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Article

Keywords:

Posted Date: November 21st, 2024

DOI: https://doi.org/10.21203/rs.3.rs-5483787/v1

Additional Declarations: Competing interest reported. M.N.H. is trained as a facilitator for conscious-connected breathwork.

Non-ordinary states of consciousness evoked by breathwork correlate with improved heart-rate variability

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Abstract

High ventilation breathwork is a breathing practice that involves deep, accelerated breathing over a prolonged duration (> 15 minutes). This basic practice underpins a wide range of traditions, from Pranayama to Holotropic and Conscious-Connected breathwork. Anecdotal reports suggest that it can benefit physical and mental health, often by evoking altered states of consciousness. However, scientific research on breathwork is still in its infancy.

This study examines the physiological and experiential effects of Conscious-Connected Breathwork (CCB). Specifically, we characterize subjective breathwork experiences using Natural Language Processing analyses of semi-structured phenomenological interviews, and relate them to changes in Heart-Rate Variability (HRV). Finally, to disentangle the effects of the breathing technique itself from context effects, we tested whether the presence of evocative music modified the impact of the session.

Our findings indicate that CCB consistently triggers altered states of consciousness, accompanied by increased emotional intensity and decreased HRV during the session, but increased baseline HRV following the session. This increase was larger for subjects who experienced a wider range of emotions during the session, but was not predicted by peri-session HRV. This suggests that post-session improvements of HRV might be a product of emotional catharsis rather than purely physiological hormesis. Finally, none of these effects was significantly modulated by music, indicating that they largely rely on the breathing practice itself.

Introduction

The fact that various conscious breathing practices can improve well-being has been documented robustly. Currently, breath-based techniques that are used for therapeutic aims (e.g. meditation, progressive relaxation, autogenic training) are typically based on slowing down the breathing frequency [1–3] . Such slow-breath practices have been associated with stress reduction and general well-being, as well as with the modulation of analgesia, stress and emotional response [2–4]. In contrast, fast breathing has often been linked to anxiety and stress [5,6], and research has highlighted the potentially problematic effects of acute hyperventilation and habitually accelerated breathing (over-breathing), for instance in terms of heightened blood pressure, potential triggering of epileptic or psychogenic-seizures and panic attacks [7–9]. Furthermore, chronic hyperventilation (hyperventilation syndrome) causes a plethora of physiological and psychological symptoms, for which the primal causal factor is chronic anxiety [10–12].

At the same time, high-intensity breathing is an integral part of several popular practices such as Sudarshan Kriya Yoga, Rebirthing, as well as Holotropic, Holorenic, Transformational and Consciously Connected breathwork, and to some extent the Wim Hof Method. All these approaches employ a breathing pattern in which participants breathe deeply, and typically at a somewhat heightened frequency, removing pauses between inhalation and exhalation to form a 'circular' or 'connected' breathing rhythm. This breath pattern is then sustained for a prolonged duration of at least 15 minutes up to several hours. We will refer to practices that share this core breathing technique under the umbrella term of High Ventilation Breathwork (see [13]).

High ventilation breathwork has been anecdotally reported to enhance various domains of mental and physical well-being (e.g. [14,15]). However, scientific studies determining the effects of high ventilation breathwork have so far been sparse, and often underpowered. The existing studies suggest that high ventilation breathwork can benefit both physical and mental health, reducing symptoms of anxiety and depression as well as inflammation, improving well-being and self-awareness, rendering immune responses more effective, and supporting processing of challenging experiences like trauma and grief [13,16–24].

While these findings are promising, the acute mechanisms by which high ventilation breathwork might achieve such outcomes are so far poorly understood [13,22,23,25]. The basic physiological dynamics set in motion by high ventilation breathwork have been established rather clearly, including decreased CO_2 saturation and increased O_2 saturation, which in turn render blood pH more alkaline, triggering sympathetic nervous activity, cortisol release, increased release of adrenal stress hormones, increased heart rate and decreased cerebral blood flow [7,26–30]. While decreased CO_2 saturation has been highlighted as a trigger condition for non-ordinary states of consciousness (NOSCs) [23], it is neither clear by what processes an altered O_2-CO_2 balance might translate to altered consciousness, nor how the physiological and experiential effects of CB interact with each other during and beyond a session.

For instance, the effects of high ventilation breathwork that have so far been documented can be seen as broadly compatible with several distinct (though potentially complementary) mechanisms: From a physiological perspective, benefits of high ventilation breathwork might be interpreted as an instance of hormesis, whereby a time-limited, manageable physiological challenge (in this case, a highly unusual blood pH) leads to improved function in the long term. Other examples of such hormetic processes are fasting and strenuous physical workouts [31–33]. From a psychological perspective, high ventilation breathwork might also engage processes of catharsis, whereby intense emotions are brought into consciousness, allowing their psychological integration within a safe context [13,16,21,34,35]. This may allow practitioners to decrease their overall experiential avoidance - a coping style that has been shown to generally impact mental health negatively [36–41]. Finally, from a neuroscientific perspective, CB might open up hyper-plastic or 'pivotal' mental states, in which neurons operate in a mode of heightened cross-area communication and plasticity, so that perception is broadened and learning is intensified. To begin to disentangle the contribution of these and other potential mechanisms to the effects of high ventilation breathwork, we need to quantify and relate physiological and psychological dynamics evoked by breathwork.

In the present study, we explore how acute physiological and psychological effects of breathwork relate to each other, and whether these dynamics are affected by context. Specifically, we tracked heart-rate variability (HRV) during a session of Conscious-Connected breathwork (CCB) - one style of high ventilation breathwork (see above). HRV refers to the variance of time intervals between successive heartbeats (RR intervals), and has been established as a proxy for parasympathetic system activity [42–44]. Moreover, increased HRV is correlated to better coping styles, emotion regulation and acceptance of negative emotions [45,46]. Our HRV measurements thus double as a reflection of acute sympathetic/parasymathetic activation during the breathwork session, and an indicator of baseline fitness and relaxation following the session [47,48] (for details, see Methods).

To quantify subjective experiences, shortly after the CCB session we asked subjects to complete a questionnaire assessing altered conscious states (the Phenomenology of Consciousness Questionnaire [49,50]). In addition, we invited subjects to freely recount their breathwork experience, and analysed their free-form descriptions using a large-language model (LLM) to classify emotional content.

By tracking physiological and experiential changes before, during and after high ventilation breathwork, we aim to generate first insights into the physiological and psychological mechanisms – and their potential interactions - that give rise to the short- and long-term effects of high ventilation breathwork.

Methods

Subjects

The study included 18 subjects: 10 women and 8 men, aged between 21 and 46 (26.76 +5.3).All participants had completed at least 14 years of education. All subjects volunteered to participate in the experiment after receiving study information in person from the experimenter, who described the duration of the experiment, measurement procedures (e.g. wearing a chest strap and verbally reporting on subjective experiences), as well as potential effects of a high ventilation breathwork session. If they expressed interest, prospective subjects then received a standardised form including a screening for the following exclusion criteria: diagnosed personality disorder; anxiety disorder; mood disorder; past invasive trauma or recent hospitalization; aneurysm/ischemia/glaucoma/retinal detachment/hypertension/osteoporosis; ongoing use of drugs; alcohol abuse or substance dependence; pregnancy. Subjects were also asked to quantify their experience with breathwork practices, rating the frequency with which they engaged in breath-related exercises before the study (never, less than once a month, monthly, more than once a month, weekly, or daily) and to specify the type of exercise (e.g. pranayama, Qi Qong, high ventilation breathwork etc.). In the condition without music one subject reported one past experience with rebirthing breathwork, two subjects practiced yoga with pranayama exercises about once a week and two about once a month, while five of the subgroup reported no significant experience with breathing practices; similarly in the condition with music, one subject stated one previous experience with holotropic breathing, four were practicing yoga with pranayama exercises at least twice a month, and half of the group had no significant experience with breathing practices. Finally, the form requested subjects to take at least half a day off following the practice, which was carried out in a time range of 9 a.m. to 6 p.m. Each participant then signed a written informed consent according to the University of Torino Ethics Committee (established by regional decree no. 6502 on the 23/10/2008).

Study procedure

Participants were randomly assigned to one of two conditions (with or without music - see section 'Music' below) by lottery before the beginning of the experiment, such that participants each underwent either the 'music' or 'no music' condition ($n_{music} = 10, n_{nomusic} = 8$). Participants were not made aware of the existence of two experimental groups, or of the experimental group they had been assigned to. At the beginning of the experiment, subjects entered a quiet room, and were informed about the upcoming CCB session, including duration, breathing pattern, possible experiences, measurements (chest belt, post-session report and questionnaire), and their right to terminate the session at any point. Subjects were then fitted with a chest belt with help of the experimenter to measure cardiac activity. Next, subjects were invited to sit with their eyes closed for one minute before completing the Phenomenology of Consciousness Inventory (PCI)[50] for the first time. At the same time, cardiac activity was recorded to gather a baseline estimate of the subject's HRV. Subjects were then asked to lie down on a mattress and begin breathing in the high-ventilation pattern used by CCB.

A session of CCB consists of four essential components, which were also adhered to in this study:

1. Connected breathing (a pattern of deep breaths at normal to high speed, with no pauses between inhalation and exhalation). It is not mandatory to keep breathing in this way for the whole session, but it is highly encouraged by the facilitator at least at the beginning to 'enter the process' (see also [23]). Each subject in the present study responded consistently to this invitation by the facilitator, breathing in the recommended CCB rhythm for at least the first fifteen minutes.
2. A quiet, dimly lit setting (a sleeping mask is usually used).
3. The presence of a trained facilitator to support breathing rhythm and emotional processes if necessary.
4. An extended session duration, which can vary from a minimum of thirty minutes to a maximum of about three hours. In this setting, sessions lasted between 36'42'' and 68'42'' minutes (mean: 52'15'' minutes), since facilitators gave participants space to 'round off' processes in their own time.

A breathwork facilitator was on hand to support participants in potentially difficult experiences. One minute after the end of the session, post-session cardiac activity was recorded for 5 minutes. After this, subjects were asked to again complete the PCI regarding their experience during the breathwork session. Finally, after completing the PCI, the free-form interview about the participant's subjective experience took place.

Music

In the condition in which the breathwork session was accompanied by evocative music, music was selected by drawing on the indications provided for holotropic breathwork [51], taken from https://musicforbreathwork.com. Specifically, the initial music tracks involved monotonous drumming of increasing intensity for approximately 35 minutes, followed by fifteen minutes of slower music tracks.

Cardiac activity and heart-rate variability

Heartbeat intervals were recorded before, during and after the breathwork session, using a Polar V800 wristwatch and a Polar H10 chest strap (Polar, Kempele, Finland). These recordings were used to compute RR intervals, i.e. the times elapsed between two R activity waves in the QRS electrocardiogram signal. The validity and reliability of RR interval measurements are discussed by [52].

HRV is commonly analysed for information on cardiovascular control and is therefore considered a non-invasive method of detecting autonomic nervous system activity. In particular, an increase in heart variability indicates the increase in activity of the parasympathetic system and its decrease in the sympathetic system [42,43]. Moreover, an acceleration of the respiratory rate has been correlated with a decrease in HRV [47] and vice versa [53]. Our HRV measurements thus double as a reflection of acute sympathetic/parasympathetic activation during the breathwork session, and an indicator of baseline fitness and relaxation following the session [47,48] , for details see Methods). Specifically, our measurements are designed to probe both tonic and phasic HRV. Tonic HRV has also been referred to as resting HRV or baseline HRV, and reflects a person's typical HRV measured in the absence of unusual external inputs. In contrast, the phasic HRV captures how the system reacts to an external stimulus and has been named reactivity [54]. In this study, we compared the effects of a CCB session on cardiac activity by comparing tonic HRV measured pre-session with phasic HRV measured during and post-session. Thus, the study design follows the structure recommended in [54]: a tripartite structure that measures the "three Rs" of HRV: resting, reactivity, and recovery.

Time-domain indices, derived from the time variations of the intervals between consecutive heartbeats, were used to compare the cardiac activity measured before and after the session of connected breathing. This is because the time-domain indices were judged to be the most suitable for quantifying HRV at the measured times [55].

To assess the variability of the HRV time series across the three distinct phases—before, during, and after the intervention —using a bootstrap resampling technique. To account for variability in the data, we repeatedly resampled points ($n_{rep} = 1000$) from each segment of the time series with replacement, calculating the variability (standard deviation) of each resample. Finally, the average variability for each phase is computed from these bootstrap samples, providing a robust estimate of the data's variability across the different phases. This approach helps ensure that the variability estimates are not overly influenced by outliers or the specific characteristics of the original sample.

Phenomenology of Consciousness Inventory

We used the Phenomenology of Consciousness Inventory (PCI)[50,56] to quantify the phenomenology of the states of consciousness induced during the session. The PCI is a retrospective self-administered questionnaire completed in reference to particular conditions, and consists of 52 items consisting of two statements of opposite meaning, separated by a 7-point Likert scale (0 to 6). Five pairs of items are included in the test to assess intra-individual replicability (Reliability Index, RI), i.e. the accuracy with which the test was compiled. This parameter ranges from a minimum of 0 (totally reliable) to a maximum of 6 (totally unreliable). If the RI value does not exceed 2, the test is considered valid. The PCI contains 26 (sub) dimensions including 12 major dimensions (e.g., Positive Affect, Negative Affect, Altered Experience), and 14 minor dimensions (e.g., Joy, Anger, Altered Body Image). Participants were asked to respond to each item on a 7-point Likert scale. The percentile on each subscale of the questionnaire after the experience was then related to the percentile obtained before the experience, to measure the effect of the practice on each subscale.

Phenomenological interview

To integrate a more detailed phenomenological analysis of the experience, an interview inspired by the micro-phenomenological paradigm was employed and considered to allow a good agreement on the reliability of first-person phenomenological reports [57]. To avoid false memories and to respect the precepts of phenomenological experience analysis, the interviews were carried out practicing the suspension of judgment known as *epoché*. The aim of the phenomenological interview is to recover as precisely as possible the embedded memory of one's own life and derive, following the work by [58], a structure of subjective experience to detect in turn a structure in the underlying physiological or neural activity. Specifically, in the study design we took inspiration from cardio-phenomenology, which aims to capture subjective lived experiences more fully by combining cardiac measures with in-depth phenomenological accounts of experience [59–61]. The interviews were conducted as follows: first of all, the subject was invited to put themself back in the position where the experience had taken place (lying supine on the *tatami*), providing a detailed description of the moment to be explored, for example: "You wore the eyeshade, then the music started and we started to breathe together", then with a very general content-empty first question to allow the stream of consciousness to emerge: "Do you remember what happened?". The resulting stream of consciousness was then guided by questions to deepen the diachronic or synchronic temporal dimension of the process. The *diachronic* dimension emphasizes the experience as a succession of instants and concerns the development or genesis of different subjective reported experiences over time. Therefore, questions without focus on the content are asked starting from the re-description performed by the experimenter of the temporal moment, often repeated several times. The obtained description of a sequence of lived moments is useful for tracing a temporal map of the experience. Here is an example contained in a short extract from an interview:

I: So, starting from the beginning: you put on the eye mask and started to breathe in a connected manner... What happened in chronological order?
A: In the beginning I had felt I was kind of moving into some kind of deeper space and there was something that I couldn't really feel but I was getting near a feeling of, yeah, desperation and solitude [...]
T: So you had a peak and you managed to cry the first time and then there was relief..
A: Yeah exactly, I could let go of the sadness, all these memories with the people and then I started to feel very well, very connected. So It was really a contrasting thing because at the beginning I was very heavy and in the end I was relieved and kind of happy when at the beginning I was not happy at all, because of this relationship stuff.

The interviewer helped the remembering and systematization of the experience by guiding the interviewees in telling their experiences from a diachronic point of view. The participant's respiratory behaviour was noted during the experience to reconstruct more faithfully what was really lived by the other:

I: But I noticed that shortly after the start you slowed down the breathing. That is, you started off on a high note and then slowed down. Does it ring a bell?
S: Yes, this first feeling of excitement I was telling you about led me to focus on my breathing, on my body, on the music. Always to see where all this would lead me as I was telling you. So I kept breathing while also listening to the music, and in my body that feeling of pre-panic excitement (laughs), I wouldn't know how to describe it to you well, remained stable for quite a while. I started to feel a great energy here (points to the diaphragm) as if there was almost a flaming ball that wanted to come out.

Such a temporal map permitted to deepening the *synchronic* dimension, which aims to clarify the structure of the considered experience by characterizing its subtle nuances, i.e:

T: Do you remember how happened the transition from sadness to laughing?
L: If you are in the beach and seeing the wave from far you see, that was the sadness. Then there is the peak of the wave, the peak of sadness and then you know the white foam of the wave on the beach, that was the laughing.

Analysis of phenomenological interviews

As a way to extract and analyse the free-form reports on subjective experience, we first transcribed them and then followed a standard Natural Language Processing (NLP) pipeline: We structured all texts into sentences and then, for each participant, we systematically quantified word-level statistics: using word clouds (Fig. S1) and computing the most common bi-grams (Supp. Fig. S2). These analyses were conducted using code custom-written in Python. They are publicly available at https://github.com/atlaie/Breathwork

To further characterize the emotional content, we were interested in attributing probabilities of each sentence belonging to pre-defined emotional categories. To this end, we defined 28 emotional categories, following the work carried out in [62].

Specifically, our list consisted of the following emotions:

'admiration', 'adoration', 'awe', 'aesthetic experience', 'entrancement', 'calmness', 'confusion', 'boredom', 'nostalgia', 'romance', 'sexual desire', 'craving', 'sadness', 'pain', 'anger', 'disgust', 'horror', 'fear', 'anxiety', 'awkwardness', 'amusement', 'relief', 'satisfaction', 'interest', 'surprise', 'excitement', 'joy', 'empathy'

In order to do this task automatically, we made use of BART, a particular version of a pre-trained Large Language Model (LLM). This particular type of architecture is known as a denoising autoencoder [63]. We decided to use this architecture instead of currently more common ones (such as GPT-based models) because it inherently allows the model to consider the entire context of a sentence (both left and right context) in a bidirectional manner. Such comprehensive context understanding is crucial when identifying emotions in sentences, as the emotional tone can depend significantly on the subtle interplay of words and phrases across the whole sentence. GPT-like models [64] on the other hand, are auto-regressive and primarily condition on previous tokens only (left context). This can limit their ability to capture the full semantic scope influenced by terms that appear later in the sentence.

After we got the model probabilities, we pooled them across participants and filtered the lowest ones using an elbow criterion (Supp. Fig. S3A). We decided to do this to improve the signal-to-noise ratio, as differences between probabilities that were extremely low to begin with would not be helpful for downstream use.

Aligned Pearson Correlation

We employed the Aligned Pearson Correlation (APC) technique to assess the degree of similarity between time-series data of Heart Rate Variability (HRV) among participants throughout the sessions. APC is an advanced statistical method that enhances the traditional Pearson correlation by introducing an alignment step, which adjusts for potential time shifts and scaling differences between comparative datasets. This technique is particularly useful in physiological studies where the synchronization of response patterns is not always exact due to individual differences in physiological and psychological response times.

The APC calculation involves first identifying the optimal alignment between the two time traces, that maximizes their Pearson correlation coefficient. This is achieved through a systematic shift of the time series data relative to each other and computing the Pearson correlation for each shift. The shift yielding the highest correlation coefficient indicates the best alignment, taking into account both lag and lead relationships between the datasets. Once the optimal alignment is determined, the corresponding Pearson correlation value at this alignment is used as the measure of similarity.

For this study, the APC allowed us to compare the HRV traces from different sessions and participants (split across music/no-music groups), providing a robust measure of how similarly participants' autonomic nervous systems responded to the CCB sessions, irrespective of individual differences in the timing of these responses. This was necessary for understanding the synchronized physiological responses that are indicative of shared experiential states during breathwork, despite the subjective variability in emotional and sensory experiences reported by the participants.

Results

To confirm that CCB can induce non-ordinary states of consciousness (NOSCs), we administered the Pekala Consciousness Inventory (PCI) [50,56] before and after the breathwork session. The resulting scores across 13 sub-scales are shown in Figure 1A, and the difference between pre- and post-session scores are summarized in Figure 1B. CCB increased PCI scores across all sub-scales except self-awareness, with statistically significant differences present in 6 of 13 sub-scales after correction for multiple comparisons (t-tests for dependent samples across 13 sub-scales; $n = 18$; $t = 1.4$ to 16.0 across 13 sub-scales; $p < 0.001$ to 0.19; 6 of 13 sub-scales statistically significant according to Dunn-Sidak correction for multiple comparisons, conservatively assuming 13 fully independent comparisons at a family-wise error rate of 0.05). Particularly the sub-scales most directly reflecting altered states of consciousness, such as 'altered experience', 'time perception' and 'body sensation', were strongly affected during CCB. Moreover, scores indicated that attention during the sessions was directed more inward (see sub-scale 'Inward Attention'). Interestingly, the only sub-scale for which scores significantly decreased during the CCB session was 'Self-awareness', in line with the idea that cognitive control is decreased during breathwork. Together, these results suggest that participants consistently entered NOSCs during CCB.

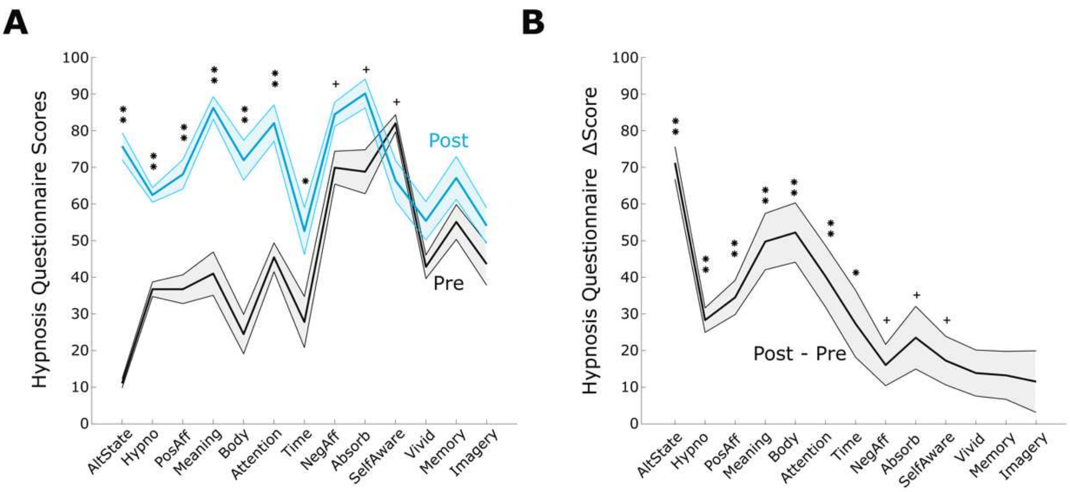

Figure 1: Altered states of consciousness evoked by circular breathwork. A) *Average for sub-scales of the Pekala Consciousness Inventory (PCI).Black: Pre-session scores. Blue: Post-session score. Shaded areas: Average ± SEM. Stars denote statistical significance of differences between pre- and post-session scores, as determined by pairwise t-tests.). ** $p < 0.01$; *$p < 0.05$; $^{+}p < 0.10$. Sub-scales are ordered by size of difference. Left-most six sub-scales show significant differences after correction for multiple comparisons (see Methods).* **B)** Same as A for the difference between pre- and post-session scores.

None of the questionnaires currently available to probe altered states of consciousness are deliberately tailored to breathwork experiences. More specifically, the PCI applied here was initially developed to quantify states of trance and hypnosis. Thus, while the questionnaire scores obtained here confirm the general occurrence of NOSCs during CCB, and an at least partial overlap between states evoked by breathwork and trance, they may not cover crucial aspects of breathwork experiences that are not shared with other NOSCs. To also quantify breathwork experiences in an open-ended and data-driven way, we analysed subjects' free-form verbal descriptions of their experience, using natural language processing (NLP) analysis. Specifically, we transcribed all verbal reports (see Supp. Material S1) and followed a standard Natural Language Processing (NLP) pipeline: We first structured them into sentences and then, for each participant, we systematically quantified word-level statistics: computing the most common bi-grams, i.e. two-word phrases (Supp. Fig. S1) and creating individual word clouds (Supp. Fig. S2).

The word cloud subsequently compiled across all participants is shown in Figure 2A. As one can see, it features a blend of terms that speak to both physical sensations and emotional experiences—e.g., "body," "laugh," "cry," "fear," "joy," and "teeth" (potentially related to jaw clenching). Words like "light," "tingle," "sensation," "intensify," and "weight" likely describe the physical sensations experienced by participants during the breathing exercises. Terms like "begin," "change," "come," and "moment" might refer to the processual nature of the breathwork session, reflecting the transitions in physical and emotional states. The presence of both positive and negative emotional words (e.g., "fear," "anger," "joy," "laugh") supports the idea that CCB sessions may facilitate the conscious experience, and potentially release, of a broad range of emotions (see also e.g. [21,24,34]).

In line with this, the diversity of dominant phrases and words across participants (Supp. Figs. S1 and S2) indicates a wide range of personal experiences and emotions, supporting the idea that CCB can evoke a broad spectrum of subjective states. Descriptions such as "emotional release" 'felt feelings' and "deep emotions" point to the conscious experiencing of intense emotions. Some participants also used phrases like "mind feels," "became aware," and "mind clearing," suggesting a component of cognitive processing and reflective thought during the session. At the same time, the appearance of phrases like "physical body," "feel the body," and "body feels" (see Fig. 2A and Supp. Fig. S1) suggests that a significant aspect of the breathwork experience involves heightened body awareness, supporting the idea of CCB as a tool for embodied experience. This is also consistent with the physiological engagement that breathwork entails and might relate to the reported changes in Heart-Rate Variability (HRV, see below).

To further characterise the emotional content of breathwork experiences, we attributed probabilities of each sentence conveying specific categories of emotion. To this end, we defined 28 emotional categories, according to previous work by [62]; however, in that work the authors used "empathic pain" as a single category, and we split it into "empathy" and "pain". To estimate the probability of a sentence expressing these pre-defined emotional qualities, we made use of BART, a particular version of a pre-trained Large Language Model (LLM). For details on the reasons we decided to use this architecture instead of currently more common ones (such as GPT-based), please see section '*Analysis of phenomenological interviews*' of Methods. For each subject, a given sentence in the transcript was analysed by the model, outputting a probability for each of the 28 pre-specified emotions. Figure 2B shows the average probabilities of different emotional qualities across subjects, with emotions being radially ordered according to their empirical proximity, as demonstrated by [62]. Three examples of the same emotional probabilities for three participants are shown in Figure 2B (see also Supp. Fig. S3C for individual probability plots across all participants).

Visually, one can discern four salient axes that seem to unite high-probability emotional qualities. These four axes are highlighted in colour in Figure 2B, and appear to centre around qualities of entrancement and aesthetic experience, relief and satisfaction, anxiety, and finally craving, desire and pain - a constellation we abbreviated to the concept of 'samsara'. Figure 2D shows the average probability per participant for all four emotional axes identified in this way. While there is certainly cross-subject variability, one can see that experiences were most likely to be shaped by entrancement and relief, followed by anxiety and 'samsara', while other emotions were less likely to occur (Mann-Whitney U-test; $n = 18$; $p_{ent-rel} = 0.012$, $p_{ent-anx} = 5.48 \cdot 10^{-5}$, $p_{ent-sam} = 1.02 \cdot 10^{-5}$, $p_{ent-oth} = 5.31 \cdot 10^{-7}$, $p_{rel-anx} = 5.97 \cdot 10^{-4}$, $p_{rel-sam} = 4.83 \cdot 10^{-6}$, $p_{rel-oth} = 3.22 \cdot 10^{-7}$, $p_{anx-sam} = 0.030$, $p_{anx-oth} = 3.57 \cdot 10^{-6}$, $p_{sam-oth} = 2.25 \cdot 10^{-6}$; where each sub index denotes "entrancement", "relief", "anxiety", "samsara" and "other", respectively; all comparisons significant according to Dunn-Sidak correction for multiple comparisons at family-wise error rate of 0.05). Note that while these axes were determined purely visually, and might thus reflect subjective biases, a Principal Component Analysis of the same data highlighted largely corresponding factors in a data-driven way (see Supp.Fig. S4).

To also quantify the occurrence of different emotional qualities in an easy-to-interpret way, we classified all 27 emotions as either positive (e.g. joy, amusement, relief), negative (e.g. fear, pain, disgust) or neutral (e.g. surprise, confusion); see *Methods - Analysis of phenomenological interviews* for the full list. Based on this simple classification, the majority of participants reported positive emotions more frequently than negative or neutral ones (Figs. 2E and F; Mann-Whitney U-test; $n = 18$; $p_{neg-neu} = 0.69$, $p_{neg-pos} = 1.57 \cdot 10^{-5}$, $p_{neu-pos} = 1.56 \cdot 10^{-3}$; where each sub index denotes "negative", "neutral" and "positive", respectively; difference between positive and negative/neutral frequency significant with Dunn-Sidak correction for multiple comparisons at family-wise error rate of 0.05). As a validation for this analysis, we also computed the ratio between the scores for the 'Positive Affect' and 'Negative Affect' sub-scales of the PCI (see Fig. 1), and correlated it with the ratio between 'positive' and 'negative' emotional qualities extracted from our NLP analysis. As Supp. Fig. S3B shows, there is a strong and statistically significant correlation between the positivity ratio we found using this NLP pipeline with the positivity ratio extracted from the post-session PCI ratings (Linear regression, $n = 18$, $R^2 = 0.32, p = 0.022$).

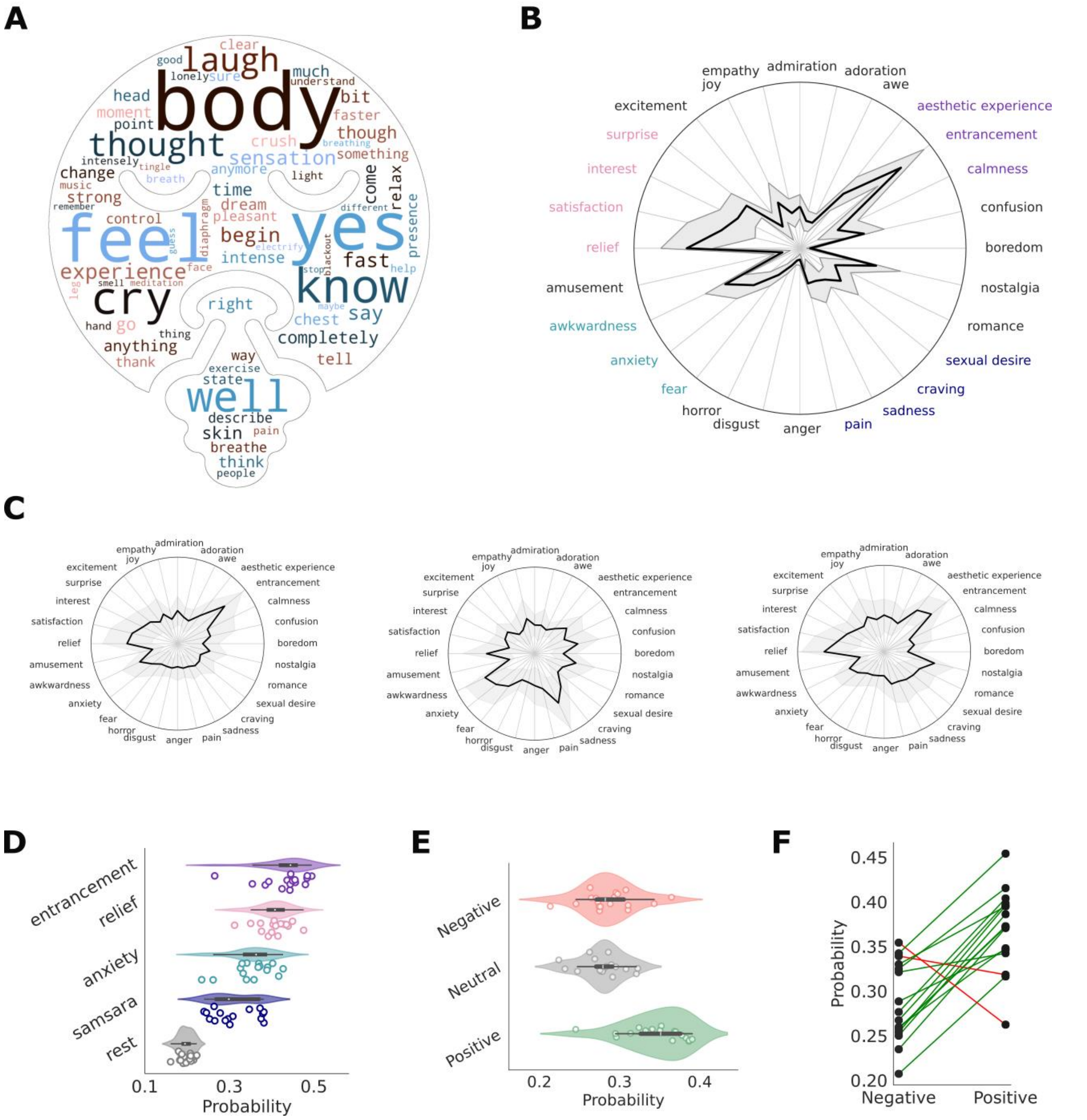

Figure 2: Emotional content of breathwork experiences. A) *Graphic representation of the most frequently occurring words across all 18 interviews, obtained through Natural Language Processing (NLP) analysis (see Methods).* **B)** *Probability of occurrence of 28 different emotional qualities across 18 participants. Black line: Average. Shaded area: Average ± SEM. Emotions are ordered according to their subjective proximity according to Cowen & Keltner (2017). Coloured emotion labels highlight clusters of emotional qualities that occur with high probability.* **C)** *Same as B for three example participants.* **D)** *Probability of occurrence of four 'emotion clusters' as highlighted in 2B. Shaded clouds: Probability distribution. Circles: Individual probabilities per subject. Thick black boxes: Percentiles 25 and 75; Black lines: percentiles 10 and 90.* **E)** *Same as D for emotions classified as 'positive', 'negative' and 'neutral' (see Methods).* **F)** *Probability of negative and positive emotions per subject. Green lines: Subjects that experience more positive than negative emotions; Red lines: Subjects that experience more negative than positive emotions.*

Next, to quantify physiological effects of CCB, we computed Heart Rate Variability (HRV) throughout the session, as well as before and after (see section 'Cardiac activity' of Methods for details). Figure 3A shows a representative example of HRV dynamics across a session. In this example, it seems apparent that while during the CCB session itself, HRV varies intensely, it settles on a somewhat higher baseline after the session than before. Both of these observations were supported across the population: On average, HRV was consistently lower pre-intervention than post-intervention (Fig. 3B; Mann-Whitney U-test; $n = 18$; $p = 2.4 \cdot 10^{-3}$), and HRV variability was higher during the CCB session than before or after (Fig. 3C; Mann-Whitney U-test; $n = 18$; $p_{pre-dur} = 0.018$, $p_{pre-post} = 0.72$, $p_{dur-post} = 0.03$; where each sub index denotes "pre", "during" and "post", respectively). This suggests that during the CCB session, participants experienced both sympathetic and parasympathetic activation in various constellations (leading to more variable HRV), whereas the sustained increase in HRV after the session suggests a more relaxed baseline state (see Discussion).

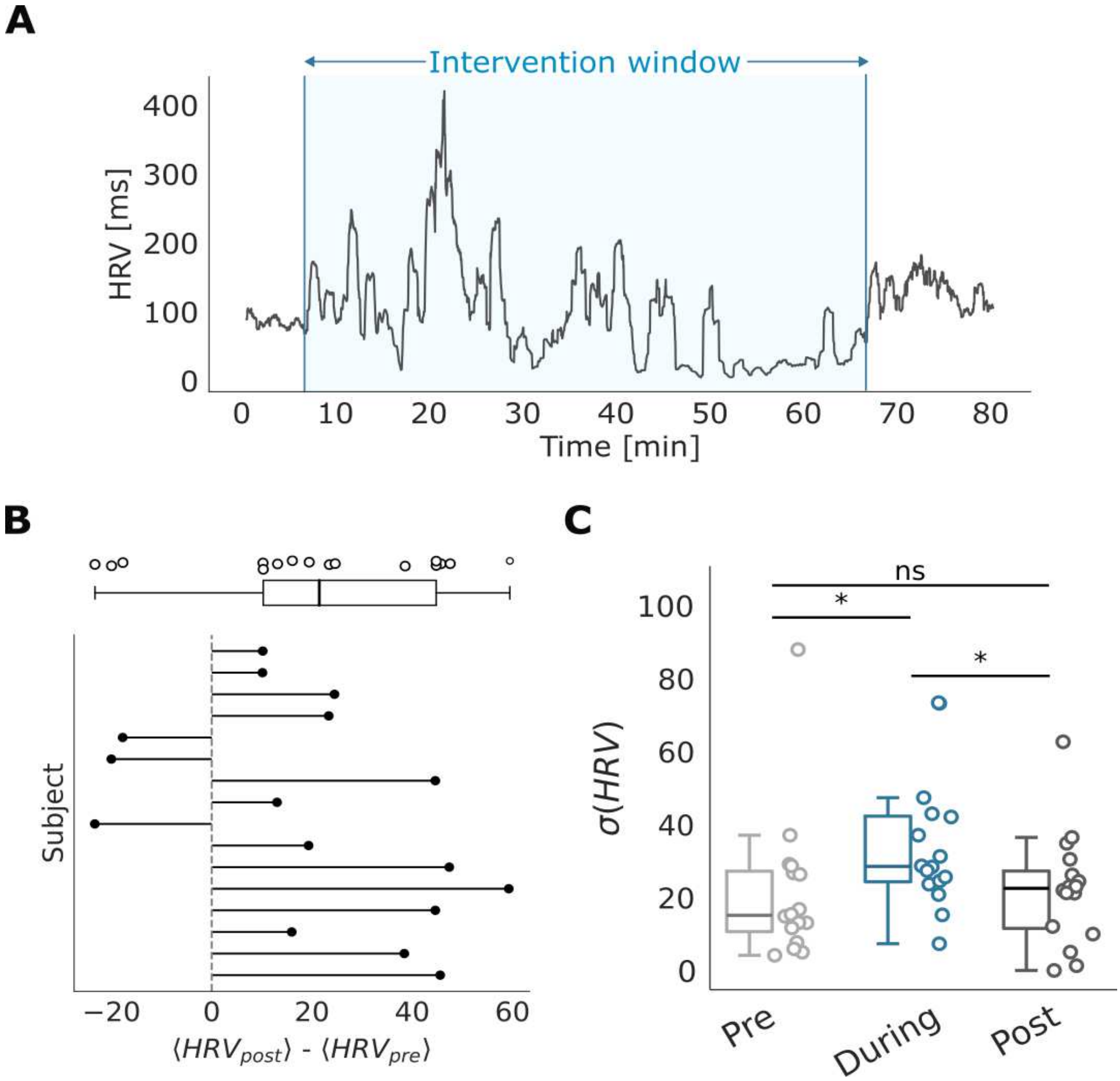

Figure 3: Effect of circular breathwork on heart-rate variability. A) *Example trace of heart-rate variability of one participant before, during and after the breathwork session. Blue shaded area indicates session duration.* **B)** *Difference between pre- and post-session HRV for all 18 participant. Open circles at top of graph and lollipops: Difference per subject. Box plot at top of graph: the box indicates percentiles 25 and 75, the whiskers are the 10 and 90 percentiles..* **C)** *Variability of HRV before, during and after the breathwork session. Boxes: same as in B. Open circles: Individual subjects. Stars indicate statistical significance of pair-wise differences as determined by t-tests. * p < 0.05. Peri-session scores differed significantly from pre- as well as post-session scores.*

Given the stark emotional and physiological dynamics triggered by CCB, as captured by the self-reports and HRV measurements presented so far, we wanted to establish if these effects were directly linked to each other. To this end, we explored to what extent the post-session increase in HRV was predicted by different aspects of the session. We first tested the hypothesis that the post-session increase in HRV was linked to the strong HRV variations during the session, which might provide some sort of 'work-out' or hormetic trigger to improve HRV long-term (see Discussion). However, HRV variations during the session did not significantly correlate with post-session changes in HRV (Fig. 4A; Linear regression, $n = 18$; p = 0,205, R^2 = 0,11). Next, we tested if HRV improvements post-session might be related to the experiential content of a session, specifically the overall intensity of altered consciousness, as well as the prevalence of positive and negative emotions (as quantified by the corresponding three sub-scales of the PCI self-reports). As shown in Figures 4B-D, there is a significant negative correlation between Altered Consciousness scores and HRV improvements (Linear regression, $n = 18$; p = 0,021, R^2 = 0,31), as well as between the amount of reported Positive Affect and HRV improvements (Linear regression, $n = 18$; p=0,026, R^2=0,32). In contrast, Negative Affect scores did not correlate significantly with HRV improvements (Linear regression, $n = 18$; p = 0,871, R^2 = 0,0). One potential interpretation of this finding would be that participants who entered a session in a more relaxed state would also be expected to show a higher pre-session HRV. This relaxed approach might in turn favour more positive emotional experiences during the session, while the high baseline HRV might also preclude significant improvements of HRV post-session due to ceiling effects. To test such a scenario, we correlated baseline HRV with the prevalence of positive emotions during the session. This correlation was not significant (see Supp. Fig. S5), indicating that the link between positive emotional contents and smaller improvements in HRV could not be explained by differences in baseline HRV. Together, these results hint at a scenario where post-session HRV is not shaped by HRV dynamics during the session, but instead by the subjective content of the breathwork experience, with the best HRV outcomes occurring when participants reported fewer positive emotions and less intense altered consciousness.

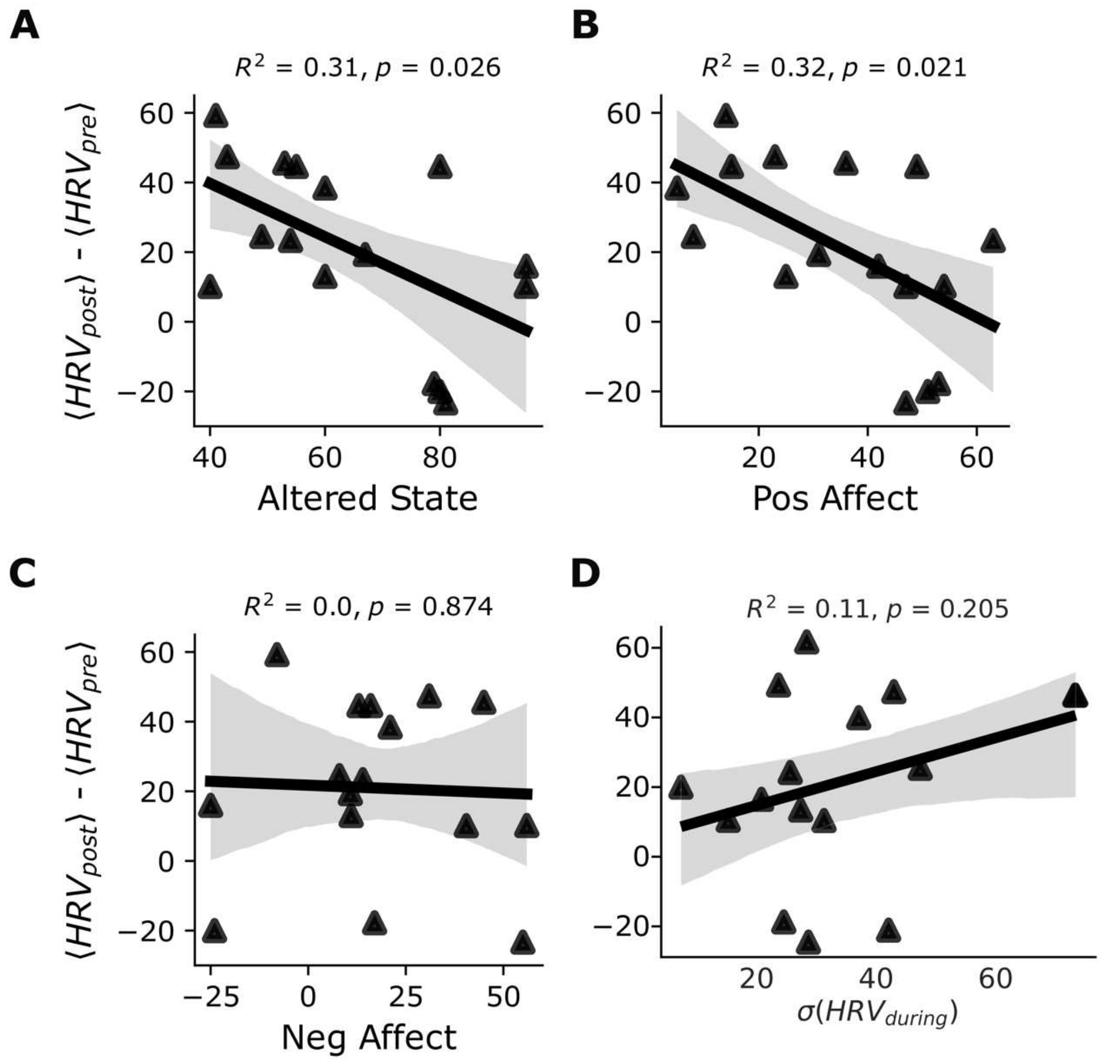

Figure 4: Emotional content of breathwork experience predicts heart-rate variability. A) *Correlation between scores on the 'Altered State' sub-scale of the PCI and the change of HRV from pre- to post-session. Triangles: individual participants. Black line: Regression line. Shaded area: 95% Confidence Interval.* **B)** *Same as A for relationship between 'Positive Affect' sub-scale scores and HRV change.* **C)** *Same as B for the 'Negative Affect' sub-scale. D) Same for the relation between variability of HRV during the session and HRV change from pre- to post-session.*

One potential trivial explanation of this outcome is that participants with a stronger baseline HRV before the session may also experience more positive sessions. At the same time, their high pre-session HRV precludes strong improvements post-session. To take this option into account we computed the correlation between pre-session HRV and the frequency at which participants expressed positive emotions according to our NLP analysis. The correlation was not significant (Supp. Fig. S5; Linear regression, $n = 18$; p = 0,455, R^2 = 0,04), indicating that positive breathwork experiences were not predicted by a high baseline HRV. Together, these results suggest a decisive role for the subjective experience of breathwork in shaping post-session outcomes.

Finally, we set out to investigate the role played by context, and specifically the emotionally evocative music played as part of a typical breathwork session, in producing - or at least enhancing - the psychological and physiological effects described above. To this end, we compared the two groups of participants that had experienced the breathwork session in the presence or absence of music, respectively ($n_{music} = 10, n_{nomusic} = 8$; see Methods). In terms of PCI scores, music and no-music condition were statistically indistinguishable across all sub-scales (Fig. 5A; t-tests for independent samples across 13 sub-scales; n = 18; t = 0.1 to 2.8 across 13 sub-scales; p = 0.01 to 0.93; none of the sub-scales statistically significant according to Dunn-Sidak correction for multiple comparisons, conservatively assuming 13 fully independent comparisons at a family-wise error rate of 0.05). Similarly, we found no significant differences in the NLP analyses for both experimental conditions, with highly similar probabilities for individual emotional qualities (Fig. 5B; 2-way ANOVA with predictors 'emotional quality' and 'music'; n = 18 participants x 28 emotion frequencies = 504 probability scores; $F_{emotion} = 41.11, p_{emotion} = 1.67 \cdot 10^{-103}$; $F_{music} = 2.15, p_{music} = 0.14$; $F_{emotionxmusic} = 0.35, p_{emotionxmusic} = 0.99$), as well as highly similar distributions of positive, negative and neutral distributions (Figs. 5C-D; 2-way ANOVA with predictors 'emotional valence' and 'music'; n = 18 participants x 3 emotional valences = 54 probability scores; $F_{emotion} = 33.43, p_{emotion} = 2.37 \cdot 10^{-14}$; $F_{music} = 0.77, p_{music} = 0.38$; $F_{emotionxmusic} = 0.21, p_{emotionxmusic} = 0.81$). This observation is also supported by the fact that music appeared very rarely in the word clouds of dominant phrases generated by our NLP analysis of participants' experiential reports (see Supp. Fig. S2), again suggesting that music did not play a dominant role in participants' experiences. Finally, music also did not significantly impact post-session changes in participants' HRV compared to baseline (Fig. 5E; Mann-Whitney-U-Test; $n = 18; p = 1.0$). Together, these results indicate that music did not significantly affect the subjective breathwork experiences measured in this study

Even if music did not seem to strongly shape the contents of an individual breathwork experience, it may still help to homogenize them across participants, e.g. by favouring different levels of activation or different emotional qualities in different phases of the session. To test this idea, we first explored if the HRV traces of participants in the 'music' condition were more comparable to each other, which might indicate e.g. that they had experienced similar phases of activation and relaxation, as suggested by the music. Specifically, we computed Aligned Pearson Correlations (see Methods) between the HRV traces between pairs of participants in the music condition, in the no-music condition, and across conditions, respectively. As shown in Figure 5F, the HRV traces of participants in the music condition were not more strongly aligned with each other than in the no-music condition or across conditions (Mann-Whitney U-test, $n_{music} = 10$, $n_{nomusic} = 8$; ; $p_{12} = 0.56$, $p_{13} = 0.13$, $p_{23} = 0.32$; where each sub index denotes "music-music", "music-no music" and "no music-no music", respectively). Finally, to also explore whether music aligned the emotional qualities experienced by participants, we computed the variance of probabilities for each of the 28 emotional qualities per subject. We found that emotional probabilities varied significantly less in the music condition (Mann Whitney U-test, $n = 18$; ; $p = 0.038$). This suggests that while different participants may have experienced different emotional qualities, they did so more consistently throughout the session when music was present.

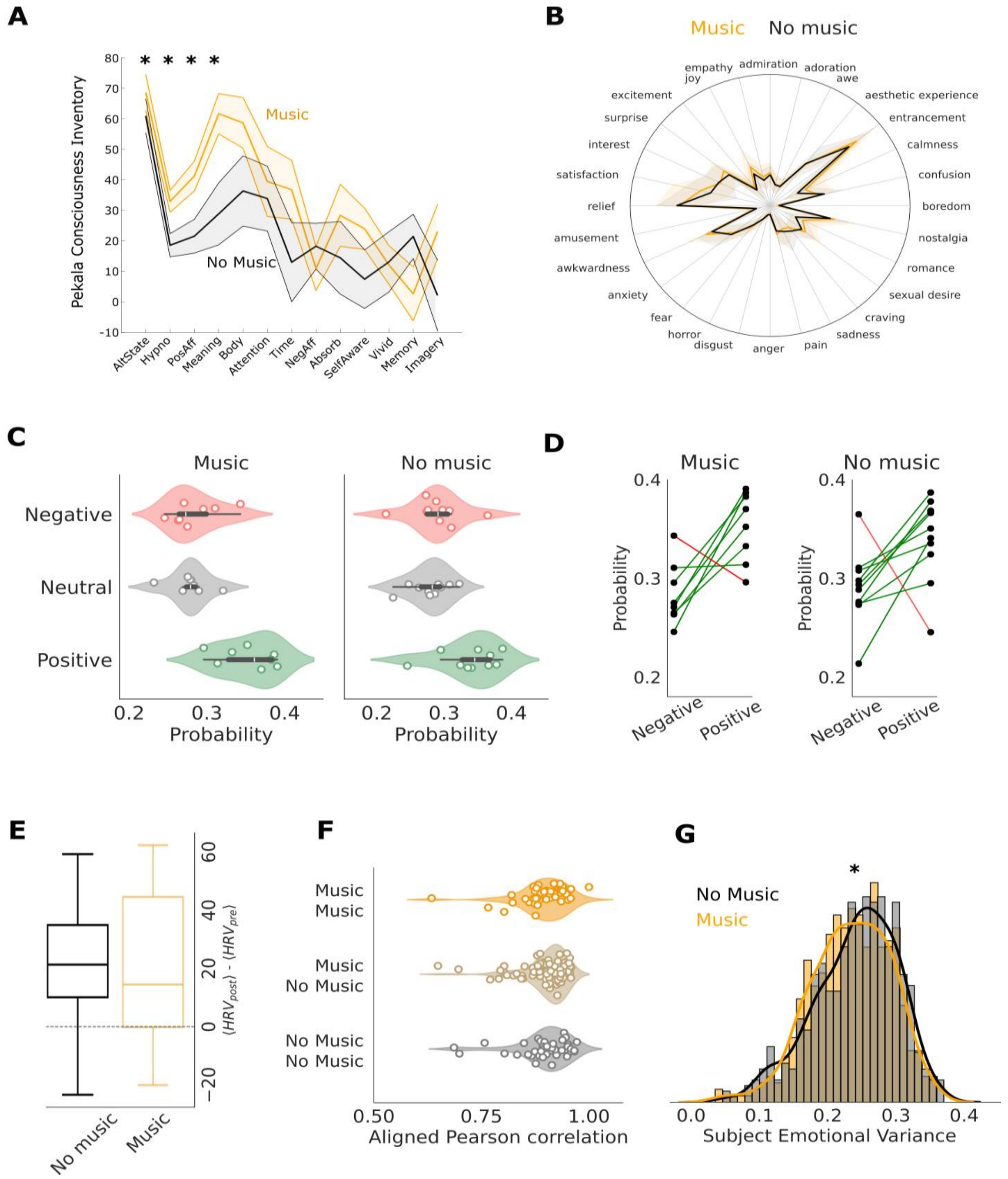

Figure 5: Music does not affect content of breathwork experience. A) *Same as Fig. 1B, split by Music (yellow) and No-Music (grey) condition. After correction for multiple comparisons, there were no significant differences in any of the sub-scales.* **B)** *Same as Fig. 2B, for probabilities split by music / no-music sessions. No significant differences were detected across any of the emotional qualities.* **C)** *Same as Fig. 2E, split by music / no-music sessions, showing no significant differences in distribution.* **D)** *Same as Fig. 2F, split by Music / No-Music condition, and showing no significant music-dependent differences..* **E)** *Distribution of differences between pre- and post-session HRV, for Music and No-Music session, showing no significant music-dependent differences.* **F)** *Pair-wise Aligned Pearson Correlations (see Methods) of HRV traces from subjects from the music condition (top), the no music condition (bottom) and across conditions (middle). Open circles: Individual pairs of subjects. Shaded area: overall distribution.* **G)** *Distributions of variances in the probability of emotional qualities (per subject and sentence) for the Music (yellow) and No-Music (grey) condition. Star indicates statistically significant difference between the two distributions.*

Discussion

In this study, we have explored the subjective and physiological effects of high ventilation breathwork, specifically Conscious-Connected breathwork (CCB). According to self-report scores from the Phenomenology of Consciousness Inventory (PCI) [50,56], participants consistently experienced non-ordinary states of consciousness (NOSCs), which significantly deviated from normal waking consciousness. The emotional content of these experiences, inferred using natural-language-processing (NLP) analysis of free-form experiential reports, was dominated by positive emotions, and also included experiences of embodiment. At the same time, heart rate variability (HRV) fluctuated more widely during the breathwork session and improved in its wake. Interestingly, post-session improvements in HRV were better predicted by the experiential content of the session than by HRV dynamics during the session, hinting at an intriguing interaction between emotional experience and physiological change. Finally, none of these effects was significantly impacted by the presence or absence of music during the session. Music appeared to neither alter nor heighten the range of emotions that was experienced. Instead, it mainly stabilized emotional experiences somewhat, such that participants reported a more consistent set of emotions throughout their session.

Phenomenology of Consciousness Inventory

According to anecdotal reports, breathwork has long been thought to evoke significantly altered states of consciousness. This notion is supported by the PCI scores reported here: Pre- and post-session scores differed significantly, and the strongest differences occurred on the sub-scales related to general state of consciousness (e.g. Altered Consciousness and Hypnosis), with additional strong increases in Positive Affect and Meaning, as well as Embodiment and Inward Attention. Importantly, Memory was one of the few sub-scales that was not significantly affected, consistent with the notion that participants were able to recount their experiences post-session.

While the PCI is not as extensively used as a metric of altered consciousness as other questionnaires, recent breathwork studies employing more common scales such as the 11-dimensional altered states of consciousness scale (11-DASC) or the mystical experiences questionnaire (MEQ) have reported similar results [22,23,25](but see [65]).

Natural Language Processing

To explore the experiential contents of breathwork sessions beyond the themes covered by pre-existing questionnaires, we collected free-form reports of participants' experiences and subjected them to Natural Language Processing (NLP) to extract the emotional qualities of the experience. The development of such AI-based analysis tools for unconstrained speech opens new avenues in how to tackle long-standing research questions, particularly when it comes to the study of subjective experiences. Traditional methods, such as structured questionnaires and scales, while useful, often constrain the range of responses to expected patterns. In contrast, AI-based tools, particularly those leveraging NLP and machine learning, allow for the analysis of free-form verbal reports, enabling participants to express their experiences in their own words without limitations imposed by predefined categories. This facilitates the capture of a wider spectrum of experiences, uncovering insights that might be overlooked in more rigid data collection methods. This is particularly relevant in the context of breathwork studies, where participants often report complex and highly individualized experiences that may not fit neatly into traditional psychometric scales.

In this study, our NLP analyses allowed us to systematically identify patterns, themes, and emotions that emerge from participants' breathwork narratives. This allowed us to first identify the most common emotional qualities encountered during breathwork experiences. The emotions identified most frequently in this way reflect the wide range of experiences that can be evoked by breathwork, covering qualities from entrancement, relief and satisfaction to anxiety, pain, sadness and desire, with a tendency for emotions linked to positive affect to occur more frequently than emotions linked with neutral or negative affect.

Our subsequent quantitative analyses of emotional content mainly focused on comparing positive and negative affect to validate our analyses in relation to more established approaches (see Supp. Fig. S3B). However, our qualitative NLP analyses suggest that there are several interesting experiential qualities to explore further in future studies. Most importantly, the overall word cloud pooled across participants (see Fig. 2A) as well as individual word clouds (see Supp. Fig. S2) suggest a central role for interoception in breathwork experiences: Descriptions are often dominated by words reflecting embodied emotional experiences (e.g. 'laugh' 'feel' and 'cry') as well as references to the body in general and to specific body parts (e.g. 'skin', 'diaphragm' and 'teeth') and to physical sensations (e.g. 'fever', 'weight' and 'hunger'). This suggests that one of the main therapeutic mechanisms of breathwork may be to enhance practitioner's ability to register their own physical sensations (and related emotional dynamics). Interoception has previously been shown to be a catalyst for improved emotional processing and mental health, as well as social cognition and empathy[66–71]. Related to this, avoidance of unpleasant sensations and emotions has been linked to worse mental health, diminished mental resources, increased stress and failure to recover e.g. from unpleasant or traumatic experiences [36–41,72–74]. In this context, breathwork can be seen as an access point to therapeutic mechanisms of catharsis, i.e. the conscious experience of feared, avoided or suppressed emotions and sensations in a safe setting, which results in feelings of relief and increased processing capacity [21,34,75]. Consistently with this notion, our study highlighted that a broader emotional experience that extended beyond purely positive emotions led to better outcomes in terms of post-session HRV (see Fig. 4).

Note that the potentially central function of increased interoception in breathwork would be extremely difficult to identify based on standard questionnaires of NOSCs such as the 11-DASC, MEQ or indeed the PCI applied here. This discrepancy between freely reported experiences and the themes addressed by typical inventories of psychedelic (or hypnotic) experiences suggests that unlike other aspects such as ego dissolution [22,23,25], which seem to be largely shared across many different NOSCs, interoception may play a more unique role in breathwork that does not translate equally to other NOSCs.

Beyond the immediate findings of this study, the ability to harness AI-based tools to analyse qualitative data will likely become increasingly important as the field of psychophysiology continues to evolve. These tools not only enhance the granularity but also the scalability of research, allowing for the handling of larger datasets and more complex relationships between variables. For instance, NLP tools have already been successfully applied to understand the relationship between psychedelic experiences and underlying chemical compounds - an achievement that would have been out of reach without automated analysis of free-form verbal [76].

Such analyses rely on extensive and freely available databases of free-form descriptions of psychedelic experiences (e.g. erowid.org; see also [77]). Generating similar databases for breathwork and other non-pharmacological NOSC experiences would benefit breathwork practice and research immensely, because such reports are one of the keys unlocking the massive potential of AI-based analyses. These research methodologies, in turn, support a more participant-centred approach, recognizing the diversity of individual experiences and enabling these to be more fully captured and understood. This shift towards richer, more individualized data analysis is essential for advancing our understanding of complex interventions like CCB and other mind-body practices, ultimately leading to more personalized and effective therapeutic applications.

Heart-rate variability

Heart rate variability (HRV), representing fluctuations in the time interval between successive heartbeats, is a central summary metric of overall well-being in psychophysiological research. Specifically, HRV appears to reflect effective engagement of the parasympathetic nervous system [78–80] (see also [81]), and has been shown to be modulated by respiratory rhythm [82]. In this context, our findings would suggest that during the breathwork session itself, participants fluctuate more intensely than usually between sympathetic and parasympathetic activity (see Fig. 3), with an overall emphasis on sympathetic drive. In contrast, after the session parasympathetic tone increases significantly, comparable to the improvements achieved with relaxation practices [83].

The decrease in HRV due to the high respiratory rate during the session can be regarded as an action-driven activation of the sympathetic system. A decrease in HRV can been seen as adaptive when facing a physical or mental challenge that does not involve complex executive function, providing the physical activation and resources to face the stressor at hand [54,84–87]. Such voluntary sympathetic activation has also been shown to improve the effectiveness of immune responses [20,27,88] and could be seen as a form of 'preconditioning' of the nervous system by introducing voluntary 'practice' stressors within a safe environment. The notion that physical and mental resilience can be boosted through exposure to stressful-but-manageable stimuli is also supported by the concept of 'hormesis', which has been applied to practices ranging from fasting and heat/cold exposure to post-traumatic growth [31–33,89–91].

Flexible and adaptive integration of sympathetic and parasympathetic signalling has been highlighted as a crucial element in the effective regulation of psychological processes, as well as the physiological dynamics they are linked to – including adaptive cardiac activity, inflammatory signalling and many more [20,27,45,88,92]. As such, one way in which high ventilation breathwork may improve well-being is by increasing the flexibility of the autonomic nervous system, which in turn boosts emotional and cognitive self-regulation [81,93–95].

While these interpretations open up intriguing directions for future research, one should note that, rather than being a direct measure of autonomic nervous system activity, HRV quantifies the organ's response to autonomic signalling, i.e. cardiac rhythm. Cardiac rhythm is under the dual control of direct sympathetic and parasympathetic innervation at the sinoatrial, but is also influenced by sympathetic-adrenal activation and other influences not attributable to the autonomic nervous system, such as mechanical/hemodynamic influences and local reflexes [96,97](a more detailed discussion of the complexity of factors influencing HRV can be found in [44,98]). In future studies, complementing HRV measurements with other, and potentially more direct, markers of autonomic nervous system signalling, such as concentrations of Alpha-amylase and other messenger molecules [99–104] (see also [81]) would provide a more complete picture of the dynamics involved in modulating HRV during and after breathwork.

Linking HRV and subjective experience

When exploring the relationship between HRV dynamics and subjective experiences, we found two potentially surprising results: First, physiological arousal before the session (with HRV as a proxy measure) does not appear to impact the subjective content of the breathwork experience (see Supp. Fig. S5). This also implies that e.g. feelings of stress at the start of the session do not seem to significantly translate into the emotional quality of the session itself. In contrast, the experiential content of the breathwork session did significantly predict HRV changes post-session, and in a potentially counter-intuitive way: The more positive and immersive the experience, the less post-session improvement in HRV. Note that while this relationship may reflect the physiological benefits of the session, it may not hold in the same way for potential psychological benefits: Psychological well-being following consciousness-altering interventions such as breathwork and psychedelics has generally been found to improve more steeply when participants reported deeper and more positive subjective experiences [23,35,105–108].

Why might more emotionally positive breathwork experiences translate to smaller post-session improvements in HRV? As mentioned in the introduction, there are currently several complementary hypotheses on the mechanisms of breathwork that have not yet been experimentally tested. The results of this study add some initial evidence that benefits of breathwork are more likely to be mediated by processes of catharsis than hormesis: Breathwork provided a potentially hormetic stimulus in terms of HRV, triggering stark HRV fluctuations throughout the session, but the size of these fluctuations did not actually predict post-session improvement in HRV, as would have been expected based on the principle of hormesis. In contrast, the fact that the HRV benefit of a CCB session increases when it is experienced as less serene and light-hearted is largely in line with the notion of catharsis, even though the lacking relationship between negative emotional content and HRV improvement does not fully support this idea either.

One other potential explanation that can be derived from the present results is the principle of ‘embodiment’, i.e. the conscious perception - and potential modulation - of one’s own physiological processes. Better body awareness has been shown to be highly beneficial for both physical and mental health [69,70,109–112], and as discussed above, phrases describing physical processes occur frequently across participants. In this context, one might hypothesize that more ‘blissful’ or ‘transcendental’ breathwork journeys may contain fewer experiential elements of embodiment.

Most importantly, regardless of the exact mechanism linking subjective experience and physiological dynamics, our findings add to a growing body of evidence suggesting that the experiential content of NOSCs is an important and meaningful mechanism of long-term change [35,106–108], and as such, both the impact of subjective experiences in treatments features NOSCs, and the context factors that may support helpful subjective experiences, call for further study.

Music

While music somewhat stabilized subjective experiences in the sense that participants in the no-music condition seem to have experienced more variable feelings throughout the session, it did not seem to significantly alter or heighten the core experiences induced by breathwork. This is a rather unexpected result, considering the effect that the type of songs used could have on subjective experience [113], and that music listening in general could have on cardiac activity [114]. In interpreting these results, one should keep in mind that in this study we tested just one specific breathwork setting, and one specific selection of music pieces. Other breathwork settings, such as group sessions, other breathing techniques, and other music selections, may yield different results. Nevertheless, our findings support the general notion that the most crucial driver of breathwork experiences is indeed the breathing, rather than context elements such as the musical accompaniment tested here (for similar findings regarding the contribution of context to breathwork experiences, see also [23]).

Data Availability

Data and analysis scripts are freely available under https://github.com/atlaie/Breathwork . All free—form experiential reports are available in Supplemental Materials.

References

1. Zaccaro, A. *et al.* How Breath-Control Can Change Your Life: A Systematic Review on Psycho-Physiological Correlates of Slow Breathing. *Front. Hum. Neurosci.* **12**, 353 (2018).
2. Jerath, R., Edry, J. W., Barnes, V. A. & Jerath, V. Physiology of long pranayamic breathing: Neural respiratory elements may provide a mechanism that explains how slow deep breathing shifts the autonomic nervous system. *Medical Hypotheses* **67**, 566–571 (2006).
3. Sevoz-Couche, C. & Laborde, S. Heart rate variability and slow-paced breathing:when coherence meets resonance. *Neuroscience & Biobehavioral Reviews* **135**, 104576 (2022).
4. Bordoni, B., Marelli, F. & Bordoni, G. A review of analgesic and emotive breathing: a multidisciplinary approach. *JMDH* **9**, 97–102 (2016).
5. Homma, I. & Masaoka, Y. Breathing rhythms and emotions. *Experimental Physiology* **93**, 1011–1021 (2008).
6. Fokkema, D. S. The psychobiology of strained breathing and its cardiovascular implications: A functional system review. *Psychophysiology* **36**, 164–175 (1999).
7. Brown, E. B. Physiological Effects of Hyperventilation. *Physiological Reviews* **33**, 445–471 (1953).
8. Indranada, A. M., Mullen, S. A., Duncan, R., Berlowitz, D. J. & Kanaan, R. A. A. The association of panic and hyperventilation with psychogenic non-epileptic seizures: A systematic review and meta-analysis. *Seizure - European Journal of Epilepsy* **59**, 108–115 (2018).
9. Rana, M., Steenari, M. & Shrey, D. Hyperventilation and Seizures: Not a New Sense: A Literature Review. *Neuropediatrics* **54**, 359–364 (2023).
10. Brashear, R. E. Hyperventilation syndrome. *Lung* **161**, 257–273 (1983).
11. Du Pasquier, D., Fellrath, J.-M. & Sauty, A. [Hyperventilation syndrome and dysfunctional breathing : update]. *Rev Med Suisse* **16**, 1243–1249 (2020).
12. Tavel, M. E. Hyperventilation Syndrome: Why Is It Regularly Overlooked? *The American Journal of Medicine* **134**, 13–15 (2021).
13. Fincham, G. W. *et al. High Ventilation Breathwork Practices: An Overview of Their Effects, Mechanisms, and Considerations for Clinical Applications*. https://osf.io/z62fv (2023) doi:10.31234/osf.io/z62fv.
14. Eyerman, J. E. A Clinical Report of Holotropic Breathwork in 11,000 Psychiatric Inpatients in a Community Hospital Setting.
15. Metcalf, B. A. Examining the Effects of Holotropic B...
16. Meuret, A. E., Ritz, T., Wilhelm, F. H. & Roth, W. T. Voluntary hyperventilation in the treatment of panic disorder—functions of hyperventilation, their implications for breathing training, and recommendations for standardization. *Clinical Psychology Review* **25**, 285–306 (2005).
17. Pompoli, A. *et al.* Dismantling cognitive-behaviour therapy for panic disorder: a systematic review and component network meta-analysis. *Psychological Medicine* **48**, 1945–1953 (2018).
18. Fincham, G. W., Strauss, C., Montero-Marin, J. & Cavanagh, K. Effect of breathwork on stress and mental health: A meta-analysis of randomised-controlled trials. *Sci Rep* **13**, 432 (2023).
19. Turner, R., Wooten, H. R. & Chou, W.-M. Changing Suicide Bereavement Narrative Through Integral Breath Therapy. *Journal of Creativity in Mental Health* **14**, 424–435 (2019).
20. Zwaag, J., Naaktgeboren, R., van Herwaarden, A. E., Pickkers, P. & Kox, M. The Effects of Cold Exposure Training and a Breathing Exercise on the Inflammatory Response in Humans: A Pilot Study. *Psychosom Med* **84**, 457–467 (2022).
21. Lalande, L., Bambling, M., King, R. & Lowe, R. Breathwork: An Additional Treatment Option for Depression and Anxiety? *J Contemp Psychother* **42**, 113–119 (2012).
22. Bahi, C. *et al.* Effects of conscious connected breathing on cortical brain activity, mood and state of consciousness in healthy adults. *Curr Psychol* **43**, 10578–10589 (2024).
23. Havenith, M. *et al.* Decreased CO2 saturation during circular breathwork supports emergence of altered states of consciousness. Preprint at https://doi.org/10.21203/rs.3.rs-3976380/v1 (2024).
24. Holmes, S. W., Morris, R., Clance, P. R. & Putney, R. T. Holotropic breathwork: An experiential approach to psychotherapy. *Psychotherapy: Theory, Research, Practice, Training* **33**, 114–120 (1996).
25. Lewis-Healey, E., Tagliazucchi, E., Canales-Johnson, A. & Bekinschtein, T. A. Breathwork-induced psychedelic experiences modulate neural dynamics. *Cerebral Cortex* **34**, bhae347 (2024).
26. Staubli, M., Stauble, U. P., Waber, U. & Straub, P. W. Hyperventilation-induced changes of the blood picture. *Journal of Applied Physiology* **58**, 1170–1175 (1985).
27. Kox, M. *et al.* Voluntary activation of the sympathetic nervous system and attenuation of the innate immune response in humans. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 7379–7384 (2014).

28. Kety, S. S. & Schmidt, C. F. THE EFFECTS OF ACTIVE AND PASSIVE HYPERVENTILATION ON CEREBRAL BLOOD FLOW, CEREBRAL OXYGEN CONSUMPTION, CARDIAC OUTPUT, AND BLOOD PRESSURE OF NORMAL YOUNG MEN 1. *J. Clin. Invest.* **25**, 107–119 (1946).
29. Godoy, D. A., Seifi, A., Garza, D., Lubillo-Montenegro, S. & Murillo-Cabezas, F. Hyperventilation Therapy for Control of Posttraumatic Intracranial Hypertension. *Front. Neurol.* **8**, (2017).
30. Bednarczyk, E. M. *et al.* Hyperventilation-Induced Reduction in Cerebral Blood Flow: Assessment by Positron Emission Tomography. *DICP* **24**, 456–460 (1990).
31. Calabrese, E. J. Hormesis: a fundamental concept in biology. *Microbial Cell* **1**, 145–149 (2014).
32. Longo, V. D. & Mattson, M. P. Fasting: Molecular Mechanisms and Clinical Applications. *Cell Metabolism* **19**, 181–192 (2014).
33. Radak, Z. & Taylor, A. W. Chapter 5 - Exercise and Hormesis. in *The Science of Hormesis in Health and Longevity* (eds. Rattan, S. I. S. & Kyriazis, M.) 63–73 (Academic Press, 2019). doi:10.1016/B978-0-12-814253-0.00005-X.
34. Rhinewine, J. P. & Williams, O. J. Holotropic Breathwork: The Potential Role of a Prolonged, Voluntary Hyperventilation Procedure as an Adjunct to Psychotherapy. *The Journal of Alternative and Complementary Medicine* **13**, 771–776 (2007).
35. Walther, R. F. E. & van Schie, H. T. 'Mind-Revealing' Psychedelic States: Psychological Processes in Subjective Experiences That Drive Positive Change. *Psychoactives* **3**, 411–436 (2024).
36. Kashdan, T. B., Barrios, V., Forsyth, J. P. & Steger, M. F. Experiential avoidance as a generalized psychological vulnerability: Comparisons with coping and emotion regulation strategies. *Behaviour Research and Therapy* **44**, 1301–1320 (2006).
37. Chawla, N. & Ostafin, B. Experiential avoidance as a functional dimensional approach to psychopathology: An empirical review. *Journal of Clinical Psychology* **63**, 871–890 (2007).
38. Tull, M. T. & Gratz, K. L. Further examination of the relationship between anxiety sensitivity and depression: The mediating role of experiential avoidance and difficulties engaging in goal-directed behavior when distressed. *Journal of Anxiety Disorders* **22**, 199–210 (2008).
39. Kumpula, M. J., Orcutt, H. K., Bardeen, J. R. & Varkovitzky, R. L. Peritraumatic dissociation and experiential avoidance as prospective predictors of posttraumatic stress symptoms. *Journal of Abnormal Psychology* **120**, 617–627 (2011).
40. Machell, K. A., Goodman, F. R. & Kashdan, T. B. Experiential avoidance and well-being: A daily diary analysis. *Cognition and Emotion* **29**, 351–359 (2015).
41. Gross, J. J. Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology* **39**, 281–291 (2002).
42. Akselrod, S. *et al.* Power Spectrum Analysis of Heart Rate Fluctuation: A Quantitative Probe of Beat-to-Beat Cardiovascular Control. *Science* **213**, 220–222 (1981).
43. Pagani, M. *et al.* Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circulation Research* **59**, 178–193 (1986).
44. Ernst, G. Heart-Rate Variability—More than Heart Beats? *Front. Public Health* **5**, (2017).
45. Thayer, J. F. & Lane, R. D. A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders* **61**, 201–216 (2000).
46. Visted, E. *et al.* The Association between Self-Reported Difficulties in Emotion Regulation and Heart Rate Variability: The Salient Role of Not Accepting Negative Emotions. *Front. Psychol.* **8**, (2017).
47. Sullivan, G. M. *et al.* Effects of hyperventilation on heart rate and QT variability in panic disorder pre- and post-treatment. *Psychiatry Research* **125**, 29–39 (2004).
48. Terathongkum, S. & Pickler, R. H. Relationships among heart rate variability, hypertension, and relaxation techniques. *Journal of Vascular Nursing* **22**, 78–82 (2004).
49. Pekala, R. J. & Kumar, V. K. The Differential Organization of the Structures of Consciousness during Hypnosis and a Baseline Condition. *The Journal of Mind and Behavior* **7**, 515–539 (1986).
50. Pekala, R. J. The Phenomenology of Consciousness Inventory. in *Quantifying Consciousness: An Empirical Approach* (ed. Pekala, R. J.) 127–143 (Springer US, Boston, MA, 1991). doi:10.1007/978-1-4899-0629-8_8.
51. Grof, S. & Grof, C. *Holotropic Breathwork, Second Edition: A New Approach to Self-Exploration and Therapy*. (SUNY Press, Albany, 2023).
52. Giles, D., Draper, N. & Neil, W. Validity of the Polar V800 heart rate monitor to measure RR intervals at rest. *Eur J Appl Physiol* **116**, 563–571 (2016).
53. Beda, A., Simpson, D. M., Carvalho, N. C. & Carvalho, A. R. S. Low-frequency heart rate variability is related to the breath-to-breath variability in the respiratory pattern. *Psychophysiology* **51**, 197–205 (2014).

54. Laborde, S., Mosley, E. & Thayer, J. F. Heart Rate Variability and Cardiac Vagal Tone in Psychophysiological Research – Recommendations for Experiment Planning, Data Analysis, and Data Reporting. *Front. Psychol.* **8**, (2017).
55. Shaffer, F. & Ginsberg, J. P. An Overview of Heart Rate Variability Metrics and Norms. *Front Public Health* **5**, 258 (2017).
56. Pekala, R. J. & Kumar, V. K. Operationalizing "Trance" I: Rationale and Research Using a Psychophenomenological Approach. *American Journal of Clinical Hypnosis* **43**, 107–135 (2000).
57. Petitmengin, C. Describing one's subjective experience in the second person: An interview method for the science of consciousness. *Phenom Cogn Sci* **5**, 229–269 (2006).
58. Gallagher, S. Phenomenology and Experimental Design: Toward a Phenomenologically Enlightened Experimental Science. *Journal of Consciousness Studies* **10**, 85–99 (2003).
59. Lutz, A. & Thompson, E. Neurophenomenology: Integrating Subjective Experience and Brain Dynamics in the Neuroscience of Consciousness. *Journal of Consciousness Studies* **10**, 31–52 (2003).
60. Depraz, N. & Desmidt, T. Cardiophenomenology: a refinement of neurophenomenology. *Phenom Cogn Sci* **18**, 493–507 (2019).
61. Depraz, N., Gyemant, M. & Desmidt, T. A First-Person Analysis Using Third-Person Data as a Generative Method: A Case Study of Surprise in Depression. *Constructivist Foundations* **12**, 190–203 (2017).
62. Cowen, A. S. & Keltner, D. Self-report captures 27 distinct categories of emotion bridged by continuous gradients. *Proceedings of the National Academy of Sciences* **114**, E7900–E7909 (2017).
63. Lewis, M. *et al.* BART: Denoising Sequence-to-Sequence Pre-training for Natural Language Generation, Translation, and Comprehension. in *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics* (eds. Jurafsky, D., Chai, J., Schluter, N. & Tetreault, J.) 7871–7880 (Association for Computational Linguistics, Online, 2020). doi:10.18653/v1/2020.acl-main.703.
64. Brown, T. B. *et al.* Language Models are Few-Shot Learners. Preprint at https://doi.org/10.48550/arXiv.2005.14165 (2020).
65. Uthaug, M. V., Mason, N. L., Havenith, M. N., Vancura, M. & Ramaekers, J. G. An experience with Holotropic Breathwork is associated with improvement in non-judgement and satisfaction with life while reducing symptoms of stress in a Czech-speaking population. *Journal of Psychedelic Studies* **5**, 176–189 (2021).
66. Kirk, U., Downar, J. & Montague, P. R. Interoception Drives Increased Rational Decision-Making in Meditators Playing the Ultimatum Game. *Front. Neurosci.* **5**, (2011).
67. Payne, P., Levine, P. A. & Crane-Godreau, M. A. Somatic experiencing: using interoception and proprioception as core elements of trauma therapy. *Frontiers in Psychology* **6**, (2015).
68. Dunn, B. D. *et al.* Listening to Your Heart: How Interoception Shapes Emotion Experience and Intuitive Decision Making. *Psychol Sci* **21**, 1835–1844 (2010).
69. Critchley, H. D. & Garfinkel, S. N. Interoception and emotion. *Current Opinion in Psychology* **17**, 7–14 (2017).
70. Hanley, A. W., Mehling, W. E. & Garland, E. L. Holding the body in mind: Interoceptive awareness, dispositional mindfulness and psychological well-being. *Journal of Psychosomatic Research* **99**, 13–20 (2017).
71. Tsakiris, M. & Critchley, H. Interoception beyond homeostasis: affect, cognition and mental health. *Philosophical Transactions of the Royal Society B: Biological Sciences* **371**, 20160002 (2016).
72. Purdon, C. Thought suppression and psychopathology. *Behaviour Research and Therapy* **37**, 1029–1054 (1999).
73. Campbell-Sills, L., Barlow, D. H., Brown, T. A. & Hofmann, S. G. Acceptability and suppression of negative emotion in anxiety and mood disorders. *Emotion* **6**, 587–595 (2006).
74. Henschel, A. V., Williams, J. L. & Hardt, M. M. The Role of Experiential Avoidance and Emotion Regulation in DSM-5 Posttraumatic Stress Symptomatology. *Journal of Loss and Trauma* **26**, 527–539 (2021).
75. Straton, D. Catharsis Reconsidered. *Aust N Z J Psychiatry* **24**, 543–551 (1990).
76. Ballentine, G., Friedman, S. F. & Bzdok, D. *Trips and Neurotransmitters: Discovering Principled Patterns across 6,850 Hallucinogenic Experiences*. http://biorxiv.org/lookup/doi/10.1101/2021.07.13.452263 (2021) doi:10.1101/2021.07.13.452263.
77. Prugger, J., Derdiyok, E., Dinkelacker, J., Costines, C. & Schmidt, T. T. The Altered States Database: Psychometric data from a systematic literature review. *Sci Data* **9**, 720 (2022).
78. Malik, M. & Camm, A. J. Components of heart rate variability — what they really mean and what we really measure. *American Journal of Cardiology* **72**, 821–822 (1993).
79. Chapleau, M. W. & Sabharwal, R. Methods of assessing vagus nerve activity and reflexes. *Heart Fail Rev* **16**, 109–127 (2011).
80. Brodal, P. *The Central Nervous System*. (Oxford University Press, Cary, 2010).

81. Bonnelle, V. *et al.* Autonomic Nervous System activity correlates with peak experiences induced by DMT and predicts increases in wellbeing. Preprint at https://doi.org/10.1101/2024.03.19.585567 (2024).
82. Van Diest, I. *et al.* Inhalation/Exhalation Ratio Modulates the Effect of Slow Breathing on Heart Rate Variability and Relaxation. *Appl Psychophysiol Biofeedback* **39**, 171–180 (2014).
83. van Dixhoorn, J. & White, A. Relaxation therapy for rehabilitation and prevention in ischaemic heart disease: a systematic review and meta-analysis. *European journal of cardiovascular prevention and rehabilitation* **12**, 193–202 (2005).
84. Marcovitch, S. *et al.* Moderate vagal withdrawal in 3.5-year-old children is associated with optimal performance on executive function tasks. *Developmental Psychobiology* **52**, 603–608 (2010).
85. Messerotti Benvenuti, S., Mennella, R., Buodo, G. & Palomba, D. Dysphoria is associated with reduced cardiac vagal withdrawal during the imagery of pleasant scripts: Evidence for the positive attenuation hypothesis. *Biological Psychology* **106**, 28–38 (2015).
86. Porges, S. W. The polyvagal perspective. *Biological Psychology* **74**, 116–143 (2007).
87. Park, G., Vasey, M. W., Van Bavel, J. J. & Thayer, J. F. When tonic cardiac vagal tone predicts changes in phasic vagal tone: The role of fear and perceptual load. *Psychophysiology* **51**, 419–426 (2014).
88. Kox, M. *et al.* The Influence of Concentration/Meditation on Autonomic Nervous System Activity and the Innate Immune Response: A Case Study. *Psychosomatic Medicine* **74**, 489–494 (2012).
89. Mattson, M. P. Hormesis defined. *Ageing Research Reviews* **7**, 1–7 (2008).
90. Calabrese, E. J. Hormesis and medicine. *British Journal of Clinical Pharmacology* **66**, 594–617 (2008).
91. Bondy, S. C. The Hormesis Concept: Strengths and Shortcomings. *Biomolecules* **13**, 1512 (2023).
92. Thayer, J. F. & Lane, R. D. Claude Bernard and the heart–brain connection: Further elaboration of a model of neurovisceral integration. *Neuroscience & Biobehavioral Reviews* **33**, 81–88 (2009).
93. Krypotos, A.-M., Jahfari, S., van Ast, V. A., Kindt, M. & Forstmann, B. U. Individual Differences in Heart Rate Variability Predict the Degree of Slowing during Response Inhibition and Initiation in the Presence of Emotional Stimuli. *Front. Psychol.* **2**, (2011).
94. Park, G., Van Bavel, J. J., Vasey, M. W. & Thayer, J. F. Cardiac vagal tone predicts inhibited attention to fearful faces. *Emotion* **12**, 1292–1302 (2012).
95. Thayer, J. F., Hansen, A. L., Saus-Rose, E. & Johnsen, B. H. Heart Rate Variability, Prefrontal Neural Function, and Cognitive Performance: The Neurovisceral Integration Perspective on Self-regulation, Adaptation, and Health. *Annals of Behavioral Medicine* **37**, 141–153 (2009).
96. Perini, R. & Veicsteinas, A. Heart rate variability and autonomic activity at rest and during exercise in various physiological conditions. *Eur J Appl Physiol* **90**, 317–325 (2003).
97. Bernardi, L. *et al.* Evidence for an intrinsic mechanism regulating heart rate variability in the transplanted and the intact heart during submaximal dynamic exercise? *Cardiovascular Research* **24**, 969–981 (1990).
98. Ernst, G. Hidden Signals—The History and Methods of Heart Rate Variability. *Front. Public Health* **5**, (2017).
99. Nater, U. M. & Rohleder, N. Salivary alpha-amylase as a non-invasive biomarker for the sympathetic nervous system: Current state of research. *Psychoneuroendocrinology* **34**, 486–496 (2009).
100. Ali, N. & Nater, U. M. Salivary Alpha-Amylase as a Biomarker of Stress in Behavioral Medicine. *Int.J. Behav. Med.* **27**, 337–342 (2020).
101. Rohleder, N. & Nater, U. M. Determinants of salivary α-amylase in humans and methodological considerations. *Psychoneuroendocrinology* **34**, 469–485 (2009).
102. Marques, A. H., Silverman, M. N. & Sternberg, E. M. Evaluation of Stress Systems by Applying Noninvasive Methodologies: Measurements of Neuroimmune Biomarkers in the Sweat, Heart Rate Variability and Salivary Cortisol. *Neuroimmunomodulation* **17**, 205–208 (2010).
103. Engeland, C. G., Bosch, J. A. & Rohleder, N. Salivary biomarkers in psychoneuroimmunology. *Current Opinion in Behavioral Sciences* **28**, 58–65 (2019).
104. Chojnowska, S., Ptaszyńska-Sarosiek, I., Kępka, A., Knaś, M. & Waszkiewicz, N. Salivary Biomarkers of Stress, Anxiety and Depression. *Journal of Clinical Medicine* **10**, 517 (2021).
105. Roseman, L., Nutt, D. J. & Carhart-Harris, R. L. Quality of Acute Psychedelic Experience Predicts Therapeutic Efficacy of Psilocybin for Treatment-Resistant Depression. *Front. Pharmacol.* **8**, (2018).
106. Ko, K., Knight, G., Rucker, J. J. & Cleare, A. J. Psychedelics, Mystical Experience, and Therapeutic Efficacy: A Systematic Review. *Front Psychiatry* **13**, 917199 (2022).
107. Yaden, D. B. & Griffiths, R. R. The Subjective Effects of Psychedelics Are Necessary for Their Enduring Therapeutic Effects. *ACS Pharmacol. Transl. Sci.* **4**, 568–572 (2021).
108. Yaden, D. B., Goldy, S. P., Weiss, B. & Griffiths, R. R. Clinically relevant acute subjective effects of psychedelics beyond mystical experience. *Nat Rev Psychol* **3**, 606–621 (2024).

109. Craig, A. D. How do you feel? Interoception: the sense of the physiological condition of the body. *Nat Rev Neurosci* **3**, 655–666 (2002).
110. Brewer, R., Cook, R. & Bird, G. Alexithymia: a general deficit of interoception. *R. Soc. open sci.* **3**, 150664 (2016).
111. Davey, S., Halberstadt, J. & Bell, E. Where is emotional feeling felt in the body? An integrative review. *PLoS ONE* **16**, e0261685 (2021).
112. Füstös, J., Gramann, K., Herbert, B. M. & Pollatos, O. On the embodiment of emotion regulation: interoceptive awareness facilitates reappraisal. *Social Cognitive and Affective Neuroscience* **8**, 911 (2012).
113. Woodside, L. N., Kumar, V. K. & Pekala, R. J. Monotonous Percussion Drumming and Trance Postures: A Controlled Evaluation of Phenomenological Effects. *Anthropology of Consciousness* **8**, 69–87 (1997).
114. Mojtabavi, H., Saghazadeh, A., Valenti, V. E. & Rezaei, N. Can music influence cardiac autonomic system? A systematic review and narrative synthesis to evaluate its impact on heart rate variability. *Complementary Therapies in Clinical Practice* **39**, 101162 (2020).

Author Contribution Statement

T.C. conceptualized the study, collected data and co-wrote the manuscript; A.T. analyzed data and co-wrote the manuscript; K.C. analyzed data; M.L.S. co-wrote the manuscript; L.P. conceptualized the study and co-wrote the manuscript; M.N.H. conceptualized the study, analyzed data and co-wrote the manuscript.

Additional Information

M.N.H. is trained as a facilitator for conscious-connected breathwork.

Acknowledgements

We would like to thank Abdellatif Nemri for feedback on earlier versions of this manuscript, and the Tiny Blue Dot Foundation for financial and moral support.

Figure Legends

Figure 1: Altered states of consciousness evoked by circular breathwork.

A) *Average for sub-scales of the Pekala Consciousness Inventory (PCI).Black: Pre-session scores. Blue: Post-session score. Shaded areas: Average ± SEM. Stars denote statistical significance of differences between pre- and post-session scores, as determined by pairwise t-tests.). ** $p < 0.01$; *$p < 0.05$; $^{+}p < 0.10$. Sub-scales are ordered by size of difference. Left-most six sub-scales show significant differences after correction for multiple comparisons (see Methods).* **B)** Same as A for the difference between pre- and post-session scores.

Figure 2: Emotional content of breathwork experiences.

A) *Graphic representation of the most frequently occurring words across all 18 interviews, obtained through Natural Language Processing (NLP) analysis (see Methods).* **B)** *Probability of occurrence of 28 different emotional qualities across 18 participants. Black line: Average. Shaded area: Average ± SEM. Emotions are ordered according to their subjective proximity according to Cowen & Keltner (2017). Coloured emotion labels highlight clusters of emotional qualities that occur with high probability.* **C)** *Same as B for three example participants.* **D)** *Probability of occurrence of four 'emotion clusters' as highlighted in 2B. Shaded clouds: Probability distribution. Circles: Individual probabilities per subject. Thick black boxes: Percentiles 25 and 75; Black lines: percentiles 10 and 90.* **E)** *Same as D for emotions classified as 'positive', 'negative' and 'neutral' (see Methods).* **F)** *Probability of negative and positive emotions per subject. Green lines: Subjects that experience more positive than negative emotions; Red lines: Subjects that experience more negative than positive emotions.*

Figure 3: Effect of circular breathwork on heart-rate variability.

A) *Example trace of heart-rate variability of one participant before, during and after the breathwork session. Blue shaded area indicates session duration.* **B)** *Difference between pre- and post-session HRV for all 18 participant. Open circles at top of graph and lollipops: Difference per subject. Box plot at top of graph: the box indicates percentiles 25 and 75, the whiskers are the 10 and 90 percentiles..* **C)** *Variability of HRV before, during and after the breathwork session. Boxes: same as in B. Open circles: Individual subjects. Stars indicate statistical significance of pair-wise differences as determined by t-tests. * $p < 0.05$. Peri-session scores differed significantly from pre- as well as post-session scores.*

Figure 4: Emotional content of breathwork experience predicts heart-rate variability.

A) *Correlation between scores on the 'Altered State' sub-scale of the PCI and the change of HRV from pre- to post-session. Triangles: individual participants. Black line: Regression line. Shaded area: 95% Confidence Interval.* **B)** *Same as A for relationship between 'Positive Affect' sub-scale scores and HRV change.* **C)** *Same as B for the 'Negative Affect' sub-scale. D) Same for the relation between variability of HRV during the session and HRV change from pre- to post-session.*

Figure 5: Music does not affect content of breathwork experience. A) *Same as Fig. 1B, split by Music (yellow) and No-Music (grey) condition. After correction for multiple comparisons, there were no significant differences in any of the sub-scales.* **B)** *Same as Fig. 2B, for probabilities split by music / no-music sessions. No significant differences were detected across any of the emotional qualities.* **C)** *Same as Fig. 2E, split by music / no-music sessions, showing no significant differences in distribution.* **D)** *Same as Fig. 2F, split by Music / No-Music condition, and showing no significant music-dependent differences..* **E)** *Distribution of differences between pre- and post-session HRV, for Music and No-Music session, showing no significant music-dependent differences.* **F)** *Pair-wise Aligned Pearson Correlations (see Methods) of HRV traces from subjects from the music condition (top), the no music condition (bottom) and across conditions (middle). Open circles: Individual pairs of subjects. Shaded area: overall distribution.* **G)** *Distributions of variances in the probability of emotional qualities (per subject and sentence) for the Music (yellow) and No-Music (grey) condition. Star indicates statistically significant difference between the two distributions.*

Supplementary Files

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