perceptual and cognitive rigidity, such as depression and PTSD (Carhart-Harris & Friston, 2019; Alpert et al., 2023). By increasing the depth and linguistic richness of creative perception, psilocybin-assisted therapy could help individuals articulate and process their thoughts and emotions more vividly, potentially leading to profound insights and therapeutic breakthroughs (Carhart-Harris & Nutt, 2017; Kuypers, 2018).

Secondly, the observed differences in contrast and fractal dimension (P1) between the active and non-active conditions indicate that psilocybin may interact with visual stimuli in a nuanced and complex manner. This finding underscores the importance of further neuroimaging research to unravel the specific mechanisms by which psilocybin affects visual perception and to explore how individual differences play a role (Muller et al., 2018; Pepin et al., 2022b). A more detailed understanding of psilocybin's influence on visual perception and creative cognition could have significant implications for its therapeutic use. By identifying how different visual characteristics, such as contrast and fractal complexity, interact with psilocybin, we could develop more targeted and personalized therapeutic approaches. This would not only optimize the benefits of psilocybin in enhancing creativity but also improve its efficacy in treating various mental health conditions, leading to more effective and individualized treatment strategies.

Thirdly, the successful training of a random forest classifier to distinguish between active and non-active pareidolia conditions with an AUC of around 0.8 for three out of four pareidolia images provides robust evidence for the reliability and validity of the findings. This suggests that psilocybin-induced changes in creative visual perception are real and measurable phenomena. The ability of machine learning classifiers to differentiate conditions based on quantified pareidolia perception opens new avenues for the objective assessment and monitoring of psychedelic experiences. This could be highly valuable in clinical and research settings, providing a quantitative means to evaluate the effects of psychedelics on cognition and perception.

Lastly, the use of pareidolia as a study system for creative visual perception, coupled with the AUT creativity dimensions, has proven effective, as evidenced by the success of the machine learning model in classifying the conditions. However, frequency-based quantification of creativity domains alone does not provide a complete picture of visual and divergent perception changes. Future studies may benefit from incorporating subjective, rater-based scoring methods, such as the snapshot approach, to obtain more accurate and meaningful measures of originality (Silvia et al., 2008).

These findings underscore the nuanced and specific ways in which psilocybin affects creative cognition. This comprehensive understanding will be crucial for maximizing

the therapeutic potential of psilocybin and developing effective, personalized treatments.

7.8. Limitations

The current study has several limitations that should be considered when interpreting the findings. Firstly, the use of paper-based drawings introduced several drawbacks. Participants viewed the pareidolia images through a paper stencil, which likely reduced the clarity of the underlying images and hindered the ability to draw multiple pareidolia in the same location. Additionally, the need to photograph the drawing sheets introduced noise and reduced contrast in the images. The absence of real-time recording of verbal descriptions of pareidolia events further complicated data analysis, as there was no clear link between participants' descriptions and the specific pareidolia drawings produced. This caused a mismatch between the number of pareidolia descriptions and the number of pareidolia drawings. The timing of the experiment also poses a limitation. Conducting the study late into the psilocybin experience, when the effects were subsiding (Fig. 3), could have influenced the results. Earlier timing after dosage could yield more robust effects and reduce individual variability in the subsidence of psilocybin's effects. Finally, blinding should be maintained during data analysis, especially during the scoring of creativity of drawings, as knowing the condition in which a drawing is produced may introduce bias in scoring.

Another potential limitation influencing the results of our study is the unequal number of drawings per subject, which may have caused unbalanced weighting of subjects in the individual pareidolia event dataset. Some subjects produced more pareidolia events than others, potentially skewing the results. This variability, combined with the small number of subjects, warrants caution when interpreting the results of the LMM analyses performed on this dataset. The large variance between subjects further complicates these analyses, as individual differences could overshadow the effects of psilocybin. These factors highlight the need for more controlled data collection methods and baseline creativity questionnaires to ensure more reliable and generalizable findings.

Finally, the use of an active placebo, rather than a true placebo, may have influenced the results, as microdoses can be associated with increases in creative performance (Bonnieux et al., 2023). However, there is also evidence suggesting that psilocybin microdosing does not acutely increase creativity (Cavanna et al., 2022). Future studies could benefit from the inclusion of a third subject group to better understand the dose-dependent effects of psilocybin on creative visual perception.

7.9. Future directions

Building on the current findings, future research should address these limitations and explore additional avenues to deepen our understanding of psilocybin's effects on creative visual perception.

Firstly, improving data collection methods is crucial. Using tablets for drawings instead of paper offers several advantages: it eliminates the need for a stencil overlaying the image, enhancing image clarity; removes noise introduced during stencil photography; and provides clear, binary drawings ready for analysis. This method also allows for drawing multiple pareidolia in the same location by refreshing the screen after each pareidolia event, as demonstrated by Diana et al. (2021). Additionally, it enables simultaneous oral description recording, addressing the issue of linking descriptions to drawings. Conducting the experiment earlier after psilocybin administration could also yield more robust effects and reduce individual variability in the subsidence of effects, providing clearer insights into psilocybin's impact on pareidolia perception.

Furthermore, incorporating subjective, rater-based scoring methods, such as the snapshot approach (Silvia et al., 2009; Diana et al., 2021), could provide a more nuanced understanding of how psilocybin affects different facets of creativity. This method can complement frequency-based measures and offer a more holistic assessment of creativity by controlling for farfetched, random, or abstract ideas.

Analyzing the content and categories of pareidolia perceived under psilocybin is another promising direction. Examining the content of pareidolia (e.g., animals, objects, shapes) between active and non-active conditions could provide additional insights into shifts in mental processes and creative ideation induced by psilocybin (see Appendix). This analysis could link pareidolia perception to a proneness or receptiveness to specific types of pareidolia, enriching our understanding of cognitive processes under the influence of psilocybin.

Moreover, supplementing creative output with neural activity measurements, such as EEG and fMRI, could deepen our understanding of the neural correlates and cognitive processes underlying psilocybin's effects on pareidolia perception. The integration of these neuroimaging techniques could help answer questions regarding the selective effects of psilocybin observed across different variables and pareidolia images, as well as provide insights into the substantial individual variability.

Finally, the successful application of machine learning techniques in this study highlights the immense potential of these methods in analyzing complex interactions between psilocybin, individual factors, and visual stimuli characteristics. As such, these advanced techniques hold significant promise for providing valuable insights across a broad range of (psychedelic) neuroscience research, facilitating a deeper understanding of the intricate and multifaceted effects of substances like psilocybin on human cognition and perception.

8. Conclusions

This research provides new insights into the effects of psilocybin on visual and divergent perception by studying the perception of pareidolia. Psilocybin was found to selectively enhance the elaboration of pareidolia descriptions, suggesting increased visual perception richness, while not significantly impacting other creativity domains across different pareidolia images. The consistent tendency towards larger pareidolia in the active condition supports this finding. Additionally, the effects of psilocybin showed considerable variability across pareidolia images, indicating a complex interplay between psilocybin, inherent stimulus characteristics like fractal dimension and contrast, and individual variance in visual and divergent perception. The effects of psilocybin were particularly pronounced in high-contrast images, further enhancing pareidolia perception in areas with higher fractal dimensions. This interplay warrants further investigation.

Furthermore, the random forest machine learning classifier effectively distinguished between pareidolia perceived under active versus non-active conditions with high confidence, demonstrating a consistent and detectable influence of psilocybin on creative perception. This success in quantifying differences in pareidolia perception supports the use of the pareidolia-AUT scoring system and other measures as a viable method for studying creative perception. However, results should be interpreted with caution due to limitations in statistical power and data collection methods. Future research should address these limitations to build on these findings and further elucidate the complex relationship between psilocybin, creativity, and visual perception.

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10. Appendix

Descriptive Statistics of AUT Categories by Pareidolia (Active Condition)

Pareidolia	Animals	Faces	People	Body Parts	Characters	Fictional	Nature	Objects	Others	Totals
1	45	20	11	0	5	6	3	3	1	94
2	32	23	11	3	5	7	6	2	3	82
3	19	8	14	3	4	3	7	13	11	104
4	27	3	5	12	3	9	9	3	6	84
Total	**123**	**54**	**41**	**18**	**17**	**25**	**25**	**21**	**21**	**364**
%	**33.8**	**14.8**	**11.3**	**4.9**	**4.7**	**6.9**	**6.9**	**5.8**	**5.8**	**100.0**

Table 4a. Overview of pareidolia categories, per pareidolia, active condition

Descriptive Statistics of AUT Categories by Pareidolia (Placebo Condition)

Pareidolia	Animals	Faces	People	Body Parts	Characters	Fictional	Nature	Objects	Others	Totals
1	53	12	7	2	6	12	3	5	4	92
2	43	13	4	2	7	4	5	11	2	77
3	29	6	8	4	5	5	4	16	7	91
4	37	16	0	20	3	8	2	5	1	92
Total	**162**	**47**	**19**	**28**	**21**	**29**	**14**	**37**	**14**	**371**
%	**43.7**	**12.7**	**5.1**	**7.5**	**5.7**	**7.8**	**3.8**	**10.0**	**3.8**	**100.0**

Table 4b. Overview of pareidolia categories, per pareidolia, placebo condition