Psychedelics and Creativity: a Review of the Quantitative Literature

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Abstract
After a 40-year hiatus, the question of whether psychedelics can increase creativity is being asked with renewed vigor. This article critically reviews the conceptual issues of studying psychedelic-induced creativity by summarizing the limited evidence on the question and suggesting two broader frameworks. There are two important challenges to researchers on this topic. One is to separate creativity from other effects of the drug that may be mistaken for creativity. The second is to develop operational measures to quantify it. This article reviews the major studies assessing creativity (or related constructs) induced by psychedelics, including a reanalysis of raw data from one study. Results are modest and inconclusive but are consistent with reports that psychedelics give rise to unusual or novel thoughts. Given the lack of robust changes in creativity measures, I suggest creativity may be too specific of a construct to accurately and fully characterize the putatively beneficial cognitive changes that psychedelic users report. Feelings of creativity may be an inconsistent result of a more general effect of these drugs, such as alterations in availability of mental representations or changes in Bayesian inference. Ultimately, creativity may not be a sufficiently creative construct to capture the beneficial effects of psychedelics.

Keywords: psychedelics, hallucinogens, creativity, LSD, mescaline

Introduction
Psychedelics such as LSD and psilocybin are often said to increase creativity. This claim is complex to evaluate — Psychedelics produce other effects that may be mistaken for creativity and creativity itself is hard to measure. Most of the empirical studies that reported increases in creativity after hallucinogen use are old and used methods that would not be accepted in modern psychopharmacology. After decades of disinterest, scientists are again attending to possible beneficial effects of psychedelics (Vollenweider and Kometer, 2010). For example, recent trials of psychedelics in patients with obsessive compulsive disorder, drug dependence, and anxiety have occurred or are underway (New York University, 2010; Grob et al., 2011; Bogenschutz et al., 2015; Johnson et al., 2014) and articles have called for research into psychedelics' effects on creativity (Sessa, 2008). It is therefore timely to examine the literature on how this difficult-to-understand class of drugs might act as cognitive enhancers and improve creativity (Lanni et al., 2008).

An association of psychedelics and creativity has been noted in a broad range of nonscientific publications. This includes well-known cases of creative individuals who attribute breakthroughs in their work to use of psychedelics, such as Nobel laureate Kerry Mullis (1998) and author Ken Kesey (1996). Architect Kiyo Izumi used LSD for inspiration when designing a hospital in Saskatchewan (Edginton, 2010). Society's encounter with LSD is believed to have led to innovative albums like the Beach Boys' *Pet Sounds* and the Beatles' *Revolver* and movies like *Easy Rider* (DeRogatis, 2003; Benshoff, 2001). Study of illustrator Robert Crumb's work suggests considerable influence of psychedelics on his style (Jones, 2007). More broadly, Markoff (2005) has argued that the hallucinogen-oriented counterculture had a profound, if difficult to quantify, influence on the early personal computing industry. Along with qualitative descriptions of

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hallucinogen effects, these anecdotes suggest that psychedelics may facilitate creativity (Sessa, 2008; Dobkin de Rios and Janiger, 2003; ten Berge, 1999; ten Berge, 2002; Krippner, 1985).

However, qualitative impressions are not always confirmed when quantitative assessments are made and there are reasons to be skeptical about the perceived effects of psychedelics on creativity. Objective tests consistently find hallucinogen-induced impairments in other cognitive domains and these impairment are often accompanied by the erroneous belief that the impaired abilities are enhanced (Hollister, 1968). It is not clear if we should expect creativity to be an exception to this pattern of objective impairments with subjective feelings of improvement. In fact, the "seeming clarity and portentous quality" of thought during hallucinogen effects can include things that later seem trivial to the same person (Jaffe, 1990), which seems consistent with an impaired sense of significance. Even when there are persisting feelings of profound significance after the drug wears off, McGlothlin (1962) points out that the impressively powerful acute effects of psychedelics might lead to a halo effect and exaggerated estimation of benefits.

In this publication, I review the projects that have measured the effects of psychedelics on creativity and discuss mechanisms by which psychedelics might enhance creativity. This literature turns out to be modest in both its size and the consistency of results. This may be partly because creativity both is an inconsistent effect and is an inadequate description of the drug effects that sometimes lead to feelings of insight and altered meaning. I therefore discuss two broader conceptualizations of psychedelic effects that may clarify creativity-related changes.

Acute effects of psychedelics potentially related to creativity

Psychedelics have a range of inconsistent effects that may be related to creativity. The inconsistency is likely a result of their pharmacological mechanisms. Psychedelics are thought to act as agonists at 5-HT_{2A} serotonin receptors (Gonzalez-Maeso and Sealfon, 2009), with interactions with other binding sites modifying their effects (Nichols, 2004). 5-HT_{2A} serotonin receptors are expressed on the soma and apical dendrites of pyramidal neurons (Willins et al., 1997; Jakab and Goldman-Rakic, 1998), where they may modulate the relationship between inputs and output (Zhang and Arsenault, 2005). The broad distribution of these receptors in the cortex may contribute to the variable effects of these drugs on cognition, mood, and perception. These effects can include perceptual changes, time-distortions, altered and frequently labile mood, feelings of depersonalization (such as changes in the perceived boundaries between self and not-self) and derealization (such as dream-like feelings), and – most relevantly for this paper – feelings of insight and altered meaning.

Feelings of insight and altered meaning are reported with enough consistency after psychedelic administration to be included in most self-report questionnaires developed to measure the effects of these drugs. For example, the Altered States of Consciousness Questionnaire (APZ-OAV) includes items such as "things around me had new, strange meanings" and "I gained insights into things that were puzzling to me before" (Dittrich, 1998). The Hallucinogen Rating Scale (HRS) includes "new thoughts or insights" and "insights into personal or occupational concerns" (Strassman, 2005). The Linton-Langs questionnaire asks "have you felt that certain things were especially clear to you or that you understood them better?" and "have you seen new connections between certain events or experiences that you hadn't seen before?" (Linton and Langs, 1962). The Subjective Drug Effects Questionnaire (SDEQ), developed with LSD as a main test drug, contains the question "have some things had a different meaning for you?" (Katz et al., 1968). Thus, feelings of increased insight and altered significance are recognized as a common acute effect of psychedelics.

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In addition to creating this sense of altered significance, psychedelics are often said to change the dynamics of thought. Rather than endorsing a single stable view or perception, individuals often report a tendency to see "multiple viewpoints of a problem in very rapid succession" (Sessa, 2008). Katz et al. (1968) describe participants on d-lysergic acid diethylamide (LSD) as reporting "a number of feelings to be occurring at approximately the same time which would appear to the rational observer as opposed and contradictory". This paradoxical effect is measured by a subscale of the SDEQ (Katz et al., 1968) as well as by individual items in the HRS ("contradictory feelings at the same time [happy and sad; hopeful and hopeless]") and APZ-OAV ("oppositions and contradictions seemed to dissolve"). This decrease in the stability of points of view and tendency to embrace oppositions may be plausibly related to creativity. Rothenberg (1988) has argued that simultaneously conceiving two or more opposites or antitheses, which he calls "janusian thinking", plays a key role in creativity.

Psychedelics increase use of unusual language (e.g., Martindale and Fischer, 1977; Natale et al., 1978b; Natale et al., 1978a; Zegans et al., 1967), with resulting language reportedly less concrete and more abstract than seen in thought-disordered schizophrenia (Honigfeld, 1965; Amarel and Cheek, 1965; but see also Krus et al., 1963). For example, Martindale and Fischer (1977), using a dictionary-based word classification approach, reported that psilocybin increased a measure of the primary process content of speech. Primary process is a term originating in psychoanalytic theory that refers to thinking that is free-associative, analogical, and often image-based. It has long been linked to creativity, with creative people sometimes seen as more able than others to shift in and out of primary process thinking (Kris, 1964; Martindale and Dailey, 1996).

Traditional approaches to studying creativity

There are many proposed definitions for creativity. Under most of them, creativity does not describe a single process in the brain. Given this diversity, creativity can be studied in different ways. Tasks used in studies of psychedelics and creativity generally treat creativity as an ability. These tasks appear to be particularly influenced by two theorists, Guilford and Mednick. Guilford (1967) described divergent thinking – generation of responses to open-ended or poorly defined problems with no single answer – as the foundation of creative thinking. He thought of divergent thinking in terms of fluency, flexibility, and originality and, to a lesser extent, redefinition and elaboration of ideas. These different aspects of divergent thinking can be assessed with a number of creative tasks, such as the widely used batteries of Torrance (1990) and Wallach and Kogan (1965), which build on Guilford's work. In contrast, Mednick (1968; 1962) emphasized the recombination of associative elements into novel ideas and argued that creative solutions derived from either serendipitous co-occurrence of elements, similarity between elements, or bridging factors that link remote elements. He operationalized this last mechanism of creativity in his Remote Associates Test (Mednick, 1968). The tasks used in psychedelic creativity research and their results are briefly summarized in **Table 1**.

These tasks can be roughly placed in three main categories. One group concerns remote associations and production of ideas. A second group of tasks includes perception and visual imagery tasks, such as mental rotation or detecting a target figure is hidden in a more complicated pattern. Finally, a group of tasks tests creative production, where individuals are asked to make designs or tell stories and the results are rated by judges for originality.

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This task-based approach to measuring creativity has several limitations. One potential limitation of standardized tasks is that they attempt to focus on specific aspect of creativity and may therefore miss relevant drug-induced changes. Furthermore, changes on specific tasks may be driven or masked by nonspecific drug effects, such as altered motivation. Finally, it must be noted that there is an important temporal element to creativity. Although creative achievement – completion of a final product -- may initially benefit from generation of numerous creative ideas, it also requires evaluation and selection of the most useful idea and successful implementation. Creative achievement, as opposed to creative thinking, accordingly requires motivation and appropriate social and nonsocial resources. Thus, if they do occur, psychedelic-induced changes in divergent thinking or some other aspect of creative ability might not be reflected in creative achievement.

Five studies of psychedelics and creativity

With one recent and important exception reporting personality change after psychedelics (MacLean et al., 2011), research on psychedelics and creativity was conducted between 1962 when new regulations made human LSD research more difficult and 1968 when LSD possession was made a felony in the United States (Stevens, 1998). These older studies accordingly represent human psychedelic research at a peak in hands-on practical experience. Differences between these four studies thus probably reflect deliberately different approaches to research with psychedelics rather than unfamiliarity with the unusual aspects of this class of drug (Johnson et al., 2008).

Studies 1 and 2: Search for long-term positive effects of LSD

In two studies, McGlothlin, Cohen, & McGlothlin (1967; 1964) sought to find lasting effects of LSD exposure in healthy normal volunteers, including changes in creativity. A strength of this approach is that the brief acute drug-induced impairment cannot prevent detection of longer lasting changes. However, although participants did attribute some attitudinal changes to the drug experience, objective measures did not support any lasting increase in creativity. Because the focus was on lasting changes, these studies were not directly comparable to the acute effects investigations of Zegans and Harman and their colleagues which I discuss later.

In a pilot study, McGlothlin, Cohen, & McGlothlin (1964) assessed fifteen (10 male, 5 female) psychedelic-naïve RAND Corporation employees before and one week after administration of 200 µg LSD, a relatively high dose. A comparison group was tested at the same intervals, although no placebo was administered. The authors saw evidence of decreased anxiety and trends for changes in attitudes after LSD, but there were no significant changes in divergent thinking, remote associations, or word associations.

In a second study, McGlothlin, Cohen, & McGlothlin (1967) assessed 24 psychedelic-naïve graduate students before and two weeks and six months after a series of three administrations of 200 µg LSD, a high dose. Two control groups received, respectively, either 25 µg LSD (N = 23) or 20 mg amphetamine (N = 23) each session. At the six-month assessment, 25% of the 200 µg LSD group felt that the drug experience had resulted in enhanced creativity (compared to 9% and 0% in the amphetamine and 25 µg LSD groups, respectively). However, standardized art tests failed to show significant changes in aesthetic sensitivity and drawings of people by the LSD group were rated as significantly less imaginative. Furthermore, the objective creativity tests showed no evidence of change either in the experimental group as a whole or in those reporting greater creativity. Nonetheless, there were other perceived changes, including increased enjoyment of art, which was reflected in reported activity changes (such as time spent in museums and number of

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musical events attended) in the post-drug period. Moreover, a recent study has supported the possibility of psychedelic-induced changes in aesthetic sensibility and interest in cultural activities.

Study 2: Increased openness after experimental psilocybin

MacLean et al (2011) pooled data from two recent psychedelic studies that used high-dose (30 mg/70 kg) experimental psilocybin. They found increases in the openness dimension of personality associated with study participation and presented preliminary analyses suggesting this might be caused by mystical experience. Openness includes correlated traits such as aesthetic appreciation, imagination, awareness of feelings, and intellectual engagement. People with high openness are 'motivated to enlarge their experience into novel territory' (DeYoung et al., 2009). Unsurprisingly, openness has been associated with creativity (Silvia et al., 2009).

The two studies in the MacLean report had somewhat different designs. In the first study (Griffiths et al., 2008), thirty-six participants received psilocybin (30 mg/70 kg body weight) on one session and an active control drug, methylphenidate (40 mg/70 kg), in the other one or two sessions. In the second study (Griffiths et al., 2011), seventeen participants received four doses of psilocybin (5, 10, 20 and 30 mg/70 kg) in ascending or descending order over four sessions, with a fifth placebo session quasi-randomly inserted in the sequence.

Personality was assessed several times: at the beginning of each study; one to two months after each drug session; and about 14 months after the last session using the NEO Personality Inventory (Costa and McCrea, 1992). This inventory measures five broad categories that capture the main dimensions of personality: openness, neuroticism, extroversion, agreeableness and conscientiousness.

Openness was the one dimension found to change comparing pretest to after the last drug sessions in the entire sample of 52 participants. The authors attempted several analyses to link this change specifically to psychedelic experience. While there was direct no control group available for this comparison (all participants had received drugs), the authors saw no significant change from pretest to post-session-one in the 32 participants who got placebo first. This comparison had less statistical power than the first analysis. Moreover, failure to detect difference is not good evidence of lack of difference. On the other hand, the authors found that measures of mystical experience correlated with the openness change, which strengthens confidence that the change was psychedelic-linked and not a more general effect of the unusual study.

One might still ask how broadly these results will generalize to other populations and settings. One concern is that the participants were unusual. Most were previously naive to psychedelics and were motivated by curiosity and the opportunity afforded for self-reflection. All were required to have some preexisting spiritual practice. Examination of their personality confirms this is a select group. Their baseline mean openness was 64, which is approximately 1.4 SDs above the population mean, while the personality dimension neuroticism (feeling anxious, moody, or insecure) was nearly 1 SD below the population normal.

A second concern is that it is not yet well documented how reliably mystical-type experiences are produced by psychedelics in settings other than the carefully describe one used by this group (Baggott, 2015). Several recent reports exist drug-related mystical experiences triggered by other drugs (Salvinorin A in Johnson et al. 2011) and in other settings (MDA in Baggott et al. 2010),

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supporting the theory that this is a broad phenomenon. Yet there are no published reports quantifying personality changes after these experiences.

Study 4: LSD and creativity in graduate students

Zegans, Pollard, & Brown (1967) conducted a between-subjects study of the effects of LSD on creativity in psychedelic-naïve male graduate students. Twenty received 0.5 μg/kg, while eleven received placebo. This relatively modest dose of LSD was chosen after a pilot study indicated that a higher dose (1.0 μg/kg) might produce nonspecific impairments in test taking in their participant population. They attempted to control expectation by reading a short statement about the drug's effects that carefully omitted the possibility of "regressive experiences" (such as increased associative and imagistic thinking) that might increase creativity.

Zegans et al. found that the LSD group had a significantly greater number of unusual word associations on the Rapaport Word Association Test compared to controls. When they compared only those LSD participants who had been predicted to improve (based on projective tests such as the Rorschach) to all controls, this measure remained significant and a trend for impaired performance in Gottschald Figure-Perception task was additionally seen. Overall, the authors concluded that semantic association tests showed some trends in the predicted direction, while tests requiring visual attention did not. However, the inconsistency of the test battery results led them also to conclude that a general enhancement did not occur and that "the administration of LSD-25 to a relatively unselected group of people for the purpose of enhancing their creative ability is not likely to be successful".

Study 5: Institute of Psychedelic Research report on psychedelics and creativity in professionals

Harman, McKim, Fadiman and colleagues (Harman and Fadiman, 1970; Harman et al., 1966: ; see also ; Fadiman et al., 1965) used a pre-versus-post drug administration design to study the effects of mescaline on creativity, which they assessed with both objective testing and qualitative assessment of participants' attempts to solve professional problems. Although this report is often discussed as a single study, it may be more accurate to describe the report as a summary of preliminary results from a research program that was still actively being refined (Harman and Fadiman, 1970).

This report also differs from the other studies in that it attempted to maximize creativity. Participants were 27 males with careers thought by the researchers to require creative-problem solving ability (including engineering, architecture, commercial art, furniture design, mathematics, and physics) and, for some measures, eight females (with unspecified backgrounds). Eight male participants had prior experience with psychedelics, in contrast to other studies, and thus may have somewhat different responses to the study drug. Additionally, the researchers attempted to produce an expectation of improvement in creativity. They advised participants that "they would not experience difficulty with such distractions as visions, involvement with personal problems, and so on" and "they would be able to concentrate on the assigned tasks with ease and would be able to work more effectively than usual" (Fadiman et al., 1965 p. 3). Because psychedelics have been reported to increase suggestibility (Middlefell, 1967; Sjoberg and Hollister, 1965; Netz and Engstam, 1968), it seems reasonable to hypothesize that the expectation of improved creativity in participants might help to increase performance (Harman et al., 1966; Barron and Harrington, 1981).

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The study tasks included one selected by the participant from the real-life problems in his (all were apparently males for this task) professional career, which could be predicted to lead to greater personal involvement and motivation to produce solutions. Several days before and approximately four hours after 200 mg mescaline (a low dose, similar to 50 µg LSD), participants completed a one-hour battery of cognitive tasks made up of the Purdue Creativity task, Miller Object Visualization task, and Witkin's Embedded Figures Test. They were then instructed to work on their self-chosen problem. As a follow-up measure, participants filled out a questionnaire about their experience.

Subjectively, "about half" of participants felt the experience enhanced their abilities to solve professional problems and reported they had accomplished much more than they would have in a typical workday. "About 20%" reported they were unable to concentrate on their chosen project and found themselves instead diverted to personal concerns. The qualitative experience of problem-solving during acute mescaline effects is described in detail in the reports (Harman et al., 1966; Harman and Fadiman, 1970; Fadiman et al., 1965).

Although it was not a primary focus of the study, self-report measures were made to monitor for potentially lasting effects. Harman and Fadiman (1970) provide some data from a subset of participants (N = 16) who filled out a questionnaire six to eight weeks after the session. Between 6 and 8 of these respondents reported continuing benefit in each of six categories (ability to solve problems, ability to relate effectively to others, attitude toward job, productivity, ability to communicate, response to pressure). This is difficult to evaluate given the lack of explanation for why data are only presented for 16 rather than a larger sample. In addition, the various reports from this group appear to make no mention of twelve single-item self-report measures of relationships with others, interest in life, awareness of reality, and general energy level. It may be reasonable to assume these measures detected no clear improvements.

The researchers reported significant improvements in all three cognitive tasks. Because the data were filed with a data archive, it proved possible to obtain and reanalyze the original raw data table from this report over forty years later. The data table is depicted in **Figure 1** and shows objective data were collected from 25 different males (two fewer than the sample size for qualitative measures) and 8 females (no details are given about their professions or perceived creativity). One participant (code number 207) appears to have undergone two sessions. Overall, quantitative tests were unevenly distributed across participants. For example, only seven males participated in all three quantitative tests. This suggests that quantitative tests may have had a secondary and exploratory role and that the qualitative self-chosen problem-solving task was the main focus of the research. Reanalysis of these data reinforces this suggestion.

As described in the appendix, I attempted to replicate the analyses of Harman et al. using their data. While Harman et al. reported clear improvement in all three quantitative tasks in their creativity study, I find that improvements are present in the Witkin's Embedded Figures and Purdue Creativity tasks, while performance in the Miller Object Visualization task does not significantly improve.

In addition, there are significant gender differences in scores in both tasks with female participants. These differences were not noted by the original authors. Gender differences have sometimes been reported in the Witkin's Embedded Figures test (Severiens and Ten Dam, 1994), while divergent thinking tasks have generally not shown consistent gender differences (Baer, 1999). In the absence

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of information on the specific female participants in this report, it is difficult to comment on these differences. The differences are probably not due to the females weighing less and therefore receiving higher drug doses because gender differences are apparent in pre-drug measures.

Methodological limitations of the Harman et al. report. Despite the improvements in some tasks, there are three caveats that must be considered before attributing these improvements to mescaline: the lack of a placebo control, the inconsistent administration of tests, and the apparent co-administration of other pharmacological agents.

First, in the absence of a placebo condition, pre-post changes could have been due to factors other than drug effects. For example, initial scores may have been artificially low due to lack of familiarity with the tests or stress during unfamiliar testing conditions. Thus, without a placebo, one cannot know if the during-mescaline measures were better-than-expected or if the before-drug measures were worse-than-expected.

Second, the inconsistent pattern of test administration suggests a potential confound. Fatigue from taking one test could decrease performance in other tests. Alternatively, if test taking was not mandatory, data might have been selectively collected from more motivated or better performing participants. To examine this, I attempted to correlate number of tests taken with scores in the three tasks. There were no significant correlations with the Purdue Creativity and Witkin's Embedded Figures tests. Number of tests significantly predicted change in performance in the Miller Object Visualization task ($R^2 = 0.2169$, $p = 0.008$, **Figure 2d**), the task with the largest sample and the one that is listed first on the data sheet. This raises the question of whether individuals who participated in fewer tests disproportionately represent those who would have shown decreased performance had further measurements been made.

Third and most worrisome, the preliminary report of the study indicates that participants received methamphetamine and chlordiazepoxide along with the mescaline: "In the individual sessions the drug regime consists of psychic energizers and a psychedelic drug (200 mg. of mescaline sulphate in these experiments), usually with additional energizer at mid-day" (Fadiman et al. 1965, p 4). The nature of these energizers is clarified later in the report where methedrine (methamphetamine) and librium (chlordiazepoxide) are explicitly mentioned (ibid, p B-1). Because the co-administration of other drugs was not described in the peer-reviewed publication by Harman et al. in Psychological Reports, very few subsequent commentators have noted this confound (Krippner (1968) notes the use of "energizers" without comment).

This polypharmacy was not unusual for psychedelic psychotherapy in the 1960s (e.g., Leuner, 1967). Nonetheless, it is unusual for controlled psychedelic research and substantially limits possible conclusions about psychedelics *per se*. Some or all of the objective measures employed by Fadiman and colleagues may be sensitive to benzodiazepines and stimulants. I have found no studies of benzodiazepines influence on the tasks used to measure creativity, but found several studies of the effects of amphetamines on these tasks. For example, stimulants can improve performance on Embedded Figures tasks (Farah et al., 2009; Callaway, 1959), although they do not appear to alter 'alternate uses' tasks like the Purdue Creativity task (Farah et al., 2009; Evans and Smith, 1964) or change a mental rotation task (Kennedy et al., 1990) similar to the Miller Object Visualization task (which involves mental folding). More generally, stimulants enhance some effects of psychedelics (e.g., animal drug discrimination in Munzar et al., 2002) and could be plausibly predicted to ameliorate some psychedelic-induced cognitive deficits, such as impairments

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in attention. Thus, even if stimulants and/or benzodiazepines do not improve creativity on their own, there may be synergistic or otherwise nonlinear effects of combining these drugs with psychedelics. This makes it perilous to attribute any changes seen in the study to mescaline alone.

What do these studies tell us about the effects of psychedelics on creativity?

To the extent that there is any trend from the quantitative measures in these studies, results are consistent with reports that psychedelics cause a change in cognition that gives rise to unusual or novel thoughts. Setting aside the discrepant trends for changes in the Embedded Figures tasks, significant improvements were seen by Harman and colleagues (1966) in the number of alternate uses suggested in the Purdue Creativity task and by Zegans and colleagues (1967) in the originality of word associations in Rapaport Word Association Test. These changes are consistent with the reports of perceived insights and altered sense of meaning discussed earlier. Yet if we consider all the tasks that failed to show significant changes, the quantitative measures in these studies appear unimpressive. This is particularly true when they are compared to self-report measures and qualitative descriptions of the strong impact psychedelics have had on some individuals. Disappointingly, the quantitative measures do not seem to have captured these changes.

Failure of these quantitative measures could be attributed to at least three potential methodological limitations. First, the quantitative tasks may have failed to tap into the specific domains improved by psychedelics. However, it might be questioned whether psychedelics really improve creativity in general if they have such specific effects that the employed batteries failed to measure the changes. A second limitation may be failure to measure and control for the variability of psychedelic effects. Individuals, particularly the psychedelic-naïve, may not only experience increased feelings of insight and altered meaning, but also dysphoric feelings of confusion and loss of meaning (e.g., (Linton and Langs, 1962). It may be that many participants in these studies had dysphoric responses. Since these studies did not include acute measures of mood or other psychedelic effects this source of variance is unaccounted for. A third potential issue is that the measures may have failed to engage the participants. Anecdotally, individuals on psychedelics may experience research procedures as less relevant and interesting than their spontaneous thoughts and experiences. Similarly, Wallach (1971) has emphasized the importance of game-like conditions for maximizing creativity. Thus, a lack of engagement may have played some role. Yet the professionally relevant problem-solving task used by Harman et al. was selected to minimize this problem, and only about 50% of participants felt their performance was improved. Given that the researchers' attempted to create an expectation of improvements and participants were not blinded to either this attempt or the study hypotheses, 50% is not an impressive number.

A final and fundamental issue is that creativity may be too specific of a construct to characterize the putatively beneficial cognitive changes that psychedelic users report. For example, in the study of McGlothlin et al. (1967), only 25% felt the LSD had increased their creativity while 50% felt it was an experience of lasting benefit and 50% felt the experience enhanced their understanding of self and others. Thus, feelings of creativity are a variable subset of the changes individuals attribute to psychedelics. As psychedelics have retained their reputation for enhancing creativity and other benefits, there may be value in studying psychedelic users in order to develop a typology of the perceived benefits and harms and learn how users attempt to maximize benefits. In the final sections of this paper, I discuss two broader theories of psychedelic effects that subsume these variable feelings of creativity: release of representations and alterations of Bayesian inference.

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Released representations as a potential general mechanism of psychedelic-induced changes in creativity

If psychedelics do not invariably improve creative performance, can we delineate the more general effects of psychedelics that only sometimes produce perceptions of improved creativity? Historically, most theories of psychedelics (and theories of hallucinations in general) have seen the drugs as facilitating release of stored representations or memories, often by decreasing sensory input, which in these theories is thought to normally constrain activation of representations.

The first release theory of hallucinations was developed by Hughlings Jackson (Taylor and Walshe, 1931) and was later extended to include LSD-induced hallucinations by West (1962). Related to this type of theory are those in which hallucinations impair the gating of representations. Geyer and Vollenweider (2001; Geyer and Vollenweider, 2008) and their colleagues hypothesize that psychedelics impair the ability of the thalamus to selectively gate information, which leads to continued inappropriate activation of representations and overprocessing of sensory and interoceptive information. Whether psychedelics are conceptualized to facilitate release of stored representations or prevent filtering out of perceptions and representations, these theories predict that the drugs will increase the availability of concepts to consciousness (Zegans et al., 1967; Harman et al., 1966). This could facilitate generation of new ideas, but would not necessarily improve accurate evaluation of these ideas.

In the influential Cattell-Horn-Carroll (CHC) model of cognitive ability, this suggested domain of psychedelic effects primarily falls under Factor Glr (Long-term Storage and Retrieval), which includes the ability to retrieve or reconstruct stored information (e.g., concepts, items, names, etc.) through association (McGrew, 1997). Changes in availability of representations to consciousness could be predicted to have effects on creativity if creativity involves the tendency or ability to form numerous or unusual associations (Barron and Harrington, 1981). The divergent thinking tasks and Mednick's Remote Associates Test that were used in the psychedelic-creativity studies reviewed above would be predicted to be sensitive to effects of drugs in this domain.

More recently, researchers have implicitly assessed changes using reaction time measures in a semantic priming paradigm (Spitzer et al., 1996; Gouzoulis-Mayfrank et al., 1998). This paradigm is conceptually similar to Mednick's Remote Associates Test but may be more sensitive to subtle changes since it uses differences in response time rather than correct solutions to word puzzles. In a semantic priming paradigm, a string of letters is shown on a computer screen and a participant has to indicate whether it is a word or a non-word. If the participant is shown a semantically-related word shortly after the string, it speeds response to related words compared to unrelated words (or nonwords). The theoretical explanation for this facilitation of response is that the initial word produces a spread of activation to representations of related words in semantic memory, which reduces the amount of additional network activation needed to identify that the target is a real word (Neely, 1977). Indirect semantic priming refers to facilitation of response when less closely related word pairs are used, which are usually pairs related by a mediating word (e.g., "lemon" and "sweet", which are related via "sour"). Use of pairs of indirectly related words allows one to test whether activation of associations extends to more distant associations than is normally the case. Studies suggest this is true in individuals with schizophrenia that includes thought disorder (Pomarol-Clotet et al., 2008).

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Spitzer et al. (1996) studied the effects of 0.2 mg/kg psilocybin on semantic priming in eight healthy participants and found increased indirect semantic priming. Gouzoulis-Mayfrank et al. (1998) attempted to replicate the results of Spitzer et al. using the same task in a placebo-controlled study with groups of eight volunteers given either 0.2 mg/kg of the psychedelic psilocybin, 2 mg/kg of the entactogen MDE, 0.2-0.4 mg/kg of the psychostimulant methamphetamine, or placebo. They found a trend towards the same effect after psilocybin, but not after MDE or methamphetamine. Except for a single outlier participant, the change in indirect semantic priming tended to correlate with blood concentrations of the psychedelic. Thus, psychedelics (but not related drugs) may alter associations and activation of representations and further work in this area would appear promising.

Hallucinogen effects on cognitive functioning as seen from a Bayesian framework

Facilitation of representations may account for some aspects of the drugs' effects and could explain their variable effects on creativity measures. However, this account does not seem to explain the broader phenomenology of psychedelics. Contemporary neuroscience has moved from filter-based models toward theories, such as hierarchical Bayesian ones, that regard the brain as attempting to predict regularities in the environment in order to successfully interact with it (Friston et al., 2006; Summerfield and Koechlin, 2008; Lee and Mumford, 2003). Although it represents only one of the many useful approaches to understanding cognition and the brain, a hierarchical Bayesian framework can provide insights into the effects of psychedelics on creativity and cognition.

Hierarchical Bayesian theories have been proposed as a basic principle for brain function (Friston et al., 2006; Summerfield and Koechlin, 2008; Lee and Mumford, 2003) and were recently used to explain the neurochemistry of psychosis (Corlett et al., 2009). In hierarchical Bayesian models, brain systems are seen as arranged in hierarchies in which each level of the hierarchy attempts to predict bottom-up input from a lower level using prior beliefs that have been obtained by top-down feedback from a higher-level area. Mismatches (prediction errors) from each level form the layer's output to the next higher level. These bottom-up prediction error signals indicate that the existing interpretation has not fully accounted for the input and some readjustment at a higher level in the hierarchy may be needed. In Bayesian theory, perception and inference are based on representations of both the likelihood (i.e., how well the hypothesis predicts the input) and the prior probability (i.e., how probable the hypothesis was before the input) of different hypotheses, according to Bayes theorem. The hypothesis with the highest posterior probability (i.e., most probable given the input) is selected as true and, for perception, determines the perceptual representation that is experienced.

Psychedelics might impair Bayesian inference in a number of ways. In their model of psychosis, Corlett et al. (2009) suggest that aberrant top-down signals might lead to hallucinations while aberrant persistent bottom-up signals can lead to delusions by indicating that the current priors are wrong and that beliefs need reevaluating. They suggest LSD-like drugs decrease the reliability of bottom-up signals while preserving the top-down signal that can add structure to this noisy bottom-up signal. This suggestion is in keeping with traditional release theories of psychedelic effects (West, 1962; Nichols, 2004) and early animal electrophysiological studies (Evarts et al., 1955; Bishop et al., 1958; Phillis and Tebecis, 1967; Curtis and Davis, 1962) that emphasize a role for decreased fidelity of bottom-up sensory signals in explaining LSD effects (although other studies paint a more complex picture: Purpura, 1967; Koella and Wells, 1959; Watakabe et al., 2009; Seeburg et al., 2004; Laurent et al., 2002). While studies in humans are limited, a recent study did find a relationship between greater visual changes after the psychedelic MDA and lower perceptual ability, consistent with the hypothesized impairment of a bottom-up signal (Baggott et al., 2010).

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From a Bayesian perspective, creativity could be interpreted as resulting from novel perceptions or other types of novel conclusions. Paradoxically, then, creativity could be caused by the aberrant bottom-up signals that Corlett et al. (2009) hypothesize to occur after psychedelic administration. Such bottom-up signals would indicate that further, higher-level (and potentially more abstract) processing is needed to understand the phenomenon at hand. Theoretically, this might lead to more extensive consideration of phenomena that are normally taken for granted. This seemingly paradoxical effect by which error could improve cognition is reminiscent of the large literature in psychology showing that disagreement can improve decision-making (references). The potential benefits of added error have also been an area of great interest in systems and theoretical neuroscience. Rather than being only disruptive, noise may increase the reliability of neural information processing (Faisal et al., 2008; Ermentrout et al., 2008). Of course, empirical research — as can be done with psychophysical procedures to estimate internal noise (Bennett et al., 1999; Hayes and Merigan, 2007; Pelli and Farell, 1999; Kersten et al., 1988) — is needed to test this account of serotonergic psychedelic effects.

Filtering failures induced by psychedelics in the theory of Vollenweider and Geyer can be re-interpreted within a Bayesian framework. Filtering and ignoring of sensory information would normally be based on statistical information about the environment and resulting expectations about what is likely. At any given level of processing, filtered-out information is that which is fully predicted. The psychedelic-induced attentional deficits and filtering failures hypothesized by Vollenweider and colleagues can thus be seen as a failure to predict the unfiltered data or, equivalently, as the judgment that these data are unexpected. This sense that data are unexpected might be plausibly related to the qualitative feelings of altered meaning reported by psychedelic users. When prediction errors have a phenomenological component, they could be experienced as the sensation that the unpredicted things are salient and meaningful. Thus, one strength of Bayesian theories is that they can provide an appealing explanation for why psychedelics cause feelings of changed meaning.

Conclusions

Psychedelics have unique and powerful effects and yet, in Western culture, only have religious and experimental use. The reported effects of psychedelics on creativity suggest other potential socially important uses for these drugs. Yet controlled research on psychedelics and creativity is lacking and available results are unimpressive. Rather than looking to this limited literature for answers, it may be more informative to conduct qualitative research to document how individuals use psychedelics to enhance their creativity or gain other perceived benefits. Ultimately, creativity may not be the most appropriate construct for characterizing either the acute or long-term changes that people often report after psychedelic exposure. Hallucinogen-induced feelings of creativity may be an inconsistent by-product of more fundamental cognitive changes, such as alterations in activation of representations or changes in Bayesian inference. Research on the effects of these drugs using these paradigms may provide insights into the drugs' sometime profound impact on individuals.

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Legends for Table and Figures

Table 1: Quantitative Creativity Measures used in Hallucinogen Studies
N.S. = Not significantly changed, SS = subjects; blank cells indicate the task was not used in that study. * = methamphetamine and chlodiazepoxide also given.

Figure 1: Archived data sheet from Harman et al. (Harman et al., 1966).

Figure 2: (A) Males perform better than females in Miller Object Visualization task (N = 19M, 8F; $F = 50.67$, $df = 1$, $p = 3.9 \times 10^{-09}$) but there is no effect of measurement time; (B) Participants improved (become faster) during mescaline on Witkin's Embedded Figures task ($F = 4.38$, $df = 1$, $p = 0.047$) and females were slower than males ($F = 50.67$, $df = 1$, $p = 3.92 \times 10^{-09}$); (C) Fluency scores improved (increased) in Purdue Creativity task during mescaline (N = 17M, using only the first session of participant 207, $t = -2.27$, $df = 16$, $p = 0.04$). (D) Change in Miller Object Visualization score is significantly predicted by number of tests taken ($R^2 = 0.217$, $p = 0.008$). Black lines are male and red dotted lines female participants. In C, triangles are participant 207's first (pointed side up) and second (pointed side down) sessions. Scores jittered to reduce overlap.

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Table 1

Task	Description	Acute effects of 0.5 µg/kg LSD, between SS (Zegans et al., 1967)	Acute effects of 200 mg mescaline, within SS (Harman et al., 1966)	Short term (1-week) effects of 200 µg LSD, within SS (McGlothlin et al., 1964)	Long term (6-month) effects of 200 µg LSD, between SS (McGlothlin et al., 1967)
Divergent Thinking / Activation of Remote Associations					
Rapaport (1958) Word Association Task	Provide word associations; responses rated on originality and latency.	Originality improved			
Guilford Alternate Uses (1967); Purdue Creativity (Lawshe and Harris, 1960)	Name as many uses as possible for pictured objects.		Purdue: Improved		Guilford: N.S.
Guilford (1967) Associational Fluency	List words similar in meaning to a given word.			N.S.	N.S.
Guilford (1967) Plot Titles	Think of clever captions to one-paragraph stories.				N.S.
Guilford (1967) Consequences	Discuss the results if people no longer needed or wanted to sleep; responses rated on originality and quantity.			N.S.	
Guilford (1967) Alternate Signs	Give signs and symbols related to the meaning of a word			N.S.	
Guilford (1967) Ideational Fluency	Name fluids that will burn.			N.S.	
Mednick (1968) Remote Associates Test	Identify a fourth word that is associated with three seemingly unrelated words, such as cottage, blue, mouse (correct response: cheese).	N.S.		N.S.	N.S.
Perception and Imagery					
Gottschaldt (1926) Figure-Perception Test; Witkin's (1950) Embedded Figures Test; Guilford (1967) Hidden Figures	Determine which simple target figure is hidden in complicated figures	Gottschald: saw trend worsening in some analyses	Witkin's: Improved		Guilford: N.S.
Miller (1955) Object Visualization task	Mentally determine the three-dimensional shape made when a flat outline is folded		Reported improved (reanalysis couldn't confirm)		
Tachistoscope image identification (Zegans et al., 1967)	Identify briefly presented line drawings and words	N.S.			
Creative Production					
Mosaic design test (Zegans et al., 1967)	Make pattern from colored geometric tiles to be rated by judges	Worsened			
Draw-A-Person (Machover, 1949)	Draw a whole person and a person of the opposite sex; responses rated for imaginativeness				Worsened
Thematic Apperception Test	Invent stories about pictures; responses rated for originality				N.S.

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Figure 1

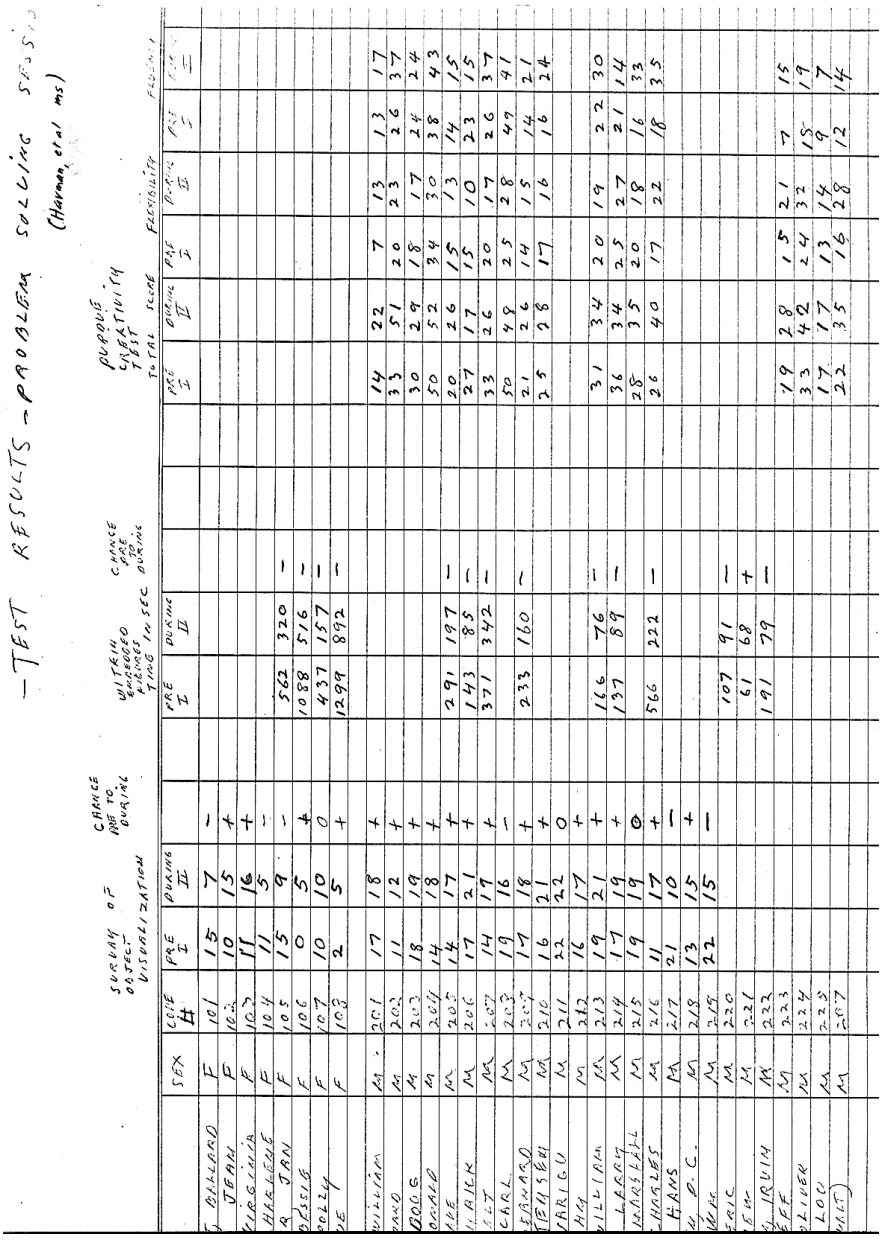
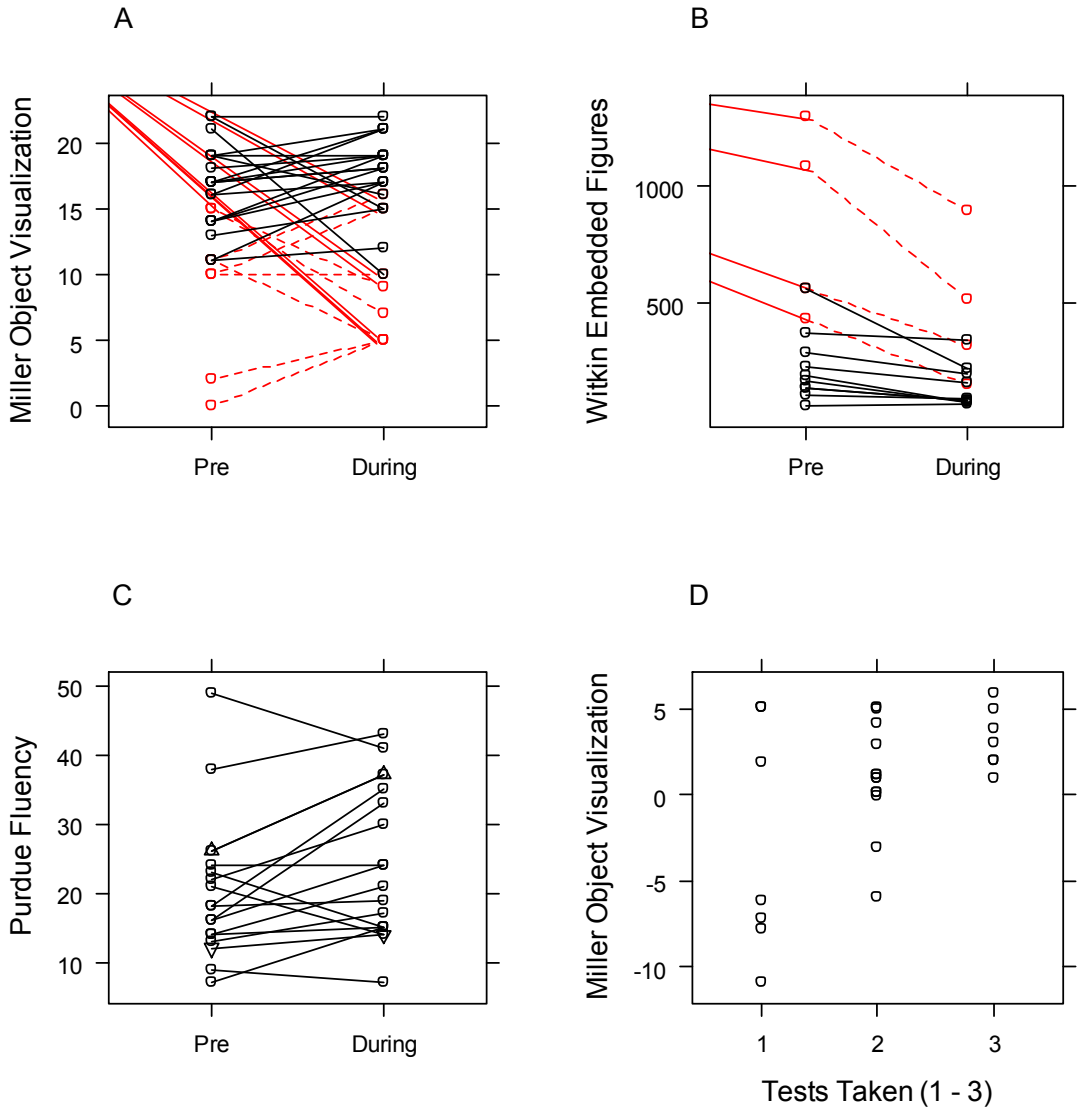


Figure 2



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Appendix: Renalysis of Harman data

Reanalysis of quantitative test results from Harman et al.
Harman and colleagues analyzed their data by first classifying whether individuals improved or not on each measure. They then used chi-square goodness-of-fit tests to determine if improvement occurred more often than expected on each measure. No graphical or tabular presentation of individual scores was presented. This analysis approach was reasonable in the mid-1960s. However, more detailed analyses are now easily conducted. Unexpectedly, it proved difficult to replicate the original chi-squared analyses and I ultimately confirmed statistical significance in only two of three tasks. In addition, I also tested for possibly overlooked gender differences in the data and detected gender differences in both tasks that included females.

Miller Object Visualization. Scores for the Miller Object Visualization task are plotted in **Figure 2a** with higher scores indicating better performance. Harman and colleagues reported significant improvements in this task. However, the reanalysis did not replicate the original findings. I initially attempted to replicate Harman's analysis and conducted a chi-squared test on data that had been categorized as improved or not. This showed a trend that did not achieve significance (18 of 27 participants improving, chi-squared = 3, df = 1, p-value = 0.08) and did not replicate the result reported by Harman and colleagues ("chi-squared = 6.00, degrees of freedom (df) = 26, $p < 0.02$"). I note that one could arrive at the reported chi-squared value if the three participants with unchanged Miller Object Visualization scores were excluded (18 of 24 improving, chi-squared = 6.00). However, excluding data points that do not fit one's hypothesis would be difficult to justify.

Rather than using the data categorically, it seemed reasonable to analyze them quantitatively. A paired two-sided t-test did not confirm any effect of measurement time (t = -0.637, df = 26, p-value = 0.53) with 95% confidence intervals for the change estimated as -2.35 to 1.24. (A one-sided t-test was of course also not significant: p = 0.26.) Visual inspection of the data in Figure 2 strongly suggested a main effect of gender, with females (in red) having lower scores than males (black). I therefore constructed a linear model in which gender and measurement time (pre, during) and a gender*time interaction term were used to predict performance. This analysis confirmed only a significant effect of gender ($F = 50.7$, df =1, $p < 0.001$**)**. Thus, while there were significant gender differences, there was no evidence of a significant effect of drug administration on this task.

Witkin's Embedded Figures. Harman and colleagues reported significant improvements in the Witkin's Embedded Figures task, plotted in **Figure 2b**. I did confirm this. The attempted replication of their chi-squared analysis of binary (improved vs. not improved) data was significant (13 of 14 participants improving, chi -squared = 10.28, df = 1, p-value = 0.0013). Because the number of participants in one cell was very small, I also conducted a binomial test and estimated the probability of improvement as 0.93 (95%CI: 0.66 – 1.00) using the method of Clopper & Pearson (1934).

Treating the data quantitatively, I conducted a paired t-test, which also confirmed that participants decreased the time needed to complete this task by 168 sec (95%CI: 68 – 269 sec, t = 3.62, df = 13, p = 0.003). To examine a possible effect of gender, I used a linear model in which gender and measurement time and a gender*time interaction term were all used to predict performance. This confirmed significant effects of measurement time ($F = 4.38$, df =1, $p = 0.047$) and gender ($F = 50.7$, df =1, $p < 0.001$**)**. Thus, there were significant gender differences (with females worse than

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males) and participants improved between the first and second administration of the task, consistent with a drug effect.

Purdue Creativity test. Finally, Harman and colleagues reported significant improvements in fluency scores of the Purdue Creativity test, plotted in **Figures 2c**. This change in fluency led to significant changes in the total score (which summed fluency with a flexibility score reflecting range of solutions). My reanalysis was not able to confirm improvement using the originally reported categorical analysis. However, fluency scores appeared significantly changed using one possible quantitative analysis. Analyzing these data was not completely straightforward because one participant (207) appeared to provide measurements twice in the 18-person sample. In an attempt to replicate the original categorical analysis, I provisionally included both of this participant's sessions and then conducted secondary analyses with individual sessions included. No matter how the data were analyzed, chi-squared (and binomial test) results were not significant for fluency scores but did provide trends in the expected direction. Accordingly, the categorical statistical analysis failed to find results consistent with the conclusion of Harman et al. ("13 of 18 males; chi-squared = 5.88, df = 12, $p < 0.02$").

Conducting a paired t-test on fluency scores and including either both of participant 207's sessions or only his first session resulted in significant results (both sessions included: $t = -2.33$, $df = 17$, $p = 0.03$; first session only: $t = -2.27$, $df = 16$, $p = 0.04$). Inclusion of only the second session produced a trend in the same direction ($t = -2.04$, $df = 16$, $p = 0.06$). Because it is questionable whether a task that asks one to name unusual uses for objects is repeatable, it seems most defensible to use the first measure only (assuming they are listed chronologically). Thus, it seems reasonable to consider this result as significant even though I have been unable to replicate Harman's exact results using their original statistical approach.

Conclusions from reanalysis of the Harman et al. report. To summarize, while Harman et al. reported clear improvement in all three quantitative tasks in their creativity study, I find that improvements are present in the Witkin's Embedded Figures and Purdue Creativity tasks, while performance in the Miller Object Visualization task does not significantly improve.

In addition, I find significant gender differences in scores in both tasks in which there were female participants. Gender differences have sometimes been reported in the Witkin's Embedded Figures test (Severiens and Ten Dam, 1994), while divergent thinking tasks have generally not shown consistent gender differences (Baer, 1999). In the absence of information on the specific female participants in this report, it is difficult to comment on these differences. The differences are probably not due to the females weighing less and therefore receiving higher drug doses because gender differences are apparent in pre-drug measures.

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