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Effects of psychedelic virtual reality on divergent thinking

Seminary work

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Running head: Effects of psychedelic virtual reality on divergent thinking

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Psühhedeelse virtuaalreaalsuse mõju divergentsele mõtlemisele

Kokkuvõte

Osad uuringud on leidnud, et psühhedeelikumid suurendavad divergentset mõtlemist, kuid seda efekti põhjustav mehhanism on teadmata. Selle uuringu eesmärk oli välja selgitada, kas psühhedeelikumide mõju üheks teguriks võivad olla nende tekitatud intensiivsed visuaalsed kogemused. Uurisime seda küsimust virtuaalreaalsuse abil, mis jäljendas psühhedeelseid kogemusi. Divergentset mõtlemist mõõdeti *AUT*-ga ja *DAT*-ga. Tulemused näitasid, et psühhedeelsel virtuaalreaalsusel puudus mõju divergentsele mõtlemisele. Arutletakse mitmete tegurite üle, mis võisid põhjustada seda negatiivset tulemust.

Märksõnad: psühhedeelikumid, virtuaalreaalsus, divergentne mõtlemine

Effects of psychedelic virtual reality on divergent thinking

Abstract

There have been studies that have found that psychedelics increase divergent thinking, but the mechanism underlying this effect is unknown. The aim of this study was to find out whether one factor underlying the effects of psychedelics could be the intense visual experiences elicited by them. We studied this question by using virtual reality that mimicked psychedelic experiences. Divergent thinking was measured with the AUT and the DAT. The results showed that psychedelic VR had no effect on divergent thinking. Several factors that might have contributed to this negative finding are discussed.

Keywords: psychedelics, virtual reality, divergent thinking

Introduction

Psychedelics induce their effects as agonists on serotonin 5-HT2A receptor (Andersen et al., 2020; Madsen et al, 2019), as it has been shown that 5-HT2A receptor antagonists (e.g. ketanserin) hinder psychedelic effects (Preller et al., 2017). The intensiveness of a psychedelic for the 5-HT2AR receptor correlates solidly with its behavioral and subjective potency (Glennon et al., 1992). Psychedelic experiences are characterized by a mystical experience (Griffiths et al., 2006; Roseman et al., 2018), geometric hallucinations (Bressloff et al., 2002) and ego dissolution (Nour et al., 2016). Most known classic psychedelics are DMT (dimethyltryptamine), mescaline (found in *Lophophora williamsii*), 5-MeO-DMT (found in *Bufo alvarius*), LSD (lysergic acid diethylamide) and psilocybin, that is found in "magic mushrooms" (Andersen et al., 2020; Nutt et al., 2020; Schultes, 1938; Weil and Davis, 1994). Thus the array of effects is mediated by 5-HT2A receptor agonism, that depends on certain psychedelic and its dosage (Haijen et al., 2018).

Psychedelics work by reducing top-down control and deactivating the default mode network (DMN) (Carhart-Harris and Friston, 2019), that has been linked to self-consciousness (Fingelkurts et al., 2012), mental time travel (Østby et al., 2012) and secondary cognition (Carhart-Harris et al., 2014). This is in accordance with the entropic brain hypothesis (Carhart-Harris et al., 2014) and the free energy principle (Friston, 2010), that proposes that living systems seek to minimize the brain entropy (uncertainty) and resist disorder while developing, processing, and behaving in a certain way (Carhart-Harris and Friston, 2019). According to the entropic brain hypothesis the mind has evolved from primary consciousness to secondary consciousness (Carhart-Harris et al., 2014). Primary consciousness is described by less ordered neurodynamics (high entropy) and unconstrained cognition. Secondary consciousness, also known as normal waking consciousness, has more ordered neurodynamics and constrained cognition. Secondary consciousness works to process the world as accurately as possible and therefore it blocks out unnecessary information. The function of this is to minimize uncertainty and surprise about the environment. The psychedelic state is associated with primary consciousness (Carhart-Harris et al., 2014) and therefore it allows more bottom-up information flow and relaxes high-level priors (Carhart-Harris and Friston, 2019).

Therapeutic use of psychedelics

Classic psychedelics have been used in healing settings since ancient times (Guerra-Doce, 2014) although their prevalence is unknown (Johnson et al., 2019). In 1938 Albert Hofmann synthesized LSD- a novel compound that sparked interest in its psychiatric applications (Hofmann et al., 2013). LSD was used as an assistance in psychotherapy (Busch and Johnson, 1950; Chandler and Hartman, 1960) and to treat addiction (Abramson, 1967). After that other classic psychedelics, e.g. psilocybin, were popularized (Hofmann et al., 2013). Classical psychedelics were studied within psychiatry from the 1950s to 1960s (Grinspoon, 1981). The best results came from treating addiction (Savage and McCabe, 1973) and cancer affiliated psychological distress (Richard, 1979). The research was also boosted by a discovery that anaesthetics, e.g. ketamine, display effects similar to psychedelics (Domino et al., 1983). The research stopped in the 1970s as many classical psychedelics were popular among the anti-Vietnam war movement (Nutt et al. 2013; Wesson, 2011). After that research reappeared late in the 20th century (Strassman and Qualls, 1994). In the 21th century the therapeutic use of psychedelics is mostly researched at Johns Hopkins University as well as at Imperial College London (Nutt et al., 2020). Recent studies (Andersen et al., 2020; Carhart-Harris et al., 2016; Griffiths et al., 2016; Rucker et al., 2018) have shown that psychedelics could still be suitable for therapeutic use despite their infamous history (Nutt et al., 2020).

An open-label feasibility study showed that a high-dose of psilocybin reduced treatment resistant depression, measured by 16-item Quick Inventory of Depressive Symptoms (QIDS), 7 days and 3 months after the treatment (Carhart-Harris et al., 2016). Results also showed a reduction in anhedonia and anxiety. As a limitation of the study the authors highlighted that it is possible that other factors like small sample, expectancy bias, open-label design also had an effect on the results. Therefore psilocybin could be effective for treating depression when done with suitable safeguards. The study concludes that because of its novel pharmacological activity psilocybin could be an effective addition to current therapies (Carhart-Harris et al., 2016). An important predictor of effective long-term outcome was high level of Oceanic Boundlessness (OBN), that is part of the altered states of consciousness questionnaire (ASC) (Roseman et al., 2018). Its subcomponents are blissful state, spiritual experience, experience of unity, disembodiment and insightfulness (Studerus et al., 2010). OBN has many similarities to the MEQ questionnaire, that evaluates the occurrence of the mystical experience. Lower

levels of Dread of Ego Dissolution (DED) (part of ASC) also predicted long-term effectiveness of the psilocybin therapy for treating treatment resistant depression. DED is associated with acute anxiety and impaired control. Thus it is suggested that the effects are also mediated by the experience and not only by the pharmacological action of psilocybin (Roseman et al., 2018). This could also apply to other classical psychedelics (Yaden and Griffiths, 2020).

A randomized double-blind study done with people who had life-threatening cancer related anxiety and depression displayed the positive effects of high psilocybin dose (Griffiths et al., 2016). Results showed a decline in self-rated and in clinician-rated measures of anxiety and depression that lasted for at least 6 months. The overall clinical response measured at 6 months was 78% for depression and 83% for anxiety. The overall symptom reduction was 65% for depression and 57% for anxiety. Other positive effects were increases in life meaning, optimism, death acceptance and quality of life. Mystical experience, measured with MEQ30, correlated significantly with the long-term therapeutic outcomes. Thus, a dose of psilocybin presented enduring and noteworthy decreases in anxiety and depression together with decline of death anxiety and rise in life meaning.

Psychedelics and creativity

The psychedelic state is described by unconstrained cognition that is linked to fluctuations in affect and increased associative thinking (Carhart-Harris et al., 2014; Girn and Christoff, 2019; Preller and Wollenweider, 2016; Studerus et al., 2011). These two components are essential to creative generation (Girn et al., 2020). There have been previous studies (Kuypers et al., 2016; Mason et al., 2019; Mason et al., 2021; Prochazkova et al., 2018) that have concentrated on the question whether the psychedelic state has an effect on divergent thinking, i.e., on finding novel and out-of-box ideas (Girn et. al, 2020). Dynamic framework of thought (Girn et al., 2020) puts creative thought in a continuous theoretical space with other forms of thought, such as dreaming, rumination, goal-directed thought and mind-wandering. Psychedelic state is with low automatic and deliberate constraints, therefore it has a high potential for generating creative ideas (Girn et al., 2020).

Kuypers and colleagues found that drinking ayahuasca plant tea that contains 5-HT2A receptor agonist (N,N-DMT) increases divergent thinking and decreases convergent thinking that were measured with Picture Concept Task (PCT) (Kuypers et al., 2016). Pattern/Line Meanings task

(PLMT) was used to measure divergent thinking, but no effects were observed on this task. Mason et al (Mason et al., 2019) found that psilocybin increased both divergent and convergent thinking but at different times. Divergent thinking was enhanced the morning after psilocybin consumption and returned to the baseline 7 days later. Convergent thinking was unchanged the morning after but increased 7 days later. In this study PCT was also used to measure convergent and divergent thinking. Prochazkova and colleagues (Prochazkova et al., 2018) found that psilocybin increased divergent thinking and also convergent thinking. Divergent thinking was measured with the AUT (The Alternative Uses Task) and convergent thinking with the PCT (Picture Concept Task). Thus the effect on convergent thinking was inconsistent in the Kuypers et al. (2016) study when compared to the two last studies (Mason et al., 2019; Prochazkova et al., 2018). Therefore different psychedelics and different tasks could have an effect on these results although increased divergent thinking during the acute phase is common to all three studies (Kuypers et al., 2016; Mason et al., 2019; Prochazkova et al., 2018).

On the contrary, a recent placebo-controlled, double-blind, parallel group design study (Mason et al., 2021) found that psilocybin decreased deliberate creativity during the acute phase. Particularly, participants managed to generate less associations and ideas compared to the placebo group. However scores on AUT, specifically on novelty, were higher 7 days later compared to the placebo group. Psilocybin also increased the feeling of "insight", that is related to spontaneous creativity, during the active phase. Authors think one of the reasons could be that spontaneous insights typically arise in a state that is associated with broad attention and unconstrained attention. This is a state similar to the psychedelic experience. On the other hand deliberate creative cognition is linked to more focused attention and task demanding effort. Convergent thinking, measured by the PCT, was decreased during the acute phase and at follow-up 7 days later. Hence it is suggested that psilocybin has a construct- and time-related impact on creative thinking (Mason et al., 2021).

Virtual reality (VR) and psychedelics

Virtual reality is a computer technology used to immerse subjects in a simulated environment (Burdea and Coiffet, 2003). It is accomplished with a VR headset that provides a 3D experience of the virtual world. VR and psychedelics both alter perceptual experience, especially visual information (Aday et al., 2020; Barker, 2018; Suzuki et al., 2017) and have the ability to evoke a mystical experience (Glowacki et al., 2020; Roseman et al., 2018). Both are also used to treat

different mood disorders (Anderson et al., 2014; Griffiths et al., 2016). Glowacki and colleagues developed "Isness" virtual reality (Glowacki et al., 2020), that was created to evoke mystical experience that is sometimes described in psychedelic states (Barrett and Griffiths, 2018). Previous studies (Garcia-Romeu et al. 2015; Griffiths et al., 2016) have shown that the mystical experience is a good predictor of long term positive psychedelic therapy outcome. Mystical experience is characterized by transcendence of space and time, positive mood, ineffability and mysticism (Griffiths et al., 2006). They found that "Isness" experience was more intense than 16 and less intense than 3 previous psychedelic studies (Glowacki et al., 2020). In 7 studies the results were indistinguishable. Therefore psychedelic VR could be used to evoke "mystical experiences" that can be useful for therapy.

Moroz and Carhart-Harris (2018) suggest that virtual reality could also be combined with psychedelics for treating psychiatric disorders, e.g. PTSD, addiction, anxiety and depression. Psychedelics could enhance presence, sensitivity to the environment and virtual reality could provide stimulus. In this way virtual reality can help to model the experience or even help to evoke a mystical experience. For example VR may prove to be useful when the setting is overly clinical and thus leads to heightened anxiety in a therapy session. Future studies should assess the safety and effectiveness of this innovative combined therapeutic intervention (Moroz and Carhart-Harris, 2018).

This study aimed to evaluate whether psychedelic VR could also have an effect on divergent thinking as it has shown promising results evoking a mystical experience (Glowacki et al., 2020). Divergent thinking is important as it helps to act flexibly (Girn et al., 2020) and generate new novel ideas (Vincent et al., 2002). Psychedelics have shown promising divergent thinking enhancing characteristics during the acute phase in many previous studies (Kuypers et al., 2016; Mason et al., 2019; Prochazkova et al., 2018). Psychedelic virtual reality could be able to replicate the visual side of psychedelic experience, e.g. geometric patterns (Bressloff et al., 2002) and color enhancement (Abraham, 1983). Therefore, we postulated that the psychedelic VR would increase divergent thinking.

Method

Subjects

Six persons participated in the study, consisting of 3 males and 3 females. All of the participants were Estonians and university students. Convenience sampling was used as half of the participants knew the instructor. An invitation was sent to people through social media platforms. People could sign up for the study through Doodle. This study was approved by the Ethics Committee of the University of Tartu. The participants had to be healthy to participate and not have experienced any epilepsy symptoms. They could not participate if they had been diagnosed with schizophrenia or had experienced psychotic episodes. The participants were told about the potential hazards associated with virtual reality. They signed a written consent for collecting and publishing their data. The data remained anonymous and could not be linked to a specific participant.

DAT- The Divergent Association Task

The Divergent Association Task (DAT) was used to measure divergent thinking (Olson et al., 2020). It has been shown to be a reliable and easy to implement test for measuring creativity. In the DAT participants have to generate 10 different words in 4 minutes. The words have to be different from each other in terms of meaning. For example, the word “car” is more similar to the word “motorbike” than to the word “fork”. Therefore the word “fork” gives more points than the word “motorbike” in this example. All the 10 words have to be as far as possible from each other to get a bigger score. The score is calculated by comparing the mean semantic interval between used words using the GloVe algorithm. The test was done in Estonian because it was the mother language of the participants. The words were later translated into English to evaluate the results. The answers were recorded after non-psychedelic VR and psychedelic VR. The DAT can be found online at datcreativity.com.

AUT- The Alternative Uses Test

The Alternative Uses Test was also used to measure creativity (Guilford, 1950; Wallach and Kogan, 1965). This task measures the ability to come up with different solutions to open-ended questions. During this task participants were given two words that were commonplace household objects (e.g. chair) and they had to find most uses for it. In this experiment the participants were given words “pencil”, “clock” or “pillow”, “sock” . They had 3 minutes to generate the most uses for each object. The score was evaluated by three variables: originality (how unique is the given use compared to the other answers), fluency (number of uses generated) and flexibility (number of categories found for object's use). Originality is calculated using all the answers. Responses with the frequency of 1%-5% get 1 point and 2 points are awarded to answers with the frequency of 1% or less. Because of the small sample in the current study, unique answers got 2 points, answers mentioned by two participants got 1 point and answers mentioned by more participants got 0 points. Flexibility categories were made subjectively by the judges and each category got one point. For example categories for the word “pen” were weapon, writing/artwork, making music, design, precision throw and put between or/and underneath something. Two people judged the score for more coherence. Answers deemed inappropriate were excluded from the scores. The answers were recorded. This test has been used before to measure whether psychedelics enhance creativity (Mason et. al 2021; Prochazkova et. al 2018) and it correlates with the DAT (Olson et al., 2020).

Psychedelic virtual reality

This VR mimicked psychedelic-induced states by altering visual experience. The experience included geometric patterns, kaleidoscopic images (Frecska et al., 2019) and color enhancement (Abraham, 1983; Figure 1). Overview effect was used, as it could help induce a mystical insight (Yaden et al., 2016). Psychedelic music was used to minimize auditory distractions and help the participants focus on the experience. At the beginning of the experience was a 10 minute meditation. The aim of the meditation was to help the participants relax and focus on the current moment. The psychedelic VR lasted 60 minutes.

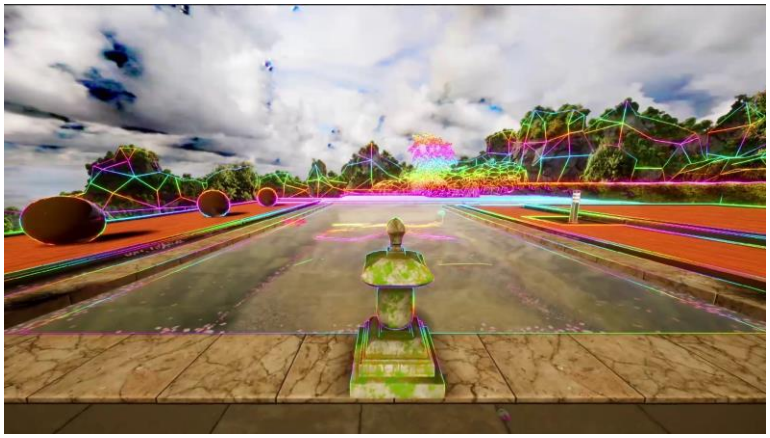

Figure 1. One example of psychedelic effects used in the current study: color enhancement in psychedelic VR condition.

Non-psychedelic virtual reality

Non-psychedelic control virtual reality consisted of different phases, but here specific psychedelic-like experiences were avoided. For example the person went through an ordinary virtual room and a plain natural setting (cave). At the beginning of the experience was a 10 minute meditation (same as before). The experience lasted 30 minutes.

Procedure

The experiment took place over three days. First the participants completed the DAT through CryptPad which was sent to their emails one day before the VR experience. Emails were collected during the sign-up to the study. The participants were guided to do the DAT task for a maximum of four minutes. The test had to be done on their personal computer, smartphone or tablet. The explanation of the test was given on CryptPad. It contained the following information: “This test is used to find out how the mind works. Please come up with 10 words that are as different as possible in terms of meaning. For example, the words car and motorcycle are alike, because both are means of transport. The words fork and car are not similar in terms of meaning and therefore give you more points. The first word is given. Rules are the following: You can only propose single words in Estonian; Only nouns (e.g., things, objects, concepts); No proper nouns (e.g., no names of specific people or places); No specialized vocabulary (e.g., no technical terms). You have four minutes to do this test. I recommend monitoring it with a timer. Please do the test on your own and do not use any help

from other sources". The given word was "car". Next two experiments were done in the University of Tartu Delta Center on two consecutive days.

On the second day the instructor guided the participant to sit on a chair that was in the middle of the laboratory. After that the participant was introduced to the virtual reality headset. The following information was given: "In this study we want to find out how virtual reality affects creativity. This is the VR headset that is used in this experiment. You can adjust it by the sides and it is connected to the computer that you can see next to the chair by a wire. The VR experience is played through the computer and its duration is about 30 minutes. At the beginning of the VR is a 10 minute meditation. After the VR experience two short tests are conducted. First one is the same test that you did yesterday on your own. The second test is similar. I will explain the tasks after the virtual reality. Please leave the headset on for these two tests. If it is okay, I would record your answers. Also be sure to let me know if you have any discomfort during the VR experience and if you happen to have any questions I would be happy to answer them now before we start." The instructor offered help with the headset and answered questions if needed. After the VR experience the participants were guided to stay lying on a chair that was in the laboratory. The instructor informed them that it was time for two tests. The same instructions were given for the DAT as in CryptPad. The instructor measured time with a timer on his phone. The first given word was "bush" or "ice". After that participants did the AUT. The following instructions were given: "Now it is time for the second test. I will say two words to you, that are common household objects (e.g. sofa) and you have to find the most uses for each word. I will record your answers. You have 3 minutes for 1 word and I will monitor the time. Be creative when doing this task." The participants were given words "pencil" and "clock" or "pillow", "sock". After the AUT the instructor thanked the participant and invited him/her to come back the next day for another VR-experience.

On the third day the instructor guided the participant to sit on a chair that was in the middle of the laboratory. He/she was given the following instructions: "Today the experiment set up is the same as yesterday but the duration of the virtual reality is about 60 minutes. Be sure to let me know if you experience any discomfort and if you happen to have any questions I would be happy to answer them now before we start the VR experience." The instructor offered help with the headset and answered questions if needed. Participants experienced psychedelic VR for about 60 minutes. After the experience the protocol was the same as in the previous day. The first given word in the DAT was "bush or "ice". In the AUT the participants had to find

most uses for the words “pillow”, “sock” or “pencil”, “clock”. After finishing the AUT a given participant was thanked for participating in the study and given a date for the experiment results. The virtual reality headset was cleaned after every participant to ensure safety. The results were revealed to the participants through email in the following months.

Data analysis

Data was analyzed using Microsoft Excel and GraphPad's t-test calculator that can be found online at https://www.graphpad.com/quickcalcs/ttest1.cfm. A within subjects design compared the outcomes of psychedelic virtual reality and non-psychedelic virtual reality on divergent thinking. Parametric paired t-test was conducted for comparing results after non-psychedelic VR and psychedelic VR. All of the 6 participants' data were used for the analysis. In the AUT the concurrence of scores and subscores (fluency, flexibility, originality) evaluated by two persons was calculated with Pearson Correlation Coefficient Calculator that can be found online at https://www.socscistatistics.com/tests/pearson/default2.aspx. Mean scores were calculated for the AUT subscores rated by two judges. The DAT results in Cryptbad were excluded from the study, because two participants gave answers that were not in accordance with the test rules. For example two words for one answer and specific names were used. Therefore the DAT scores after non-psychedelic VR and psychedelic VR were submitted for the final analysis and were calculated with paired t-test.

Results

AUT- The Alternative Uses Test

The results for the AUT are shown in Figure 2. The first rater's parametric paired t- test results for non-psychedelic VR and psychedelic VR were $t(5)=0.446$, $p=0.674$, $d=0.248$ for fluency, $t(5)=0.745$, $p=0.490$, $d=0.443$ for flexibility and $t(5)=0.968$, $p=0.377$, $d=0.201$ for originality. The second rater's parametric paired t- test results for non-psychedelic VR and psychedelic VR were $t(5)=0.000$, $p=1.000$, $d=0$ for fluency, $t(5)=0.202$, $p=0.847$, $d=0.084$ for flexibility and $t(5)=0.203$, $p=0.847$, $d=0.046$ for originality. The concurrence of all the AUT scores evaluated by two persons was 0.441(Pearson correlation coefficient) and $p=0.007$. Correlation

between two scorers was r=0.29, p= 0.368 for fluency, r=0.50, p=0.098 for flexibility and r=0.31, p=0.328 for originality.

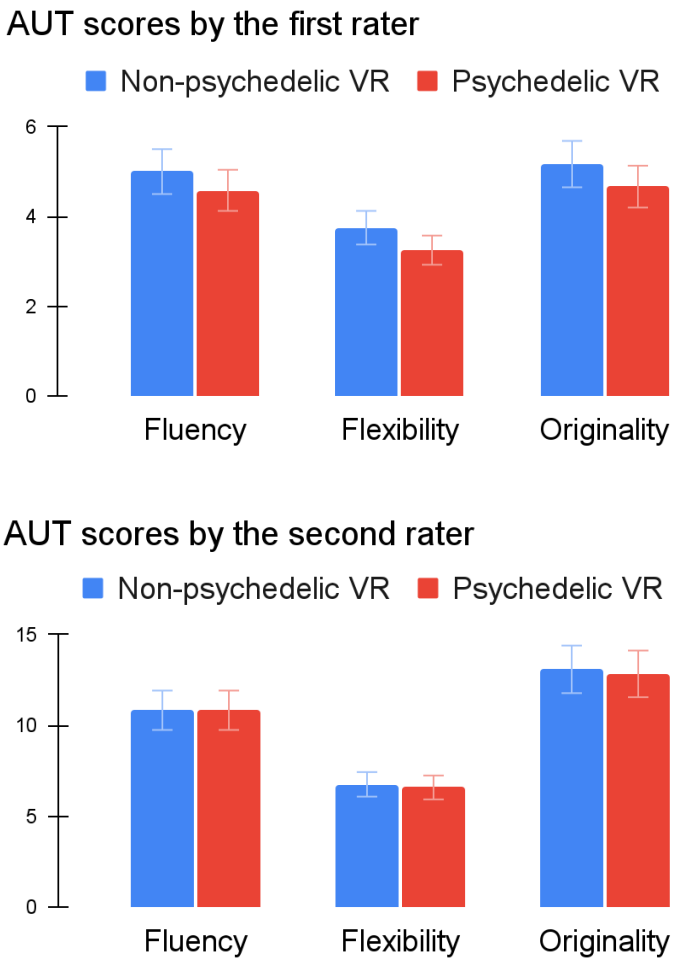

Figure 2. The AUT scores evaluated by two raters. Error bars indicate the standard error of the mean.

The mean scores (M) and standard deviation (SD) evaluated by the first rater were M=5, SD=1.483 (non-psychedelic VR), M=4.583, SD=1.855 (psychedelic VR) for fluency, M=3.75, SD=1.037 (non-psychedelic VR), M=3.25, SD=1.214 (psychedelic VR) for flexibility and M=5.166, SD=2.582 (non-psychedelic VR), M=4.666, SD=2.380 (psychedelic VR) for originality. The mean scores (M) and standard deviation (SD) evaluated by the second rater were M=10.833, SD=2.978 (non-psychedelic VR), M=10.833, SD=4.708 (psychedelic VR) for fluency, M=6.75, SD=1.605 (non-psychedelic VR), M=6.583, SD=2.289 (psychedelic VR) for flexibility and M=13.083, SD=4.387 (non-psychedelic VR), M=12.833, SD=6.353 (psychedelic VR) for originality.

DAT- The Divergent Association Task

A two-tailed parametric paired t-test was performed to compare the DAT scores between non-psychedelic VR and psychedelic VR. The difference between the two groups was not significant: t(5)=0.500, p=0.638, d=0.150. The mean scores (M) and standard deviation (SD) were M=82.193, SD=7.405 for non-psychedelic VR and M=83.160, SD=5.342 for psychedelic VR.

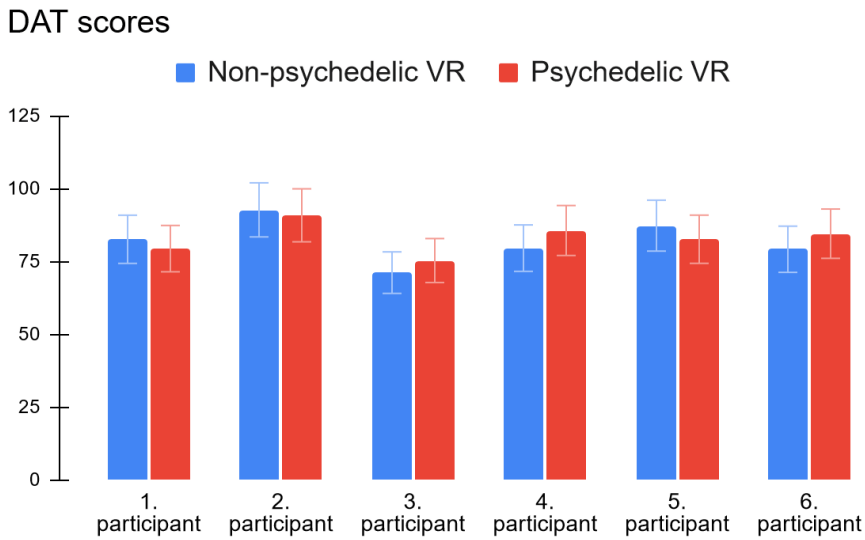

Figure 3. The DAT scores per participant. Error bars indicate the standard error of the mean.

Discussion

The aim of the experiment was to find out whether psychedelic substances could affect divergent thinking through the induction of intense psychedelic visual experiences. To study this question we created a novel VR setup that mimicked psychedelic effects. We tested whether this psychedelic VR can enhance creativity. The results showed no significant effect on AUT subscores, although the score sizes were different. The DAT score changes were also not statistically significant. The DAT scores from CryptPad were excluded as several answers were not submitted according to the rules.

The sample in the current study was only 6 persons, who were all university students. This might have had an effect on the results. Bigger and more diverse sample could have made the results more reliable. Perhaps the effect of psychedelic virtual reality is relatively small and could only be captured with a larger sample. Future studies are therefore needed to assess this problem. Two of the participants had two mother languages and that may have affected the results. The learning effect for both divergent thinking tests might have occured. The DAT was done three times and the AUT two times. To minimize the learning effect different words were used for both tests. The AUT rating is highly subjective and the inter-rater correlation was moderate (r=0.4). The ratings of both raters were consistent in the sense that neither of them observed any effects of psychedelic VR.

Glowacki and colleagues found that virtual reality could induce mystical experience (Glowacki et al., 2020), which was measured by Mystical Experience Questionnaire- MEQ30 (Barrett et al., 2015). In “Isness” VR people could interact with each other and used Mudra gloves for manipulating the experience (Glowacki et al., 2020). Social interaction could have had mood-enhancing effects (Forstmann et al., 2020). The mystical experience and divergent thinking share some similarities (Geels, 1982; Gowling, 1985). It is interesting to hypothesize whether social interaction and interactive experience could have changed current study results. Positive mood could enhance creativity (Fredrickson, 2001), although the effects are probably more complex (Du et al., 2021). In the current study the participants sat alone in comfortable chair and could not interact with the experience. Rominger and colleagues found that bodily movement increases creativity (Rominger et al., 2021). Jaak Panksepp's brain's SEEKING system has been associated with creativity (Nalbantian and Matthews, 2019; Reuter et al., 2005). This system is primarily activated by dopamine that has been linked to movement (Gepshtein et al., 2014). Therefore sitting still for a long time may have decreased divergent thinking.

Psychedelics have other effects than visual stimuli and they could influence creativity through pharmacological effects mediated through 5-HT receptors (Andersen et al., 2020; Madsen et al, 2019) and DMN (Carhart-Harris and Friston, 2019). Although the effects on divergent thinking are probably more complex as several other brain regions and their interaction is likely to affect creativity (Beaty et al., 2018). This means that psychedelics may not always directly increase divergent thinking. Three studies found increased divergent thinking during psychedelic acute effects (Kuypers et al., 2016; Mason et al., 2019; Prochazkova et al., 2018).

However Mason and colleagues found decreased divergent thinking during the acute phase, but increased divergent thinking scores 7 days later (Mason et al., 2021). In these studies the sample sizes were 26 (Kuypers et al., 2016), 55 (Mason et al., 2019), 38 (Prochazkova et al., 2018) and 60 (Mason et al., 2021), again highlighting that the current study might simply have had too few participants. In the studies with psychedelic compounds, participants' beliefs could have had an effect on these results as they may believe in psychedelics' creativity enhancing effects and may seek out such experiences. There have not been many empirical studies on divergent thinking and psychedelics. The used psychedelic compound and dose often vary between studies. Kuypers et al. study used ayahuasca that contains N,N-dimethyltryptamine (Kuypers et al., 2016) and several other studies used psilocybin (Mason et al., 2019; Mason et al., 2021; Prochazkova et al., 2018). This is important, because different psychedelics have different visual and pharmacological effects (Johnson et al., 2019). Different people have variations in brain neurochemistry and anatomy (Mueller et al., 2013; Seghier and Price, 2018). Consequently they have different responses to psychedelics (Zamberlan et al., 2018), that are also affected by set (user's state) and setting (surrounding environment) (Studerus et al., 2012).

One of the participants of the current study did not perceive her body while being in psychedelic VR. This event could share similarities with out-of-body experience. Psychedelics could induce near-death/out-of-body experience as they share some similarities (Moody, 1975; Strassman et al., 1994; Timmermann et al., 2018). States caused by DMT and near-death experiences have both been described as being "realer than real" (Moody, 1975; Strassman, 2001). During the VR-experience out-of-body experiences are more difficult to achieve as participants have to wear a big VR-headset. One of the participants said that his neck became stiff from the headset and two other participants said that the virtual reality was exhausting. Hence some of the participants could not focus entirely on the VR experience. That was probably more relevant for the psychedelic-VR as it lasted 60 minutes. Sounds coming from the surrounding environment could have also disrupted the experience although it was minimized by using music that came from the VR-headset headphones. Such complications could be solved by future technological innovations that make VR-technology more comfortable and effective (Cipresso et al., 2018). Future studies should assess whether out-of-body experiences during psychedelic trips contribute to increased divergent thinking. If it turns out to be true, then this data can be used to design better virtual realities for enhancing divergent thinking.

As both VR sessions included meditation, it might have been that any potential effect of psychedelic experiences on creativity was “masked” or “canceled” by a far stronger effect of meditation. Meditation was used to help the participants relax and focus on the experience. Open-monitoring meditation (OM) increased divergent thinking measured by the AUT (Colzato et al., 2012). In OM meditation one is open to any sensation or thought. Second type of meditation is focused-attention (FA) meditation, where the person focuses on one thing. Most meditations combine these two approaches (Cahn and Polich, 2006). It is important to mention there are many classification systems for different types of meditations (Matko and Sedlmeier, 2019). Meditation used in the current study has many different characteristics, but can be broadly classified as FA meditation. Other studies have also found meditation to boost creativity (Colzato et al., 2014; Ding et al., 2014). Thus higher AUT fluency scores in the first day could have been caused by shorter VR experience, that provided continuity for meditation's effects.

At the beginning of the VR following note was given: “In this study we want to find out how virtual reality affects creativity”. This may have affected the results through making some participants believe that VR has an effect on creativity. This belief may have worked as a placebo (Lundh, 1987; Moerman and Jonas, 2002), that has a noteworthy effect on people's emotions, that consecutively influences creativity (Du et al., 2021; Fredrickson, 2001). Although it is important to mention that the note did not say whether VR could increase or decrease creativity. Hence belief may have changed the results either way.

Overall the results were influenced by aspects discussed above. Several remedies can be used in future studies to reduce them. This experiment was conducted as a preliminary study that connected VR, psychedelics and divergent thinking. Therefore future studies are needed to find VR's capacity to affect creativity.

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Käesolevaga kinnitan, et olen korrektselt viidanud kõigile oma töös kasutatud teiste autorite poolt loodud kirjalikele töödele, lausetele, mõtetele, ideedele või andmetele.

Olen nõus oma töö avaldamisega Tartu Ülikooli digitaalarhiivis DSpace.

/Marten Kase/