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Comparison in electrophysiological activity during processing of self-related thoughts in psychedelics users versus non-users

Porównanie aktywności elektrofizjologicznej w czasie myślenia o sobie u osób używających i nie używających psychodeliki

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bez Waszych podróży nauka psychodeliczna nie byłaby możliwa

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Abstract

Psychedelic substances are gaining increasing attention in scientific research due to their potential to induce significant changes in consciousness and emotions. Numerous studies indicate a mixed impact of psychedelics on mental health, though the mechanisms underlying the relationship between psychedelic use and mental health remain poorly understood. One key element of psychedelic experiences is the alteration of self-awareness, known as ego dissolution. Some correlational studies suggest that ego dissolution and subsequent long-term changes in self-awareness may be key mechanisms through which psychedelic experiences can influence mental health. However, little is known about how the self-awareness of individuals using psychedelics in natural (non-clinical or non-experimental) settings differs from that of non-users.

To address this gap, I focused on one aspect of self-awareness, namely processing of self-related thoughts and associated brain activity. In this study, my aim was to investigate differences in both behavioral and neurophysiological activity during the processing of self-related information between naturalistic psychedelic users and non-users. I utilized electroencephalography (EEG) with source localization to investigate neural oscillatory activity in the alpha and beta frequency bands. I conducted analysis on two separate datasets, labeled Dataset I and Dataset II. Dataset II was used to assess the replicability of the findings from Dataset I. The methods and hypotheses of this study were preregistered.

Results based on Dataset I indicated a lower increase in alpha and beta power during the processing of self-related thoughts in psychedelic users compared to non-users. These effects were particularly prominent in temporal, posterior, and medial-parietal brain regions, which are known to be involved i.e. in self-related information processing. Additionally, in Dataset I users reported significantly lower levels of depression, anxiety, and rumination compared to non-users. Correlations between the number of psychedelic

uses in one's lifetime, depression scores, and activity in the medial-parietal and temporal brain regions were observed, but after multiple comparison corrections, none of these correlations were statistically significant. Additionally, disruptive effects of meditation practice and cannabis use were noted, which, when included in the regression model, diminished the group effect.

The effects observed in Dataset I were not replicated in Dataset II, potentially due to sample size limitations and lower spatial resolution. Lack of replication makes it challenging to draw definite conclusions regarding the observed effects. Nevertheless, this research contributes to the existing literature on psychedelic use and self-related information processing. It suggests possible differences in self-awareness, particularly self-related thinking, between psychedelic users and non-users. An additional strength of this study lies in its innovative research approach that combines psychological and neural aspects in the examination of psychedelic users. The insights gained from this research pave the way for further exploration of the psychological and neural mechanisms related to self-related thoughts processing and mental health among naturalistic psychedelic users.

Streszczenie

Substancje psychodeliczne zyskują coraz większą uwagę w badaniach naukowych ze względu na ich potencjał do wywoływania znaczących zmian w świadomości i emocjach. Liczne badania wskazują na mieszany wpływ psychodelików na zdrowie psychiczne, aczkolwiek mechanizmy będące podłożem zależności między zażywaniem psychodelików a zdrowiem psychicznym pozostają mało zbadane. Jednym z kluczowych elementów doświadczeń psychodelicznych jest zmiana samoświadomości nazywana rozpuszczeniem ego. Niektóre badania korelacyjne sugerują, że rozpuszczenie ego i konsekwentne długofalowe zmiany w samoświadomości mogą być jednym z kluczowych mechanizmów, poprzez które doświadczenia psychodeliczne mogą oddziaływać na zdrowie psychiczne. Wciąż niewiele wiadomo na temat tego, jak samoświadomość osób używających psychodeliki w warunkach naturalnych (niekontrolowanych klinicznie bądź eksperymentalnie) różni się od samoświadomości osób nie używających substancji psychodelicznych. Pragnąc uzupełnić tę lukę, skupiłam się na jednym aspekcie samoświadomości, czyli myśleniu o sobie oraz towarzyszącej aktywności mózgowej.

W niniejszej pracy miałam na celu zbadanie różnic w aktywności psychicznej i mózgowej podczas przetwarzania informacji związanych z "ja" między naturalistycznymi użytkownikami psychodelików a osobami nie używających tych substancji. Do zbadania aktywności neuronalnej wykorzystałam elektroencefalografię (EEG) z użyciem lokalizacji źródeł. Skupiłam się na aktywności oscylacyjnej w pasmach alfa i beta. Przeprowadziłam analizę na dwóch zestawach danych (Zestaw I oraz Zestaw II). Użyłam danych z Zestawu II po to, by ocenić replikowalność wyników z Zestawu I. Metoda oraz hipotezy obecnego badania były prerejestrowane.

Wyniki bazujące na danych z Zestawu I wskazywały na niższy wzrost w mocy alfa i beta podczas przetwarzania myśli na własny temat u osób używających psychodeliki w

porównaniu do osób, które nie zażywają psychodelików. W szczególności zaobserwowano efekty w obszarach skroniowych, potylicznych oraz przyśrodkowo-ciemieniowych mózgu. Badania wskazują, że te rejony są zaangażowane między innymi w przetwarzanie informacji związanych z “ja”. Ponadto, osoby używające z Zestawu I raportowały istotnie niższe poziomy depresji, lęku i ruminacji niż osoby nie używające. Takie wskaźniki, jak liczba zażyć psychodelików w ciągu życia oraz poziom depresji dodatnio korelowały z aktywnością w okolicach przyśrodkowo-ciemieniowych i skroniowych. Choć wyniki te miały podobny wzorzec w różnych okolicach mózgowych, po przeprowadzeniu korekty na wielokrotne porównania żadna korelacja między danymi elektrofizjologicznymi i behawioralnymi nie była statystycznie istotna. Zaobserwowałam również zakłócające efekty praktyki medytacji i używania konopi, przy włączeniu ich do modelu regresji efekt grupy malał.

Efekty zaobserwowane w Zestawie I nie zostały zreplikowane w Zestawie II, potencjalnie z powodu ograniczeń związanych z liczebnością próby i niższą rozdzielczością przestrzenną. Brak replikacji wyników utrudnia jednoznaczne wnioskowanie o prawdziwości efektów zaobserwowanych w Zestawie I. Niemniej, ta praca stanowi istotny wkład w dotychczasową literaturę na temat funkcjonowania osób zażywających psychodeliki. Wskazuję tu na możliwą różnicę w takim aspekcie samoświadomości, jak myślenie o sobie między osobami używającymi psychodelików, a osobami nie używającymi. Dodatkowym atutem tej pracy jest zastosowanie nowatorskiego schematu badań nad użytkownikami_czkami psychodelików, łączącego płaszczyznę psychologiczną i neuronalną. Wnioski płynące z tej pracy otwierają drogę do dalszego badania mechanizmów psychologicznych i neuronalnych związanych z doświadczeniami psychodelicznymi w kontekście przetwarzania myśli na własny temat oraz zdrowia psychicznego u naturalistycznych użytkowniczek_ków psychodelików.

Introduction

Psychedelic substances are a subgroup of psychoactive compounds that have the potential to profoundly alter the state of consciousness. Lysergic acid diethylamide (LSD), psilocybin, mescaline, and N,N-dimethyl- tryptamine (DMT) are classic examples of psychedelics. In recent years there has been a rise in the number of research and literature on psychedelic effects i.e. in medical, neurobiological and humanistics sciences. Although neurophysiological research on psychedelic effects in the laboratory setting is constantly evolving, to my best knowledge there is very little research on neuropsychological functioning of individuals who use psychedelics outside of the laboratory setting. In the present work I aimed to fill this gap by performing a research on electrophysiological and psychological functioning of psychedelic users. Here, I focus on the one of the most exposed effects of psychedelics - that is changes in the self-consciousness.

Psychedelic experiences, well-being and mental health

Classic psychedelics act mainly through activation of subtypes of serotonin receptors (5-HT2A), although other serotonin and other neurotransmitters (dopamine, glutamate, noradrenaline) pathways are involved in psychedelics' action (Vollenweider & Preller, 2020). Serotonin plays a crucial role in regulation of i.e. emotions and cognition, sleep, appetite. Psychedelic experiences are diverse and depend on set and setting, i.e. personal and environmental circumstances in which psychedelic experiences take place. Effects can include change in perception, emotional enhancement, visions, dread, bliss, awe, feelings of self-disintegration, and sense of connection to the world, nature and other people (Johnson et al., 2019). Indigenous groups in North and South America have historically used psychedelics in sacred rituals for religious, spiritual, and social purposes (Wasson, 1978; Carod-Artal, 2015). In the 1950s, psychiatrists, neuroscientists, and psychotherapists in the West began exploring the therapeutic and self-improvement potential of psychedelics through scientific research. It is estimated that around 40000 individuals were given LSD as a treatment for near-death anxiety, alcohol dependance, pain and other, mainly mental health, conditions (Garcia-Romeu, Kersgaard & Addy, 2016). However, psychedelic research faced setbacks in the 1970s when these substances were banned due to exaggerated beliefs about risks propagated by mass media, their association with counterculture movements, and anti-war protests. Nonetheless, contemporary research on psychedelics has witnessed a resurgence and now spans various disciplines, including mental health, neuroscience, the science of consciousness, and philosophy.

Initial evidence suggests that use of psychedelics in controlled, supervised environments is associated with long-term, (up to 14-months), well-being improvements in both clinical and healthy samples. Specifically, participants suffering from depression, anxiety or addiction-disorders show symptom reduction, while healthy individuals exhibit increased well-being and life satisfaction (for review see Aday et al., 2020). Recently, at the beginning of 2023, psilocybin was legalized for medical use in Australia. However, this step was recognized as too hurried, given the relatively early stage of the research and lack of knowledge regarding long-term effectiveness and adverse reactions to psychedelics (Elk & Fried, 2023). Moreover, as addressed by Aday et al. (2020), experimental studies do suffer from some methodological limitations, regarding, for example, generalizability of the effects.

For studies with healthy individuals, researchers recruit participants with a previous history of psychedelic drug use. According to Aday et al. (2020) depending on previous experience with psychedelic drugs subjects may be more or less willing to take part in studies that require its administration. Similarly, even psychedelic-naive individuals applying to take part in studies where psychedelic drugs would be administered oftentimes will likely be more open to psychedelic experience than the general population, which may significantly affect the outcome of the study. Findings summed up by Aday et al. (2020) are collected from studies on psychedelic use in controlled, research settings, though it would be intriguing and ecologically more valid to explore potential risks and benefits associated with psychedelic use in non-controlled, out of laboratory, settings. Population studies can grasp another aspect of psychedelic drug use, e.g. explore functioning of a more diverse group of psychedelic drugs users and take into account more diverse patterns of use than experimental studies allow. Research on the naturalistic use of psychedelics in large population samples has indicated that such usage is not associated with an increased likelihood of individuals reporting mental health issues in the year prior to the study (Johansen & Krebs, 2013, 2015). Instead, it is associated with a significantly reduced odds of experiencing psychological distress in the past month, as well as reduced odds of having suicidal thoughts, engaging in planning, or attempting suicide in the past year (Hendricks et al., 2015; Johansen & Krebs, 2013, 2015). In a recent online study naturalistic psychedelic users retrospectively reported lower depressive and anxious symptoms and increased emotional well-being after psychedelic use (Raison et al., 2022).

There are various suggestions regarding the psychological and physiological components that underlie the effects of psychedelics on well-being and mental health (for a comprehensive review, see: van Elk & Yaden, 2022; Vollenweider & Preller, 2020). Proposed mechanisms include psychological (emotional relief through breakthroughs, insights, increased social connection, changes in self-perception, changes in self-consciousness) and neural (changes in brain circuits functioning, that is connectivity and excitation, neuroplasticity and neuroinflammation) (van Elk & Yaden, 2022; Vollenweider & Preller, 2020). The main or single mechanism behind these effects remains unknown and changes are hypothesized to result from multiple processes. Interplay between psychedelic experience, psychedelic integration and socio-cultural context is also proposed to have a crucial role as a part of set & setting[1], but is either not included in research design, or not acknowledged for while interpreting the results (Canvar & Labate, 2021).

Psychedelics and self-consciousness

In the present thesis I focus on psychedelic-related changes in self-consciousness which has been investigated in previous experimental studies on psychedelics (van Elk & Yaden, 2022, Vollenweider & Preller, 2020). Self-consciousness is a complex phenomenon and can have various dimensions and definitions, and there is no consensus on its meaning in cognitive neuroscience. There are vast spectrum of possible notions of the self:

"[...] the cognitive self, the conceptual self, the contextualized self, the core self, the dialogic self, the ecological self, the embodied self, the emergent self, the empirical self, the existential self, the extended self, the fictional self, the full-grown self, the interpersonal self, the material self, the narrative self, the philosophical self, the physical self, the private self, the representational self, the rock bottom essential self, the semiotic self, the social self, the transparent self, and the verbal self" (Strawson, 2000, p. 39).

Given the discrepancy of the concept of self or self-consciousness, I believe it is important to define the term in the context of psychedelic research. First, I would like to introduce the related phenomenon "ego dissolution", since psychedelics related changes in

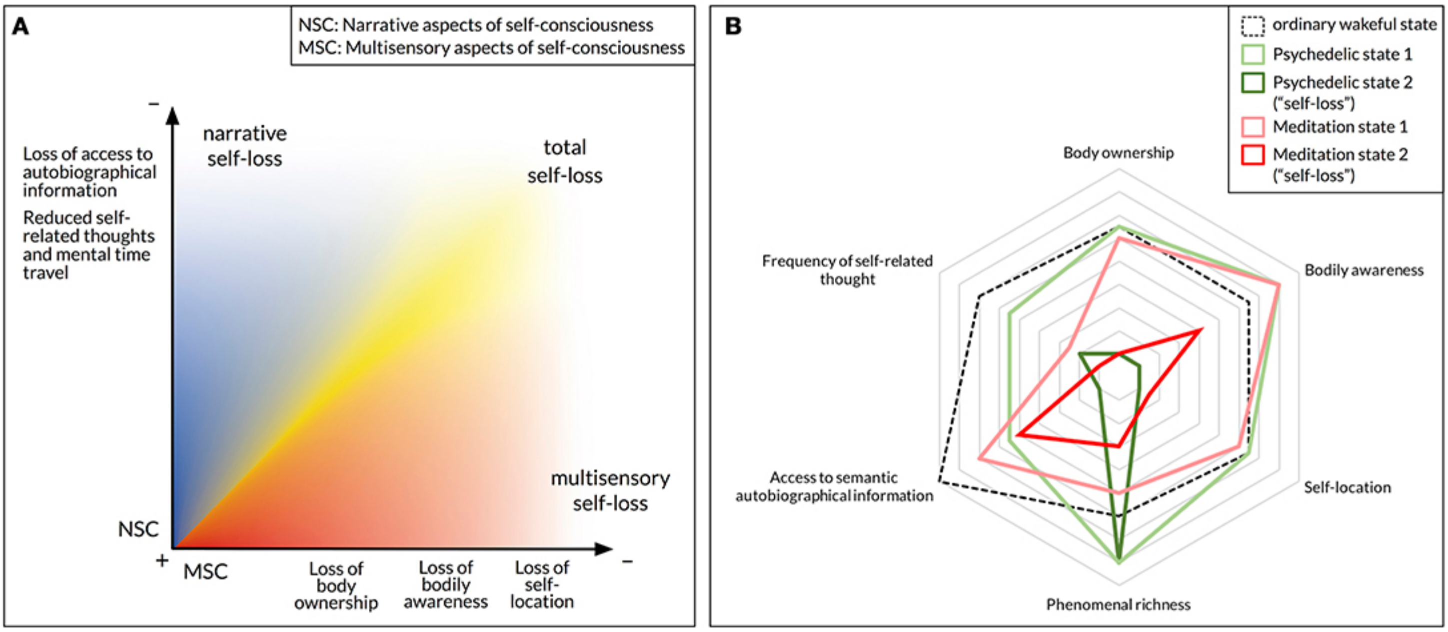
[1] Set & setting within the context of psychoactive substances, refer to two pivotal factors influencing an individual's experience. "Set" pertains to the individual's psychological state, including their mindset, mood, and expectations, while "setting" encompasses the physical, social, and environmental factors, such as cultural context, location, company, that surround the experience. These intertwined elements significantly shape the nature and impact of psychoactive substance encounters, with careful attention to both considered crucial for optimizing outcomes.

self-consciousness are often explained through it. Ego dissolution is a distortion in the usual sense of self or ego. Using Metzinger (2009) definition, ego comprises the substance of a self-model constructed by the brain, which serves as the means through which we engage with both our inner realm and the external environment, fostering a comprehensive interaction. It is also necessary to control our behavior and to understand the behavior of other individuals.Specifically this encompasses in the sense of agency, sense of identity, bodily ownership and awareness, self-location, self-other boundaries, self-related narrative, autobiographical memories (Milliere et al., 2018). Stanislav Grof - a psychiatrist well known as a pioneering researcher of LSD and its psychotherapeutic effects - described ego-dissolution as "*an ecstatic-state, characterized by the loss of boundaries between the subjective and the objective world, with ensuing feelings of unity with other people, nature, the entire Universe, and God*" (Grof, 1980).

The intensity and quality of ego dissolution can vary significantly throughout the psychedelic experience, influenced by factors such as the type of substance used and the set & setting. Figure 1 demonstrates different kinds and dimensions of ego dissolution proposed by Milliere et al. (2018). Qualitatively the phenomenon ranges from a blissful sense of unity with the surroundings to a more unsettling and disorienting state resembling psychosis. Interestingly, anecdotal evidence suggests the initial dreadful ego dissolution may evolve into an ecstatic state as the psychedelic journey unfolds and vice versa. The positive pole of ego dissolution can be compared to mystical experience. William James identified self-loss as a main feature of mystical experience, which can be occasioned by different spiritual practices such as prayer or meditation (James, 1985). Mystical experience is most frequently understood as a blissful, ineffable state of connection with the world/God/nature. Walter Pahnke, a psychiatrist and one of the first psychedelic researchers, framed ego dissolution role in mystical experience as follows: "*[...] a sense of* *cosmic oneness is achieved through positive ego transcendence. Although the usual sense of identity, or ego, fades away, consciousness and memory are not lost; instead, the person becomes very much aware of being part of a dimension much vaster and greater than himself.*" (Pahnke, 1969).

Figure 1

Multidimensional models of self-loss in global states of consciousness [eg. spectra of possible characteristics of meditation or psychedelic experiences].



Note. **(A)** A simplified two-dimensional model with the X-axis representing the disruption of multisensory aspects of self-consciousness, and the Y-axis representing the disruption of narrative aspects. The color gradients indicate varying degrees of disruption of narrative, multisensory aspects, or both in altered states induced by meditation and psychedelics. This two-dimensional model can be conceived as a conceptual sketch that reduces the dimensionality of the notion of self-consciousness to two orthogonal principal dimensions, somewhat similarly to Principal Component Analysis. The shortcomings of this simplified model are tentatively addressed in the more complex **(B)**. **(B)** The model is represented on a radar chart with six dimensions: (1) a sense of body ownership, (2) awareness of bodily sensations, (3) awareness of spatial self-location, (4) rich phenomenology, (5) access to semantic autobiographical information, and (6) self-related thoughts. The chart includes examples of different states, such as an ordinary waking state (dotted black line), meditation-induced states (pink - typical meditative state; and red - "selfless" state described by experienced meditators), and drug-induced states (light green - state induced by moderate dose of psychedelics and dark green - example of high dose psychedelic-induced ego dissolution). (Milliere et al., 2018)

Perhaps, ego dissolution might be better understood through reports of individuals, who have had this kind of experience. Below I provide some examples:

"*I became sure that if I allowed my brain to fully reach that Final Conclusion, that my ego would fully die, and I would cease to be anymore. I really felt like the 2C-E [*a psychedelic substance*] was trying to kill me, but this was a complete and total death, on an infinite number of levels that I never even knew existed until last night. Holding on was causing me extreme anguish and duress, not to mention acute physical symptoms. My heart rate felt as if it was going up, up, up, to impossible levels, though I had no quantitative way of measuring this nor the presence of mind to try. I was having chest and shoulder pains, and severe abdominal twinges. [...] I felt that even dying a physical death would save me from my eternal, spiritual death that I was facing [...]. It was as if every instant I was waking up further, reaffirming the absolute terrifying knowledge that I was not, in fact, real. It was the only logical conclusion.*"

The example above relates to the dreadful ego dissolution, which is frequently described as the feeling of dying a physical and mental death, accompanied by intense anxiety and insight about the illusory nature of the self. Interestingly, the same vision of the self - that self is nothing but an illusion - is presented in Eastern religious traditions (Buddhism and Hinduism) and in Western philosophy (Metzinger, 2009; Hume 1896; Kant

1999; Sartre 2003). The example below relates to the ego dissolution (strong distortion of language function, sense of bodily ownership and location in space is deteriorated, lack of self-narrative) accompanied by feeling of immersion with all the universe and knowledge. It is much different from the previous example and this discrepancy between both illustrates how different an ego dissolution might be experienced.

"*I lost all awareness of my body, my surroundings, everything around me. I felt myself fall right through the earth, like a neutrino, like the earth was nothing but empty space. I left my body completely and dissolved into the universe. My mind became placed into the mind of the universe, expanded into it, knowing everything to be known, but completely unable to think in thoughts, words, my mind-voice was completely gone, yet I was completely aware of ideas knowledge, wisdom, abstractions which were so perfectly clear and understandable to me outside of any known constructs of language, way beyond language, completely nonlinear thought and yet not-thought. Just knowing. Pure knowing. My mind, my consciousness, my poor little brain struggled to keep up with it, struggled to keep up with everything streaming in, struggled to fit the mind of the universe within.*"

In the Western culture ego dissolution is proposed to be central to the psychedelic experience (Nour et al., 2016). The roots of such proposition reach the beginning of spreading of psychedelic use in the West 1950-70s. The writer Aldous Huxley, one of the first western intellectuals who took mescaline (psychoactive component found in certain types of cacti) and together with psychiatrist Humpher Osmond proposed the term "psychedelic", interpreted his experience using the framework of Eastern religions (Buddhism and Hinduism). Huxley described his experience with mescaline in the well-known book "The Doors of Perception". Further, influential counterculture psychologists Timothy Leary, Ralph Metzner, and Richard Alpert were inspired by "The Doors of Perception" and Tibetan Buddhist texts such as "The Tibetan Book of the Dead".

In their guide to psychedelic experiences (*The Psychedelic Experience*) they linked ego dissolution to a spiritual transformation: "*.. one of the oldest and most universal practices for the initiate to go through the experience of death before he can be spiritually reborn. Symbolically he must die to his past, and to his old ego, before he can take his place in the new spiritual life into which he has been initiated.*" (Leary, Metzner & Alpert et al., 1964). This corresponds to understanding of ego in Buddhism, where the ego holds no inherent or permanent existence and is considered an illusion. It is seen as a construct of the mind that gives rise to the idea of a separate and enduring self. Buddhist teachings emphasize the impermanence and interconnectedness of all phenomena, including the self. Through meditation and introspection, practitioners aim to realize the transient nature of thoughts, emotions, and sensations, breaking free from the illusion of a fixed identity. The ultimate goal is to attain enlightenment or Nirvana by transcending the ego and experiencing profound interconnectedness with all life. By letting go of ego-driven attachments and desires, individuals can find genuine peace and liberation from suffering. This transformation leads to a profound understanding of the true nature of self and reality (Kornfield, 2002).

It is commonly suggested by psychedelic researchers that mystical experience, specifically its positive ego dissolution component, is associated with therapeutic effects of psychedelics and their capacity to minimize authoritarianism and increase nature relatedness (Gearin & Devenot, 2021; Roseman, Nutt & Carhart-Harris, 2018). Ego dissolution allows individuals to temporarily transcend their self-identity and experience a profound sense of interconnectedness with others and the world. This dissolution of the ego can break down rigid thought patterns, open individuals to new perspectives, and facilitate emotional release. By providing a glimpse of a broader reality beyond the self, ego dissolution may enable individuals to gain insight into their issues and promote changes in behavior and attitudes. Additionally, this experience of interconnectedness may foster feelings of unity, compassion, and acceptance, leading to improved therapeutic outcomes and long-term well-being.

Although widely discussed in scientific and media literature, ego-dissolution and related mystical experiences are concepts not free of criticism. This criticism should be acknowledged for, since it points towards limitations in results interpretations and puts ego-dissolution in a wider socio-cultural context. Gearin and Devenot (2021) noticed that media narratives on psychedelic psychotherapy are concentrated around mystical experiences and ego dissolution presenting phenomena as inherently positive and crucial for psychotherapy effectiveness. This is supported by researchers commentaries and correlation study results. However, there is no definitive proof that ego dissolution is essential for psychotherapeutic outcome of the psychedelic experience.

Moreover, psychedelic or other practices inducing ego-dissolution will not necessarily lead to mental health improvement individually or globally, nor should it be the central element of psychedelic psychotherapy. Carl Gustav Jung warned against reckless experimentation with alternative states of consciousness given the potential dangers. Jung believed ego continuity was necessary, as it serves as a mediator between the unconscious and conscious, essential for successful integration of unconscious experiences without experiencing ego inflation[2]. In her essay (published in the anthology edited by Hauskeller and Sjöstedt-Hughes (2023)) on Jungian approach to ego-dissolution Johanna Sopanen

[2] Ego inflation is a phenomenon that amplifies and heightens an individual's self-esteem and self-regard, leading to an elevated sense of confidence, superiority, and overall arrogance. In this state, individuals may perceive themselves as significantly more intelligent, valuable, and capable than those in their vicinity. This experience bears resemblance to narcissistic personality disorder in its manifestation. In Jungian terms, this typically happens when the ego identifies too strongly with certain aspects of the unconscious psyche, such as archetypal images, personal accomplishments, or external symbols of success and power.

described this as follows: "*He [Jung] argued that the unconscious can 'flood' the conscious mind, which could result in one of the two conflicting modes of reaction. In the first, the individual may feel burdened by the new and overwhelming experience and run the risk of becoming depressed. In the second scenario, the individual may become filled with self-importance and confidence, in actuality to conceal a profound sense of impotence. Jung related this state of psychological inflation to Goethe's and Adler's notion of 'godlikeness', which is characterized by the individual attributing a number of omnipotent qualities to themselves. „In this case, the person mistakes the collective and personal layers of the unconscious, and subsequently views their ego as identical with the experience. This can, in turn, result in an inflation of the personality towards religious frenzy, megalomania, and delusional ideation.*" Jung held a prejudice against psychoactive substances, emphasizing the need for persistent integrative work to accompany such experiences.

The individualistic approach to psychedelic psychotherapy, with its emphasis on ego-dissolution, tends to attribute sources of distress solely to the individual, placing responsibility for their problems on themselves. However, mental health is influenced by a complex interplay of various cultural, social, and economic factors, as well as psychological ones (Zeira, 2022; Lehman et al., 2017; Knapp & Wong, 2020). Consequently, a singular focus on ego-dissolution within individualistic frameworks may inadvertently overlook systemic causes of suffering and neglect the potential benefits of community-based healing methods.

Furthermore, an excessive focus on ego-dissolution and mystical experiences may overshadow other essential aspects of psychedelic use, which carry cultural significance in diverse contexts. Recognizing the multifaceted nature of these experiences and their contextual dependencies can foster more inclusive, adaptable, and culturally sensitive harm reduction and education efforts related to psychedelics. A comprehensive understanding that integrates individual and systemic factors is essential to ensure equitable support for individuals exploring the potential benefits of psychedelic substances. This approach can promote mental well-being and responsible psychedelic use while respecting the diverse cultural backgrounds and values of those involved in these experiences.

With the criticism expressed above I do not aim to diminish the significance of ego-dissolution but rather to present a broader perspective that acknowledges the multifaceted context in which ego-dissolution occurs, encompassing psychological, biological, cultural, social, and economic factors. This context plays a crucial role in shaping the outcomes of psychedelic experiences, and it is essential not to over interpret the findings of the present research within a limited scope.

Summing up, in the realm of psychedelic research, self-consciousness is often explored through the lens of ego-dissolution, which is believed to be central to the long-term effects of psychedelics. However, it is crucial to recognize that self-consciousness is not a precisely defined concept, and various models have been proposed to describe different aspects of the self in the context of psychedelic experiences. As I described above - self is hard to define, not to say about difficulties in the measurement. Therefore, for this research, I will focus on one module of the self that can be operationalized - self-related thoughts, as suggested by the model put forth by Milliere et al. (2018).

Self-related thoughts and mental health

Self-related thoughts play a crucial role in an individual's well-being and overall mental health. These thoughts involve reflections on oneself, self-identity, and evaluations of personal experiences and actions, relationships with other people. The way individuals process and interpret self-related thoughts can significantly impact their emotional state, psychological resilience, and overall life satisfaction. Affirmative self-related thoughts, such as self-acceptance, self-compassion, and self-efficacy, are closely linked to well-being. When individuals have a positive self-perception and display self-compassion, they are more likely to experience higher levels of resilience and contentment (Mantelou, Karakasidou, 2019; Liu, Wang, Wu, 2021; Trompetter, De Kleine, Bohlmeijer, 2017). Additionally, a healthy sense of self-efficacy, which refers to the belief in one's ability to handle challenges and achieve goals, can enhance motivation and a sense of empowerment, leading to a more fulfilling life (Seggelen-Damen, van Dam, 2016; Azizli et al., 2015). On the other hand, negative self-related thoughts, such as self-criticism, self-doubt, and rumination, can be detrimental to well-being. Self-criticism and self-doubt can lead to increased stress, anxiety, and depression (Ehret, Joormann, Berking, 2015). Understanding the interplay between psychedelic experiences and self-related thoughts is an essential area of research that may shed light on the therapeutic potential of psychedelics in improving mental health and overall well-being. By exploring how psychedelics influence the processing of self-related information, I may gain valuable insights into the mechanisms underlying their effects and their potential applications in promoting psychological resilience and well-being.

Psychedelic-induced changes in self-consciousness, like alteration of self-related thoughts (Millière 2015; Millière et al. 2018) are particularly of my interest because they may counteract rumination - intrusive, repetitive negative thoughts regarding one's self and relationships with others. Rumination is considered to be a maladaptive form of self-related information processing and is closely related to depression and other mental health conditions such as anxiety, binge eating, binge drinking, and self-harm (Nolen-Hoeksema, Wisco, B.E. & Lyubomirsky, 2008). Interestingly, most of these conditions are proposed to be relieved by psychedelic-assisted therapy (Luoma et al., 2022, Bogenschutz & Johnson, 2016, Zeifman et al., 2022). Giving the link between rumination and psychological issues, well-being and mental health are related to the way people process information regarding oneself. For individuals with depressive or anxious tendencies self-referential thoughts will be intrusive and dysphoric. On the other hand, adaptive forms of the self-related mental processes are related to psychological resilience (Falon et al., 2021). In a recent online study of my research group psychedelic users reported higher levels of adaptive (reflectiveness) and lower maladaptive (social anxiety and rumination) self-related information processing than non-users (Orłowski et al., 2022). This lead us to the assumption that in some cases psychedelic experiences are related to shift from maladaptive forms of self-consciousness to adaptive ones. If psychedelics in fact alter the way individuals process self-related information, they can show potential not only as a treatment of psychological disorders, but as a prevention from them. Importantly, this might be true only for some psychedelic users, such as self-selected participants of psychedelic studies. To which extent this sample represents the whole population of psychedelic users is yet unknown. Psychedelic use might as well worsen well-being in some cases and this might not be well-captured in all research (Elk & Fried, 2023).

Despite a growing number of questionnaire and qualitative studies on psychedelic use in natural settings, to my best knowledge there is currently no literature focusing on functioning of naturalistic psychedelics users assessed with behavioral tasks and physiological measures. To fill this gap I aimed to conduct an investigation focusing on processing of self-related information while recording electrophysiological responses of naturalistic psychedelics users. Hence, I explored neurophysiological differences between users and non-users that accompany processing of self-related information.

Electrophysiological measures

Electroencephalography (EEG) is a central method used in the present research. Therefore, before I continue with the description of the findings of EEG studies on psychedelics, I shall provide an introduction into the nature of the EEG signal. EEG enables us to delve into the manifestations of bioelectric processes within the brain. Neuronal activation is intricately linked with transient shifts in cell membrane electric gradients and extracellular charge alterations (Jackson and Bolger, 2014). These cyclical changes in neuronal membrane potential, termed neuronal oscillations, play a pivotal role in brain function. When substantial groups of neurons synchronize their activity at the same frequency, their coordinated rhythmic oscillations, marked by simultaneous changes in electric current, result in neural waves. These waves amplitude is what is measured using EEG sensors placed on the scalp's surface. Notably, the EEG signal primarily stems from the activity of pyramidal cells within the brain cortex. This is because pyramidal cells align in parallel, and this organizational pattern, combined with the synchronized activity of neurons, leads to the amalgamation of their activity, resulting in the generation of a robust signal (Jackson and Bolger, 2014).

Synchronized neuronal activity (oscillations) is essential for effective communication, that is information transfer, between neurons, both within specific brain structures and across different regions (Fries, 2005). Oscillatory activity is thus considered a facilitator of extra- and inter-regional communication. Oscillations are treated as an indicator of changes in mental processes (Siegel and Donner, 2011). These oscillations exhibit variations in frequency (cycles per unit time, measured in Hertz) and amplitude (voltage - the power of the fluctuation) (Biasiucci, Franceschiello, and Murray, 2019). Frequency ranges are typically defined in the following (or alike) way: delta (1 - 4 Hz)[3], theta (4 - 7 Hz), alpha (7 - 12 Hz), beta (12 - 30 Hz), and gamma (30-50 Hz). Depending on the type of activity

[3] It's important to note that there isn't a universally agreed-upon standard for defining the limits of all mentioned frequency ranges.

performed by subjects, amplitude of the wave of particular frequency can increase or decrease, this is addressed in the literature correspondingly as lower/higher power/activity in the particular frequency or frequency range[4].

Modifications in oscillatory brain activity have been observed in various neurological and mental health disorders, including schizophrenia, addiction, mood disorders, personality disorders, and many other mental and neuronal dysfunctions (Whitfield-Gabrieli and Ford, 2012, Vecchio et al., 2013, Faust et al., 2015). While it is widely accepted that oscillatory activity reflects mental states, there remains substantial heterogeneity in the results of EEG studies and uncertainty in their interpretation.

EEG has both advantages and limitations (Biasiucci, Franceschiello, and Murray, 2019). EEG records the activity of groups of neurons almost instantaneously, offering high temporal resolution. However, it has a significant drawback - a poor spatial resolution. EEG sensors are placed on the surface of the skull and collect information a few centimeters above the brain cortex, necessitating the transmission of electrophysiological signals through scalp tissues. This process results in the overlap of electric currents and distortion of the original signal by the time it reaches the sensors (Biasiucci et al., 2019, Jackson and Bolger, 2014). Consequently, it is challenging to precisely pinpoint the cortical source of the activity from which the signal originates. To address this limitation, researchers employ source localization techniques that utilize algorithms to estimate the cortical origin of the signals observed at the scalp level.

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[4] If changes in the activity/power of frequency range is mentioned, this will in most cases - and in the case of previous thesis - be based on the averaged amplitude from frequency bins included in the frequency range. This might not be the case with some types of analyses (for example, cluster-based permutation test in frequency domain).

Electrophysiology and neurophysiology of psychedelics

In line with research on the effects of psychedelics on self-consciousness, previous studies have demonstrated that these substances impact the brain circuits responsible for processing self-related content. Electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) investigations into the acute effects of psychedelics have revealed alterations in the connectivity and activity of the default-mode network (DMN) (Muthukumaraswamy et al., 2013; Kometer et al., 2015; Carhart-Harris et al., 2012; Palhano-Fontes et al., 2015). The DMN is a large-scale functional brain network involved in mind-wandering, mental time travel, and the processing of self-related stimuli, including self-referential thoughts (Buckner, Andrews‐Hanna & Schacter, 2008; Zhou et al., 2020). Key structures within the DMN (see Figure 2 for visual representation of the structures included in the DMN) include the medial prefrontal cortex, posterior cingulate cortex (PCC), and precuneus, and sometimes, additional regions like the parahippocampal and temporal areas are also considered part of the DMN (McCormick & Telzer, 2018). The exact mechanism through which psychedelics influence the DMN is linked to their interaction with the serotonin 2A receptor (5HT2A), which is widely distributed in the brain, specifically in DMN (Beliveau et al., 2017), and plays a crucial role in mediating the effects of psychedelics (Vollenweider & Preller, 2020). Activation of 5HT2A receptors by psychedelics results in alterations in neural activity, connectivity, and neurotransmitter release, ultimately leading to the changes observed in the DMN during psychedelic experiences.

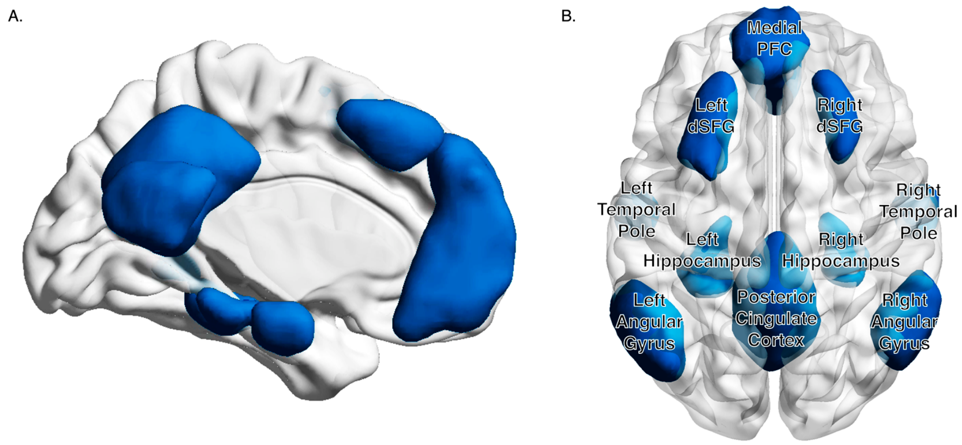
In an EEG study, psilocybin was found to decrease the source-localized current source density of neuronal oscillations at 1.5–20 Hz within a neural network comprising the anterior cingulate cortex (ACC) and PCC (Kometer et al., 2015). Utilizing MEG, Muthukumaraswamy et al. (2013) observed that psilocybin reduces source-localized oscillatory power in the posterior and frontal association regions in the frequency bands of 1-50 Hz and 8-100 Hz, respectively. This effect was particularly prominent in regions overlapping with DMN hubs. Another MEG study demonstrated decreased power in low frequencies (1-30 Hz) following LSD intake, with a specific reduction in the alpha, theta, and beta frequency bands found in DMN regions (Carhart-Harris et al., 2016). These findings are consistent with results from fMRI studies indicating a decrease in DMN activity during the psychedelic experience (Carhart-Harris et al., 2012; Palhano-Fontes et al., 2015).

The role of the DMN in the psychedelic experience has been a subject of considerable interest and interpretation. Some (Carhart-Harris et al., 2012; Palhano-Fontes et al., 2015) had linked changes in DMN activity and connectivity to temporary dissolution of the boundaries of self and a sense of interconnectedness with the external world. Furthermore, some researchers propose that the changes in DMN activity during the psychedelic experience are related to a process of "reorganization" of the self. Psychedelics may promote neural plasticity and facilitate the formation of new neural connections, allowing for novel perspectives and insights about oneself and the world (Smigielski et al., 2019). This reorganization of the self could be related to the therapeutic effects of psychedelics, where individuals often report profound shifts in their beliefs, behaviors, and emotional processing. The involvement of the DMN in the psychedelic experience has also been connected to the concept of the "REBUS" (Relaxed Beliefs Under Psychedelics) model. According to this model, the altered state of consciousness induced by psychedelics leads to a relaxation of top-down cognitive control and belief systems, allowing novel patterns of thought and perception to emerge (Carhart-Harris & Friston, 2019). Summing up, from ego dissolution to the reorganization of the self and the relaxation of cognitive constraints, the DMN is proposed to play a pivotal role in shaping the transformative and introspective nature of the psychedelic experiences.

In contrast to the reductions in default-mode network (DMN) activity observed in relation to psychedelic experiences, some fMRI studies have reported increased DMN activity following rumination induction (Burkhouse et al., 2018; Cooney et al., 2010). Interestingly, this heightened DMN activity has been associated with higher rates of depression symptoms and rumination (Burkhouse et al., 2018). Moreover, investigations using EEG have indicated the involvement of DMN structures in the processing of self-related information. Specifically, certain studies engaging both fMRI and EEG have demonstrated a correlation between DMN activity and alpha power (Knyazev et al., 2013, 2016; Lui et al., 2017; Bowman et al., 2017). Other authors have found associations between DMN activity and different frequency bands, such as delta, beta, and theta, but not alpha, using intracranial recordings (Das, de Los Angeles, Menon, 2022). A study by Ferdek et al. (2016) using EEG revealed that individuals with a propensity for rumination displayed lower beta power in the left dorsolateral prefrontal cortex and increased beta power in the left temporal lobe, particularly during rumination. Additionally, higher resting-state connectivity between the superior frontal gyrus (sgPFC) and PCC in the beta band was associated with rumination scores in participants with remitted major depressive disorder, as observed in another EEG study (Benschop et al., 2021). Bocharov et al. (2021) demonstrated a relationship between depression, rumination, and the dominance of the DMN over task-positive networks in the temporal cortex. However, this study did not provide specific information regarding the frequency bands involved in this interaction. It is worth noting that due to the diversity in the definitions of the self, experimental procedures, and analytical approaches used across these studies, a single consistent mechanism underlying DMN activity and its associations with depression and rumination remains elusive. In the present research, I focus on investigating the role of alpha and beta frequency bands in the context of DMN activity and its link to self-related thoughts processing for two connected reasons. First, I wanted to reduce the number of analyzed frequency ranges to avoid multiple comparisons problems and related rigorous corrections linked to it, which might diminish sensitivity of analyses to subtler effects. Therefore, I had to narrow the analyzed field and decide which frequencies to select to the ones that would have the most promising explanatory value. Second, reports on both alpha and beta activity overlapped in studies on key concepts I aim to address in the present research: that is DMN functioning (Knyazev et al., 2013, 2016; Lui et al., 2017; Bowman et al., 2017; Das, de Los Angeles, Menon, 2022), neural activity during rumination (Ferdek et al., 2016; Benschop et al., 2021), neural activity during acute psychedelic effects (Carhart-Harris et al., 2016; Kometer et al., 2015; Muthukumaraswamy et al. 2013). This points to the suggestion that alpha and beta could have the most significant relevance and explanatory potential for self-related thoughts processing in the context of psychedelic research. By examining these specific frequency bands, I aim to contribute to a deeper understanding of the complex relationship between DMN electrophysiological activity, self-related thoughts processing, and their potential implications for mental health.

Figure 2

Structures of the default-mode network



Note. Figure was originally present in the paper of McCormick & Telzer (2018)

Hypothesis

Here, I explored psychological and electrophysiological differences between psychedelics users and non-users in terms of the processing of self-related thoughts. To this aim I used induction of self-related thoughts, and investigated differences between psychedelic users and psychedelic naive individuals willing to take psychedelics in the future using self-reports measures and EEG with beamforming source localisation. I collected data at two sites and analyzed it separately to be able to examine replicability of my findings.

I hypothesize that 1) psychedelic users will have lower rumination and higher reflection levels measured with Rumination Reflection Questionnaire (RRQ); 2) after self-related thoughts induction DMN activity will increase and this increase will be less pronounced in psychedelic drug users than in non-users. Based on previous findings, I assumed that lower DMN activity, expected in psychedelic drugs users, should be reflected in lower alpha and beta power in source localized DMN regions (Knyazev et al., 2013, 2016; Lui et al., 2017). Hypotheses are summarized below in Figure 3.

Figure 3

Schematic representation of hypothesis. Grey marks group/condition with lower expected group/condition means in a given comparison.

	Within-groups	Between-groups
Reflection (RRQ)	-	Users > Non-users
Rumination (RRQ)	-	Users < Non-users
Alpha power	Self-related thoughts > Distraction	-
Beta power	Self-related thoughts > Distraction	-
Alpha power increases during self-related thoughts	-	Users < Non-users
Beta power increases during self-related thoughts	-	Users < Non-users

There are suggestions that activity in other regions besides DMN (i.e. task positive network) might be involved in acute and post-acute psychedelic effects (van Elk & Yaden, 2022). Therefore, after theory-driven, confirmatory analysis I conducted exploratory analysis to inspect potential differences besides DMN activity.

Hypothesis nr 2, research plan and procedures were preregistered here: https://archive.org/details/osf-registrations-z6tky-v1. Although, some minor discrepancies between preregistered research plan and final research plan arised and are addressed in footnote.[5]

[5] Initially, the hypothesis suggested an increase in the Default Mode Network (DMN) within the alpha band. However, upon a thorough analysis of the literature on self-processing, I decided to expand the hypothesis to include increases in the beta band, which has been identified as a neural indicator of self-processing in several studies. Although I initially planned an exploratory analysis

Methods

Participants

I used data collected at two sites: Dataset I and II. Dataset I included data from 70 individuals, Dataset II included data from 38 participants. Exclusion criteria applied in both studies were as follows: no consent to be contacted for EEG studies; a history of regular use of certain psychoactive substances (such as empathogens, stimulants, dissociatives) exceeding 15 occasions in their lifetime or more than 5 occasions in the past year; occasional use of substances from the benzodiazepine, synthetic cannabinoid, or opioid class exceeding 3 occasions in their lifetime; 4 points or higher score on any question of the AUDIT-C questionnaire; diagnosed psychiatric or neurological disorder or addiction; current use of prescribed psychoactive medications.

From the initial participant pool, two subgroups were formed: users, who reported having 15 or more experiences with classical psychedelics, and non-users, who had never used psychedelic substances but expressed a willingness to try them in the future. These subgroups were further divided based on the preferred location (selection between two sites, where the Dataset I or Dataset II were collected, more information in the section *EEG recording*) for the laboratory-based EEG sessions. To ensure comparability, gender, age, and education were matched between the user and non-user subgroups tested in each location. As a result, there were 36 users and 36 non-users tested in Dataset I site, and 20 users and 19 non-users tested in Dataset II site. In Dataset I two participants dropped out from the analysis due to incomplete EEG recordings during the procedure, in Dataset II 1 participant dropped out due to the high contamination of EEG signal with artifacts.

covering a wider spectrum of bands (theta, alpha, beta, and gamma), I ultimately decided to narrow the focus to alpha and beta. This choice was made to avoid the pitfalls of multiple hypothesis testing and the associated higher error rates.

Participants were enlisted through an online survey conducted using the LimeSurvey software (version 3.22.7), an open-source platform. I shared the survey via the social media profiles of several Polish organizations associated with harm reduction and drug policy (The Polish Drug Policy Network; Social Initiative of Drug Policy; Polish Psychedelic Society). Participants provided detailed information regarding a history of psychoactive substances use, and answered questions regarding basic socio-demographic information, the history of medication use, meditation practice, and of psychological, psychiatric, and neurological disorders, as well as the shortened version of Alcohol Use Disorders Identification Test (AUDIT-C; Bush et al., 1998). Finally, participants were asked for consent to be contacted regarding future online, EEG, and MRI studies. I invited all participants in advance and instructed them to abstain from using any psychedelic substances for at least 30 days prior to the scheduled EEG testing session.

The research comprising both datasets was approved by the Human Ethics Committee of the SWPS University of Social Sciences and Humanities (Warsaw, Poland; 13/2020).

Experimental session

Experimental sessions for each participant started with signing relevant documents, questionnaires filling, verbal instructions from experimentator, and EEG preparation, which took around 45 minutes. Afterwards, EEG recordings were conducted. In the present thesis I analyzed EEG data collected during *self-related thoughts (SRT) induction.* However, before the relevant SRT procedure, EEG recording sessions included other procedures, which were not included in the present research. The whole EEG session had the same order for all participants and contained following recordings: resting state procedure with eyes open and closed conditions (lasting circa 10 minutes), emotional faces recognition task (lasting circa 15 minutes) and perception of self vs. others names task (lasting circa 15 minutes), SRT induction was the final procedure and lasted circa 20 minutes. In the present thesis I analyzed only data from the last part, that is the SRT induction.

Materials

Below I will provide a description of materials used in the present research. This will include questionnaires, which participants filled before the EEG measurements and detailed description of SRT procedure.

Questionnaires

- *Ego Dissolution Questionnaire (EDI)*. EDI is an 8-item self-report scale designed to measure experience of ego-dissolution, which is considered to be among key phenomenological features of the psychedelic experience (Nour et al., 2016). Importantly, in my research, EDI was translated and used to measure the recalled intensity of the past ego-dissolution experiences induced by psychedelics. EDI measures various aspects of ego dissolution including disturbances in the sense of identity, self, feeling of oneness, self-importance and absorption with one's issues.

- *Reflection Rumination Questionnaire (RRQ).* RRQ is a 13-items questionnaire used to assess rumination and reflective thinking (Carter, 2010; Trapnell and Campbell, 1999; Polish translation: Radoń, 2014a). RRQ has Rumination and Reflection scales. Reflection scale comprises eight items and assesses the tendency to engage in adaptive and constructive self-reflection. It measures how often individuals think deeply about themselves, their emotions, and their experiences. High scores on this scale indicate a greater inclination for thoughtful and meaningful self-reflection. Items in this scale might include questions like "I often think about the reasons for my actions" or "I like to explore my thoughts and feelings." The rumination scale consists of five items and evaluates the tendency to engage in repetitive and unproductive thinking patterns, especially those related to distress and negative emotions. High scores on this scale suggest a greater tendency toward rumination and dwelling on negative thoughts. Sample items for this scale could include statements like "I often dwell on what I should have done differently" or "I find it hard to stop thinking about my worries."

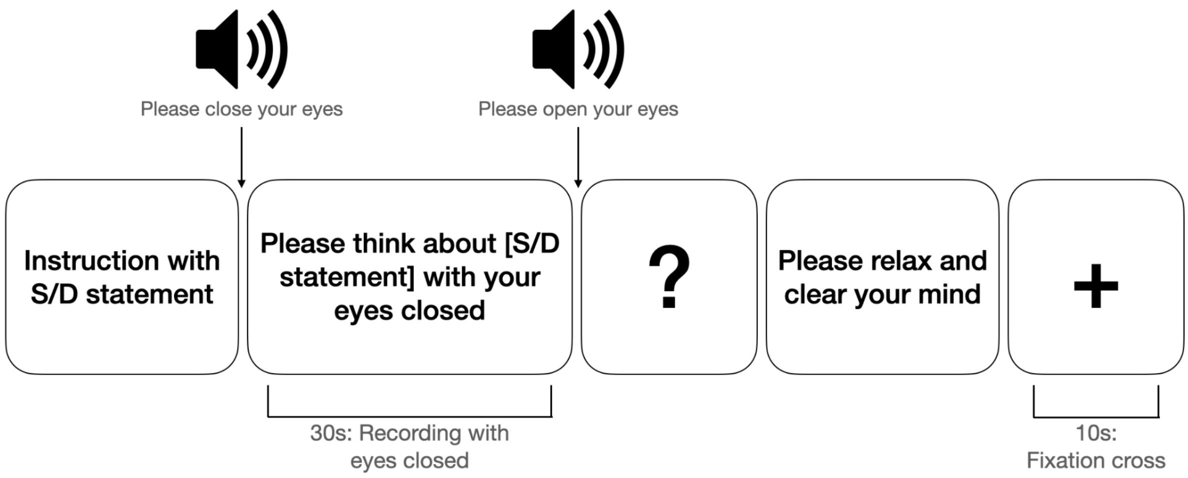
- *Beck Depression Inventory version II (BDI-II)* (Beck et al., 1996) is a 21-item questionnaire used to assess levels of depressive symptoms. The BDI-II assesses a range of emotional, cognitive, and physical symptoms of depression, including feelings of sadness, pessimism, guilt, and worthlessness, as well as changes in appetite, sleep patterns, and fatigue. Each item is scored on a scale of 0 to 3, with higher scores indicating more severe depressive symptoms. The total score is then interpreted to categorize the individual's level of depression, typically as minimal, mild, moderate, or severe.
- *State-Trait Anxiety Inventory (STAI)* (Spielberger, 1983) is a 40-items questionnaire used to assess levels of anxiety as a trate and a state. The STAI consists of two separate 20-item scales: one for assessing state anxiety (STAI-I) and another for trait anxiety (STAI-II). Each scale comprises items that describe various feelings, thoughts, and behaviors associated with anxiety. Respondents rate how they feel or have felt on a 4-point scale, with options typically ranging from "Not at all" to "Very much so". The State Anxiety scale (STAI-I) assesses an individual's current or momentary experience of anxiety, making it particularly useful for gauging anxiety in specific situations or contexts. In contrast, the Trait Anxiety scale (STAI-II) measures the individual's general predisposition to experience anxiety across different situations, reflecting a more stable aspect of their personality.

Self-related thoughts induction procedure

SRT induction (Fig. 1) was based on a paradigm used in previous studies on rumination, i.e. using Nolen-Hoeksema's protocole (Cooney et al., 2010, Burkhouse et al., 2018). There are two conditions in the task: the SRT condition and the distraction condition. Statements for SRT induction held such instructions as: “Think about why you react the way you do”, “Think about the kind of person you think you should be”. Distraction condition included instructions to focus on abstract ideas: “Think about the change in seasons”, “Think about why you like the books you do”. Instructions were delivered via presentation on computer monitor and loudspeakers, participants were asked to sit with their eyes closed during focus on the statement. Participants were instructed to focus on each statement for 30 seconds. Each statement from SRT or distraction condition was followed by three questions regarding the participant's focus on the statement (To what extent did you manage to focus on the statement?), focus on the self (How much were you focused on yourself?) and level of sadness (How sad were you during the focus on the statement?). Questions were presented in the same order and had no time limit for the response. After the questions participants were asked to clear one's thoughts before the next statement will be delivered. An instruction to focus on a statement, the time for the focus on the statement, subsequent questions and a break constituted one trial. Distraction and SRT statements were presented in blocks consisting of 3 trials from one condition each. Statements from the given condition were randomly assigned to each block. Blocks were repeated in a subsequent order either SDSSDD or DSDDSS, where S is for SRT condition and D is for distraction. This resulted in nine statements for each condition. The total recording from one condition with all statements was 270 seconds long. Detailed description and visualization of single trial is presented below (Figure 4).

Figure 4

Schematic depiction of a single trial in the rumination induction procedure.



Notes. *S* - self-related thoughts claim, *D* - distraction claim, *?* - 3 questions assessing focus on the statement, focus on the self and level of sadness. One sequence included three trials with either SRT or distraction conditions in a row. Sequences were presented either in SDSSDD or DSDDSS order, where S stands for sequence with self-related thoughts and D stands for sequence with distraction claim. Order type (SDSSDD or DSDDSS) was randomly assigned to a person.

EEG recording

Dataset I

Data from Dataset I was collected at the Neurocognitive Research Center based at SWPS University of Social Sciences and Humanities in Warsaw. The EEG signal was recorded with 64-channel (Ag/AgCl active electrodes) Brain Products ActiCap system and BrainVision software at a sampling rate of 1000 Hz and downsampled off-line to 250 Hz. Impedance was kept below 10 kΩ.

BrainVision Captrak was used for the registration of electrode positions. This data was later used to create reconstructed 3D models of electrode position on the participants head in relation to referential points (Nasion, LPA, RPA).

Dataset II

Data from Dataset II was collected at the Institute of Psychology of Jagiellonian University in Krakow. The EEG signal was recorded with 64-channels (Ag/AgCl active electrodes) using a BioSemi ActiveTwo amplifier system (BioSemi, Amsterdam, NL) and the BioSemi ActiView software. Sampling rate was 2048 Hz and downsampled off-line to 250 Hz. Impedance was kept below 15 kΩ.

EEG preprocessing

EEG signal was preprocessed using the MNE Python toolbox (Gramfort et al., 2014). Preprocessing steps were identical for data from both datasets. Continuous EEG signal was 1 Hz high pass filtered. EEG recordings were visually inspected and segments containing strong, non-stereotypic artifacts were marked as bad. These fragments were not included in further preprocessing or analysis steps. Independent component analysis (ICA) was applied to remove remaining stereotypical artifacts (such as eye blinks, eye movements, and muscular activity) from the data (Hipp and Siegel, 2013; McMenamin et al., 2010; Shackman et al., 2009). Independent components signal, topographies, and power spectra were visually inspected and components related to stereotypical artifacts were marked for removal. The average number of total components among all participants were: Dataset I: $M = 37.2$, $SD = 6.63$; Dataset II: $M = 31.03$, $SD = 8.83$. The average number of removed components were as follows: Dataset I $M = 3.16$, $SD = 1.41$; Dataset II: $M = 4.34$, $SD = 1.49$. Bad channels were not included in the ICA and were interpolated. At the last step the signal was re-referenced to the common average (AVG).

EEG analysis

All EEG and statistical analyses were performed using *MNE-python* (Gramfort et al., 2014), *pingouin* (Vallat, 2018), *statsmodel* (Seabold, Skipper, Perktold, 2010), *scipy* (Virtanen et al., 2020), *borsar* and *sarna* (Magnuski, 2022) packages and custom code (Ruban, 2023).

MRI scans and source space reconstruction

MRI scans and individual electrode positions were collected only for participants in Dataset I due to feasibility reasons, that is the lack of the availability of captrak hardware on site where data for the Dataset II was collected and lack of sufficient funds and too small number of participants in Dataset II to perform MRI scans as this would risk in too low number of scans due to the drop out.

Individual electrode positions were recorded using the BrainVision Captrak system. I obtained electrode positions for 59 out of 70 participants (84.29%) due to captrak-related technical issues during 11 registrations. For participants with no individual channel positions I created a template using averaged electrode coordinates from the participants with captrak data. In the following step digitized electrode positions were coregistered either with individual MRI scans or with *fsaverage* FreeSurfer head model (Dale et al., 1999). For participants with available captrak data, but lacking individual MRI scans, *fsaverage* was scaled to fit cap size.

MRI scans were performed in Interinstitute Laboratory of New Diagnostic Applications of Magnetic Resonance Imaging, Nalecz Institute of Biocybernetics and Biomedical Engineering, Polish Academy of Sciences (CNSLab IBIB PAN) using GE Discovery MR750w 3.0T scanner. MRI scans were collected for 29 out of 70 participants (41.43%) participants due to drop out (not responding to the invitation to participate in

MRI scans, n=31) or not meeting criteria for MRI registration (safety requirements, declaration of a consent to take part in this part of the research, n=10).

Total number of participants from Dataset I with available captrak or/and MRI scans is summarized in Table 1.

Table 1

Summary of available eeg data, individual captrack channel positions, MRI scans.

	Captrak available	**No captrak**
MRI available	e = 12 | c = 9	e = 17 | c = 9
No MRI	e = 26 | c=30	e = 4 | c = 3

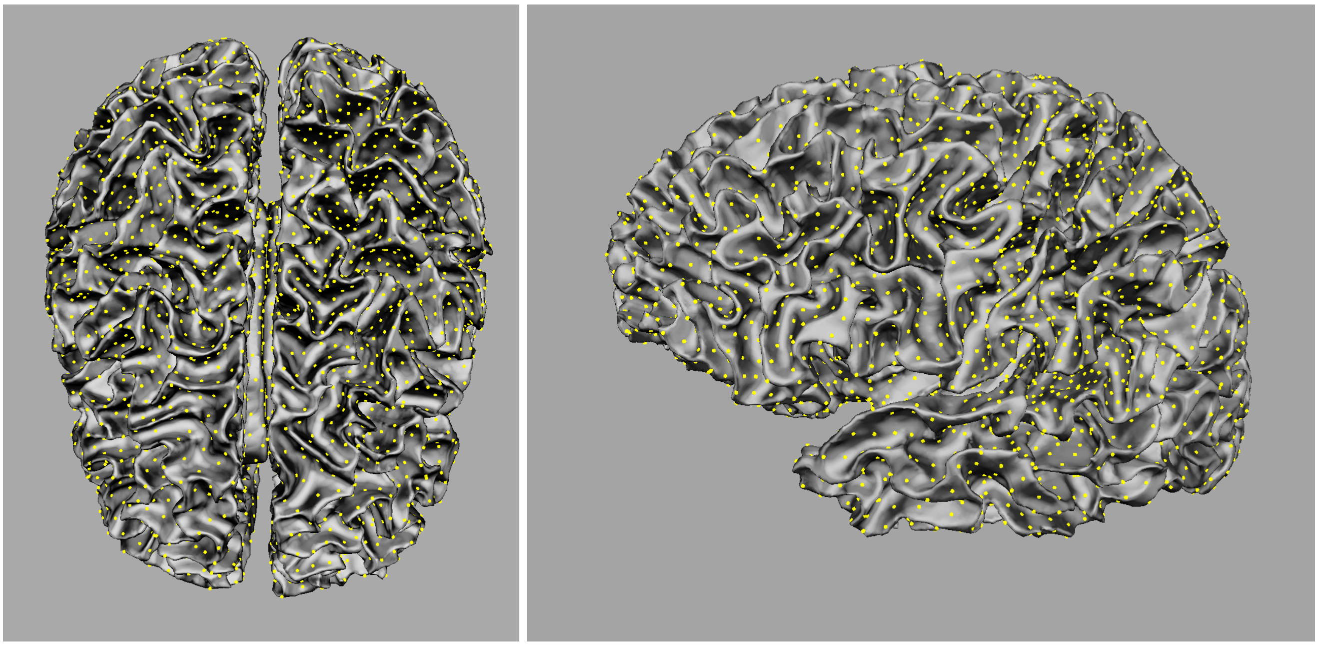
Note. Shortcuts present in the table stand for: *e - experimental group; c - control group*.

I reconstructed the scalp, inner/outer skull and cortical surfaces using FreeSurfer software (Dale et al., 1999). In case anatomical models were incorrect, i.e. the inner skull reconstructed layer interfered with the outer skull, models were manually fixed using Blender software (https://www.blender.org/). The inference of the outer and inner skull was found in 9 participants. To correct reconstructions I used Shrinkwrap mode to move fragments of the inner skull interfering with the outer skull inside the outer skull following instructions in the MNE python tutorial (MNE Developers, 2023). Alternatively, I used a tool for local corrections (Grab Brush) and moved interfering surface fragments inside the outer skull as well.

I employed the Boundary Element Method (BEM) for the forward problem[6] (Fuchs et al., 2002). I created a three-layer (inner/outer skull, outer skin) BEM model either using individual MRI reconstruction or *fsaverage* template. Next, the source space model was constructed for a grid of equidistant source points covering the whole *fsaverage*/MRI cortical surface. Depending on the MRI (*fsaverage* or individual) number of source points was slightly different and oscillated around 5124 points. Mean number of points for individual scans was 5108.22 with SD=16.75. Example of source points distribution is presented in Figure 5.

Figure 5

Volume source space grid on a brain surface with 5124 points.



Note. Source points are marked with yellow. Based on *fsaverage* brain BEM reconstruction.

[6] The forward problem in the context of EEG source reconstruction involves predicting the distribution of electrical potentials on the scalp's surface resulting from neural activity within the brain.

Cross-spectral density matrices and source localisation

To extract features of the EEG signal I used Morlet wavelet transformation. In EEG analysis Morlet wavelet transformation is a mathematical tool used to extract information from the EEG signal. Describing the signal's time-frequency properties is achieved by convolving it with wavelets of increasing frequencies (Kumar, Alam, and Siddiqi, 2017). By breaking down the EEG signal into these components, we gain insights into how the brain's electrical patterns change over time and across different frequencies, which is crucial for understanding and neural dynamics accompanying various cognitive processes. A wavelet is a type of wave-like pattern that starts at zero, goes up and down - respectively increasing or decreasing in the amplitude - one or more times, and then returns to zero. They come in different varieties depending on the number and direction of their pulses. A metaphor can be used to better understand the concept of the wavelet: imagine you have a song, and you want to know which instruments and how intense they are playing at different moments. Wavelets can help you look at the song in both fine detail and a broader view. So, you can zoom in to see tiny changes, like individual notes, or zoom out to see larger patterns, like musical sections. Likewise, wavelets come in two forms: compressed (with a high number of cycles), are suitable for capturing abrupt changes, thus are characterized by better temporal resolution; stretched (with a low number of cycles), which capture gradual changes and allow for the high frequency resolution. An advantageous aspect of wavelet transformation is its flexibility in defining the number of cycles independently of wavelet frequency. This flexibility enables us to optimize the time and frequency resolution of the wavelet analysis for various frequencies of interest. In my study, I set the number of wavelet cycles to seven.

Before applying the beamforming source localization technique to address the inverse problem[7], I constructed cross-spectral density (CSD) matrices. Cross-spectral density represents the covariance between two channels at a specific frequency. The CSD matrix is a map that illustrates the covariance between all possible electrode pairs and is needed for further inquiries on localisation of the signal. The CSD matrices were computed using Morlet wavelets separately for rumination and distraction conditions for 4-30 Hz frequency range. Events were defined based on the stimulus marking the onset of instruction to begin the focus on the statement. I used a 30-second long signal for each event, starting 5 seconds after event onset. This resulted in nine 30-second long epochs for each condition, where each epoch corresponded to a statement. Bad signal segments were ignored.

I used beamforming (Dynamic Imaging of Coherent Sources, DICS: Gross et al., 2001) to infer the source-level activity of signal record with scalp electrodes (solve the inverse solution). DICS was successfully used in EEG and MEG research allowing for the estimation of brain source locations and their associated power spectra (van Vliet et al., 2018; Halder et al., 2019; Moeller et al., 2013; Pscherer et al., 2020). It operates by estimating the spatial filters that maximize the power of interest while minimizing the interference from noise and other unwanted sources, in other words this filter amplifies activity from one point in source space while suppressing contribution from the other sources (Van Vliet et al., 2018). We can think of beamforming like a powerful microphone that can pick up individual voices in a noisy room. When you're in a crowded place, like a party, and you want to listen to a specific person speaking, you use a special microphone that can focus on that person's voice while reducing background noise. This microphone amplifies the sound of the person you're interested in, making it louder and clearer, while

[7] Inverse problem - estimation of the brain source of the signal, which was collected with electrodes placed on the scalp.

minimizing all the other chatter and music around. In the case of the present research, DICS is like that special microphone. It helps us pinpoint and enhance the brain activity happening in a specific area while reducing interference from other brain signals, just like the microphone isolates one voice from the many in a noisy room. With DICS, we can listen to what's happening in different parts of the brain and analyze it in detail, almost like tuning in to different conversations at the party.

To estimate oscillatory power coming from all points on the cortex, beamformers are created for every source respectively. Beamformer utilizes the CSD computed from the recorded EEG/MEG data and provides a frequency-specific analysis of brain activity. DICS beamforming enables us to examine these oscillatory activities in specific frequency bands with better spatial resolution. To obtain power maps (that is information on amplitude of waves in particular frequency range in particular brain regions), I applied a DICS spatial filter to CSDs. Localized power maps in case of participants with MRI scans were morphed to *fsaverage* to allow for a group-level analysis. This resulted in calculation of power spectral densities (PSDs) for all points in vertices by frequency space.

In order to enhance the stability and noise resistance of the inverse solution, I implemented a regularization parameter. Van Vliet et al. (2018), suggested that regularization values should be within the range of 0.01 to 0.1. The level of regularization directly affects the sensitivity of the analysis: with higher regularization values, the analysis becomes less sensitive. This means that the resulting power map will predominantly reflect signals from the most robust sources, potentially omitting finer details in the data. To maintain a good tradeoff between noise-resistance and sensitivity, I implement a regularization parameter of 0.05.

Statistical analyses of EEG data overview

All statistical analyses were performed in source space for alpha (7-12 Hz) and beta (14-30 Hz) frequency ranges. Overall, analyses consisted of three main steps: (a) exploratory within-group analysis: examination of differences between self-related thoughts (SRT) and distraction (DIS) conditions; (b) ROI between-group analysis on differences in power in SRT-DIS conditions, (c) exploratory between-group analysis on differences in power in SRT-DIS conditions. Summary of analysis plan with description of the purpose of the analysis can be found in Table 2.

Table 2

Summary of analyses with information regarding relevant statistical tests, analysis type and analysis purpose.

datasets included	analysis	statistical test	purpose of the analysis	type
BEHAVIORAL ANALYSES				
Dataset I and II	between group contrast in RRQ	Mann-Whitney U test	examination of differences in rumination and reflection scales of RRQ	confirmatory
Dataset I and II	between group contrast in BDI-II and STAI	Mann-Whitney U test	examination of differences in depression and anxiety state and trait levels between groups	exploratory
Dataset I and II	between-group and within-group differences in reaction to self-related thoughts induction task	Mixed ANOVA	examination of between- and within-group differences in response to self-related thoughts versus distraction conditions	exploratory
ELECTROPHYSIOLOGICAL ANALYSES				
Dataset I and II	within-group contrast, whole brain	cluster-based permutation test	ROI definition for Warsaw and Krakow sites (based on Warsaw data only); exploration of within group differences between neural response to self-related thoughts vs. abstract thinking	confirmatory

Dataset I and II	between group contrast, ROI	Welch t test, p values obtained either using Welch t test or permutations; bayesian between-group comparison	hypothesis-driven analysis of difference in neural response to processing of self-related information between users and non-users	confirmatory
Dataset I and II	between group contrast, whole brain	cluster-based permutation test	exploration of any broader between-group effects	exploratory
Dataset I	correlation between behavioral and electrophysiological data	non-parametric Shepherd pi correlation	exploration of the relationship between electrophysiological and behavioral data, aiming to interpret neural results in the light of theory	exploratory
Dataset I	regression with confounders	Bayesian regression	examination of predictive value of group alone and group with confounders (lifetime meditation hours, cannabis use)	exploratory

For between-group analyses I calculated the difference between conditions by subtracting PSD in DIS condition from PSD in SELF condition for each participant. *I further refer to the PSDs difference between conditions as DIFF.*

I used a cluster-based permutation t-test in all analyses performed on whole-brain sensor space. That is a within-group comparison of power in SRT vs. DIS conditions (a) and a complementary exploratory analysis of DIFF between groups (c). Given the significant difference between users and non-users groups in terms of cannabis use and meditation practice[8] (more detailed result presented in the Result section) in the Dataset I, I decided to perform Bayesian linear regression to explore the contribution of these variables to the effect of differences between groups. Therefore, ROI analyses included t-tests and Bayesian linear regression. Between-group whole brain analysis included

[8]The significant between-group difference in lifetime use of empathogens and dissociatives was indeed observed in both datasets, with participants in the users group reporting more occasions of use of substances from these groups. However, these differences, while statistically significant, did not have practical relevance due to the relatively small magnitudes of the group means. Therefore, it was deemed unnecessary to include these variables in the regression models as their impact on the outcomes was expected to be negligible.

Bayesian regression on averaged cluster data (for detailed procedure of averaging see the *ROI analysis* section). In the Bayesian regression models, I included group as a predictor and lifetime occasions of cannabis use and lifetime meditation hours as confounders. Significant diSpecifically, I compared the Null model, which included only the confounders, to a model that additionally included the group variable. Bayesian regression allowed us to assess the evidence for the inclusion of the group variable in predicting the outcome, while accounting for the influence of lifetime cannabis use and lifetime meditation hours as confounding factors.

Finally, to assess associations between behavioral and electrophysiological data I performed Shepherd correlations. Shepherd correlation calculates the correlation coefficient by comparing the relative distances between pairs of data points in two datasets, providing a measure of how closely the datasets follow a similar pattern. It is a suitable measure for EEG data analysis as it captures both linear and nonlinear dependencies, is robust to volume conduction effects, handles missing data and outliers (Schwarzkopf, De Haas & Rees, 2012).

Cluster-based permutation test for whole-brain analysis and ROI size control

I used a cluster-based permutation t test for the whole-brain analysis, since it accounts for the multiple comparison problem (Maris & Oostenveld, 2007). The multiple comparison problem arises when conducting analyses in multidimensional space, such as considering effects along different data dimensions like source space and frequency. In order to address this issue, the cluster-based permutation test employs a permutation test at the cluster-level statistics. This approach considers the clustering of effects across multiple dimensions, allowing for a more rigorous and accurate assessment of statistical significance while controlling for false positives. By utilizing the cluster-based permutation test, I can confidently evaluate the presence of significant effects in the multidimensional data analysis. In reported analyses clusters are formed based on chosen statistical test (either t test or regression) performed in vertices by frequency space. Once t values for all vertices by frequency points are obtained, adjacent points, where t value passes the pre-defined threshold of 2 are grouped in clusters. In the next step, cluster summaries (sum of the statistics of each cluster point) are compared to null distribution of the maximum cluster statistic to obtain a p-value. The null distribution is drawn by Monte-Carlo method where in each iteration the condition (for within-group comparison) or group (for between-group comparison) labels are randomly assigned to a subject data and cluster statistics are computed once again on permuted data. Initial cluster statistics are then compared to null-distribution statistics aggregated from multiple permutations (here I used 1000 permutations) and a probability of obtaining clusters t value under the null hypothesis is estimated.

To ensure distinct and well-localized statistical maps, I implemented a maximum cluster size limit of 100 vertices. This step was not part of the cluster-based testing procedure itself but rather an optimization process for the sigma value in the trimmed t-test. The aim was to enhance spatial inference by selecting an appropriate sigma value that would result in optimal spatial selectivity, measured by the cluster size. I iteratively computed clusters using a t threshold of 2 for point inclusion, starting with a sigma value of 0.001. By gradually increasing the sigma value by a factor of 1.05, I determined the smallest sigma value that yielded clusters meeting the predefined threshold. The number of vertices within each frequency bin was assessed separately, and the cluster size was ultimately determined based on the frequency bin with the highest vertex count. This procedure aimed to optimize spatial inference and ensure reliable statistical outcomes. The specific sigma value obtained for each analysis is reported in the *Results* section.

I used a pingouin package (version 0.5.2) to calculate effect sizes (ES, Hedges' g). To calculate effect sizes and 95% confidence intervals of a given cluster I used averaged PSDs of all points comprising a given cluster in vertices by frequency dimensions. The procedure of averaging was identical to the one described below in the *ROI analysis* section.

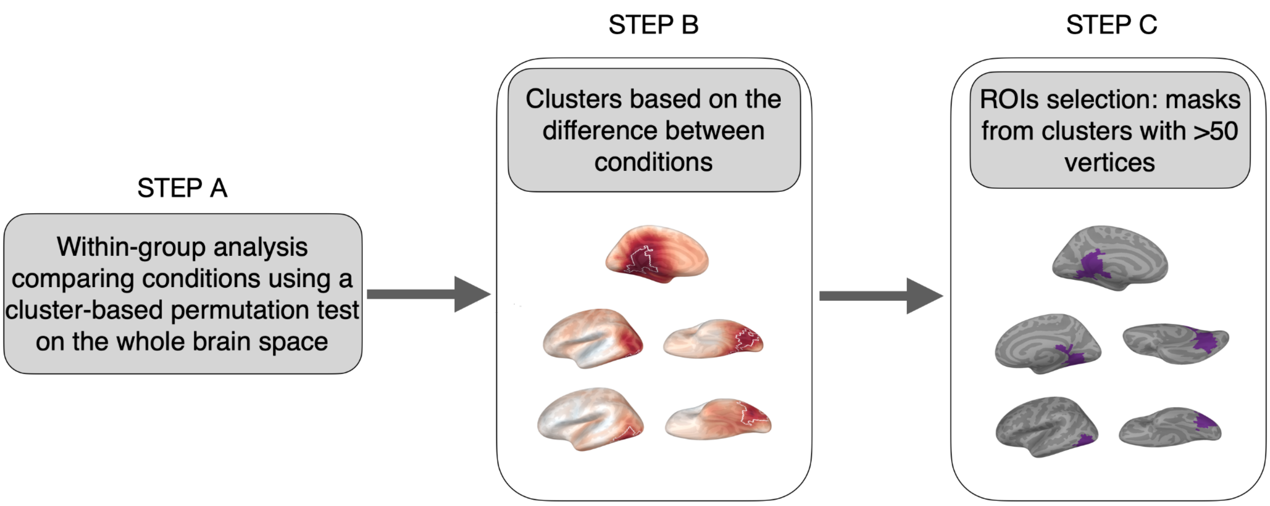
ROI analysis

I performed ROI analysis for group-level comparisons of differences between SELF and DIS conditions. Since DMN regions are differently defined from study to study, including psychedelic research (McCulloh et al. 2022), I identified no clear guidelines, which would allow for an atlas-based DMN region selection. For the ROI analysis, I utilized cluster masks derived from the within-group analysis (SELF vs. DIS) conducted on the whole brain on data collected at the Dataset I (schematic procedure described in Figure 6). I decided to use data from this dataset for the ROI selection given the availability of captrak and scans for some participants and thus presumably better source localisation. ROIs defined on this stage are presented in the *Results* section (*Within-group comparison self-related thought vs. distraction conditions - whole brain space*). Defined ROIs further were used for analysis for data from both datasets.

To limit the number of potential ROIs I selected only those clusters that consisted of more than 50 vertices. This selection criterion aimed to focus on clusters that exhibited sufficient spatial extent and statistical robustness. By setting a minimum vertex threshold, I aimed to reduce the number of smaller, less reliable clusters and prioritize larger clusters that potentially represented more meaningful and significant findings. These cluster masks were then applied to the PSD DIFF in both sites to extract the PSDs specifically for the points within the clusters, considering the vertices and frequency dimensions. Subsequently, I calculated the average PSDs across dimensions and employed them as the predicted variable. It is worth noting that the masks were defined based on the within-group analysis, while the ROI analysis was conducted between the groups. This approach ensured the independence of the within and between-group contrasts, thus mitigating any potential issues of circularity.

Figure 6

ROI selection scheme.



Note. ROI selection represented in three steps: STEP A: conduction of within-group cluster-based analysis of differences between SELF and DIS conditions. STEP B: Exemplary cluster masks obtained based on the within-group differences, places with highest t values marked with red, white line defines cluster limits, thus cluster masks. STEP C: Selection of clusters with more than 50 vertices and using selected clusters' masks for ROIs (vertices included within cluster limits). Violet color marks vertices within a given cluster mask, i.e. vertices included in ROI analyses.

Results

In the present section I describe results encompassing data from demographics, behavioral responses to SRT induction and EEG. I will begin with a description of the results regarding psychological functioning (that is demographics and questionnaire data). Later I would go into the electrophysiological results from the Dataset I - comprising within and between-group analyses and regression analysis with confounders. At the end of the subsection, with description of electrophysiological results from Dataset I, I will relate to correlation analysis, where I examine the relationship between behavioral and electrophysiological data. Finally, I will describe electrophysiological results from the Dataset II. Since there were no significant findings in this subsection, I will skip correlational analysis between EEG and behavioral data for the Dataset II. Full list of analyses and description of the purpose of the analyses are available in Table 2.

Behavioral results

Here I present results from behavioral data. This analysis encompassed demographic data, data regarding substance use and questionnaire data as well as behavioral response to the SRT induction task performed during the EEG recording in the laboratory. Demographic data and behavioral results are summarized in Tables 3, 4 and 5.

Demographics and questionnaires

Participants had similar characteristics in terms of age, sex and education. However, participants in both datasets differed in terms of number of meditation hours, number of occasions of dissociative and emapthogenes use with participants in users group presenting significantly higher rates in mentioned variables. Users in Dataset I had more occasions of cannabis use than non-users. In terms of questionnaire data, users had significantly lower rates of state and trait anxiety, depression and rumination measured respectively with STAI I and II, BDI II and RRQ. In contrast, participants in Dataset II did not exhibit differences in anxiety, depression and rumination, however, users in Dataset II had significantly higher reflection scores on the rumination scale of RRQ. These results are summarized in Table 3.

Table 3

Demographics, substance use, questionnaire data of participants included in Dataset I, II.

	DATASET I			DATASET II		
	Psychedelic users	**Non-users**	**Mann-Whitney U test comparison (Users - Non-users)**	**Psychedelic users**	**Non-users**	**Mann-Whitney U test comparison (Users - Non-users)**
N	36	34		20	19	
Demography						
Age	M=29.22, SD=4.8	M=27.35, SD=4.71	t=739.0, p=0.136	M=27.15, SD=5.43	M=28.95, SD=7.1	t=165.0, p=0.489
Sex						
Female	N=11	N=11		N=9	N=10	
Male	N=25	N=23		N=11	N=9	
Education						
Secondary	N=14	N=9		N=6	N=7	
Bachelor's degree	N=10	N=8		N=3	N=4	
Master's degree	N=11	N=16		N=7	N=6	
Higher than master's	N=1	N=0		N=1	N=2	
Below secondary	N=0	N=1		N=0	N=0	
Material situation						
Very bad	N=0	N=0		N=0	N=0	
Bad	N=1	N=0		N=0	N=0	
Moderate	N=6	N=10		N=5	N=3	
Good	N=24	N=17		N=8	N=10	
Very good	N=5	N=7		N=1	N=2	
Place of living						
Village	N=2	N=1		N=1	N=0	
City—population up to 50K	N=1	N=2		N=0	N=0	
City—population from 50K to 150K	N=2	N=2		N=0	N=1	

City—population from 150K to 500K	N=4	N=1		N=3	N=1	
City—population over 500K	N=27	N=28		N=10	N=13	
Substance use & meditation						
Psychedelics	M=25.53, SD=10.8	NA		M=38.8, SD=38.01		
EDI	M=531.17, SD=195.58	NA		M=635.11, SD=138.14		
Cannabis	M=322.67, SD=332.42	M=107.7, SD=198.81	**t=459.5, p=0.011**	M=146.54, SD=294.67	M=226.38, SD=524.72	t=99.5, p=0.455
Empathogens	M=3.92, SD=3.96	M=1.18, SD=2.2	**t=897.5, p<0.001**	M=5.42, SD=5.81	M=1.06, SD=2.59	**t=254.5, p=0.004**
Stimulants	M=2.36, SD=3.52	M=2.0, SD=3.72	t=702.0, p=0.254	M=2.05, SD=4.49	M=0.5, SD=1.3	t=215.0, p=0.102
Dissociatives	M=0.33, SD=0.82	M=0.0, SD=0.0	**t=731.0, p=0.007**	M=0.47, SD=0.82	M=0.0, SD=0.0	**t=225.0, p=0.011**
Opioids	M=0.19, SD=0.57	M=0.03, SD=0.17	t=663.5, p=0.179	M=0.05, SD=0.22	M=0.0, SD=0.0	t=180.0, p=0.358
Benzodiazepines	M=0.03, SD=0.16	M=0.0, SD=0.0	t=629.0, p=0.346	M=0.0, SD=0.0	M=0.0, SD=0.0	t=180.5, p=1.0
Alcohol (AUDIT-S)	M=2.61, SD=1.75	M=2.97, SD=1.93	t=534.0, p=0.354	M=1.92, SD=1.55	M=2.54, SD=2.17	t=67.0, p=0.561
Meditation hours	M=399.64, SD=878.43	M=119.71, SD=346.82	**t=835.0, p=0.008**	M=826.5, SD=2169.23	M=245.16, SD=773.5	**t=271.0, p=0.022**
Anxiety, depression, self						
STAI-I	M=29.66, SD=6.78	M=35.47, SD=7.73	**t=332.0, p=0.001**	M=29.78, SD=4.48	M=34.2, SD=9.01	t=100.5, p=0.217
STAI-II	M=34.51, SD=7.18	M=42.68, SD=8.37	**t=299.0, p<0.001**	M=34.32, SD=5.28	M=37.75, SD=8.94	t=118.0, p=0.267
BDI-II	M=4.36, SD=3.97	M=9.21, SD=7.12	**t=298.5, p=0.001**	M=6.26, SD=4.83	M=6.12, SD=5.27	t=155.5, p=0.92
RRQ: Rumination	M=15.7, SD=5.69	M=19.76, SD=4.05	**t=286.5, p<0.001**	M=13.33, SD=3.89	M=15.62, SD=5.38	t=112.0, p=0.274
RRQ: Reflection	M=27.43, SD=6.38	M=25.32, SD=5.89	t=763.5, p=0.075	M=29.0, SD=3.61	M=24.81, SD=6.03	**t=202.5, p=0.044**

Note. For the categorical variables such as group, sex, education, material situation and place of living I provide *N* (number) of participants in each group in each category. For numeric variables (questionnaires, substance use and meditation hours) I provide *M* (mean) and *SD* (standard deviation). Whenever group comparison was possible I provide results of Mann-Whitney U test.

Self-related thoughts induction procedure - behavioral response

Next, I analyzed the difference in the behavioral response between SRT and DIS conditions. ANOVA was conducted to examine the effect of group, condition and their interaction on the level of focus on the statement, participants' focus on themselves and level of sadness. Below, I describe results for each of these variables for both datasets. Results are summarized in the form of figure and table in Figure 7, Table 4 (ANOVA table) and Table 5 (descriptive statistics).

Focus on the statement. The analysis in the Dataset I revealed a significant main effect of the group ($F(1, 68) = 8.87$, $p = 0.004$, $\eta2 = 0.115$), indicating that participants in the users group were significantly more focused on the statement than participants in the non-users group. There was no significant effect of condition and no significant interaction effect between group and condition. However, in the Dataset II I observed a significant effect of the condition ($F(1, 36) = 5.23$, $p = 0.028$, $\eta2 = 0.127$), indicating that during the focus on the distraction condition participants were significantly more focused on the statement than during the SRT condition. There were no significant effects of group and interaction between group and condition.

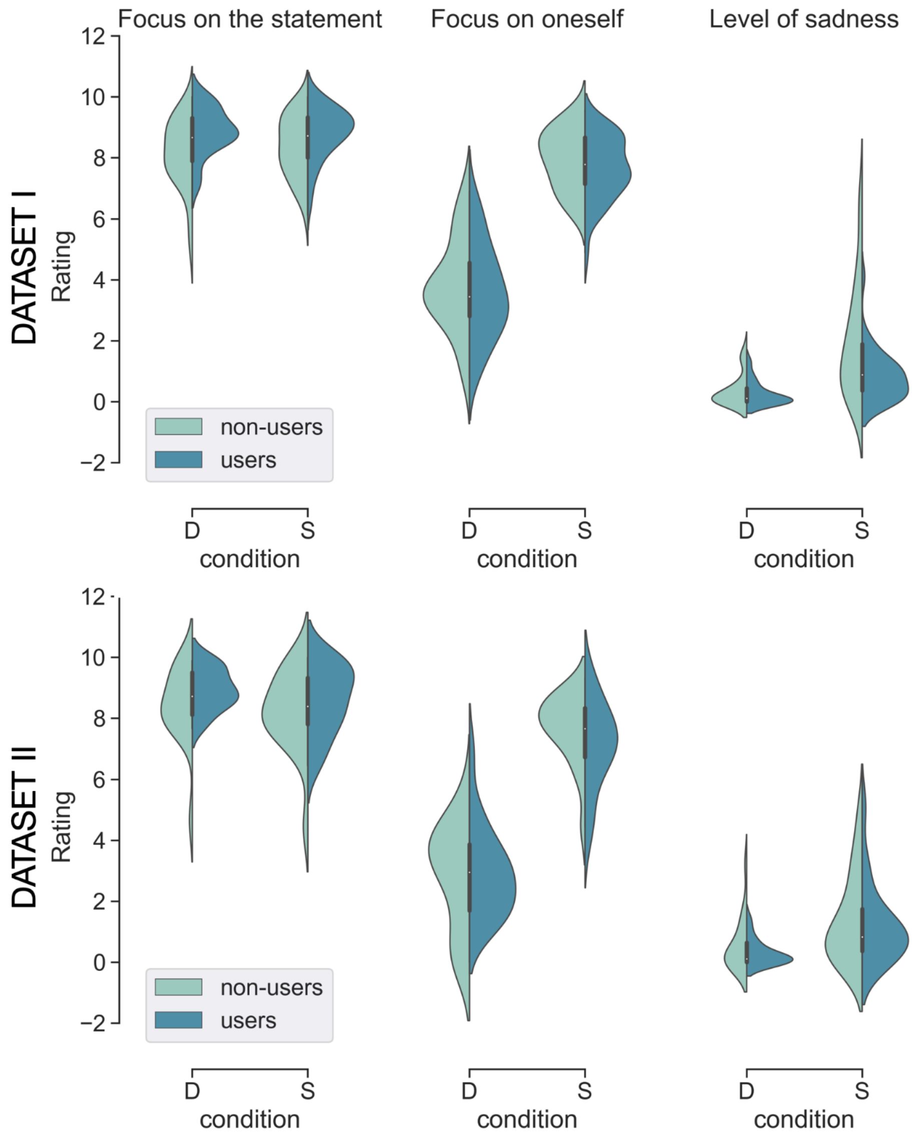
Focus on the self. In both datasets participants were significantly more focused on themselves during the SRT condition (DI: M=, SD; DII: M=7.38, SD=1.3) than during distraction condition (correspondingly: M=, SD; M=2.86, SD=1.56), (DI: $F(1, 68) = 405{,}74$, $p < 0.001$, $\eta2 = 0.86$; DII: $F(1, 36) = 282.37$, $p < 0.001$, $\eta2 = 0.89$). This is relevant information, as it confirms that participants were actually more focused on themselves during the SRT condition, as we expected.

Level of sadness. In both datasets participants reported higher levels of sadness during the SRT condition (DI: M=, SD; DII: M=7.38, SD=1.3) than during the distraction condition (DI: M=, SD; DII: M=7.38, SD=1.3) (DI: $F(1, 68) = 58{,}91$, $p < 0.001$, $\eta2 = 0.46$;

DII: F(1, 36) = 282.37, $p < 0.001$, $\eta2 = 0.89$). Additionally, in the Dataset I significant effect of group (F(1, 68) = 9,28, $p = 0.003$, $\eta2 = 0.12$) and interaction (F(1, 68) = 14.39, $p < 0.001$, $\eta2 = 0.18$) was observed, implying that participants in users group were significantly less sad during the SRT condition than participants in non-users group. Interaction and group effects were not significant in the Dataset II.

Figure 7

Averaged ratings of the answers to the questions following rumination induction procedure.



Note. Conditions*: D* - distraction*, S* - self-related thoughts.

Table 4.

Results of mixed ANOVA (group x condition) for Dataset I and II.

		How much were you focused on the statement?			How much were you focused on yourself?			How sad were you?		
	Variable	F	p-unc	np2	F	p-unc	np2	F	p-unc	np2
DATASET I	Group	8,866	**0,004**	0,115	1,265	0,265	0,018	9,277	**0,003**	0,12
	Condition	0,702	0,405	0,01	405,737	**<0.001**	0,856	58,911	**<0.001**	0,464
	Interaction	2,053	0,157	0,029	0,019	0,89	0	14,392	**<0.001**	0,175
									DF1	1
									DF2	68
									EPS	1
DATASET II	Group	1,757	0,193	0,047	0,363	0,551	0,01	0,605	0,442	0,017
	Condition	5,228	**0,028**	0,127	282,37	**<0.001**	0,887	19,641	**<0.001**	0,353
	Interaction	0,204	0,654	0,006	1,577	0,217	0,042	0,042	0,838	0,001
									DF1	1
									DF2	36
									EPS	1

Note. Table presents statistical values for effect of group (users vs. non-users), condition (self vs. distraction) and interaction of the above. Following statistics are presented: *SS* - sum of squares, *MS* - mean sum of squares, *F* - F value, *p-unc* - p uncorrected, *np2* - eta-squared (η^2).

Table 5

Descriptive statistics for ANOVA analysis.

		Focus on the statement			Focus on oneself			Level of sadness		
	group/condition	SRT	DIS	overall	SRT	DIS	overall	SRT	DIS	overall
DATASET I	**users**	M = 8.83, SD = 0.82	M = 8.88, SD = 0.77	M = 8.86, SD = 0.79	M = 7.66, SD = 1.02	M = 3.59, SD = 1.53	M = 5.63, SD = 4.42	M = 0.83, SD = 0.83	M = 0.27, SD = 0.39	M = 0.55, SD = 0.7
	non-users	M = 8.35, SD = 0.99	M = 8.14, SD = 1.12	M = 8.25, SD = 10.6	M = 7.95, SD = 0.98	M = 3.82, SD = 1.51	M = 5.88, SD = 2.44	M = 2, SD = 1.86	M = 0.37, SD = 0.52	M = 1.19, SD = 1.58
	overall	M = 8.6, SD = 0.93	M = 8.52, SD = 1.02		M = 7.8, SD = 1	M = 3.7, SD = 1.51		M = 1.4, SD = 1.53	M = 0.32, SD = 0.46	
DATASET II	**users**	M = 8.61, SD = 1.11	M = 8.94, SD = 0.67	M = 8.78, SD = 0.92	M = 7.11, SD = 1.42	M = 2.91, SD = 1.45	M = 5.01, SD = 2.55	M = 1.2, SD = 1.26	M = 0.31, SD = 0.41	M =0.75 , SD = 1.03
	non-users	M = 8.22, SD = 1.32	M = 8.44, SD = 1.23	M = 8.33, SD = 1.26	M = 7.68, SD = 1.11	M = 2.8, SD = 1.71	M = 5.24, SD = 2.85	M = 1.38, SD = 1.44	M = 0.57, SD = 0.87	M = 0.98, SD = 1.24
	overall	M = 8.43, SD = 1.21	M = 8.71, SD = 0.99		M = 7.38, SD = 1.3	M = 2.86, SD = 1.55		M = 1.23, SD = 1. 33	M = 0.43, SD = 0.67	

Note. Shortcuts: SRT - self-related thoughts condition; DIS - distraction condition; M - mean; SD - standard deviation.

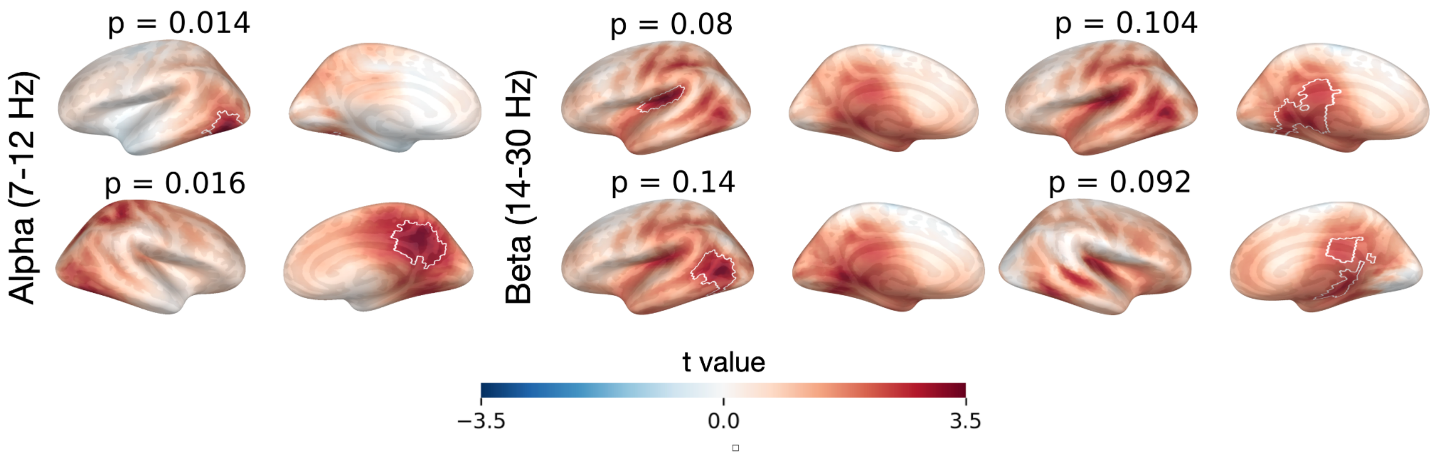
EEG Results - Dataset I

Within-group comparison self-related thought vs. distraction conditions - whole brain space

Here I present results for clusters which had a sufficient number of vertices. As described in the *Methods* section, to restrict the number of ROIs and ensure statistical robustness, I used only those cluster masks that had more than 50 vertices. Therefore, size of clusters in within-group analysis is an outcome of primary importance for the further between-group analysis. Below, however, I also provide statistical significance for those clusters as an additional result. The within-group results could be of interest in itself, since it contributes to the existing literature on electrophysiological correlates of self-related thoughts processing. Results visual summary is available in Figure 8.

Figure 8

Selected results for the whole-brain within-group contrast for Dataset I.



Note. Figure shows spacial t values and number of vertices included in cluster in each frequency bin. Cluster limits are marked with white outlines, and corresponding cluster p-values are shown at the left top of each panel. Color bar at the bottom presents color coding for the t values.

Alpha range (7-12 Hz). I applied a cluster-based permutation test on PSDs covering alpha range to compare activity between SELF and DIS conditions. Overall, 9 clusters were defined for this analysis out of which 2 clusters included 50 or more vertices and were selected for subsequent ROI analyses. Differences between conditions were significant, higher alpha power was observed for SELF condition (p values for clusters A, B correspondingly: p=0.014, p=0.016). Clusters covered parietal and ventral-temporal regions.

Beta range (15-30 Hz). Cluster-based permutation test on PSDs covering beta range showed that beta power was not significantly higher for SELF vs. DIS conditions (p values for clusters C, D, E, F correspondingly: p=0.08, p=0.104, p=0.92, p=0.14). I have indicated 21 clusters out of which 4 had more than 50 vertices and were selected as ROIs for further analysis. Description of other clusters is presented in Supplementary materials (Sup X). Presented clusters (C, D, E, F) covered insular, ventral-temporal and posterior regions.

Between-group comparison of differences in conditions - ROI space

Between group comparison was part of the hypothesis-driven analysis of difference in neural response to processing of self-related information between users and non-users. This was used to test Hypothesis 2: after self-related thoughts induction DMN activity will increase and this increase will be less pronounced in psychedelic drug users than in non-users. Results for between-group contrasts analyses in alpha and beta bands are presented in Table 6.

Table 6

Description of between-group comparisons results for all defined ROI's for the Dataset I and Dataset II:

ROI	Frequencies	t (Welch)	dof	p (Welch)	p (permuted)	Hedges' g	Hedges' g BCI (95%)	BF10	power
				DATASET I					
A	7-12 Hz	2,51	65,614	0,015	**0,02**	0,596	0.14 | 1.05	3.424	0,7
B	7-12 Hz	1,724	59,257	0,09	0,089	0,412	-0.05 | 0.82	0.868	0,404
C	14-30 Hz	2,385	63,248	0,02	**0,019**	0,568	0.14 | 0.96	2.671	0,658
D	14-30 Hz	1,739	60,551	0,087	0,084	0,406	-0.06 | 0.78	0.887	0,395
E	14-30 Hz	2,302	65,943	0,024	**0,021**	0,541	0.13 | 0.91	2.277	0,616
F	14-30 Hz	2,564	64,348	0,013	**0,008**	0,601	0.16 | 0.91	3.828	0,707
				DATASET II					
A	7-12 Hz	-0,383	35,788	0,704	0,718	-0,12	-0.71 | 0.57	0.334	0,066
B	7-12 Hz	0,578	23,258	0,569	0,622	0,176	-0.53 | 0.67	0.36	0,084
C	14-30 Hz	-0,327	30,314	0,746	0,762	-0,101	-0.68 | 0.62	0.329	0,061
D	14-30 Hz	0,473	32,713	0,64	0,644	0,147	-0.46 | 0.84	0.344	0,074
E	14-30 Hz	0,021	33,824	0,983	0,983	0,007	-0.61 | 0.64	0.315	0,05
F	14-30 Hz	0,542	35,032	0,591	0,602	0,17	-0.5 | 0.8	0.354	0,082

Note. *dof* - degrees of freedom; *Hedges' g BCI (95%)* - Hedges' g 95% bootstrap confidence intervals; *BF10* - Bayes Factor indicating the strength of evidence for the alternative hypothesis.

Alpha range (7-12 Hz). Averaged DIFF for alpha range for vertices included in cluster A was significantly lower for Users compared to Non-Users groups (Figure 8). That is, the difference in PSDs between SELF-DIS conditions was significantly smaller for users than for non-users (t(Welch) = 2,51, p (Welch) = 0.015, p (permuted) = 0.02). Further, I tested evidence for alternative hypothesis (H1) against the null hypothesis (H0) using Bayes Factor (BF). H1 assumed that groups differ in terms of difference between conditions, whereas H0 assumed the lack of difference between groups. The BF provided evidence for the alternative hypothesis (H1) over the null hypothesis (H0), with a BF value of 3.24 indicating substantial support for H1.

Averaged DIFF for alpha range for vertices included in cluster B was not significantly lower for users compared to non-users groups ((t(Welch) = 1,724, p(Welch) = 0.09, p(permuted) = 0.089) (Figure 9). The BF provided evidence for the H0 over the H1, with a BF value of 0.868 indicating weak support for H0.

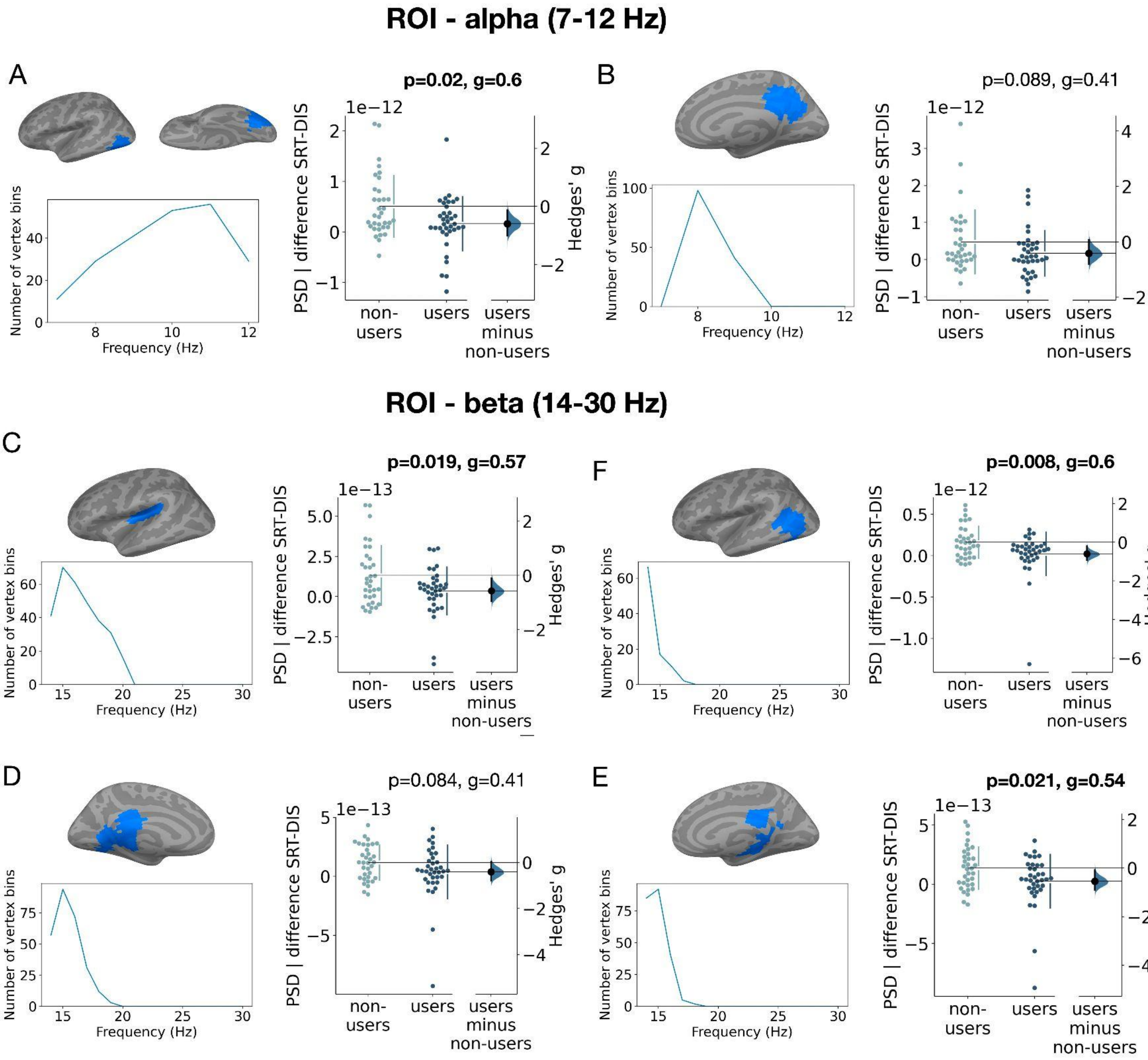
Extended results containing statistical power, effect size and effect size CIs are presented in Table 6.

Beta range (14-30 Hz). Averaged DIFF for beta range for vertices included in cluster C, E and F was significantly lower for Users compared to Non-Users groups (Figure 8). Statistics for each ROI were: C - t(Welch) = 2,385, p (Welch) = 0.02, p (permuted) = 0.019; E - t(Welch) = 2,302, p (Welch) = 0.024, p (permuted) = 0.021; F - t(Welch) = 2,564, p (Welch) = 0.013, p (permuted) = 0.008. The BF provided evidence for the alternative hypothesis (H1) over the null hypothesis (H0) for above-mentioned ROIs (C, E and F). BF values for ROIs C and E were correspondingly 2.671 and 2.277 indicating weak support for H1. BF value for ROI F was 3.828 indicating substantial support for H1.

Averaged DIFF for beta range for vertices included in cluster D was not significantly different between groups (t(Welch) = 1.739, p(Welch) = 0.087, p(permuted) = 0.084) (Figure 8). The BF provided evidence for the H0 over the H1, with a BF value of 0.707 indicating weak support for H0.

Figure 9

Results for the ROIs in between-group contrast for alpha and beta bands.



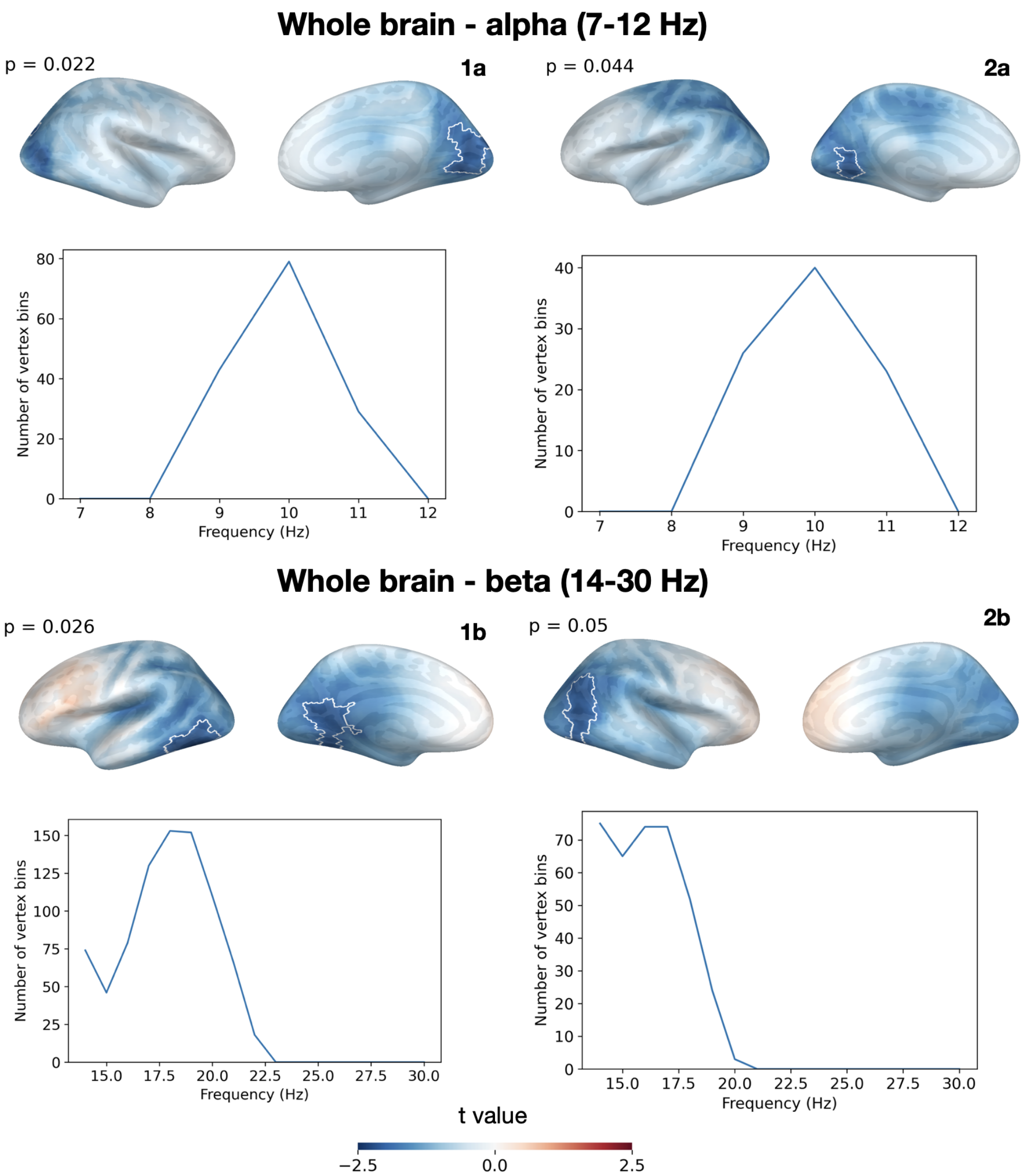
Note. ROI regions are marked with violet color on a brain model in the top left of each cluster panel. Bottom left plot presents the number of vertices included in a given ROI for each frequency bin. On the right of each panel swarmplot presents DIFF value for each observation in each group and a Hedges' g.

Between-group comparison between DIFF, whole brain space

Below I present findings from the exploratory between-group comparison on the whole brain space. Results summary available in Figure 10.

Figure 10

Selected results for the whole-brain between-group contrast showing spacial t values and number of vertices included in cluster in each frequency bin.



Note. Cluster limits are marked with white outlines, and corresponding cluster p-values are shown at the left top of each panel. Color bar at the bottom presents color coding for the t values.

Alpha range (7-12 Hz). I performed a cluster-based permutation test on PSDs covering alpha range on the whole brain space to compare DIFF between users and non-users. Overall, X clusters were defined for this analysis. Here I discuss only clusters, which had p value below 0.15. Differences between conditions were significant, smaller DIFF was observed for users group (p values for clusters 1a, 1b correspondingly were: p=0.022, p=0.044). Clusters covered occipital, medial and lateral regions.

Beta range (14-30 Hz). Cluster-based permutation test on PSDs covering alpha range to compare DIFF between users and non-users. Differences between conditions were significant, smaller DIFF was observed for users group (p values for clusters 1b, 2b correspondingly were: p=0.026, p=0.05). Clusters covered occipital medial and lateral regions.

Bayesian regression - confounders control (alpha and beta ranges)

Baysian regression was performed to examine the predictive value of group variable alone and group with confounders such as lifetime meditation hours and cannabis use. This approach helps to understand the role of group variable in predicting the outcome (that is PSDs in each ROI or cluster), when controlling for the influence of the confounding factors. Results of Bayessian regression are summarized in Table 7.

Table 7

Results of Bayesian regression for alpha and beta ranges, for ROIs and WB clusters.

	ROI			WHOLE BRAIN		
			ALPHA (7-12 Hz)			
Models	**P(M|data)**	**BF10**	**R^2**	**P(M|data)**	**BF10**	**R^2**
		ROI A			**CLST 1a**	
Null model	0.514	1.000	0.119	0.200	1.000	0.123
group	0.486	0.945	0.149	0.800	**3.990**	0.196
		ROI B			**CLST 2a**	
Null model	0.564	1.000	0.030	0.146	1.000	0.058
group	0.436	0.774	0.053	0.854	**5.843**	0.147
			BETA (14-30 Hz)			
		ROI C			**CLST 1b**	
Null model	0.440	1.000	0.139	0.599	1.000	0.430
group	0.560	1.274	0.178	0.401	0.669	0.451
		ROI D			**CLST 2b**	
Null model	0.800	1.000	0.359	0.626	1.000	0.447
group	0.200	0.250	0.360	0.374	0.596	0.466
		ROI E				
Null model	0.718	1.000	0.306			
group	0.282	0.393	0.315			
		ROI F				
Null model	0.694	1.000	0.457			
group	0.306	0.441	0.471			

*** P(M) was set to 0.5 for all models; null model includes confounders only (lifetime cannabis and meditation hours), alternative model includes confounders + group**

Note. Here I present: *P(M|data)* - the posterior probability of a model given the data; BF10 - Bayes Factor.

Region of interest analysis. In the analysis on ROI the model comparisons indicate that the null model, including confounders, that is lifetime cannabis and meditation hours, tends to have higher posterior probabilities across various frequency ranges and brain regions. However, the evidence supporting the null model is generally weak, suggesting that the group model's performance cannot be completely disregarded. The Bayes factors (BF10) ranged from 0.25 to 1.27, favoring the null model in all cases besides one cluster in beta range. The coefficients of determination (R^2) for the group models ranged from 0.053 to 0.471, indicating moderate explanatory power in these models.

Whole brain analysis. The model comparisons for the alpha range in whole-brain space show stronger evidence in favor of the model that includes the group compared to the null model (clusters 1a and 2a BFs respectively: BF10 = 3.990, BF10 = 5.843). However, in the beta range, the null model has slightly stronger evidence (clusters 1b and 2b BFs respectively: BF10 = 0.669, BF10 = 0.596) compared to the model that includes the group as a predictor.

Correlations between PSDs and behavioral data

In this section of the result description, I will focus on correlations between behavioral variables and clusters' average PSDs to establish a relationship between electrophysiological data and psychological functioning of participants. For the correlation analysis I used Shepherd's phi correlation, which is a type of robust correlation able to handle non-normal data and outliers. Due to the high number of correlation analyses (clusters ids x behavioral variables = 90) here I will describe only correlations for behavioral variables where Shepherd's pi was above 0.3 in two or more clusters (for detailed statistics see Table 8). Shepherd's correlation showed a positive relationship between clusters' average PSDs and lifetime psychedelic use in ROIs (B, C, E and F) and 2a, 1b, 2b in WB space. Abovementioned clusters and ROIs in the alpha band covered media-occipital and media-posterior brain areas (ROI A, cluster 2a) and lateral occipito-temporal, media-posterior and insular areas in beta band (ROIs C, E and F, clusters 1b, 2b). Shepherd's pi values were between 0.302 and 0.542. Uncorrected p values for these correlations were below alpha of 0.05 in all mentioned clusters besides E (p=0.096) and F (p = 0.088). However, after FDR and Holm corrections for multiple comparisons these relationships were no longer significant. Positive correlations were also found between clusters' average PSDs and BDI-II in clusters C, D, E, F in ROI space and 1b, 2b in WB space. Uncorrected p values for these correlations were below alpha of 0.05 in all mentioned clusters and above 0.05 after FDR and Holm corrections.

Given the similar pattern of correlation with averaged clusters' PSDs for BDI II or lifetime psychedelic use, I further explored the relationship between BDI II and lifetime psychedelics use directly. BDI II was not correlated with lifetime psychedelics use (pi = -0.03 (95% CI's = -0.39; 0.33), p = 0.873).

Table 8

Selected correlations between behavioral data and clusters'/ROIs' average DIFF.

Variable	ROI/Cluster	Frequencies	n	Outliers	pi (shepherd)	CI95%	power	p-val	p-val (FDR)	p-val (Holm)
ROI										
BDI II	**C**	14.0-30.0	67	7	0,37	[0.13 0.57]	0,839	0,004	0,090	0,348
BDI II	**D**	14.0-30.0	67	5	0,317	[0.07 0.52]	0,718	0,012	0,154	1
BDI II	**E**	14.0-30.0	67	5	0,317	[0.07 0.53]	0,718	0,012	0,154	1
BDI II	**F**	14.0-30.0	67	4	0,385	[0.15 0.58]	0,887	0,002	0,060	0,180
EDI	**C**	14.0-30.0	36	5	-0,235	[-0.54 0.13]	0,251	0,202	0,530	1
EDI	**D**	14.0-30.0	36	4	-0,205	[-0.52 0.15]	0,205	0,26	0,544	1
EDI	**F**	14.0-30.0	36	3	-0,358	[-0.62 -0.02]	0,547	0,041	0,231	1
Lifetime psychedelics use	**B**	7.0-12.0	36	6	0,542	[0.23 0.75]	0,892	0,002	0,060	0,180
Lifetime psychedelics use	**C**	14.0-30.0	36	6	0,309	[-0.06 0.6]	0,392	0,096	0,346	1
Lifetime psychedelics use	**D**	14.0-30.0	36	5	0,419	[0.08 0.67]	0,669	0,019	0,165	1
Lifetime psychedelics use	**E**	14.0-30.0	36	6	0,419	[0.07 0.68]	0,652	0,021	0,165	1
Lifetime psychedelics use	**F**	14.0-30.0	36	2	0,34	[0. 0.61]	0,514	0,049	0,245	1
RRQ : Reflection	**F**	14.0-30.0	68	5	0,375	[0.14 0.57]	0,867	0,002	0,060	0,180
STAI I	**C**	14.0-30.0	70	8	0,279	[0.03 0.49]	0,601	0,028	0,180	1
STAI II	**C**	14.0-30.0	70	6	0,269	[0.02 0.48]	0,582	0,032	0,192	1
STAI II	**D**	14.0-30.0	70	5	0,214	[-0.03 0.44]	0,406	0,087	0,330	1
STAI II	**E**	14.0-30.0	70	5	0,285	[0.04 0.49]	0,641	0,022	0,165	1
STAI II	**F**	14.0-30.0	70	5	0,216	[-0.03 0.44]	0,411	0,085	0,330	1
WHOLE BRAIN										
BDI II	**1a**	7.0-12.0	67	4	0,253	[0.01 0.47]	0,524	0,045	0,238	1
BDI II	**1b**	14.0-30.0	67	5	0,338	[0.1 0.54]	0,776	0,007	0,126	0,602
BDI II	**2b**	14.0-30.0	67	4	0,303	[0.06 0.51]	0,683	0,016	0,165	1
Concentration on self	**2a**	7.0-12.0	70	6	0,2	[-0.05 0.42]	0,357	0,113	0,377	1
Level of sadness	**1a**	7.0-12.0	70	5	0,215	[-0.03 0.44]	0,41	0,085	0,330	1
Lifetime psychedelics use	**1a**	7.0-12.0	36	3	0,205	[-0.15 0.51]	0,21	0,253	0,544	1
Lifetime psychedelics use	**2a**	7.0-12.0	36	3	0,302	[-0.05 0.58]	0,408	0,088	0,330	1
Lifetime psychedelics use	**1b**	14.0-30.0	36	5	0,403	[0.06 0.66]	0,631	0,024	0,166	1
Lifetime psychedelics use	**2b**	14.0-30.0	36	5	0,411	[0.07 0.67]	0,649	0,022	0,165	1
RRQ : Rumination	**1b**	14.0-30.0	70	6	-0,224	[-0.45 0.02]	0,434	0,075	0,330	1
RRQ : Rumination	**2b**	14.0-30.0	70	4	-0,219	[-0.44 0.02]	0,428	0,077	0,330	1

Note. Only correlations with pi > 0.2 are displayed. Shortcuts: pi (shepherd) - Shepherd's pi correlation coefficient 95% CI - 95% confidence intervals; p-val - uncorrected p value; p-val (Holm/FDR) - p value after Holm/FDR correction.

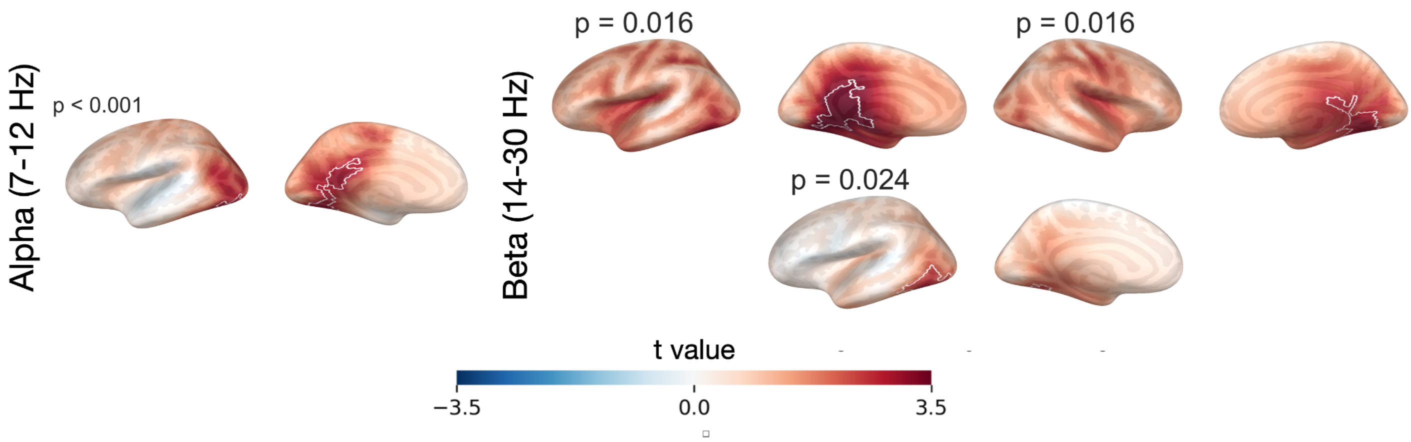
EEG results - Dataset II

Within-group comparison SELF vs. DIS, whole brain space

Below I provide within-group analysis on data from Dataset II. Importantly, unlike in case with the Dataset I this analysis did not aim to establish ROIs, but to only explore within-group effects. In Dataset II ROIs were established based on Dataset I (find more information in *Method* section). Description and figures of within-group results are provided below. Visual representation of analysis is available in Figure 11.

Figure 11

Selected results for the whole-brain within-group contrast for Dataset II showing spacial t values and number of vertices included in cluster in each frequency bin.



Note. Cluster limits are marked with white outlines, and corresponding cluster p-values are shown at the left top of each panel. Color bar at the bottom presents color coding for the t values.

Alpha range (7-12 Hz). I applied a cluster-based permutation test on PSDs covering alpha range to compare activity between SELF and DIS conditions. Differences between conditions were significant, higher alpha power was observed for SELF condition (cluster $p < 0.001$). Cluster covered ventral-temporal region.

Beta range (15-30 Hz). Cluster-based permutation test on PSDs covering beta range showed that beta power was significantly higher for SELF vs. DIS conditions (p values for clusters: p=0.016, p=0.016, p=0.024). Presented clusters covered ventral-temporal and posterior regions.

Between-group comparison between DIFF, ROI space

No significant differences were found between groups in predefined ROIs in alpha and beta ranges. Full results available in Table 6.

Between-group comparison between DIFF, whole brain space

I have not found any clusters in the whole brain space neither for alpha, nor for beta frequencies.

I did not conduct additional exploratory analyses for data from the Dataset II site, since there were no effects for the further investigation.

Results summary

Summing up, I concluded confirmatory (hypothesis-driven) and exploratory analyses in the behavioral and electrophysiological domains. Confirmatory analysis for Hypothesis 1 (psychedelic users will have lower rumination and higher reflection levels measured with Rumination Reflection Questionnaire (RRQ)) were inconclusive: in the Dataset I psychedelics users exhibited lower levels of rumination, whereas in Dataset II psychedelics users and non-users did not differ in terms of rumination, but had significantly higher depression scores.

Exploratory analysis of behavioral response to SRT induction differed between Dataset I and II. In Dataset I, users were significantly more focused on the statement than non-users during the SRT condition, while in Dataset II participants were more focused on the statement during the distraction condition. Participants in both datasets were consistently more focused on themselves during the SRT condition. Furthermore, higher levels of sadness were reported during the SRT condition in both datasets, with Dataset I showing an additional significant effect of group and interaction, indicating that users were less sad during SRT than non-users.

Confirmatory analysis for Hypothesis II (after self-related thoughts induction DMN activity will increase and this increase will be less pronounced in psychedelic drug users than in non-users) also were not conclusive: first, in both Dataset I and II I observed an increased alpha power in regions associated with self-related information processing, therefore confirming the first part of the hypothesis; however, results from confirmatory analysis for Dataset I indicated ROIs and clusters with significant between-groups difference in alpha and beta increases during SRT condition, this increase was significantly higher in non-users group. However, this effect was not replicated in the Dataset II. Additionally, exploratory electrophysiological results of regression with control of confounders (lifetime meditation hours and lifetime number of occasions of cannabis use) showed diminished effect of the group variable. Further, exploratory correlation between psychological and electrophysiological data did not provide any significant correlations after correction for multiple comparisons. Results of hypothesis testing are summarized in Figure 12.

Figure 12

Summary of results in confirmatory (hypothesis driven) analysis.

	Hypothesis		Results	
	Within-groups	Between-groups	Dataset I	Dataset II
Reflection (RRQ)	-	Users > Non-users	confirmed	not confirmed
Rumination (RRQ)	-	Users < Non-users	not confirmed	confirmed
Alpha power	Self-related thoughts > Distraction	-	confirmed	confirmed
Beta power	Self-related thoughts > Distraction	-	not confirmed	confirmed
Alpha power increases during self-related thoughts	-	Users < Non-users	confirmed	not confirmed
Beta power increases during self-related thoughts	-	Users < Non-users	confirmed	not confirmed

Note. For simplicity I use the word "confirmed" here. However, this is simplification and relates to the cases where hypothesis testing either provided evidence for alternative hypotheses (Bayes Factor) or lack of evidence for null (p-value testing), which would be a more accurate interpretation.

Discussion

In the present thesis I aimed to explore differences between psychedelic users and non-users in terms of processing self-related thoughts on behavioral, declarative, and electrophysiological levels. I hypothesized that psychedelic users would exhibit higher levels of reflection and lower levels of rumination. I also conducted exploratory analyses comparing anxiety and depression levels between the two groups using standardized questionnaires STAI and BDI respectively. Furthermore, I examined behavioral responses to self-related thoughts and distraction during a self-induction task. On the neurophysiological level, I hypothesized that differences in self-processing would be reflected in lower power in the alpha and beta bands within default mode network (DMN) regions, which I investigated using the region-of-interest (ROI) approach. Additionally, I explored the whole brain space to identify any broader effects. To the best of my knowledge, this research is the first to investigate self-related thought processing in psychedelic users and its electrophysiological correlates.

I collected data from two sites to examine the replicability and robustness of my results, taking into account the prevalent replication crisis in the neuroscientific and psychological field, including psychedelic research. Initially, I conducted analyses on data from the Dataset I to establish the analysis strategy and regions of interest (ROIs). Subsequently, I analyzed the data from Dataset II to assess the replicability of the findings from Dataset I. Notably, I observed different results between the two sites. While significant between-group and within-group effects were observed in both behavioral and electrophysiological measures in Dataset I, only within-group effects were observed in Dataset II. In the following sections, I will present an interpretation of the results from Dataset I and subsequently discuss the findings from Dataset II. It is important to note that the proposed interpretations should be considered preliminary and require further confirmation through additional research.

At the Dataset I participants in the non-users group had significantly higher levels of rumination. This was partly in line with my first hypothesis, still, groups did not differ in terms of scores on the reflection scale. Moreover, users had significantly lower levels of depression and state and trait anxiety measured respectively with BDI II and STAI. This is in line with previous initial research reporting lower anxiety and depression scores both in clinical and naturalistic-users populations (Raison et al., 2022; Schimmel et al., 2022) and lower rumination levels in naturalistic psychedelic users when compared to non-users (Orłowski et al., 2022). Similar patterns of differences in depression, anxiety and rumination are not surprising, since rumination repeatedly was shown to go in hand with depression, anxiety and other psychological dysfunctions (Nolen-Hoeksema, Wisco, B.E. & Lyubomirsky, 2008).

The questionnaire results were consistent with the differences observed in the responses to self-related thoughts versus distraction in the self-induction task in the Dataset I. Both groups reported higher levels of self-focus during the self-condition compared to the distraction condition, confirming that participants were indeed engaged in self-related processing during the task. In self-thoughts induction procedure participants in the users group declared higher levels of focus on the statement (both in self and distraction conditions) and lower levels of sadness while thinking about themselves. Questions regarding inner states of participants during the task were limited to focus on the task, focus on the self and level of sadness, whereas differences in self-processing and related emotionality form a more complex landscape of experiences. Still, lower levels of sadness declared in self-condition in users are of initial interest, especially when put in context of previous findings on lower rumination, depression and trait anxiety in users group.

In both Dataset I and II I observed within-group differences in alpha and beta power between the self and distraction conditions. Alpha power was significantly higher for SELF condition. Clusters covered medial posterior and temporal-occipital regions. Beta power was as well higher for the SELF condition, however, significant difference was observed only in Dataset II. Clusters covered medio-posterior, occipitotemporal and insular regions. While the spatial resolution of myEEG analyses was limited (this will be discussed below in detail), these effects were consistent with previous fMRI research and my hypotheses. For example, the medial posterior regions, including the posterior cingulate cortex and precuneus, have been implicated in self-referential processing (Northoff et al., 2006; Sui et al., 2013). The temporal-occipital regions, such as the fusiform gyrus, are associated with the retrieval of self-related visual information (Sui et al., 2015; Zhang et al., 2016). The insular cortex has been involved in interoception and self-reflection (Craig, 2009). Both alpha and beta were previously found to be engaged in self-related processes. Fronto-central and posterior alpha was greater during mind-wandering than during the task (Polychroni et al., 2021). In another study increased alpha and beta power in DMN regions were found in spontaneous self-referential thoughts (Knyazev et al., 2012). Left temporal and dorsolateral prefrontal beta was higher in ruminators than in non-ruminators, especially during the ruminative condition (Ferdek, van Rijn, & Wyczesany, 2016). Marino and colleagues (2019) and Samogin and colleagues (2019) suggested that alpha oscillations support DMN functioning at rest. Moreover, alpha and beta activity were both repeatedly associated with DMN activity (Knyazev et al., 2013, 2016; Lui et al., 2017; Bowman et al., 2017; Marino et al., 2019), although not in all studies (for example see: Das, de Los Angeles, Menon, 2022).

I continued with analyses in ROI regions defined based on the findings from within-group analyses on the Dataset I. Averaged between-group difference in the difference between distraction and self-related thoughts conditions in temporo-occipital cluster in alpha and insular, right medio-posterior and occipital-temporal cluster in beta was lower for users than non-users. This is in line with my hypothesis regarding lower increases in alpha and beta band activity during self-related thoughts processing in psychedelic users. Although I found differences in medial posterior regions, which could have been a part of DMN, I cannot infer the exact location of the effect due to imperfect space resolution of the EEG signal. This prevented us from fully testing my hypothesis regarding the localization of the effects. Moving to the whole-brain analysis, the difference between conditions was lower in users than non-users in the alpha band in occipital and posterior regions and in the beta power in occipital and ventral-temporal regions. These results are in line with my expectations and previous research. EEG and MEG research on acute psychedelics effects have shown decrease in posterior and frontal beta and alpha bands (Kometer et al., 2015; Muthukumaraswamy et al. 2013; Carhart-Harris et al., 2016). Although, in my research I did not find differences in frontal regions, effects in posterior regions are worth considering in terms of alteration in self-related thoughts processing. I could speculate that if psychedelic acutely diminishes posterior alpha and beta activity, multiple exposition to psychedelics might prolong this effect and this would be related to differences in processing of self-related information. To establish to which psychological process these differences might be attributed I conducted exploratory correlational analysis between behavioral data and averaged PSDs in clusters obtained in ROI and whole brain analysis.

Behavioral data used in correlation analyses included RRQ, BDI, STAI and average difference between responses to questions regarding focus on the self and level of sadness in self-thoughts induction procedure. No correlation was below alpha of 0,05 after FDR and Holm corrections for multiple comparisons. I examined effect sizes and corresponding confidence intervals to complement information about significance (Calin-Jageman, 2019). BDI II scores and lifetime psychedelic use had weak to moderate positive correlations with several clusters' averaged PSDs, revealing a pattern of relationship between behavioral and electrophysiological data. Still, these results were not significant and should be considered as preliminary and needing further exploration. Of note, lifetime psychedelic use did not correlate with BDI II. I can consider a few possibilities for the interpretation here: a) these results could in fact be artificial; b) number of lifetime psychedelic use grows with age and self-related thought processing and brain functioning attributed to it might vary for people in different ages; c) observed differences in brain activity might be intervened with larger-scale neural functioning, eg. connectivity, thus it is plausible that different global brain processes are responsible for correlation between EEG activity and BDI II than for its relationship with lifetime psychedelics use.

Lack of the correlation with self-related measures, that is RRQ, is also surprising given widely discussed alterations in self-consciousness during and after ingestion of psychedelics (Millière et al. 2018, van Elk & Yaden, 2022), my previous findings from cross-sectional research (Orłowski et al., 2022), declarative differences in rumination and emotional reaction to self-related thoughts between groups in my research and associations between the various aspects of the self and posterior regions activity (eg. PCC) (Davey, Pujol & Harrison, 2016). Noteworthy, here I focused on the self-narrative aspect of the self, however, self might also include and not be limited to identity, bodily aspects of self such as localisation in time and space, self-other boundaries both psychological and physical. Thus, between-group differences in physiological activity of regions involved in self-consciousness might be related to some other self-related process than measured with RRQ. Moreover, not all psychedelic-induced alteration in self-related processes will be related to depression, anxiety or rumination. Alternatively, those might be related to quality of life, relationships with others or/and nature, personality traits and other variables found to be affected by psychedelics (MacLean, Johnson & Griffiths, 2011; Ko et al., 2022; Watts et al., 2022). Research regarding the relationship between various aspects of the self and mental health or long-term changes after psychedelic experience is very limited. Good theory construction, theory-based operationalisation of the research construct and the decision which aspect of the self and its relationship with mental health markers one would like to explore and why, would be helpful for interpreting future research findings (see analysis of theory crisis role in replication crisis here: Oberauer & Lewandowsky, 2019).

To mitigate potential confounding factors, such as cannabis use and lifetime meditation hours, commonly reported among psychedelic users, I performed Bayesian regression analyses. These analyses indicated that models including cannabis use and lifetime meditation hours were more probable than models with these variables and group for most ROIs. Regarding the whole brain analysis, models including group as a factor were more probable in the alpha band, but not in the beta band. Group effects could have been mitigated by cannabis use and meditation, since both activities have somewhat similar phenomenology with psychedelic-induced experiences, specifically regarding changes in self-related processing (Millière et al. 2018; Earleywine et al., 2021). My interpretation abilities are limited here, since there is not much electrophysiological research on cannabis effects on self-related processing. There are also methodological differences in EEG research on meditation, which restrict the replicability of findings on electrophysiology of meditation. However, a recent systematic review summarized that changes i.e. in alpha band and DMN activity have been reported by various study sites (Deolindo et al., 2020). Similar findings were reported in research on psychedelics effects and in the present research. Moreover, psychedelics and meditation have synergic effects and are capable of boosting each other's acute and long-term effects (Śmigielski et al., 2019; Griffiths et al., 2018). Additionally, meditation was proposed as a method of psychedelic integration (Bathje, Majeski & Kudowor, 2022). Further exploration and comparison of acute effects of psychedelics, meditation and cannabis would be beneficial to understand relationships between those.

Whole-brain between group effects in the alpha band were not mitigated when adding cannabis use and meditation to the model. It is possible that cannabis, meditation and psychedelics provide similar effects, but only in certain brain regions. Effects in occipital alpha are worth considering in light of potential engagement of visual processing during the procedure. Since some sentences in distraction condition could have been stimulating for visual imagination (for instance, "Consider what it's like to wear well-fitted shoes."; "Contemplate the process of plant growth."; "Reflect on the transformation of seasons throughout the year."), it is plausible they have stimulated the visual cortex more than self-related thoughts condition. Therefore, differences in alpha activity in occipital regions might as well be mediated by visual imagination, which could be more affected by psychedelics than by cannabis use and meditation practices.

The absence of significant between-group effects in the Dataset II raises important considerations and calls for explanations. Firstly, the smaller number of participants in Dataset II compared to Dataset I resulted in a less statistically powered dataset, reducing the likelihood of detecting an effect if present and wider effect sizes' confidence intervals. This might be the case for the lack of behavioral and electrophysiological effects. Secondly, the absence of MRI scans and captrack for the Dataset II limited the spatial resolution, potentially affecting the precision of the results. It is important to acknowledge that while these data-related factors could account for the lack of observed effects in Dataset II, the possibility of non-replicability cannot be ruled out. Thirdly, I did not observe between-group differences in behavioral response to self-related thoughts induction procedure in Dataset II. Lack of behavioral effects is consistent with lack of electrophysiological effects. The limited successful replication of my findings restricts the extent to which far-reaching conclusions can be drawn from the research as a whole. The lack of replicated effects in the Dataset II underscores the ongoing challenge of replication in psychedelic research (McCulloch et al., 2022, Elk & Fried, 2023), emphasizing the need for rigorous validation and consistency in findings. Interestingly, discrepancy in results in study sites points towards the possibility that psychedelics would produce different effects in different individuals and depending on the sample, research might show different results.

Given my focus on naturalistic use, I complement studies on psychedelic use in control settings, which have specific limitations i.e. the effect of researcher/clinician and laboratory setting on psychedelic experience. On the other hand, the present research is not free of limitations typical for cross-sectional studies on naturalistic drug use including no ability to infer causal relationship, less control of confounding variables present in naturalistic setting, no control over trustworthy of declarations neither quality, dosage, acute effects and environment of the substance use. Still, research on naturalistic psychedelics users provide valuable insights, complementing data collected at laboratory and clinical settings. Below I address limitations and strategies applied to handle those.

EEG data is known to have high resolution in the temporal domain, but low spatial resolution. Implementation of the source localization technique allowed for better space resolution, than channel-level analysis. Unfortunately, I did not manage to collect scans for all the participants and this might have affected the quality of source localization. Further, I used a cluster-based permutation test, which allowed us to control for multiple comparisons problem. However, it does not allow for inferences regarding exact localisation or frequency range of the effect. To complement cluster-based analysis on whole brain data and check the effect in points belonging to certain regions, I examined effect sizes of averaged power of points included in clusters. ROI analysis also provided complementary information regarding effects in defined areas and frequencies.

To minimize the effect of potential confounders such as drug use and mental health I applied narrow inclusion criterias and matched groups by sex, age and education. I aimed to match groups by lifetime meditation hours and lifetime occasions of cannabis use, however, I was not able to achieve the desired sample size once trying to do so. Therefore, I compared predictability of models including only confounders against models including confounders and groups as a predictor. Further, psychedelic users might have different personality profiles than non-users, which makes them more predisposed to use psychedelics. Individuals with different personality profiles can differ in terms of processing of self-related information and underlying physiology. To minimize this issue I selected only those non-users, who declared willingness to try psychedelic substances in the future. Moreover, I recruited participants from social media connected with drug policy, harm reduction and psychedelic science. On the one hand, this could allow us to unify participants' personality profiles and social backgrounds. Still, I did not measure personality type directly to limit the quantity of questionnaires and time involvement of participants. Further, since users were recruited from platforms connected with harm reduction practices, they could have been more prepared to handle challenging experiences and difficult long-term effects, thus potentially having more beneficial experiences with psychedelics and positive attitudes towards those substances. As psychedelics users who actively follow the psychedelic renaissance movement[9], research participants could have been more motivated to provide such information regarding themselves, that would be beneficial for a positive narrative about psychedelics. Therefore, my group might have included participants, who either had more positive expectations about psychedelic experiences or were biased by the motivation to contribute to the psychedelic renaissance. All of the above resulted in a selective and possibly unrepresentative sample. In fact,

[9] "Psychedelic renaissance" is characterized by a resurgence of interest and research into the therapeutic potential of psychedelic substances like psilocybin, LSD, and MDMA. This revival includes clinical trials exploring their efficacy in treating mental health conditions, a shift toward decriminalization and medical legalization in some areas, and increased public discourse and integration into mainstream culture. It signifies a transition from stigmatization to a more nuanced, evidence-based approach to psychedelics for enhancing mental health and well-being.

prolonged effects of psychedelic use are not well-known and might highly vary from subject to subject. Control of self-selection bias in psychedelic research in general and in naturalistic users research specifically is very challenging due to strong relationship between psychedelic research, mass media, medicalization approaches or social movement for regulations change. Some (Noorani & Muthukumaraswamy, 2023) have suggested that social mechanisms and narratives around psychedelic renaissance should be realized or/and controlled in study settings. To assess self-selection bias, future research could assess participants' expectations, social background, proficiency in harm reduction practices, quality of psychedelic experiences and level of engagement with medial narratives around psychedelics.

Conclusion

In the present thesis, I investigated differences between psychedelic users and non-users in terms of self-related thought processing at behavioral, declarative, and electrophysiological levels. I have found psychedelic users to exhibit lower levels of rumination, but no higher reflection, as well as lower levels of depression and anxiety compared to non-users. The electrophysiological analysis revealed lower differences between SELF and DIS conditions in users group compared to non-users. This effect was pronounced in alpha and beta power within temporal, occipital and medial parietal regions. These findings are consistent with previous research on self-referential processing, as well as research on acute psychedelic effects. However, in most of the regression models including cannabis use and lifetime meditation hours, adding a group as a predictor did not improve the models' predictive value, potentially due to mitigation of effects of psychedelics. Correlation analysis did not show any significant dependencies between clusters' PSD and behavioral data. This might be due to the diversity of self-related processes that present research did not account for. Still, the repeating pattern of positive correlation between difference in SELF-DIS in various clusters and psychedelics lifetime use and BDI-II is interesting preliminary finding and worth further exploration.

My research was the first to explore self-related thoughts processing in psychedelic users. Given its novelty and low number of previous studies on naturalistic users, some methodological imperfections occurred. The main limitations of the research include the cross-sectional design, potential self-selection bias in the participant sample, limited control over patterns of psychedelic use, limited assessment of self-related processes and the limited spatial resolution of EEG analysis. Above I discuss in detail ways of addressing limitations in future research.

Summing up, this thesis provides valuable insights into the self-related thought processing of psychedelic users compared to non-users. Although there are limitations to be addressed in future research, the present work contributes to the growing body of knowledge on the effects of psychedelics on cognition and mental health, highlighting the importance of further investigation in this field to better understand the potential effects of psychedelic substances. In this research I applied new methodological strategies for research on psychedelic users and provided data for further hypothesis generation and testing.

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