Current Psychology (2024) 43:10578–10589
https://doi.org/10.1007/s12144-023-05119-6

Effects of conscious connected breathing on cortical brain activity, mood and state of consciousness in healthy adults

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Accepted: 10 August 2023 / Published online: 8 September 2023

Abstract

Breathwork as a means of inducing non-ordinary states of consciousness is gaining traction as a potential therapeutic modality. We examined the effects of breathwork (in the form of connected breathing) on electroencephalography (EEG) and mood in 20 healthy participants (aged between 23 and 39 years (female = 11, $M_{age} = 29$). In addition, to compare with other means of inducing non-ordinary states of consciousness, we assessed the subjective effects of breathwork using the 11 Dimension Altered State of Consciousness questionnaire. EEG spectral power analysis of eyes closed rest recordings before and after the breathwork session showed a decrease in delta (1–4 Hz) and theta (4–8 Hz) frequencies in frontotemporal and parietal regions, respectively no changes were seen in Alpha (9–12 Hz) and Beta (12–30 Hz) bands. However, after decomposing the beta waves in Beta 1 (12–15 Hz), Beta 2 (15–20 Hz), Beta 3 (20–30 Hz), decreases in power were observed across Beta1 and Beta 2 in parietotemporal regions. Notably, the spectral power in gamma increased in experienced practitioners. Scores on the Profile of Mood States questionnaire showed a reduction in negative affect (anger, tension, confusion, and depression) and an increase in esteem. Scores on the 11D-ASC scale indicated that subjective experiences during breathwork were similar to those after medium to high doses of psilocybin, suggesting the occurrence of experiences of mystical quality. Present results indicate that breathwork changes brain activity and mood, and induces mystical experiences. These results are promising and suggest that such techniques could be useful to improve mental well-being.

Keywords EEG · Breathwork · Mood · Consciousness

Controlled breathing techniques (commonly called breathwork) have been employed across various contemplative and religious traditions to induce meditative states and changes in physiology through the combination of attentional guidance and spontaneous, deep, accelerated breathing (Vago & David, 2012). These techniques have also become incorporated within modern breathwork practices and are increasingly applied in therapy context as body-mind complementary health practices (Victoria & Caldwell, 2013), due to the inherent connection of the breath not only with our physiology but also with our emotions (Homma & Masaoka, 2008).

Scientific research shows that regulating one's own breathing can induce psychological changes such as a reduction in anxiety. For instance, slow-paced breathing

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in healthy adults has been found to increase vigor and to reduce tension, depression, hostility and confusion as measured by the Profile of Mood States questionnaire (Fumoto et al., 2004; Yu et al., 2011). Recently a review of sixteen studies indicated that a range of breathwork interventions resulted in a decrease of anxiety in adults with clinically diagnosed anxiety disorders. In contrast, two of these studies, applying Surdashan Kriya Yoga (including alternate nostril breathing) and respiratory biofeedback-assisted therapy, found an increase in anxiety and depression (Banushi et al., 2023). Notably, the majority of studies used slow breathing techniques while in particular those studies utilizing slow diaphragmatic breathing showed positive effects on outcome measures. A review including three studies in healthy adults indicated that after implementation of a diaphragmatic breathing intervention breathing rates decreased and stress was reduced as indicated by lower scores on the stress subscale of the Depression Anxiety Stress Scales-21 (DASS-21) and reduced respiratory rate, salivary cortisol levels, systolic and diastolic blood pressure (Hopper et al., 2019). A recent meta-analysis of 12 randomised-controlled trials in healthy adults (10 studies were primarily focussed on slow-paced breathing and 2 studies on fast-paced breathing) on self-reported/subjective stress showed that breathwork was associated with lower levels of stress than control conditions (Fincham et al., 2023). The above studies demonstrate that particularly slow-paced breathing might have a positive effect on lowering psychological and physiological stress in adults with or without anxiety disorders. Slow breathing has as any rate from 4 to 10 breaths per min (0.07–0.16 Hz). The typical respiratory rate in humans is within the range of 10–20 breaths per min (0.16–0.33 Hz) (Zaccaro et al., 2018).

In addition to induce psychological and physiological changes, breathwork has been found to change brain activity in healthy subjects, as measured by electroencephalography (EEG). With respect to slow paced breathing, as well as beta-power (Stancák et al., 1993) as alpha-power were found to increase while theta power was found to decrease (Fumoto et al., 2004; Yu et al., 2011). More recently, results of a study in healthy subjects on the effects of slow breathing (bradynpea) and fast breathing (tachynpea) on EEG power indicated that fast breathing increased theta power in frontal parietal and occipital areas while slow breathing did not result in any change in theta power (Sinha et al., 2020). Research shows that the frontoparietal network demonstrates a large degree of connectivity to many diverse brain networks and is crucial for supporting superior cognitive functioning (Marek & Dosenbach, 2018).In a subsequent study in healthy participants, comparing EEG power during slow breathing to that of fast breathing, lowered beta power observed in the frontoparietal cortex (more to the right hemisphere than the left) was found in slow deep breathing compared to faster breathing suggesting increased relaxation, calmness, and anxiety reduction. In addition, alpha power appeared lower in the slow breathing than the faster breathing mainly in the right frontotemporal cortex. In contrast, the observed power of the delta band in the parietal cortex appeared higher in the slow breathing than that in the rapid breathing condition (Patnaik et al., 2022). It must be noted that in this study the EEG measures during the two breathing conditions were not compared to a control condition of normal breathing. Summarizing the EEG findings above slow breathing yielded contradictory results, e.g. increase as well as decrease of alpha and beta power. In addition, slow breathing appeared to increase delta power and faster breathing theta power. Changes in EEG activity were mainly seen in frontoparietal and frontotemporal cortex.

As breathwork has been shown to improve medical conditions such as asthma, hypertension, anxiety states, and post-traumatic stress disorder, slow breathing exercises in people with epilepsy has been hypothesized to reduce seizure frequency by affecting cortical activity and/or reducing anxiety (Yuen & Sander, 2010). As epileptic and non-epileptic EEG signals can be identified and predicted accurately using adaptive fractal analysis (Buchanna et al., 2022), it would be interesting to study the effect of slow breathing on epileptic signals.

The effects of breathwork on body and brain are attributed to an interplay between the O2-CO2 balance, blood pH level, cortical blood flow, vagal nerve stimulation and neurotransmitter release (Gerritsen & Band, 2018). However, as shown above the neurophysiological correlates are contradictory and potential effects of breathwork on mental well-being and potential as therapeutic method are still not fully understood. Additionally, its effects have not been assessed in a way that is comparable to other altered states of consciousness, such as psychedelics. In order to advance understanding of the effects of breathwork, and assess its viability as a therapeutic methodology for future research, this study explored its effects on consciousness with the 11 Dimension Altered State of Consciousness questionnaire (11D-ASC; Studerus et al., 2010) and investigated changes in mood using the Profile of Mood States questionnaire (McNair et al., 1971) together with changes in resting-state cortical brain activity by comparing EEG spectral power before and after the session.

Due to the richness of breathwork techniques, it is important to specify which type of breathwork is used in this study. In general, breathwork is seen as either a passive, calming practice to observe and follow the breath, or as an active practice, to open, energize and break through (physiological and psychological) patterns (Caldwell & Victoria, 2011). The technique used in this study is an active practice referred to as 'conscious connected breathing'. The person is invited to deliberately breathe in a faster and deeper-than-normal way, in a cyclical and spontaneous fashion without a pause between inhale and exhale. One smooth deep full diaphragmatic inhale connects with the exhalation accomplished simply through relaxation of diaphragm. This type of breathing has been utilized in the Western world in a protocolized way by multiple schools since the late 1960's. For example, by Leonard Orr and Sondra Ray (1977) within a technique called Rebirthing, by the Czechoslovakian psychiatrist Stanislav Grof and his late wife Christina (1989) within the Holotropic Breathing technique, and by Wilhelm Reich, originally a protégé of Sigmund Freud within a technique called Reichian breathwork (1920).

In general, these types of breathwork combine full body breathing with music (or other forms of acoustic stimulation). The participant is sitting or lying down and encouraged to be as free as possible, making any sounds or movements that come forth over the course of the session. The goal is for the individual to reach a level of safety that allows them to freely release any impulses or emotions they experience during the breathing exercises. The breathwork process used in this study was deliberately chosen without a psychological/theoretical framework to avoid priming of the participants in any direction (see section 'Breathwork intervention').

In psychosomatic therapeutic practices, sustained attention is used to create awareness of the breathing itself and of the bodily sensations in connection with the psychological experiences that arise during the session (Grof, 1988; Hendricks, 1995; Lalande et al., 2012; Middendorf & Roffler, 1994; Taylor, 1994). Especially, the awareness of the connection between the way of breathing and holding patterns associated with emotions might grow, for example how breathing becomes shallow when feeling anxious (Gilbert & Chaitow, 2002). Through the combination of breathing and conscious awareness, the participants are thus encouraged to immerse themselves in their current experience. More specifically, to uncover repressed memory (De Wit et al., 2019), to open psychophysiological defenses (De Wit et al., 2018) and to induce non-ordinary states of consciousness which have a therapeutic, transformative, evolutionary and heuristic potential. The name non-ordinary is referred to as holotropic, and suggests something that might come as a surprise: in our everyday state of consciousness we identify with only a small fraction of who we really are and do not experience the full extent of our being (Grof & Grof, 2010).

Within the framework of Stanislav and Christina Grof, the states that are reached by participants are often compared to a psychedelic experience for their similarities regarding the subjective changes in consciousness they induce (Eyerman, 2013). To measure this, we applied the 11 Dimensions of Altered states of consciousness (Studerus et al., 2010), as it is the most commonly used psychometric tool for assessing altered states of consciousness. The paradigm of research on altered states of consciousness is the notion that different types of pharmacological or non-pharmacological induction methods evoke similar neural mechanisms and therefore overlap in their subjective effects (Dittrich, 1998). Although Holotropic Breathwork was developed to induce non-ordinary states of consciousness which can emulate psychedelic experiences, no study up to date has assessed its subjective profile using a comparable assessment method.

As the majority of above-cited studies provide knowledge on the effects of slow breathing, the overall objective of the present study was to examine whether faster breathing intervention would induce comparable outcomes. Specifically, a first objective of the present study was to establish the neurophysiological correlates of conscious connected breathing intervention. In line with previous findings on faster breathing we expected to find an increase in theta power in frontoparietal areas, while no expectations could be defined with respect to the other frequency bands. A second objective was to examine the effects of conscious connected breathing on mood status. We questioned whether conscious connected breathing intervention would reduce tension and depression similar to the above mentioned slow breathing-induced reduction in stress and depression.

Additionally our aim was to assess the subjective experience of breathwork via the ASC questionnaire (11D-ASC; Studerus et al., 2010) and compare it to more well-established intervention methods, i.e. the dose–response profile of psilocybin (Hirschfeld & Schmidt, 2021). Questionnaire data from these types of studies was collected into the most comprehensive database on altered states of consciousness (www.asdb.info) up to date, which make it possible to compare our data, with various other types of intervention methods.

Methods

Participants

Twenty participants aged between 23 and 39 (female = 11, $M_{age} = 29$) were recruited via advertisement, and an online student pool (vu.sona-systems.com) of the Vrije Universiteit Amsterdam (VU). The study received a positive advice of the Scientific and Ethical Review Board of the Faculty of Behavioral and Movement Sciences of the Vrije Universiteit. All subjects gave their written informed consent prior to participation in the study. A total of 5 participants reported having prior breathwork experience. All participants were screened based on strict health exclusion criteria (see Appendix).

Design

Upon arrival at the University participants completed the Profile of Mood States (POMS) questionnaire (Grove & Prapavessis, 1992) and the EEG was applied. Then a 5-min eyes closed resting state EEG was recorded using a Neuroscan NuAmps amplifier (https://compumedicsneuroscan.com. Accessed 29 August 2023) with a Neuroscan waveguard 32 channels caps (https://www.ant-neuro.com/products/waveguard_original. Accessed 29 August 2023) and a sampling rate of 500 Hz. Participants then received the breathing instructions, after which they laid down on a mattress with lights slightly dimmed to engage in the breathwork experience. After completion, the eyes closed resting state EEG activity was recorded again. Last, the participants filled in the POMS (Grove & Prapavessis, 1992) and 11D-ASC (Studerus et al., 2010).

POMS questionnaire

The Profile of Mood States (POMS) questionnaire (Grove & Prapavessis, 1992) is a standard validated psychological instrument for measuring mood states via a series of descriptive words pertaining to various feelings across 60 items scored on a 5-point Likert scale. For this study, we used a modified version of the POMS consisting of only 40 items (Grove & Prapavessis, 1992). These items comprise of five negative subscales (fatigue, anger, tension, confusion, depression) and two positive subscales (vigor, esteem).

11D-ASC questionnaire

The shortened version of the altered states of consciousness 11D-ASC (Studerus et al., 2010) was originally developed to measure transient deviations of a healthy individual's normal state of waking consciousness across different induction methods (Dittrich, 1998; Dittrich et al., 2010). It contains three primary dimensions which are termed "oceanic boundlessness" (OBN), "dread of ego dissolution" (DED), and "visionary restructuralization" (VRS), with eleven subscales.

Breathwork intervention

The session was held in a dim-lit room with the participant lying down on a comfortable mattress. To standardize the breathwork session, a private breathwork facilitator provided verbal instructions on an audio recording together with a music playlist for during the breathing. The instructions comprised 15 min and included a basic breathwork introductory talk and instructions. The actual breathing time was 45 min. Participants were asked to lie down in a comfortable position and instructed to take full conscious connected diaphragmatic breaths leaving no pause between the inhalation and exhalation. A specific feature of the breathwork technique applied in this study is that there was no psychological/theoretical priming before the session. Additionally, even though the participants were advised to breathe slightly faster than normal, they could set their own rate, pattern and nature of breathing in the session, to give full autonomy in exploring their own experiences. As a consequence, although the procedure of this session was standardized as much as possible, the setup of parameters like breathing rate and pattern was not fixed.

Cleaning procedure EEG

The EEG data was analyzed using the Matlab version of eeglab software (https://eeglab.org). The signals were bandpass-filtered between 1 and 45 Hz using the eeglab FIR (First Impulse Response) for filtering and channels with bad signal and unexploitable data segments were removed upon visual inspection. The average reference was computed for all the remaining channels, excluding the EOG and EMG channels. Artifacts were labelled and flagged for removal using Independent Component Analysis (ICA) algorithm (Hyvärinen & Oja, 2000) in eeglab using IC label algorithm (Pion-Tonachini et al., 2019). The remaining components were projected back to signal space and missing electrodes were interpolated. Data from 3 participants was excluded because the data was of unsatisfying quality.

Analysis

Spectral power of both, the pre and post, resting-state recording was computed for each frequency band (delta 1–4 Hz, theta 4–8 Hz, alpha 9–12 Hz, beta 12–30 Hz and gamma 30–45 Hz, beta1 12–15 Hz, beta 2 15–20 Hz, beta 3 20–30 Hz) (Abhang et al., 2016). Notably, in particular Theta, Alpha, Beta and Gamma frequencies have been associated with emotional reactions and specific brain states, i.e. Theta with relaxation, Alpha with passive attention, Beta with outwardly attentive and Gamma with concentration (Wardoyo et al., 2022). To test for differences between the pre and post breathwork conditions, a permutation (Monte Carlo) T-test (Pesarin & Salmaso, 2010) was performed using eeglab statistics, and corrected for multiple comparisons using the Benjamini Hochberg false discovery rate (FDR) correction method (Benjamini & Hochberg, 1995) as post hoc test at a significance level of 0.05.

The mood changes, as measured by the pre and post POMS questionnaire, were analyzed using paired t-tests per mood facet and subsequently correlated with the changes in EEG using the non-parametric test Kendall's Tau which is most suited method for the ordinal nature of the POMS variable (Arndt et al., 1999). The results of the 11D-ASC are reported as total scores and visually compared to the dose–response profile of psilocybin (Hirschfeld & Schmidt, 2021).

Results

Breathwork decreases power in lower frequency bands

Comparing resting state before (pre) and after (post) breathwork showed a significant decrease in delta (1–4 Hz) and theta (4–8 Hz) frequencies especially in parietal and temporal regions (see Fig. 1 A-B). Decrease in Delta was predominantly fronto-temporal.

Alpha (9–12 Hz) and beta (12–30 Hz) showed no significant change, however, when the beta waves were decomposed in beta 1 (12–15 Hz), beta 2 (15–20 Hz), beta 3 (20–30 Hz) sub frequency ranges, significant decreases in power were observed across beta1 and beta 2 (see Fig. 1 C-D) at a parieto-temporal level.

Gamma (30–45 Hz) power increased after breathwork; however, these results did not survive correction for multiple comparison using the FDR post-hoc analysis.

Descriptive statistics (mean and standard deviation) for each electrode that displayed significant variation across each frequency bands are reported in Appendix Table 2.

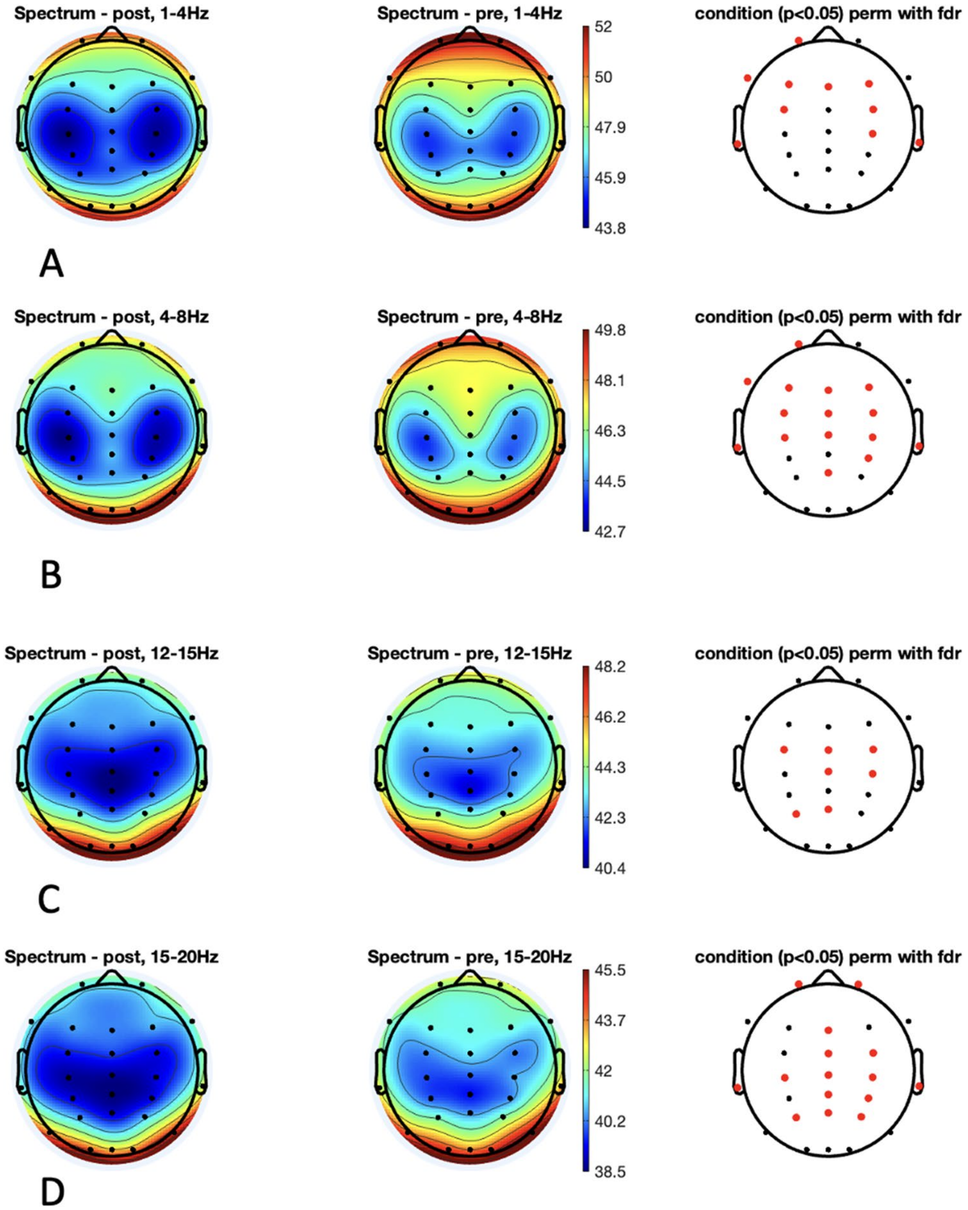


Fig. 1 Averaged topography across frequency bands that displayed significant changes for $p < 0.05$, significance displayed at individual channels. Panel 1 and 2 represent the averaged power of the pre and post condition, respectively, while significant difference in power is represented by the red dots in the third panel. **A** shows the averaged topography across delta frequency band. **B** Averaged topography across theta frequency band. **C** Averaged topography across beta 1 frequency band. **D** Averaged topography across beta 2 frequency band

Breathwork increases gamma frequencies in experienced practitioners

Since a significant change in power across gamma frequency band was observed before correction for multiple comparison, a subgroup analysis was conducted on participants with breathwork experience. A significant increase in gamma power was observed at the right parietal level and temporo-frontal level (see Fig. 2), which remained significant after correction for multiple comparison, in this subset of participants.

Breathwork induces changes in mood states

To test the effects of breathwork on mood the participants filled in the POMS (Grove & Prapavessis, 1992) before and after the session. We conducted a series of paired-sample t-tests to determine how their mood changed after the breathwork session compared to before.

Breathwork decreased tension ($t(20) = -3.89$, $p < 0.001$), confusion ($t(20) = -2.18$, $p = 0.041$) and depression ($t(20) = -2.71$, $p = 0.013$), while anger was on the verge of reaching significance ($t(20) = -2.1$, $p = 0.053$) (see Fig. 3 & Table 1). Esteem on the other hand increased after breathwork ($t(20) = 4$, $p < 0.001$).

Fatigue did not reach significance despite strong reduction.

Decrease in POMS depression is correlated to decrease in EEG spectral power delta and theta

For the correlation analysis only the POMS facets and EEG frequency bands were used that showed an effect of the breathwork session. The reduction of depression was found to be correlated with a decrease in delta ($r(17) = 0.56$, $p = 0.019$) and theta ($r(17) = -0.54$, $p = 0.027$) in the occipital region (Fig. 4).

Changes in 11- ASC are comparable with dose–response profile of psilocybin

Figure 3 shows the response data gathered via the 11D-ASC scale immediately after breathwork. Since our study did not have a control condition, we plotted the subjective

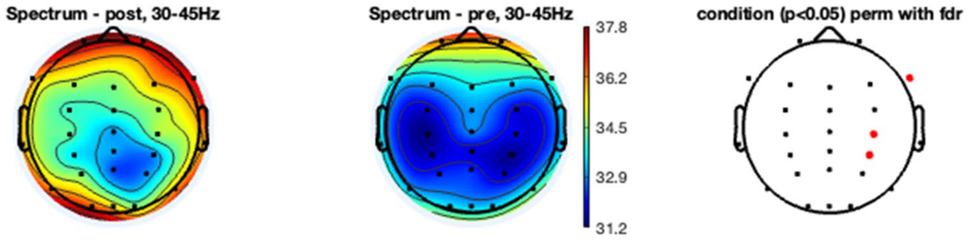


Fig. 2 Averaged topography across gamma frequency band and significant changes in experienced breathwork participants for $p < 0.05$ displayed at individual channels

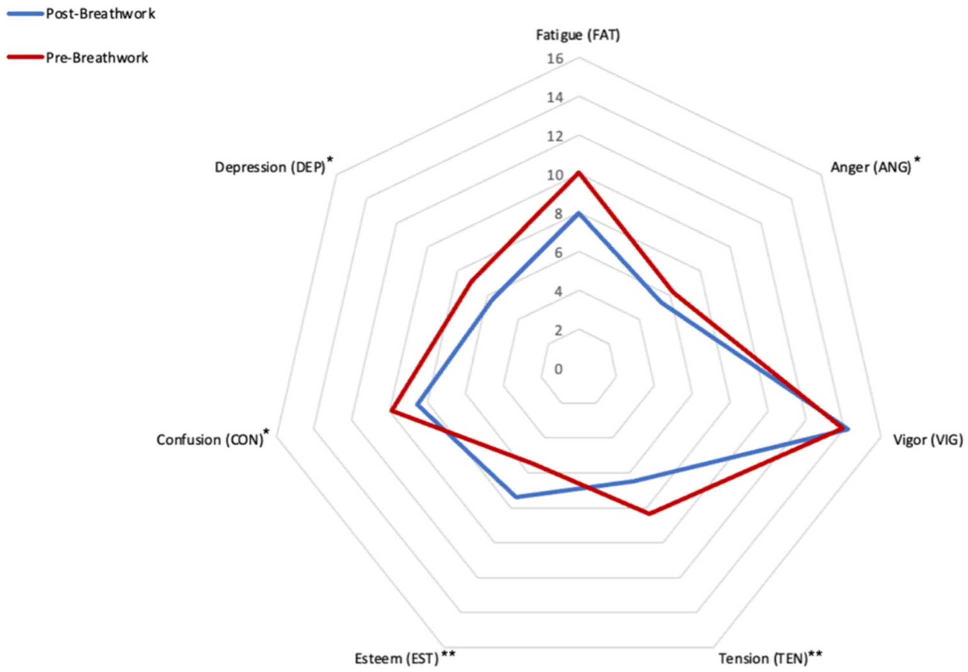


Fig. 3 Mean mood scores (POMS (Grove & Prapavessis, 1992) before and after the session. Red represents before, blue after breathwork. *significant at 0.05 level, **significant at 0.001 level

Table 1 Mean scores on Profile of Mood States before and after Breathwork. Higher scores meaning worse mood except for Vigor and Esteem, for which higher scores mean better mood

Paired Samples T-Test

	Pre-Breathwork	Post- Breathwork					95% CI for Cohen's d	
	M (SD)	M (SD)	t	df	p	Cohen's d	Lower	Upper
Fatigue (FAT)	10.09 (3.69)	8.0 (4.2)	–186	20	0.076	5.26	–0.042	0.827
Anger (ANG)	6.23 (1.69)	5.4 (0.96)	–2.05	20	0.053	1.87	–005	0.871
Vigor (VIG)	14.23 (5.05)	13.95 (5.17)	–0.27	20	0.079	4.74	–0.475	0.361
Tension (TEN)	8.36 (2.13)	6.5 (1.92)	–3.89	20	< 0.001	2.26	0.334	1.306
Esteem (EST)	5.46 (2.58)	7.41 (2.40)	3.99	20	< 0.001	2.29	–1.333	–0.353
Confusion (CON)	9.91 (3.21)	8.55 (4.0)	–2.18	20	0.041	2.93	0.190	0.900
Depression (DEP)	7.09 (2.56)	5.68 (1.17)	–2.71	20	0.013	2.44	0.119	1.023

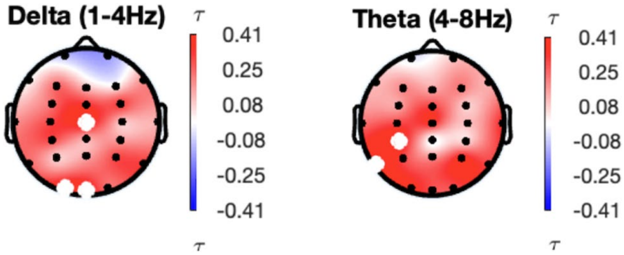


Fig. 4 Correlation of change in POMS depression with change in EEG. Topoplots show a positive correlation between the changes in Depression with changes in EEG, ie more reduction in power is related to more reduction in depression scores. Significant channel at $p < 0.05$. are marked white

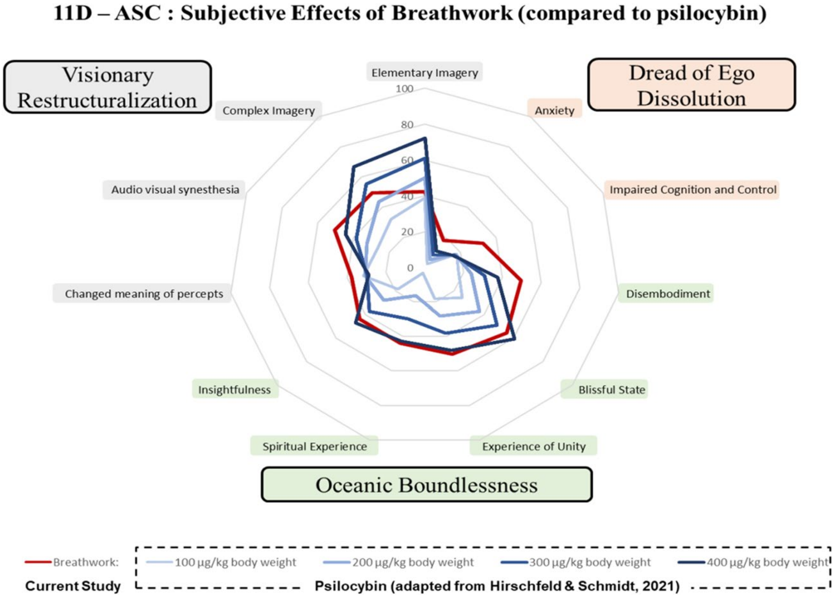
experience during breathwork alongside the dose-dependent relationships of psilocybin-induced subjective experiences (Hirschfeld & Schmidt, 2021) for the purpose of qualitative comparison, and because the subjective effects of these two techniques have been compared in the past (Eyerman, 2013). We did not conduct a quantitative comparison given that these data stem from independent studies.

On all subscales of the ‘Oceanic Boundlessness’ subdimension (blissful state, experience of unity, spiritual experience, insightfulness, disembodiment) breathwork exhibited scores similar to high doses of psilocybin. On the ‘Visionary Restructuralization’ subdimension breathwork exhibited scores similar to medium doses of psilocybin, with ‘changed meaning of percepts’ showing highest scores. On the ‘Dread of Ego-Dissolution’ subdimension, participants scored very low compared to the other subdimensions, but higher compared to psilocybin (Fig. 5).

Discussion

To the best of our knowledge, this study presents the first investigation into the immediate neuropsychological effects of a connected breathing breathwork session, as well as

Fig. 5 Subjective Effects of Breathwork Compared to Dose-Dependent Subjective Effects of Psilocybin (adapted from Hirschfeld & Schmidt, 2021). Red line represents breathwork, blue lines are dose dependent effects of Psilocybin



perceived changes in mood and consciousness during the experience, in healthy individuals.

With respect to the neurophysiological recordings, spectral analysis of resting state EEG recorded before and after the session showed decreases in lower frequency bands (delta, theta, low beta), while gamma increased, albeit only in experienced participants. The mood states as measured by the POMS questionnaire indicated that after the breathwork session, participants experienced a reduction in negative affect states (tension, confusion, depression and anger), while esteem increased. Finally, as described above, scores on the 11D-ASC scale indicated that subjective experiences during breathwork were similar to the experiences after medium to high doses of psilocybin, which may be indicative of the occurrence of experiences of mystical quality.

With respect to the neurophysiological findings, we observed a decrease of Delta power. Delta activity has been linked to sleep states, known as Spontaneous Slow Wave (Harmony, 2013). In normal waking consciousness, delta activity has been linked to cortical and behavioural inhibition and appear to originate from the medial prefrontal, orbitofrontal, and anterior cingulate cortices (Harmony, 2013), coherent with the frontal decrease in power found in our study. The decrease in Delta Power observed in this study suggest the modulation of cortical and behavioural inhibition in response to breathwork.

In addition to a decrease in Delta power, Theta power was also found to decrease. Theta activity during normal waking consciousness in adults is associated with memory encoding and problem solving (Herweg et al., 2020). Elevated Theta power has been consistently described in neuroticism and avoidance (in particular at a frontal and central level) (Neo & McNaughton, 2011), while a decrease in frontal Theta cordance was associated with depression remission (Cook et al., 2009). The decrease in Theta power observed in this study could suggest a more open, less self-centered mindset and could be involved in changes in memory processing linked to the breathwork practice.

Notably, also the power of low Beta waves was found to decrease after the breathwork session. Beta waves have been associated with alertness, focus, stress, and anxiety (Abhang et al., 2016). Increased Beta, and in particular Beta1 and 2 power have been linked to increased rumination (Ferdek et al., 2016), a phenomenon recurrently described in anxiety and depression.

In line with the notion that breathwork might alleviate depression, the present results show a positive effect on mood. Breathwork decreased tension, confusion, depression and tended to reduce anger. Esteem on the other hand increased after breathwork. This is also in line with psychodynamic theories of breathwork which commonly attribute the occurrence of emotional breakthroughs as a consequence of releasing bodily tensions that have accumulated through the suppression of negative emotions over a long time (Everly & Reese, 2007; Lalande et al., 2012; Lowen, 1975; Rhinewine et al., 2007; Victoria & Caldwell, 2013; Young et al., 2010). During a connected breathing experience, the connection between the habitual way of breathing, and the holding patterns of our emotions (Gilbert & Chaitow, 2002), gets interrupted. Consciously choosing to 'break' the pattern during the session may allow for a freeing of these negative emotions, as seen in our study in a reduction of all the negative mood facets after the breathwork session. The increase in esteem found after the session could possibly be related to a sense of autonomy over one's own emotional efficacy, as it is one's own effort and attention that allowed the transformation. Future research could look deeper into this underlying mechanism.

As the subjective experience during breathwork sessions was anecdotally paralleled to the effects of meditation or psychedelics, it was a natural impulse to compare our findings with these modalities. The spectral changes found in our study are in similar frequency bands as found influenced by psychedelic states, for example DMT (Ayahuasca) which also displayed a decrease in theta, delta and beta power and an increase in gamma power (Schenberg et al., 2015). Delta and Theta power has also been shown to be decreased during the acute response to psilocybin in rodents (Golden & Chadderton, 2022; Tyls et al., 2016). Likewise, several meditative practices (Braboszcz et al., 2017), acute response to psilocybin (Tyls et al., 2016), as well as the antidepressant response to ketamine all display an increase in gamma power (Gilbert & Zarate, 2020), as was observed in the experienced practitioners. Moreover, the increased Gamma power observed with ketamine consistently subsisted for hours post infusion (Gilbert & Zarate, 2020). These results suggest potential similarities regarding the neurological correlates of these practices, and these resemblances might be worth further investigation.

Further we looked into the subjective reports of how breathwork changes consciousness during the experience and compare it to another non-ordinary state induced by psychedelics, in this case psilocybin (Hirschfeld & Schmidt, 2021). On a descriptive level, based on ratings of the 11D-ASC scale, participants indeed reported changes in their subjective experiences that on all subscales of the 'Oceanic Boundlessness' subdimension (blissful state, experience of unity, spiritual experience, insightfulness, disembodiment) exhibited similar scores to high doses of psilocybin. This indicates that indeed their experiences had a mystical quality. On the ‘Visionary Restructuralization’ subdimension, breathwork induced scores similar to medium doses of psilocybin, with highest scores for ‘changed meaning of percepts’. This subdimension is associated with objects “appearing more salient and personally significant than they ordinarily do” (Bayne & Carter, 2018). Breathwork does not have as strong visual distortions and hallucinations as high doses of psychedelics but seems to increase personal significance and salience of internal visions. On the ‘Dread of Ego-Dissolution’ subdimension, participants scored very low. This dimension was also the lowest during psilocybin experiences. While further investigations are necessary for conclusive statements, our results visually give an indication that breathwork is a mean of inducing non-ordinary states of consciousness, in a similar manner to psychedelics.

Implication and explanation of findings

It is interesting to notice that the decrease in slow wave spectral power together with an increase in gamma rhythm, which we observed in experienced participants, is a sign of cortical excitation which has also been found responsible for alleviating depression symptoms (Fitzgerald & Watson, 2018). This view is supported by results of multiple studies indicating that the most prominent EEG frequency marker for depression is an increase in absolute power in delta, theta and beta during eyes closed rest (Newson & Thiagarajan, 2019). Exactly in these three bands we found a reduction after the breathwork. Further analysis confirmed that the reduction in delta and theta correlated with the reduction in depression observed. These observations leave us with an interesting clue about the potential of breathwork in this framework of depression.

Strengths and limitations

As a strength of the present study we would like to highlight that the multitude of EEG measurements are rather objective indices which are hard to influence in a particular direction. Therefore, specific expectancy effects could not be assumed. This implicates that our results are an objective testimony of the efficacy of breathwork, showing neuropsychological and emotional changes after only a single session. Moreover, we could establish the relationship between objective brain activity and subjective mood status by combining EEG recordings with more subjective measures of mood. Finally, the inclusion of the 11D-ASC scale in combination with the EEG measures made it possible to examine the potential of breathwork to induce non-ordinary states of consciousness, comparable to psychedelics. An apparent weakness of the study is the small sample size. It would have been better to include a sample consisting of males and females, practiced and naïve participants, a large range of ages and participants suffering from, for instance, stress complaints that is large enough to make comparisons between different groups.

Conclusion

The present findings indicate that ‘connected breathing’, a type of breathwork that is characterized by faster diaphragmatic breathing than breathwork interventions usually apply, affects those parameters of brain activity and mood status that are associated with a better mental condition. As a consequence, our explorations highlight the potential of breathwork as a complementary therapeutic modality by activating therapeutic benefits on a neuropsychological level. To confirm its therapeutical value as an adjuvant treatment option to psychotherapy, it can be recommended to investigate the effects of breathwork in depressed patients. In addition, further investigation of the similarities between the consciousness altering modalities discussed in this manuscript could be beneficial in exploring how these modifications are related to their therapeutic potential.

Appendix

Participant in and exclusion criteria

Participants were screened out on the basis of having any significant mental health challenges (such as psychotic episodes, depression, anxiety, PTSD, or other relevant life events); having a history of psychosis, schizophrenia, or bipolar disorder in the family; or having any of the following contra-indications: pregnancy, cardiovascular problems, heart problems or a history of heart diseases, high or abnormal blood pressure, asthma, glaucoma, osteoporosis, recent surgery or physical injury, epilepsy or a history of seizures, an active addiction.

Inclusion criteria were being healthy and aged between 18 and 39.

Participants were asked to abstain from drinking alcohol and consuming any recreational drugs on the same day, or caffeinated drinks two hours prior to the experiment.

Table 2 Descriptive statistics for every significant electrode across each frequency bands. (Power is expressed as Log Power 10*Log$_{10}$(μV^2))

	Condition	Fp1	Fp2	F7	F3	Fz	F4	F8	Fc3	FCz	Fc4
delta	Pre	53.04 ± 1.57	52.71 ± 1.44	51.03 ± 1.04	48.95 ± 1.06	49.09 ± 0.96	48.94 ± 0.96	50.77 ± 1.92	47.00 ± 0.86	48.15 ± 0.81	46.3 ± 0.80
	Post	50.71 ± 1.51*	50.55 ± 1.36	49.53 ± 1.06*	47.47 ± 1.08*	47.70 ± 0.94*	47.35 ± 0.94*	50.20 ± 1.01	45.59 ± 0.95*	46.77 ± 0.83	45.05 ± 0.81*
theta	Pre	48.29 ± 0,49	48.18 ± 0.56	47.65 ± 0.54	46.29 ± 0.29	46.87 ± 0.40	46.37 ± 0.30	47.54 ± 0.58	45.01 ± 0.21	46.57 ± 0.30	44.49 ± 0.30
	Post	46.59 ± 0.28*	46.69 ± 0.68	46.43 ± 0.37*	44.97 ± 0.40*	45.62 ± 0.49*	45.08 ± 0.40*	46.92 ± 0.49	43.49 ± 0.34*	45.07 ± 0.42*	43.18 ± 0.37*
beta 1	Pre	45.36 ± 2.42	45.49 ± 2.37	45.03 ± 2.32	44.12 ± 2.43	44.13 ± 2.50	43.56 ± 2.45	44.82 ± 1.86	43.22 ± 2.47	43.34 ± 2.43	42.95 ± 2.35
	Post	44.57 ± 2.85	44.65 ± 2.43	44.35 ± 2.20	43.27 ± 2.32	43.34 ± 2.56	43.28 ± 2.28	44.37 ± 1.92	42.25 ± 2.37*	42.34 ± 2.44*	41.89 ± 2.34*
beta 2	Pre	42.18 ± 0.20	42.38 ± 0.20	41.84 ± 0.87	41.20 ± 0.12	41.20 ± 0.16	41.36 ± 0.17	41.82 ± 0.46	40.28 ± 0.19	40.97 ± 0.16	40.25 ± 0.20
	Post	41.26 ± 0.15*	41.43 ± 0.20*	41.14 ± 0.29	40.4 ± 0.10	40.20 ± 0.07*	40.51 ± 0.10	41.67 ± 0.43	39.44 ± 0.05	39.76 ± 0.06*	39.23 ± 0.10*
gamma (experienced subgroup)	Pre	36.26 ± 1.04	35.86 ± 0.99	34.73 ± 1.16	33.09 ± 0.20	32.94 ± 1.43	33.43 ± 1.53	33.78 ± 1.13	32.12 ± 1.72	32.82 ± 1.54	31.79 ± 1.84
	Post	37.52 ± 1.25	37.28 ± 1.11	37.31 ± 0.84	35.05 ± 1.25	33.46 ± 1.88	35.61 ± 1.35	37.90 ± 0.86*	34.82 ± 1.13	34.10 ± 1.78	34.49 ± 1.37
		T3	C3	Cz	C4	T4	Cpz	Cp4	P3	Pz	P4
delta	Pre	49.77 ± 0.78	45.75 ± 0.76	46.99 ± 0.84	45.90 ± 1.54	49.94 ± 1.65	46.19 ± 0.79	45.79 ± 0.91	47.10 ± 0.90	47.49 ± 0.86	47.58 ± 0.94
	Post	48.14 ± 0.77*	44.30 ± 0.92	45.80 ± 0.86	44.46 ± 1.62*	48.54 ± 0.89*	46.15 ± 0.90	44.98 ± 0.98	45.95 ± 0.87	46.03 ± 0.99	46.78 ± 1.019
theta	Pre	47.33 ± 0.48	43.74 ± 0.59	46.06 ± 0.23	44.06 ± 0.36	48.07 ± 0.48	44.87 ± 0.50	43.97 ± 0.39	45.17 ± 0.47	45.66 ± 0.34	45.40 ± 0.37
	Post	45.82 ± 0.44*	42.34 ± 0.39*	44.23 ± 1.21*	42.60 ± 0.40*	46.43 ± 0.58*	44.55 ± 0.85	42.84 ± 0.39*	44.00 ± 0.58	44.26 ± 0.50*	44.44 ± 0.37
beta 1	Pre	45.47 ± 1.81	42.82 ± 2.44	42.25 ± 2.17	43.22 ± 2.38	46.01 ± 1.57	41.58 ± 2.10	43.50 ± 2.64	45.16 ± 2.61	43.69 ± 2.42	45.51 ± 2.92
	Post	44.47 ± 1.89	42.03 ± 2.72	40.96 ± 2.22*	41.69 ± 2.66*	45.02 ± 1,71	41.04 ± 2.33	42.79 ± 2.73	44.26 ± 2.58*	42.42 ± 2.54*	44.60 ± 2.79
beta 2	Pre	42.69 ± 0.42	39.92 ± 0.14	40.05 ± 0.16	40.53 ± 0.08	43.46 ± 0.46	39.48 ± 0.16	40.29 ± 0.13	41.50 ± 0.20	40.39 ± 0.29	41.69 ± 0.16
	Post	41.42 ± 0.49	38.57 ± 0.08*	38.63 ± 0.04*	39.10 ± 0.10*	42.53 ± 0.32	38.45 ± 0.11*	39.14 ± 0.18*	40.44 ± 0.23*	39.02 ± 0.36*	40.59 ± 0.34*
gamma (experienced subgroup)	Pre	34.08 ± 1.28	31.30 ± 2.13	32.33 ± 2.14	31.95 ± 2.16	34.03 ± 1.42	31.65 ± 2.06	31.44 ± 1.89	32.41 ± 1.74	32.40 ± 1.32	32.3 ± 1.61
	Post	35.73 ± 0.84	35.82 ± 1.44	32.46 ± 2.18	35.20 ± 2.12*	36.91 ± 1.11	33.29 ± 1.87	32.85 ± 1.59*	35.11 ± 1.28	32.64 ± 1.53	33.36 ± 1.66

Power is expressed as Log Power 10*Log$_{10}$(μV^2)

NB for convenience and readability, only the frequency bands that displayed significant variation in power are displayed; *Pre* pre breathwork resting state recording; *Post* post breathwork EEG recording

Acknowledgements We would like to thank Cor J.J. Stoof for providing technical support and experimental room setup.

Author contributions KF is creator of concept theory. All authors contributed to the study conception and design. Material preparation was done by MI, data collection was performed by CB and AS. Analysis was performed by CB, AS, GF and MI. The first draft of the manuscript was written by MI incorporating theses written by CB, KF, AS and GF. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conceptualization: KF, CB, GF, MI, JBD, HE; Methodology: KF, CB, GF, MI, JBD,; Formal analysis and investigation: CB, GF, MI, JBD; Writing—original draft preparation: CB, GF, MI; Writing—review and editing: KF, JBD, HE; Supervision: MI, KF, JBD, HE.

Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Scientific and Ethical Review Board of the Faculty of Behavioral and Movement Sciences of the Vrije Universiteit (*Date* 28.6.2021*/No* 2021-141).

Consent to participate and publish Informed consent was obtained from all individual participants included in the study.

Competing interest of authors All authors declare not having any financial or non-financial conflicts of interest except for non-financial conflicts of interest of KF as founder and director of Open Up, Breathwork and inner development Institute, Amsterdam.

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