Original Paper

LSD and creativity: Increased novelty and symbolic thinking, decreased utility and convergent thinking

Journal of Psychopharmacology
1–12

DOI: 10.1177/02698811211069113
journals.sagepub.com/home/jop
SAGE

Isabel Wießner[1,2], Marcelo Falchi[1,2], Lucas Oliveira Maia[1,2], Dimitri Daldegan-Bueno[2,3], Fernanda Palhano-Fontes[4], Natasha L Mason[5], Johannes G Ramaekers[5], Madeleine E Gross[6], Jonathan W Schooler[6], Amanda Feilding[7], Sidarta Ribeiro[4], Draulio B Araujo[4] and Luís Fernando Tófoli[1,2]

Abstract

Background: Controversy surrounds psychedelics and their potential to boost creativity. To date, psychedelic studies lack a uniform conceptualization of creativity and methodologically rigorous designs.

Aims: This study aimed at addressing previous issues by examining the effects of lysergic acid diethylamide (LSD) on creativity using multimodal tasks and multidimensional approaches.

Methods: In a randomized, double-blind, placebo-controlled, crossover study, 24 healthy volunteers received 50 µg of LSD or inactive placebo. Near drug peak, a creativity task battery was applied, including pattern meaning task (PMT), alternate uses task (AUT), picture concept task (PCT), creative metaphors task (MET) and figural creativity task (FIG). Creativity was assessed by scoring creativity criteria (novelty, utility, surprise), calculating divergent thinking (fluency, originality, flexibility, elaboration) and convergent thinking, computing semantic distances (semantic spread, semantic steps) and searching for data-driven special features.

Results: LSD, compared to placebo, changed several creativity measurements pointing to three overall LSD-induced phenomena: (1) 'pattern break', reflected by increased novelty, surprise, originality and semantic distances; (2) decreased 'organization', reflected by decreased utility, convergent thinking and, marginally, elaboration; and (3) 'meaning', reflected by increased symbolic thinking and ambiguity in the data-driven results.

Conclusion: LSD changed creativity across modalities and measurement approaches. Three phenomena of pattern break, disorganization and meaning seemed to fundamentally influence creative cognition and behaviour pointing to a shift of cognitive resources 'away from normal' and 'towards the new'. LSD-induced symbolic thinking might provide a tool to support treatment efficiency in psychedelic-assisted therapy.

Keywords

Psychedelics, creativity, divergent and convergent thinking, semantic distance, symbolic thinking

Introduction

Creativity promotes the prosperity of societies, from education, arts, technology and economy to therapy (Cropley, 2020; Desrochers, 2001; Florida, 2002; Snyder, 1997). Given its importance for society, numerous studies have attempted to promote creativity in individuals (Carson, 2014; Gino et al., 2010; Scott et al., 2004). Recent years have brought renewed interest in

[1]Department of Medical Psychology and Psychiatry, School of Medical Sciences, University of Campinas, Campinas, SP, Brazil
[2]Interdisciplinary Cooperation for Ayahuasca Research and Outreach (ICARO), School of Medical Sciences, University of Campinas, Campinas, SP, Brazil
[3]Schools of Population Health and Pharmacy, Faculty of Medical and Health Sciences, The University of Auckland, Auckland, New Zealand
[4]Brain Institute, Federal University of Rio Grande do Norte, Natal, RN, Brazil
[5]Department of Neuropsychology and Psychopharmacology, Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands
[6]Psychological and Brain Science Department, University of California, Santa Barbara, CA, USA
[7]The Beckley Foundation, Oxford, UK

Corresponding authors:
Isabel Wießner, Interdisciplinary Cooperation for Ayahuasca Research and Outreach (ICARO), School of Medical Sciences, University of Campinas, Rua Tessália Vieira de Camargo 126, Cidade Universitária Zeferino Vaz, CEP 13083-887 Campinas, São Paulo, Brazil.
Email: isabel.wiessner@gmail.com

Luís Fernando Tófoli, Interdisciplinary Cooperation for Ayahuasca Research and Outreach (ICARO), School of Medical Sciences, University of Campinas, Rua Tessália Vieira de Camargo 126, Cidade Universitária Zeferino Vaz, CEP 13083-887 Campinas, São Paulo, Brazil.
Email: tofoli@unicamp.br

examining the potential of serotonergic psychedelics to promote creativity, which has long been anecdotally claimed by artists, scientists and entrepreneurs including Aldous Huxley, Kary Mullis and Steve Jobs (Huxley, 1954; Markoff, 2005; Mullis, 2000). However, early attempts to capture these effects were fraught with methodological shortcomings, including small sample sizes and unclear operational definitions of creativity (Iszáj et al., 2017).

An application-oriented approach reported low mescaline doses to facilitate problem-solving of professional issues (e.g. engineering, mathematics, architecture), as compared to baseline (Harman et al., 1966). Psychedelics and other psychoactive substances such as alcohol and cannabis are discussed to facilitate the creative process especially among artists (Iszáj et al., 2012, 2018). The probably most comprehensive long-term study examined the effects of repeated lysergic acid diethylamide (LSD) administration on 60 artists over 7 years. Over 250 drawings were rated as showing increased expressionism, sharpening of colour, mental freedom, syntactical organization and accessibility of past impressions (Dobkin De Rios and Janiger, 2003). Behavioural approaches suggested that psychedelics alter several creative domains. These include anecdotal descriptions of drawings and paintings being more simple, crude, distorted and bizarre, but also aesthetic and free, playing with colours, forms and styles (Berlin et al., 1955; Leuner, 1962; Mátéfi, 1952; Tonini and Montanari, 1955). Text and speech analyses observed language under psychedelics being more simple, short and concrete but also more unpredictable, stereotyped and bizarre (Amarel and Cheek, 1965; Kraehenmann et al., 2017b; Landon and Fischer, 1970; Sanz et al., 2021). Semantic-oriented approaches reported psychedelic-induced increases in semantic priming, semantic errors, semantic distances and originality of word associations pointing to disintegrated semantic information processing (Family et al., 2016; Spitzer et al., 1996; Wießner et al., 2021a; Zegans et al., 1967). Cognitive-oriented approaches focused on divergent and convergent thinking (necessary for creative generation and evaluation, respectively), often used naturalistic settings and baseline comparisons and yielded inconclusive results. While some studies reported psychedelics to increase fluency and originality, others reported decreased fluency, originality and convergent thinking (Frecska et al., 2012; Harman et al., 1966; Kuypers et al., 2016; Mason et al., 2021). This could be attributed to relatively high doses impairing cognitive processing, in line with findings of increased fluency, originality and convergent thinking after psychedelic ceremonies and under microdoses (Mason et al., 2019; Prochazkova et al., 2018; Uthaug et al., 2018, 2019).

Overall, these studies suggest that psychedelics change creativity-related aspects but comprise methodological limitations regarding design (e.g. lacking placebo-control), sample (e.g. artists), setting (e.g. ceremonies) or dose (e.g. impairing). Moreover, they followed different approaches using diverse methodologies, which reduce their comparability. In light of this, our study aimed at systematically mapping the effects of a relatively low dose of LSD (50 µg) on creativity in a methodologically rigorous design over diverse modalities and approaches. These include a multimodal task battery on several creative domains (e.g. visual/drawn, verbal/written) (Silvia et al., 2009) and an evaluation of task responses by a theory-driven approach scoring the creativity criteria 'novelty', 'utility' and 'surprise' (Simonton, 2012), a data-driven approach searching for special features (Elo and Kyngäs, 2008) and established parameters which are more objective, easy to measure and predictors of real-world creative achievements, namely divergent thinking (fluency, originality, flexibility, elaboration), convergent thinking and semantic indices (semantic distances between words) (Cropley, 2006; Gray et al., 2019; Kim, 2008).

Methods

This work is part of a larger study which is published elsewhere, including further information on participants, drug and procedures (Wießner et al., 2021a, 2021b).

Study design

The study used a randomized, double-blind, placebo-controlled, crossover design with two treatment sessions (LSD, placebo) and washout period of 14 days between sessions. Participants were randomly assigned to treatment order.

Participants

Twenty-five healthy participants were recruited in a convenience sample. Inclusion criteria were ⩾22 years, ⩾one experience with LSD, ⩾2 weeks of abstinence from psychedelics and 3 days from alcohol and other drugs before each session, abstinence from tobacco and caffeine during the study days. Exclusion criteria were presence of psychiatric symptoms, personal or first-degree family member history of psychotic disorder, use of psychiatric medication, history of severe complications after psychedelic use, alcohol or drug use disorder, heart disease or other relevant medical conditions, pregnancy and non-native speaking of Brazilian Portuguese. Participants provided written informed consent before participation. One participant ceased participation after the first session for personal reasons, resulting in a final sample of 24 subjects (8 women; age (mean ± SD) = 35 ± 11 years (range = 25–61)).

Study drug

Participants orally received 50 µg of LSD (dissolved in alcohol solution) or inactive placebo (alcohol solution) diluted in 30 mL of water. The low dose was chosen to minimize the risk of adverse reactions while exerting noticeable effects without impairing the ability to perform the tasks.

Study procedures

This study was approved by the National Health Surveillance Agency and Research Ethics Committee of the University of Campinas (CAAE: 04179918.2.0000.5404) and conducted following the Declaration of Helsinki and safety guidelines for psychedelic research in humans (Johnson et al., 2008). The study consisted of a screening interview, a day of drug administration and additional follow-up measurements. The day of drug administration began at 7:30 a.m. with baseline measurements. LSD or placebo was administered at 9:30 a.m. At 11:00 a.m., a standardized snack was served. Creativity measurements started after

drug peak at 12:00 p.m. and lasted until 1:15 p.m. Lunch was served at 1:40 p.m. The session ended 8 h after drug administration at 5:30 p.m. when it was ensured that subjects were feeling well before being left into the custody of a family member or friend.

Creativity tasks

Five tasks of diverse stimulus-response modalities were applied (for details, see Supplemental Methods). To avoid learning effects, two parallel task versions (A, B) were applied in balanced order across participants and counterbalanced across treatments.

The *pattern meaning task* (PMT) involves writing as many creative interpretations as possible for abstract line patterns (8 patterns, 2 min each) (Claridge and McDonald, 2009).

The *alternate uses task* (AUT) involves writing as many uncommon uses as possible for everyday objects (2 objects, 3 min each) (Guilford, 1967).

The *picture concept task* (PCT) involves (1) selecting pictures from slides which belong to a common group (convergent thinking) and (2) generating as many alternative, creative picture combinations as possible (divergent thinking) (17 slides, 1 min each) (Kuypers et al., 2016).

The *creative metaphors task* (MET), created by our team, involves writing up to 10 creative or poetic metaphors (5 min in total).

The *figural creativity task* (FIG) involves producing drawings based on simple line patterns on a sheet of paper and writing creative titles for them (2 patterns, 10 min in total) (Artola et al., 2012).

Creativity variables

Over all tasks, diverse variable groups were assessed, based on theory-driven (creativity criteria), established (divergent thinking, convergent thinking), semantic (semantic structure) and data-driven (special features) approaches (Figure S1). Examples for all variables are listed in Supplemental Table S1. Two trained, independent raters scored the subjectively evaluated variables (Silvia et al., 2008). Interrater reliability, as estimated by intraclass correlation coefficients (ICC) and 95% confident intervals (mean-rating ($k=2$), consistency, 2-way random-effects model; Koo and Li, 2016), ranged from moderate to excellent with few exceptions (Supplemental Table S2). For each task and variable, average scores over all responses and stimuli were calculated for statistical analysis.

Creativity criteria. *Novelty, utility* and *surprise* of each response was rated on a 3-point scale (0 = not at all; 2 = very much) based on how novel/useful/surprising responses were within the general socio-cultural context.

Relative novelty, utility and *surprise* were assessed by calculating the ratios to the number of total responses.

Divergent thinking. *Fluency* was calculated by the number of total responses (PMT, AUT, PCT, MET).

Originality was assessed by grouping the sample's responses for each stimulus into categories. In PMT, AUT and PCT, responses in categories containing more than 5% of all responses for the stimulus received zero points, those containing between 1% and 5% received one point and those containing less than 1% received two points of originality (Prochazkova et al., 2018). In FIG, assessments comprised stimulus originality (response points weighted inversely by category size), title originality (0 = without or just descriptive title; 2 = metaphoric, surprising title) and special details (one point per detail) (Artola et al., 2012).

Flexibility was assessed by calculating (PMT, AUT, PCT) and rating (MET) the number of different response categories per subject.

Elaboration was assessed by the number of details within one response (PMT, AUT, PCT, MET) (Guilford, 1967) and by rating FIG picture elaboration (0 = without special details; 2 = much elaboration and abundant details) and colour elaboration (0 = without colours and shadows; 2 = many colours and shadows) (Artola et al., 2012).

Relative originality, flexibility and *elaboration* were assessed by calculating the ratios to fluency.

Convergent thinking. Convergent thinking comprised the number of correct combinations in the PCT (Kuypers et al., 2016).

Semantic structure. Semantic distances between responses were calculated based on a Portuguese Wikipedia corpus by Fast text method in Text Similarity Tool (version 0.6.1) (Mota et al., 2020). For details on preprocessing, see Supplemental Methods. From each semantic distance matrix, two distance indices were calculated:

Semantic spread, the average distance over all responses;
Semantic steps, the average distance between two neighbouring responses (Wießner et al., 2021a).

Special features. To identify common, data-driven features within the responses, we applied a qualitative content analysis-inspired approach (Elo and Kyngäs, 2008). We first developed a categorization matrix and then coded the data according to the generated main categories and subcategories (for details, see Supplemental Methods). Four main categories (**bold**) subdivided into subcategories (*italic*) were created:

Content was assessed by assigning each response to content subcategories in MET (*symbols, nature, objects, persons, body parts, animals, characteristics, sensation, cognition, emotion*) and FIG (*symbols, nature, objects, persons, body parts, animals*).

Techniques were assessed by assigning each response to technique subcategories in MET (*union, exaggeration, contrast, wordplay*) and by rating techniques in FIG (*background, spatiality, symmetry, frame break, colours, connections*).

Ambiguity was evaluated based on whether the response (MET, FIG) was interpretable in different ways (0 = not at all; 2 = very much). Relative ambiguity was assessed by calculating the ratio to fluency.

Symbolic thinking was assessed by the number of symbolic or abstract responses (PMT, AUT, PCT), by the content subcategory *symbols* (MET) and by scoring (FIG) *title symbolism, picture symbolism* (0 = very concrete; 2 = very symbolic) and *colour*

abstractness (0 = very realistic; 2 = very abstract). Relative symbolic thinking was assessed by calculating ratios to fluency.

Data analysis

Statistical analyses were conducted by IBM SPSS Statistics (version 22). A repeated-measures general linear model (GLM) with 'treatment' as within-subjects factor and 'treatment order' as between-subjects factor was performed for each task and variable. Main effects of treatment (LSD, placebo), period (session 1, session 2) and order (LSD-placebo, placebo-LSD) were evaluated. Effect sizes were estimated using partial eta squared (η_p^2). Results were corrected post hoc for multiple comparisons within variable groups (creativity criteria, divergent thinking, semantic structure, special feature categories) by Benjamini–Hochberg (BH) procedure with false discovery rate (FDR) of $q = \alpha = 0.05$ (Benjamini and Hochberg, 1995). Spearman's rank correlation coefficients (r_s) were calculated between LSD-induced changes (Δ = LSD − placebo) with significance level corrected for multiple comparisons by the number of tasks ($\alpha = 0.05/5 = 0.01$).

Results

Detailed values for all treatment, period and order effects are shown in Table 1.

Creativity criteria

LSD, compared to placebo, increased novelty ($p = 0.038$), relative novelty ($p < 0.001$) and relative surprise in PMT ($p = 0.016$), while increased relative novelty in AUT ($p = 0.034$) did not survive correction for multiple testing. LSD decreased utility in PMT ($p = 0.021$) and relative utility in PMT ($p < 0.001$) and AUT ($p = 0.008$; Figure 1(a)).

In PCT, there were period effects for relative novelty ($p < 0.001$) and relative surprise ($p < 0.001$), with lower means in session 2 indicating habituation effects, and for relative utility ($p < 0.001$), with higher means in session 2 indicating learning effects. Two effects of period (PMT relative utility: $p = 0.043$) and order (AUT relative novelty: $p = 0.029$) did not survive correction for multiple testing. No other effects of treatment, period and order were observed.

Divergent thinking

LSD, compared to placebo, increased title originality in FIG ($p = 0.007$), while increased special details in FIG ($p = 0.031$) and relative originality in PMT ($p = 0.019$) did not survive correction for multiple testing. LSD decreased relative flexibility in MET ($p = 0.029$), elaboration in PMT ($p = 0.022$), AUT ($p = 0.043$) and FIG ($p = 0.025$) and relative elaboration in MET ($p = 0.033$), but these effects did not survive correction for multiple testing (Figure 1(b)).

There was a period effect for relative flexibility in PCT ($p < 0.001$), with higher means in session 2 indicating learning effects. Two order effects (FIG special details: $p = 0.039$; AUT relative flexibility: $p = 0.029$) did not survive correction for multiple testing.

Convergent thinking

LSD, compared to placebo, increased convergent thinking in PCT ($p = 0.023$; Figure 1(c)). There was no period and order effect.

Semantic structure

LSD, compared to placebo, increased semantic spread ($p = 0.047$) and semantic steps in PMT ($p = 0.025$; Figure 1(d)). No other treatment, period and order effect reached significance.

Special features

Content under LSD, compared to placebo, exhibited more *sensation* in MET ($p = 0.019$) and fewer *objects* in MET ($p = 0.011$) and FIG ($p = 0.023$), but these effects did not survive correction for multiple testing (Supplemental Figure S2).

Techniques demonstrated more *contrast* in MET ($p = 0.005$), while decreased *exaggeration* in MET ($p = 0.035$) and increased *frame break* in FIG ($p = 0.017$) did not survive correction for multiple testing (Supplemental Figure S2).

LSD increased ambiguity in MET ($p = 0.028$) and FIG ($p = 0.044$) and relative ambiguity in MET ($p = 0.039$).

LSD increased symbolic thinking in PMT ($p = 0.036$), AUT ($p = 0.022$) and FIG (*title symbolism:* $p = 0.011$; *picture symbolism:* $p = 0.022$; *colour abstractness:* $p = 0.001$) and relative symbolic thinking in PMT ($p = 0.018$) and AUT ($p = 0.033$), while increased symbolic thinking in PCT ($p = 0.032$) did not survive correction for multiple testing (Figure 1(e)).

There was a period effect for ambiguity in MET ($p = 0.021$) with lower means in session 2. Two period effects (MET *contrast:* $p = 0.018$; PCT symbolic thinking: $p = 0.048$) and two order effects (FIG *body parts:* $p = 0.043$; AUT relative symbolic thinking: $p = 0.043$) did not survive correction for multiple testing.

For an overview of the effects, see Figure 2. For an illustration of ambiguity and symbolic thinking in FIG, see Figure 3.

Correlations

There was a positive correlation of novelty with surprise, but negative correlations of both criteria with utility (PMT; Table 2). Utility correlated positively with elaboration (PMT) and negatively with symbolic thinking (AUT). Surprise (PMT) correlated positively with symbolic thinking (AUT). Title originality correlated positively with ambiguity (FIG) and symbolic thinking (FIG *title symbolism*, FIG *picture symbolism*). Elaboration correlated negatively (MET) and positively (FIG) with ambiguity and positively with symbolic thinking (PMT). Semantic steps (PMT) correlated negatively with ambiguity (FIG) and symbolic thinking (FIG *picture symbolism*). Techniques (MET *contrast*) correlated positively with ambiguity (MET) and symbolic thinking (PMT). Ambiguity (FIG) correlated positively with symbolic thinking (PMT, AUT, FIG *picture symbolism*, FIG *colour abstractness*).

Table 1. Values for the effects of treatment, period and order in the repeated-measures general linear models for the different creativity measurement approaches, variables and tasks.

Approach	Variable	Task	Results[a]	Means ± SD[b]
Treatment effects				
Creativity criteria	novelty	PMT	**$F(1,22) = 4.85$, $p = 0.038$, $\eta_p^2 = 0.18$***	Means ± SEM of treatment effects are displayed in **Figure 1**
	rel novelty	PMT	**$F(1,22) = 18.0$, $p < 0.001$, $\eta_p^2 = 0.45$***	
		AUT	$F(1,22) = 5.13$, $p = 0.034$, $\eta_p^2 = 0.19$	
	rel surprise	PMT	**$F(1,22) = 6.77$, $p = 0.016$, $\eta_p^2 = 0.24$***	
	utility	PMT	**$F(1,22) = 6.20$, $p = 0.021$, $\eta_p^2 = 0.22$***	
	rel utility	PMT	**$F(1,22) = 26.0$, $p < 0.001$, $\eta_p^2 = 0.54$***	
		AUT	**$F(1,22) = 8.60$, $p = 0.008$, $\eta_p^2 = 0.28$***	
Divergent thinking	title originality	FIG	**$F(1,22) = 8.87$, $p = 0.007$, $\eta_p^2 = 0.29$***	
	special details	FIG	$F(1,22) = 5.28$, $p = 0.031$, $\eta_p^2 = 0.19$	
	rel originality	PMT	$F(1,22) = 6.42$, $p = 0.019$, $\eta_p^2 = 0.22$	
	rel flexibility	MET	$F(1,22) = 5.43$, $p = 0.029$, $\eta_p^2 = 0.19$	
	elaboration	PMT	$F(1,22) = 6.07$, $p = 0.022$, $\eta_p^2 = 0.22$	
		AUT	$F(1,22) = 4.61$, $p = 0.043$, $\eta_p^2 = 0.17$	
		FIG	$F(1,22) = 5.78$, $p = 0.025$, $\eta_p^2 = 0.21$	
	rel elaboration	MET	$F(1,22) = 5.18$, $p = 0.033$, $\eta_p^2 = 0.19$	
Convergent thinking		PCT	**$F(1,22) = 5.99$, $p = 0.023$, $\eta_p^2 = 0.21$***	
Semantic structure	spread	PMT	**$F(1,22) = 4.44$, $p = 0.047$, $\eta_p^2 = 0.17$***	
	steps	PMT	**$F(1,22) = 5.76$, $p = 0.025$, $\eta_p^2 = 0.21$***	
Special features	cont *sensation*	MET	$F(1,22) = 6.38$, $p = 0.019$, $\eta_p^2 = 0.23$	
	cont *objects*	MET	$F(1,22) = 7.67$, $p = 0.011$, $\eta_p^2 = 0.26$	
		FIG	$F(1,22) = 5.94$, $p = 0.023$, $\eta_p^2 = 0.21$	
	tec *contrast*	MET	**$F(1,22) = 9.68$, $p = 0.005$, $\eta_p^2 = 0.31$***	
	tec *exagg*	MET	$F(1,22) = 5.02$, $p = 0.035$, $\eta_p^2 = 0.19$	
	tec *frame*	FIG	$F(1,22) = 6.67$, $p = 0.017$, $\eta_p^2 = 0.23$	
	ambiguity	MET	**$F(1,22) = 5.56$, $p = 0.028$, $\eta_p^2 = 0.20$***	
		FIG	**$F(1,22) = 4.57$, $p = 0.044$, $\eta_p^2 = 0.17$***	
	rel ambiguity	MET	**$F(1,22) = 4.85$, $p = 0.039$, $\eta_p^2 = 0.18$***	
	symb think	PMT	**$F(1,22) = 4.98$, $p = 0.036$, $\eta_p^2 = 0.18$***	
		AUT	**$F(1,22) = 6.05$, $p = 0.022$, $\eta_p^2 = 0.22$***	
		PCT	$F(1,22) = 5.21$, $p = 0.032$, $\eta_p^2 = 0.19$	
		FIG (tit)	**$F(1,22) = 7.63$, $p = 0.011$, $\eta_p^2 = 0.26$***	
		FIG (pic)	**$F(1,22) = 6.13$, $p = 0.022$, $\eta_p^2 = 0.22$***	
		FIG (col)	**$F(1,22) = 14.3$, $p = 0.001$, $\eta_p^2 = 0.39$***	
	rel symb think	PMT	**$F(1,22) = 6.50$, $p = 0.018$, $\eta_p^2 = 0.23$***	
		AUT	**$F(1,22) = 5.18$, $p = 0.033$, $\eta_p^2 = 0.19$***	
Period effects				
Creativity criteria	rel novelty	PCT	**$F(1,22) = 116$, $p < 0.001$, $\eta_p^2 = 0.84$***	1.51 ± 0.21; 0.51 ± 0.31
	rel surprise	PCT	**$F(1,22) = 29.8$, $p < 0.001$, $\eta_p^2 = 0.58$***	1.63 ± 0.84; 0.85 ± 0.29
	rel utility	PCT	**$F(1,22) = 59.4$, $p < 0.001$, $\eta_p^2 = 0.73$***	0.88 ± 0.29; 1.53 ± 0.17
		PMT	$F(1,22) = 4.63$, $p = 0.043$, $\eta_p^2 = 0.17$	1.53 ± 0.19; 1.63 ± 0.15
Divergent thinking	rel flexibility	PCT	**$F(1,22) = 85.0$, $p < 0.001$, $\eta_p^2 = 0.79$***	0.91 ± 0.04; 0.99 ± 0.02
Special features	tec *contrast*	MET	$F(1,22) = 6.48$, $p = 0.018$, $\eta_p^2 = 0.23$	1.67 ± 1.78; 0.92 ± 1.48
	ambiguity	MET	**$F(1,22) = 6.21$, $p = 0.021$, $\eta_p^2 = 0.22$***	6.58 ± 5.21; 5.02 ± 4.98
	symb think	PCT	$F(1,22) = 4.40$, $p = 0.048$, $\eta_p^2 = 0.17$	0.39 ± 0.35; 0.24 ± 0.22
Order effects				
Creativity criteria	rel novelty	AUT	$F(1,22) = 5.43$, $p = 0.029$, $\eta_p^2 = 0.20$	0.88 ± 0.28; 0.61 ± 0.28
Divergent thinking	special details	FIG	$F(1,22) = 4.82$, $p = 0.039$, $\eta_p^2 = 0.18$	0.51 ± 0.33; 0.22 ± 0.33
	rel flexibility	AUT	$F(1,22) = 5.43$, $p = 0.029$, $\eta_p^2 = 0.20$	0.97 ± 0.04; 0.93 ± 0.04
Special features	cont *body pts*	FIG	$F(1,22) = 4.63$, $p = 0.043$, $\eta_p^2 = 0.17$	0.27 ± 0.22; 0.06 ± 0.22
	rel symb think	AUT	$F(1,22) = 4.63$, $p = 0.043$, $\eta_p^2 = 0.17$	0.19 ± 0.15; 0.06 ± 0.15

rel: relative; spread: semantic spread; steps: semantic steps; cont: content; body pts: body parts; tec: technique; exagg: exaggeration; frame: frame break; symb think: symbolic thinking; tit: title symbolism; pic: picture symbolism; col: colour abstractness; PMT: pattern meaning task; AUT: alternate uses task; PCT: picture concept task; MET: creative metaphors task; FIG: figural creativity task; LSD: lysergic acid diethylamide.

[a]Significant effects (**bold***) after correction for multiple comparisons.

[b]Means and standard deviations are displayed for session 1 and session 2 (period effects) and treatment order LSD-placebo and placebo-LSD (order effects).

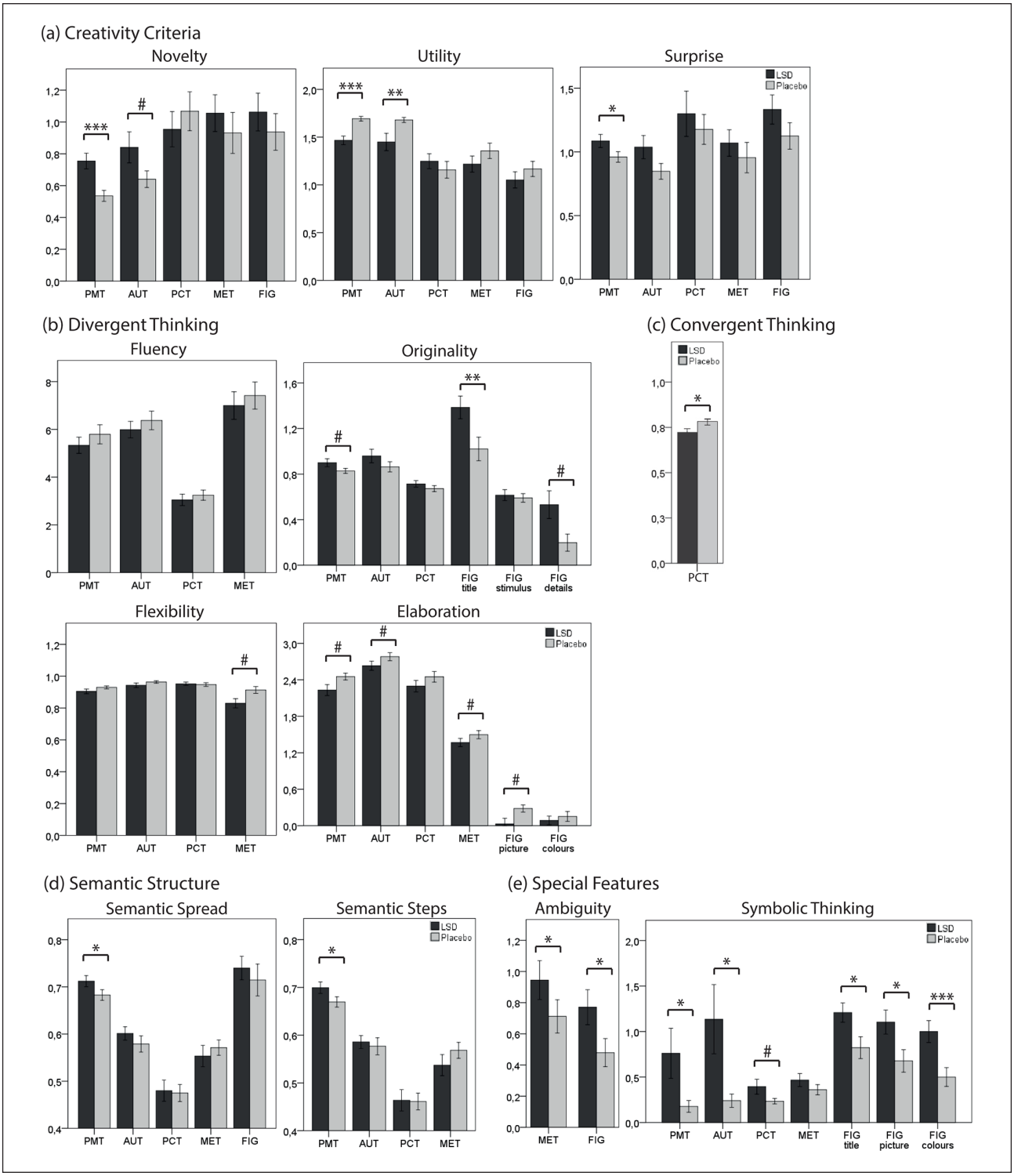

Figure 1. The effects of LSD on creativity as measured by several approaches within several tasks. Overall, LSD compared to placebo (a) changed creativity criteria, as measured by increased novelty and surprise and decreased utility (PMT, AUT); (b) changed divergent thinking towards increased originality (PMT, FIG) and decreased flexibility (MET) and elaboration (PMT, AUT, MET, FIG), but most effects did not survive correction for multiple testing; (c) decreased convergent thinking (PCT); (d) changed semantic structure, as measured by increased semantic spread and semantic steps (PMT); and (e) induced special features, as reflected by increased ambiguity (MET, FIG) and symbolic thinking (PMT, AUT, PCT, FIG). All values are displayed as means (±SEM) in 24 subjects. For presentation purposes, relative values are displayed wherever applicable, except for elaboration (PMT, AUT, PCT). Elaboration values were log-transformed. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$ (corrected), $^{\#}p < 0.05$ (uncorrected).

PMT: pattern meaning task; AUT: alternate uses task; PCT: picture concept task; MET: creative metaphors task; FIG: figural creativity task; Originality: title: title originality; stimulus: stimulus originality; details: special details; Elaboration: picture: picture elaboration; colours: colour elaboration; Symbolic thinking: title: title symbolism; picture: picture symbolism; colour: colour abstractness.

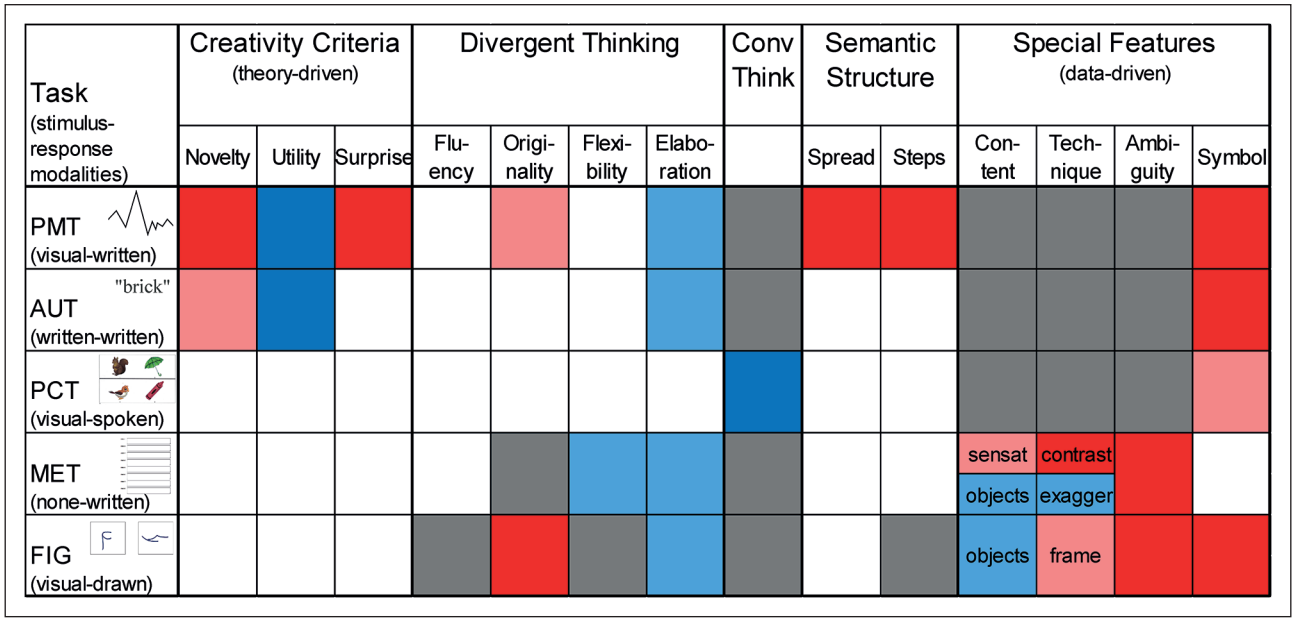

Figure 2. An overview of the effects of LSD, compared to placebo, on creativity, as measured by tasks of diverse stimulus-response modalities (lines) and by diverse approaches (columns). Overall, effects were most pronounced in PMT and for special feature symbolic thinking. Cells represent LSD-induced increases (dark red: corrected; light red: uncorrected) and decreases (dark blue: corrected; light blue: uncorrected) and no effects (white) for 24 subjects at $\alpha = 0.05$. Non-assessed variables are depicted in grey.
PMT: pattern meaning task; AUT: alternate uses task; PCT: picture concept task; MET: creative metaphors task; FIG: figural creativity task; Conv Think: convergent thinking; Spread: semantic spread; Steps: semantic steps; Symbol: symbolic thinking; sensat: sensation; exagger: exaggeration; frame: frame break.

Discussion

This study aimed at systematically mapping the effects of a relatively low dose of LSD on creativity across modalities and approaches. LSD, compared to placebo, changed creativity on several levels and seemed to elicit two opposing phenomena of 'pattern break', reflected by increased novelty (PMT), surprise (PMT), originality (FIG) and semantic distances (PMT), and decreased 'organization', reflected by decreased utility (PMT), convergent thinking (PCT) and, marginally but consistently across tasks, elaboration (PMT, AUT, MET, FIG; Figure 2). The consistency within both phenomena is underscored by positive correlations of novelty with surprise and utility with elaboration (Table 2). The inverse relationship between both phenomena is underlined by negative correlations of novelty and surprise with utility. Moreover, a data-driven phenomenon of 'meaning' seemed to arise, reflected by increased symbolic thinking (PMT, AUT, FIG), ambiguity (MET, FIG) and verbal techniques (MET *contrast*) (Figure 3). These effects correlated positively with each other, pointing to consistency within the phenomenon, and negatively with semantic distances and utility and positively and negatively with elaboration, pointing to contrasting relationships to the formerly described phenomena. Overall, the effects were specific to task and variable, pointing to influences of stimulus-response modalities and drug intensity, since results were most pronounced in PMT near drug peak.

Creativity criteria – LSD increases novelty and surprise and decreases utility

On a phenomenological level, LSD increased novelty and surprise and decreased utility of responses, indicating that responses were more remote and nonobvious but also 'chaotic' and less useful, while there was no change in the amount of highly creative responses, as measured by high novelty, utility and surprise (Simonton, 2012). Considering that novelty is regarded as essential for creativity, while usefulness adds merely additional value (Diedrich et al., 2015), our findings indicate that LSD provides a basis for creative thinking but impairs further sophisticated processes, similar to the proposal that psychedelics support creative generation but not creative evaluation (Girn et al., 2020). The notion of more 'chaotic' and 'less useful' thinking is in line with findings of LSD-induced cognitive bizarreness during mental imagery (Kraehenmann et al., 2017b) and chaos during mind-wandering (Wießner et al., 2021a).

Effects were pronounced in PMT and AUT, possibly due to stronger drug effects during these tasks and the medium task difficulty (in contrast to more demanding (PCT) or unconstrained tasks (MET, FIG)), indicating that acute, medium doses and medium task difficulties foster the creation of novel and surprising responses. Notably, novelty (FIG) and utility (PCT, MET, FIG) elicited partially poor interrater reliability (Supplemental Table S2), indicating that the evaluation of novelty (drawings) and utility (associations, metaphors, drawings) might yield unreliable results possibly obscuring effects. Therefore, future studies should complement novelty ratings with surprise ratings and refine evaluation frames of utility (e.g. utility regarding personal, aesthetic, societal or political value).

Divergent and convergent thinking – LSD decreases convergent thinking and elaboration

On a cognitive level, LSD increased title originality (FIG), while other originality parameters did not survive correction for

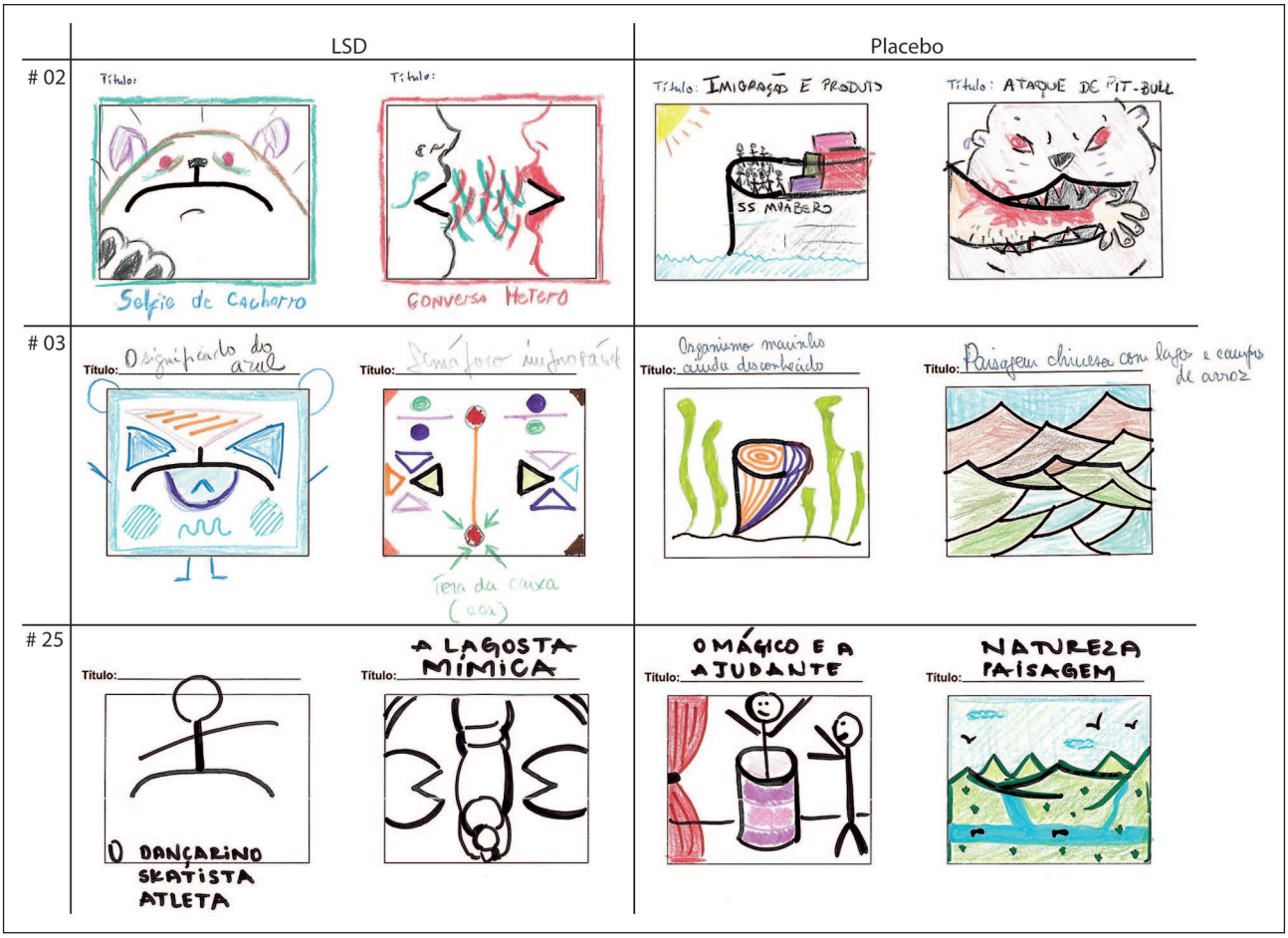

Figure 3. Drawings produced under LSD (left) and placebo (right) in the figural creativity task (FIG) as exemplified by three subjects (#02, #03 and #25). Symbolic thinking was enhanced as reflected by increased symbolism and abstractness in title, picture and colours. In a similar vein, ambiguity was enhanced reflecting increased interpretability of titles and drawings in several ways.
The translated titles are as follows, from left to right: #02: 'Dog selfie', 'Hetero conversation', 'Immigration and product', 'Pitbull attack'. #03: 'The meaning of blue', 'Improbable traffic light', 'Still unknown marine organism', 'Chinese landscape with lakes and rice fields'. #25: 'The skating athletic dancer', 'The mimic crayfish', 'The magician and the assistant', 'Nature landscape'.

multiple testing (FIG special details, PMT originality) or remained unchanged. Similarly, previous studies observed psychedelic-induced originality depending on task and parameter (Frecska et al., 2012; Kuypers et al., 2016; Zegans et al., 1967). Moreover, drug doses seem to influence effect directions, with increases under microdoses and decreases under high doses (Mason et al., 2021; Prochazkova et al., 2018). Together with these findings, our results suggest that psychedelics increase specific originality aspects, especially under lower doses.

Similarly, LSD decreased convergent thinking (PCT), in line with previous findings of impairments under regular doses (Kuypers et al., 2016; Mason et al., 2021) and improvements under microdoses (Prochazkova et al., 2018). LSD consistently decreased elaboration (PMT, AUT, MET, FIG at uncorrected level), similar to previous reports of psychedelic-induced impairments in technical execution of written and graphic productions, which was attributed to impaired psychomotricity and concentration (Bercel et al., 1956; Krippner, 1985; Landon and Fischer, 1970; Mátéfi, 1952). In line with this, effects emerged only for written (PMT, AUT, MET) and drawn (FIG) but not spoken (PCT) tasks. Notably, elaboration tended to decrease but fluency did not, indicating unchanged idea generation but less detail development. Altogether, these results might point towards impaired cognitive control, including selective (convergent thinking) and sustained (elaboration) attention and executive functions, important for divergent thinking (Zabelina and Ganis, 2018) and impaired under psychedelics (Pokorny et al., 2019; Umbricht et al., 2003; Vollenweider et al., 2007).

Semantic structure – LSD increases semantic spread and semantic steps

On a semantic level, LSD increased PMT semantic spread and semantic steps (distances between all and between neighbouring responses), indicating a random semantic spread of ideas. Contrastingly, LSD did not increase semantic spread but semantic distances to previous and subsequent words during free word association in this sample, pointing to meaningful but not randomly increased semantic distances between words (Wießner et al., 2021a). Altogether, these findings suggest that LSD-induced semantical dispersion is meaningful at simple task level (word

Table 2. Relationships between LSD-induced effects (Δ) on several creativity variables and tasks.

Approach			Creativity criteria						Divergent thinking				Sem	Tec	Ambiguity		
	Variable		nov	rel nov	utility	rel utility		rel surp	tit orig	elab[a]		rel elab	steps	contr		rel	
		Test	PMT	PMT	PMT	PMT	AUT	PMT	FIG	PMT	AUT	MET	PMT	MET	MET	MET	FIG
Creativity criteria	util	PMT	0.36	–0.45													
	rel util	PMT	**–0.60**	**–0.73**												1.0	
		AUT	–0.18	–0.42												0.8	
	rel surp	PMT	0.47	**0.87**	–0.32	**–0.79**	–0.37									0.6	
Divergent thinking	tit orig	FIG	0.11	0.15	0.12	–0.12	–0.31	0.19								0.4	
	elab	PMT	0.44	0.02	**0.58**	–0.11	–0.23	0.16	0.46							0.2	
		AUT	0.33	0.17	0.24	–0.20	–0.42	0.35	0.44							0.0	
	rel elab	MET	0.26	–0.14	0.46	0.15	0.28	0.04	0.09							–0.2	
Sem	steps	PMT	0.07	–0.12	0.13	0.15	0.07	–0.33	–0.46	–0.39	–0.23	–0.27				–0.4	
Tec	contr	MET	0.14	0.42	–0.16	–0.44	–0.32	0.39	0.34	0.18	0.09	–0.13	–0.32			–0.8	
Ambiguity		MET	–0.07	0.12	0.03	–0.09	–0.32	0.00	0.23	0.12	0.16	–0.34	–0.18	**0.61**		–1.0	
	rel	MET	–0.21	0.08	–0.21	0.06	–0.25	–0.26	0.00	–0.14	–0.15	**–0.59**	0.15	0.34			
		FIG	0.22	0.26	–0.02	–0.36	–0.50	0.39	**0.68**	0.39	**0.58**	0.04	**–0.54**	0.33			
Symbolic thinking		PMT	0.24	0.25	0.04	–0.39	–0.43	0.30	0.33	**0.52**	0.35	0.13	–0.46	**0.54**	0.47	0.22	**0.57**
	rel	PMT	0.23	0.31	–0.05	–0.45	–0.40	0.37	0.31	0.41	0.34	0.08	–0.45	**0.54**	0.44	0.20	**0.58**
		AUT	0.47	0.46	0.01	**–0.57**	**–0.59**	**0.53**	0.34	0.38	0.44	–0.13	–0.12	0.26	0.32	0.06	**0.55**
	rel	AUT	0.40	0.35	0.06	–0.49	**–0.53**	0.42	0.33	0.40	0.42	–0.15	–0.12	0.26	0.36	0.11	0.48
	title	FIG	–0.10	–0.27	0.25	0.16	–0.15	–0.18	**0.66**	0.46	0.06	0.13	–0.46	0.32	0.16	0.03	0.40
	picture	FIG	0.14	–0.06	0.31	0.00	–0.19	0.03	**0.74**	**0.53**	0.29	0.23	**–0.54**	0.35	0.21	0.05	**0.57**
	colour	FIG	0.42	0.26	0.23	–0.37	–0.49	0.45	0.48	**0.61**	**0.55**	0.21	–0.30	0.19	–0.01	–0.21	**0.66**

Approaches and variables: rel: relative variables as calculated by ratios to fluency; nov: novelty; util: utility; surp: surprise; tit orig: title originality; elab: elaboration; Sem: semantic structure; steps: semantic steps; Tec: Technique; contr: contrast; Symbolic thinking: title: title symbolism; picture: picture symbolism; colour: colour abstractness; Tasks: PMT: pattern meaning task; AUT: alternate uses task; FIG: figural creativity task; MET: creative metaphors task; PCT: picture concept task; LSD: lysergic acid diethylamide.

Displayed are Spearman's rank correlation coefficients for 24 subjects. **Bold** numbers indicate significant correlations at corrected significance level $\alpha = 0.01$. For presentation purposes, only variables with significant effects are depicted.

[a]Despite not surviving correction for multiple testing, elaboration was maintained in the correlation analysis for depicting consistent tendencies over most tasks, for a comprehensive understanding of the results.

association) and chaotic at complex level (idea generation), similar to findings of psychedelic-induced semantic priming and naming errors for semantically similar words/pictures (Family et al., 2016; Spitzer et al., 1996) and unpredictability of spontaneous speech (Amarel and Cheek, 1965). Notably, semantic distances increased for abstract (PMT) but not for concrete (AUT, PCT) or without (MET) stimuli. Similarly, semantic distances in free association increased for abstract but not concrete seed words (Wießner et al., 2021a), indicating that abstract, more than concrete, input stimulates the generation of semantically distinct thinking under LSD.

Special features – LSD affects content and technique in metaphors and drawings

On a behavioural level, metaphor and drawing content under LSD exhibited tendentially fewer *objects*, pointing to a weak but cross-modal phenomenon. Metaphors demonstrated tendentially more *sensation*, potentially related to the LSD-induced intensification and synaesthesia of senses (Leuner, 1962; Terhune et al., 2016; Wießner et al., 2021a). This implies that metaphors were influenced by and possibly used to express subjective experiences, similar to metaphors use in ayahuasca ceremonies and by people with psychotic disorders to express and handle subjective experiences (Mould et al., 2010; Shanon, 2002).

Metaphor techniques under LSD exhibited more *contrast* and tendentially less *exaggeration*, suggesting that the evaluation of semantic characteristics remains stable, while their associations shift from similarities to differences. Similarly, *contrast* correlated positively with ambiguity (MET) and symbolic thinking (PMT), suggesting an association between contrast-focused and meaning-laden thinking. Drawings under LSD showed unchanged colour quantity but increased *colour abstractness*, similar to previous observations on sharpened colours and changed colour combinations in drawings and paintings (Dobkin De Rios and Janiger, 2003; Tonini and Montanari, 1955). This might be related to psychedelic-induced visual effects (Kometer and Vollenweider, 2016; Wießner et al., 2021b), implying that subjective experiences might have been expressed by figural techniques.

Special features – LSD increases symbolic thinking and ambiguity

On an ontological level, symbolic thinking and ambiguity emerged as the most noticeable data-driven features. LSD increased metaphor and drawing ambiguity pointing to a cross-modal feature. Similarly, previous works observed logical contradictions in speech and paradoxical ideas and perceptions under psychedelics (Barr et al., 1972; Pahnke and Richards, 1966), reinforcing the notion that verbal and graphic means were spontaneously used to express subjective experiences. Drawing ambiguity correlated positively with title originality (FIG) and elaboration (AUT) and negatively with semantic steps (PMT), suggesting that figural ambiguity might be related to semantic organization. Contrastingly, metaphor ambiguity correlated negatively with elaboration (MET), suggesting that verbal ambiguity reflects condensed or reduced information, in line with findings of LSD-induced condensation of speech (Barr et al., 1972) and the notion of reduced cognitive control, as discussed above. Especially the latter notion seems supported by the period effect (lower ambiguity in session 2) pointing to learning effects (lower difficulties in creating metaphors in session 2), probably due to certain critical task procedures (e.g. few instructions, no training).

LSD increased symbolic thinking across modalities and tasks (PMT, AUT, FIG *title symbolism, picture symbolism, colour abstractness*). In the PCT, demanding procedures and concrete, child-like stimuli possibly restrained symbolization, in contrast to abstract patterns (PMT, FIG) and imagined objects (AUT), indicating that symbolic thinking is best induced by abstract stimuli. Remarkably, several anecdotal reports described psychedelics to induce a spontaneous 'symbolic level', with symbols that can be positive or negative, historical, mythical or religious, comprise eidetic images or complex scenes and influence figural creativity (Gasser et al., 2015; Leuner, 1962; Masters and El Houston, 1966; Mátéfi, 1952; Pahnke, 1967). Similarly, psychedelics seem to increase symbolism in Rorschach interpretations and mental imagery (Barr et al., 1972; Kraehenmann et al., 2017a), further supporting the notion that abstract and imagined stimuli promote LSD-induced symbolic thinking. In the therapeutic context, psychedelic-induced symbolization was hypothesized to unveil unconscious material, facilitate problem confrontation and solving, supporting psychological growth and maturation (Cohen, 1967; Eisner and Cohen, 1958; Gasser et al., 2015; Masters and El Houston, 1966). With this in mind, our results suggest that abstract stimuli and drawing tasks, for example within psychedelic-assisted psychotherapy or art therapy, might constitute intriguing techniques to stimulate symbolic thinking to express and process problems on personally meaningful level.

The correlations reveal insights into relationships of symbolic thinking with other processes. Negative correlations with utility (AUT) and positive correlations with originality (FIG), elaboration (PMT) and ambiguity (FIG) suggest that symbolic responses are perceived as less useful but original, require cognitive control and transmit multiple meanings. These contrasting relationships suggest that symbolic thinking and ambiguity constitute a third phenomenon of increased 'meaning', differentially related to 'pattern break' and decreased 'organization'. Meaning attribution under psychedelics is widely reported but poorly understood, being associated with psychedelic-induced symbolization, mystical experiences, creativity, psychotic-like and therapeutic effects (Hartogsohn, 2018; Leptourgos et al., 2020; Liechti et al., 2017; Masters and El Houston, 1966; Preller et al., 2017; Wießner et al., 2021b), pointing to a fundamental mechanism within the psychedelic phenomenology requiring further exploration.

Limitations

In order to provide a more comprehensive picture of the effects of psychedelics on creativity, a variety of variables were assessed using diverse methods including several exploratory procedures. Considering the relatively small sample size, this high number of variables increases the risk of false positives, despite correction for multiple comparisons, and the results should therefore be interpreted with caution. The special features were newly introduced variables, which is why their psychometric qualities need to be explored in future studies. Specifically, content and techniques might not reflect ideal material classifications with partly small group sizes (e.g. MET *body parts*, MET *wordplay*) and poor interrater reliability (e.g. FIG *symbols*). Moreover, cultural adequacy of the PCT pictures (e.g. sledges) was reduced within our Brazilian sample and possibly affected convergent thinking performance. Finally, due to the low amount of applicable responses, symbolic thinking remained a broadly defined concept including symbolic (e.g. use a pen 'to put in the shirt pocket of an adult to make him feel important'), abstract (e.g. 'to mark time and space'), poetic (e.g. 'to write real universes') or fantasy-like responses (e.g. 'support stick for gnomes'), with non-concreteness as common denominator. Future studies should carefully disentangle these constructs to specify underlying cognitive mechanisms and evaluate therapeutic applicability in clinical populations.

Conclusion

This study aimed at elucidating the psychedelic effects on creativity by diverse tasks and approaches. This diversity allows approximating the question of how psychedelics change creativity on different levels and provides insights into psychedelic creativity per se. On a phenomenological level, creativity criteria alterations seem to reflect more 'chaotic' and 'useless' ideas. On a cognitive level, divergent and convergent thinking changes may indicate decreased cognitive control. On a semantic level, associations seem to shift towards distances and differences. On a behavioural level, figural and verbal content and techniques might serve as tools to express subjective experiences. Overall, these effects point to elementary phenomena of 'pattern break' and decreased 'organization'. Furthermore, the data-driven approach unveiled a phenomenon of enhanced 'meaning', characterized by symbolic thinking and ambiguity. Therefore, on an ontological level, our findings suggest that psychedelics may not merely disrupt cognitive-behavioural processes 'away from normal', but relocate them 'towards the new'.

Acknowledgements

We thank Raphael Egel for his help in preparing the test material and Rodolfo Olivieri for his help in data collection.

Author contributions

I.W., L.O.M. and L.F.T. contributed to study design. I.W., M.F. and L.F.T. recruited and selected the participants. I.W. and M.F. collected the data. N.L.M., J.G.R., M.E.G. and J.W.S. provided technical support. I.W., M.F., L.O.M., D.D.-B. and F.P.-F. analysed the data. I.W. wrote the manuscript. M.F., L.O.M., D.D.-B., F.P.-F., N.L.M., J.G.R., M.E.G., J.W.S., A.F., S.R., D.B.A. and L.F.T. reviewed the manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship and/or publication of this article: This study received financial support from the Beckley Foundation and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) – Finance Code 001.

ORCID iDs

Isabel Wießner https://orcid.org/0000-0003-1653-2565
Marcelo Falchi https://orcid.org/0000-0002-7407-880X
Lucas Oliveira Maia https://orcid.org/0000-0002-9931-1938
Dimitri Daldegan-Bueno https://orcid.org/0000-0002-9352-2873
Natasha L Mason https://orcid.org/0000-0001-7115-0389
Draulio B Araujo https://orcid.org/0000-0002-6934-2485

Data availability

The data underlying the analyses are available under https://osf.io/kuhgw/.

Supplemental material

Supplemental material for this article is available online.

References

Amarel M and Cheek FE (1965) Some effects of LSD-25 on verbal communication. *Journal of Abnormal Psychology* 70(6): 453–456.

Artola T, Barraca J, Mosteiro P, et al. (2012) *PIC-A: Prueba de imaginación creativa para adultos*. Madrid: TEA Ediciones. Available at: http://www.web.teaediciones.com/Ejemplos/PIC-A_Manual_extractobook.pdf%5Cnhttp://dialnet.unirioja.es/descarga/articulo/1071118.pdf

Barr HL, Langs RJ, Holt RR, et al. (1972) *LSD: Personality and Experience* (ed. IB Weinered). New York; London; Sydney, NSW, Australia; Toronto, ON, Canada: Wiley-Interscience.

Benjamini Y and Hochberg Y (1995) Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)* 57(1): 289–300.

Bercel NA, Travis LE, Olinger LB, et al. (1956) Model psychoses induced by LSD-25 in normals: I – Psychophysiological investigations, with special reference to the mechanism of the paranoid reaction. *Archives of Neurology and Psychiatry* 75(6): 588–611.

Berlin L, Guthrie T, Weider A, et al. (1955) Studies in human cerebral function: The effects of mescaline and lysergic acid on cerebral processes pertinent to creative activity. *The Journal of Nervous and Mental Disease* 122(5): 487–491.

Carson S (2014) The impact of mindfulness on creativity research and creativity enhancement. *The Wiley Blackwell Handbook of Mindfulness* 1–2: 328–344.

Claridge G and McDonald A (2009) An investigation into the relationships between convergent and divergent thinking, schizotypy, and autistic traits. *Personality and Individual Differences* 46(8): 794–799.

Cohen S (1967) Psychotherapy with LSD: Pro and Con. In: Abramson HA (ed.) *The Use of LSD in Psychotherapy and Alcoholism*. Indianapolis, IN; New York; Kansas City, KN: The Bobbs-Merrill Company, pp.577–597.

Cropley AJ (2006) In praise of convergent thinking. *Creativity Research Journal* 18(3): 391–404.

Cropley AJ (2020) Creativity-focused technology education in the age of industry 4.0. *Creativity Research Journal* 32: 184–191.

Desrochers P (2001) Local diversity, human creativity, and technological innovation. *Growth and Change* 32(3): 369–394.

Diedrich J, Benedek M, Jauk E, et al. (2015) Are creative ideas novel and useful? *Psychology of Aesthetics, Creativity, and the Arts* 9(1): 35–40.

Dobkin De Rios M and Janiger O (2003) *LSD, Spirituality, and the Creative Process: Based on the Groundbreaking Research of Oscar Janiger, MD*. Rochester, VT: Inner Traditions/Bear & Co.

Eisner BG and Cohen S (1958) Psychotherapy with lysergic acid diethylamide. *The Journal of Nervous and Mental Disease* 127(6): 528–539.

Elo S and Kyngäs H (2008) The qualitative content analysis process. *Journal of Advanced Nursing* 62(1): 107–115.

Family N, Vinson D, Vigliocco G, et al. (2016) Semantic activation in LSD: Evidence from picture naming. *Language, Cognition and Neuroscience* 31(10): 1320–1327.

Florida R (2002) *The Rise of the Creative Class and How It's Transforming Work, Leisure, Community and Everyday Life*. New York: Basic Books.

Frecska E, Móré CE, Vargha A, et al. (2012) Enhancement of creative expression and entoptic phenomena as after-effects of repeated ayahuasca ceremonies. *Journal of Psychoactive Drugs* 44(3): 191–199.

Gasser P, Kirchner K and Passie T (2015) LSD-assisted psychotherapy for anxiety associated with a life-threatening disease: A qualitative study of acute and sustained subjective effects. *Journal of Psychopharmacology* 29(1): 57–68.

Gino F, Argote L, Miron-Spektor E, et al. (2010) First, get your feet wet: The effects of learning from direct and indirect experience on team creativity. *Organizational Behavior and Human Decision Processes* 111(2): 102–115.

Girn M, Mills C, Roseman L, et al. (2020) Updating the dynamic framework of thought: Creativity and psychedelics. *NeuroImage* 213: 116726.

Gray K, Anderson S, Chen EE, et al. (2019) 'Forward flow': A new measure to quantify free thought and predict creativity. *American Psychologist* 74(5): 539–554.

Guilford JP (1967) *The Nature of Human Intelligence*. New York: McGraw-Hill.

Harman WW, McKim RH, Mogar RE, et al. (1966) Psychedelic agents in creative problem-solving: A pilot study. *Psychological Reports* 19(1): 211–227.

Hartogsohn I (2018) The meaning-enhancing properties of psychedelics and their mediator role in psychedelic therapy, spirituality, and creativity. *Frontiers in Neuroscience* 12: 10–14.

Huxley A (1954) *The Doors of Perception*. Londres: Chatto and Windus.

Iszáj F, Ehmann B and Demetrovics Z (2012) The effects of psychedelic substances on artistic creation. In: Wouters M, Fountain J and Korf DJ (eds) *The Meaning of High: Variations According to Drug, Set, Setting and Time*. Lengerich: Pabst Science Lengerich, pp.40–53.

Iszáj F, Ehmann B, Griffiths MD, et al. (2018) A qualitative study on the effects of psychoactive substance use upon artistic creativity. *Substance Use and Misuse* 53(8): 1275–1280.

Iszáj F, Griffiths MD and Demetrovics Z (2017) Creativity and psychoactive substance use: A systematic review. *International Journal of Mental Health and Addiction* 15(5): 1135–1149.

Johnson MW, Richards WA and Griffiths RR (2008) Human hallucinogen research: Guidelines for safety. *Journal of Psychopharmacology* 22(6): 603–620.

Kim KH (2008) Meta-analyses of the relationship of creative achievement to both IQ and divergent thinking test scores. *Journal of Creative Behavior* 42(2): 106–130.

Kometer M and Vollenweider FX (2016) Serotonergic Hallucinogen-induced visual perceptual alterations. In: Halberstadt AL, Vollenweider FX and Nichols DE (eds) *Behavioral Neurobiology of Psychedelic Drugs*. Berlin; Heidelberg: Springer, pp.257–282.

Koo TK and Li MY (2016) A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine* 15(2): 155–163.

Kraehenmann R, Pokorny D, Aicher H, et al. (2017a) LSD increases primary process thinking via serotonin 2A receptor activation. *Frontiers in Pharmacology* 8: 1–9.

Kraehenmann R, Pokorny D, Vollenweider L, et al. (2017b) Dreamlike effects of LSD on waking imagery in humans depend on serotonin 2A receptor activation. *Psychopharmacology* 234(13): 2031–2046.

Krippner S (1985) Psychedelic drugs and creativity. *Journal of Psychoactive Drugs* 17(4): 235–246.

Kuypers KPC, Riba J, de la Fuente Revenga M, et al. (2016) Ayahuasca enhances creative divergent thinking while decreasing conventional convergent thinking. *Psychopharmacology* 233(18): 3395–3403.

Landon M and Fischer R (1970) On similar linguistic structures in creative performance and psilocybin-induced experience. *Confinia Psychiatrica: Borderland of Psychiatry – Grenzgebiete der Psychiatrie: Les Confins de la Psychiatrie* 13(2): 115–138.

Leptourgos P, Fortier-Davy M, Carhart-Harris RL, et al. (2020) Hallucinations under psychedelics and in the schizophrenia spectrum: An interdisciplinary and multiscale comparison. *Schizophrenia Bulletin* 46(6): 1396–1408.

Leuner H (1962) *Die Experimentelle Psychose: Ihre Psychopharmakologie, Phänomenologie Und Dynamik in Beziehung Zu Person*. Berlin; Göttingen; Heidelberg: Springer.

Liechti ME, Dolder PC and Schmid Y (2017) Alterations of consciousness and mystical-type experiences after acute LSD in humans. *Psychopharmacology* 234(9–10): 1499–1510.

Markoff J (2005) *What the Dormouse Said: How the Sixties Counterculture Shaped the Personal Computer Industry*. New York: Penguin Press.

Mason NL, Kuypers KPC, Reckweg JT, et al. (2021) Spontaneous and deliberate creative cognition during and after psilocybin exposure. *Translational Psychiatry* 11(1): 01335.

Mason NL, Mischler E, Uthaug MV, et al. (2019) Sub-acute effects of psilocybin on empathy, creative thinking, and subjective well-being. *Journal of Psychoactive Drugs* 51(2): 123–134.

Masters REL and Houston J (1966) *The Varieties of Psychedelic Experience*. New York: *Dell Publishing*.

Mátéfi L (1952) Mezcalin- und Lysergsäurediäthylamid-Rausch. *Confinia Neurologica* 12: 146–177.

Mota N, Weissheimer J, Ribeiro M, et al. (2020) Dreaming during COVID-19 pandemic: Computational assessment of dreams reveals mental suffering and fear of contagion. *PLoS ONE* 15(11): e0242903.

Mould TJ, Oades LG and Crowe TP (2010) The use of metaphor for understanding and managing psychotic experiences: A systematic review. *Journal of Mental Health* 19(3): 282–293.

Mullis KB (2000) *Dancing Naked in the Mind Field*. New York: Vintage Books.

Pahnke WN (1967) LSD and religious experience. In: Debold RC and Lea RC (eds) *LSD, Man & Society*. Middletown, CT: Wesleyan University Press, pp.60–85.

Pahnke WN and Richards WA (1966) Implications of LSD and experimental mysticism. *Journal of Religion & Health* 5: 175–208.

Pokorny T, Duerler P, Seifritz E, et al. (2019) LSD acutely impairs working memory, executive functions, and cognitive flexibility, but not risk-based decision-making. *Psychological Medicine* 50: 9002393.

Preller KH, Herdener M, Pokorny T, et al. (2017) The fabric of meaning and subjective effects in LSD-induced states depend on serotonin 2A receptor activation. *Current Biology* 27(3): 451–457.

Prochazkova L, Lippelt DP, Colzato LS, et al. (2018) Exploring the effect of microdosing psychedelics on creativity in an open-label natural setting. *Psychopharmacology* 235(12): 3401–3413.

Sanz C, Pallavicini C, Carrillo F, et al. (2021) The entropic tongue: Disorganization of natural language under LSD. *Consciousness and Cognition* 87: 103070.

Scott G, Leritz LE and Mumford MD (2004) The effectiveness of creativity training: A quantitative review. *Creativity Research Journal* 16(4): 361–388.

Shanon B (2002) *The Antipodes of the Mind*. Oxford: Oxford University Press.

Silvia PJ, Kaufman JC and Pretz JE (2009) Is creativity domain-specific? Latent class models of creative accomplishments and creative self-descriptions. *Psychology of Aesthetics, Creativity, and the Arts* 3(3): 139–148.

Silvia PJ, Winterstein BP, Willse JT, et al. (2008) Assessing creativity with divergent thinking tasks: Exploring the reliability and validity of new subjective scoring methods. *Psychology of Aesthetics, Creativity, and the Arts* 2(2): 68–85.

Simonton DK (2012) Taking the U.S. Patent Office criteria seriously: A quantitative three-criterion creativity definition and its implications. *Creativity Research Journal* 24(2–3): 97–106.

Snyder BA (1997) Expressive art therapy techniques: Healing the soul through creativity. *The Journal of Humanistic Education and Development* 36(2): 74–82.

Spitzer M, Thimm M, Hermle L, et al. (1996) Increased activation of indirect semantic associations under psilocybin. *Biological Psychiatry* 39(12): 1055–1057.

Terhune DB, Luke DP, Kaelen M, et al. (2016) A placebo-controlled investigation of synaesthesia-like experiences under LSD. *Neuropsychologia* 88: 28–34.

Tonini G and Montanari C (1955) Effects of experimentally induced psychoses on artistic expression. *Stereotactic and Functional Neurosurgery* 15(4): 225–239.

Umbricht D, Vollenweider FX, Schmid L, et al. (2003) Effects of the 5-HT2A agonist psilocybin on mismatch negativity generation and AX-continuous performance task: Implications for the neuropharmacology of cognitive deficits in schizophrenia. *Neuropsychopharmacology* 28(1): 170–181.

Uthaug MV, Lancelotta R, van Oorsouw K, et al. (2019) A single inhalation of vapor from dried toad secretion containing 5-methoxy-N, N-dimethyltryptamine (5-MeO-DMT) in a naturalistic setting is related to sustained enhancement of satisfaction with life, mindfulness-related capacities, and a decrement of psychopathological symptoms. *Psychopharmacology* 236(9): 2653–2666.

Uthaug MV, van Oorsouw K, Kuypers KPC, et al. (2018) Sub-acute and long-term effects of ayahuasca on affect and cognitive thinking style and their association with ego dissolution. *Psychopharmacology* 235(10): 2979–2989.

Vollenweider FX, Csomor PA, Knappe B, et al. (2007) The effects of the preferential 5-HT2A agonist psilocybin on prepulse inhibition of startle in healthy human volunteers depend on interstimulus interval. *Neuropsychopharmacology* 32(9): 1876–1887.

Wießner I, Falchi M, Palhano-Fontes F, et al. (2021a) Low-dose LSD and the stream of thought: Increased Discontinuity of Mind, Deep Thoughts and abstract flow. *Psychopharmacology*. Epub ahead of print 28 October 2021. DOI: 10.1007/s00213-021-06006-3.

Wießner I, Falchi M, Palhano-Fontes F, et al. (2021b) LSD, madness and healing: Mystical experiences as possible link between psychosis model and therapy model. *Psychological Medicine*. Epub ahead of print 13 July 2021. DOI: 10.1017/S0033291721002531.

Zabelina DL and Ganis G (2018) Creativity and cognitive control: Behavioral and ERP evidence that divergent thinking, but not real-life creative achievement, relates to better cognitive control. *Neuropsychologia* 118: 20–28.

Zegans LS, Pollard JC and Brown D (1967) The effects of LSD-25 on creativity and tolerance to regression. *Archives of General Psychiatry* 16(6): 740–749.