

Supplementary Information

Decreased CO₂ saturation during circular breathwork supports emergence of altered states of consciousness

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Supplementary Table S1: Distribution of self-reported gender, age and employment status across experimental groups.

	<i>Holotropic (n=30)</i>		<i>Conscious-Connected (n=31)</i>	
	<i>active</i>	<i>passive</i>	<i>active</i>	<i>passive</i>
<i>Gender</i>				
<i>Female</i>	12	7	11	4
<i>Male</i>	6	3	10	3
<i>Non-binary</i>				1
<i>n/a</i>	2		2	
<i>Mean Age (SD)</i>	33.17(5.70)	35.9(8.34)	29.71(6.11)	36.5(8.68)
<i>n/a</i>	2		2	
<i>Employment</i>				
<i>Employed</i>	9	5	9	4
<i>Self-employed</i>	5	4	6	2
<i>In education</i>	2	1	5	0
<i>Unemployed</i>	2	0	0	1
<i>n/a</i>	2		2	1

Supplementary Table S2: Number of participants included in different analyses

	<i>Total</i>	<i>Active</i>	<i>Passive</i>	<i>Holotropic</i>	<i>Conscious-Connected</i>
<i>etCO₂</i>	61	43	18	30	31
<i>Subjective experience</i>	61	43	18	30	31
<i>QIDS/WEMBWS</i>	25	20	5	11	14
<i>Biomarkers</i>	55	40	15	27	28

Supplementary Table S3. Statistical metrics for all reported results

a) Mean etCO₂ across groups: Two-Way ANOVA active/passive breath x breathing style

Outcome metric	df	F	p	Cohen's D	Bf01	Interpretation
Active/passive CO2	Total: 60 Error: 57 Comparison: 1	111.4	<0.001	3.03 CI (low): 2.72 CI (high): 3.35	< 0.001	Mean CO2 Active < Mean CO2 Passive
Holotropic/Con-connected CO2	Total: 60 Error: 57 Comparison: 1	0.0	0.91	0.14 CI (low): 0.01 CI (high): 0.28	3.4	Mean CO2 Holotropic = Mean CO2 Con.-Con.
Interaction	Total: 60 Error: 57 Comparison: 1	0.0	0.91	n.a.	n.a.	No interaction

b) Minimum etCO₂ across groups: Two-Way ANOVA active/passive breath x breathing style

Outcome metric	df	F	p	Cohen's D	Bf01	Interpretation
Active/passive CO2	Total: 60 Error: 57 Comparison: 1	119.0	< 0.001	3.12 CI (low): 2.79 CI (high): 3.44	< 0.001	Min CO2 Active < Min CO2 Passive
Holoropic/Con-connected CO2	Total: 60 Error: 57 Comparison: 1	0.1	0.81	0.06 CI (low): -0.07 CI (high): 0.20	3.7	Min CO2 Holotropic = Min CO2 Con.-Con.
Interaction	Total: 60 Error: 57 Comparison: 1	0.2	0.64	n.a.	n.a.	No interaction

c) Mean rating of experience depth across groups: Two-Way ANOVA active/passive breath x breathing style

Outcome metric	df	F	p	Cohen's D	Bf01	Interpretation
Active/passive depth rating	Total: 60 Error: 57 Comparison: 1	20.8	< 0.001	1.31 CI (low): 1.12 CI (high): 1.50	0.001	Mean depth (active) > Mean depth (passive)
Holotropic/Con-connected depth rating	Total: 60 Error: 57 Comparison: 1	4.8	0.03	0.56 CI (low): 0.42 CI (high): 0.70	0.5	Mean depth (Holotr) $\approx$ < Mean depth (Con.Con)
Interaction	Total: 60 Error: 57 Comparison: 1	0.4	0.53	n.a.	n.a.	n.a.

d) Maximum rating of experience depth across groups: Two-Way ANOVA active/passive breath x breathing style

Outcome metric	df	F	p	Cohen's D	Bf01	Interpretation
Active/passive depth rating	Total: 60 Error: 57 Comparison: 1	15.0	< 0.001	1.12 CI (low): 0.95 CI (high): 1.31	0.01	Max depth (active) > Max depth (passive)
Holotropic/Con-connected depth rating	Total: 60 Error: 57 Comparison: 1	5.1	0.03	0.54 CI (low): 0.41 CI (high): 0.68	0.59	Max depth (Holotr) $\approx$ < Max depth (Con.Con)
Interaction	Total: 60 Error: 57 Comparison: 1	0.95	0.33	n.a.	n.a.	n.a.

e) 11-DASC scores active-breathwork group scores minus **placebo** reference scores: t-tests for difference from zero, across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Unity	42	13.9	< 0.001	n.a. (since there is only one group's standard deviation)	< 0.001	Breathwork > Placebo
Spiritual	42	6.4	< 0.001	-	< 0.001	Breathwork > Placebo
Bliss	42	13.1	< 0.001	-	< 0.001	Breathwork > Placebo
Insight	42	10.6	< 0.001	-	< 0.001	Breathwork > Placebo
Disembodiment	42	10.3	< 0.001	-	< 0.001	Breathwork > Placebo
Impaired Control	42	9.9	< 0.001	-	< 0.001	Breathwork > Placebo
Anxiety	42	12.1	< 0.001	-	< 0.001	Breathwork > Placebo
Complex Imagery	42	9.3	< 0.001	-	< 0.001	Breathwork > Placebo
Simple Imagery	42	9.0	< 0.001	-	< 0.001	Breathwork > Placebo
Synaesthesia	42	11.2	< 0.001	-	< 0.001	Breathwork > Placebo
Changed meaning	42	13.2	< 0.001	-	< 0.001	Breathwork > Placebo

f) MEQ scores active-breathwork versus placebo reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Transcendence	21	12.9	< 0.001	n.a. (see above)	< 0.001	Breathwork > Placebo
Positive Mood	21	12.1	< 0.001	-	< 0.001	Breathwork > Placebo
Ineffability	21	14.0	< 0.001	-	< 0.001	Breathwork > Placebo
Mystical Experience	21	10.2	< 0.001	-	< 0.001	Breathwork > Placebo

g) 11-DASC scores active-breathwork minus **psilocybin** reference scores: t-tests for difference from zero, across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Unity	42	4.1	< 0.001	n.a. (see above)	0.01	Breathwork < Psilocybin
Spiritual	42	10.8	< 0.001	-	< 0.001	Breathwork < Psilocybin
Bliss	42	10.2	< 0.001	-	< 0.001	Breathwork < Psilocybin
Insight	42	1.2	0.25	-	3.26	Breathwork = Psilocybin
Disembodiment	42	3.5	< 0.001	-	0.03	Breathwork < Psilocybin
Impaired Control	42	2.2	0.03	-	0.67	Breathwork < Psilocybin
Anxiety	42	-5.6	< 0.001	-	< 0.001	Breathwork > Psilocybin
Complex Imagery	42	7.9	< 0.001	-	< 0.001	Breathwork < Psilocybin
Simple Imagery	42	10.6	< 0.001	-	< 0.001	Breathwork < Psilocybin
Synaesthesia	42	4.5	< 0.001	-	0.002	Breathwork < Psilocybin
Changed meaning	42	1.6	0.12	-	1.89	Breathwork = Psilocybin

h) MEQ scores active-breathwork versus **psilocybin** reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Transcendence	21	-0.1	0.91	n.a. (see above)	4.7	Breathwork = Psilocybin
Positive Mood	21	-0.1	0.94	-	4.7	Breathwork = Psilocybin
Ineffability	21	0.3	0.74	-	4.5	Breathwork = Psilocybin
Mystical Experience	21	0.7	0.50	-	3.8	Breathwork = Psilocybin

i) 11-DASC scores active-breathwork versus **LSD** reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Unity	42	4.1	< 0.001	n.a. (see above)	0.01	Breathwork < LSD
Spiritual	42	4.5	< 0.001	-	0.003	Breathwork < LSD
Bliss	42	5.1	< 0.001	-	< 0.001	Breathwork < LSD
Insight	42	0.9	0.38	-	4.16	Breathwork = LSD
Disembodiment	42	7.0	< 0.001	-	< 0.001	Breathwork < LSD
Impaired Control	42	4.4	< 0.001	-	0.003	Breathwork < LSD
Anxiety	42	-6.6	< 0.001	-	< 0.001	Breathwork > LSD
Complex Imagery	42	12.0	< 0.001	-	< 0.001	Breathwork < LSD
Simple Imagery	42	13.9	< 0.001	-	< 0.001	Breathwork < LSD
Synaesthesia	42	12.8	< 0.001	-	< 0.001	Breathwork < LSD
Changed meaning	42	1.1	0.27	-	3.39	Breathwork = LSD

j) MEQ scores active-breathwork versus **LSD** reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Transcendence	21	0.04	0.97	n.a. (see above)	4.7	Breathwork = LSD
Positive Mood	21	-5.0	< 0.001	-	0.002	Breathwork > LSD
Ineffability	21	0.6	0.54	-	3.9	Breathwork = LSD
Mystical Experience	21	-3.8	0.001	-	0.03	Breathwork > LSD

k) 11-DASC scores active-breathwork versus **MDMA** reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Unity	42	4.6	< 0.001	n.a. (see above)	0.002	Breathwork > MDMA
Spiritual	42	4.2	< 0.001	-	0.01	Breathwork > MDMA
Bliss	42	-4.1	< 0.001	-	0.01	Breathwork > MDMA
Insight	42	6.5	< 0.001	-	< 0.001	Breathwork > MDMA
Disembodiment	42	5.2	< 0.001	-	< 0.001	Breathwork > MDMA
Impaired Control	42	4.1	< 0.001	-	0.01	Breathwork > MDMA
Anxiety	42	10.6	< 0.001	-	< 0.001	Breathwork > MDMA
Complex Imagery	42	5.9	< 0.001	-	< 0.001	Breathwork > MDMA
Simple Imagery	42	6.7	< 0.001	-	< 0.001	Breathwork > MDMA
Synaesthesia	42	9.8	< 0.001	-	< 0.001	Breathwork > MDMA
Changed meaning	42	6.6	< 0.001	-	< 0.001	Breathwork > MDMA

l) MEQ scores active-breathwork versus MDMA reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Transcendence	21	11.5	< 0.001	n.a. (see above)	< 0.001	Breathwork > MDMA
Positive Mood	21	9.2	< 0.001	-	< 0.001	Breathwork > MDMA
Ineffability	21	10.2	< 0.001	-	< 0.001	Breathwork > MDMA
Mystical Experience	21	9.4	< 0.001	-	< 0.001	Breathwork > MDMA

m) 11-DASC scores across groups: Two-Way ANOVA active/passive breath x 11-DASC sub-scale

Outcome metric	df	F	p	Cohen's D	Bf01	Interpretation
Active/passive 11DASC score	1 (total: 670)	94.0	< 0.001	0.77 CI (low): 0.75 CI (high): 0.79	0.1	11DASC (active) > 11DASC (passive)
11 sub-scales 11DASC score	10 (total: 670)	6.4	< 0.001	0.42 ± 0.35 CI (low): 0.35±0.35 CI (high): 0.49±0.36	2.0 ± 2.0	11DASC subscales may differ from each other
Interaction	10 (total: 670)	1.4	0.19	n.a.	n.a.	n.a.

n) MEQ scores across groups: Two-Way ANOVA active/passive breath x MEQ sub-scale

Outcome metric	df	F	p	Cohen's D	Bf01	Interpretation
Active/passive MEQ score	1 (total: 119)	19.0	< 0.001	0.22 CI (low): 0.16 CI (high): 0.29	0.4	MEQ (active) > MEQ (passive)
4 sub-scales MEQ score	3 (total: 119)	2.4	0.08	0.37±0.25 CI (low): 0.25±0.25 CI (high): 0.50±0.25	1.8 ± 1.6	MEQ subscales do not differ from each other
Interaction	3 (total: 119)	0.7	0.53	n.a.	n.a.	n.a.

o) 11-DASC scores passive-breathwork versus placebo reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Unity	42	7.3	< 0.001	n.a. (see above)	< 0.001	Passive Breathwork > Placebo
Spiritual	42	2.5	0.02	-	0.4	Passive Breathwork > Placebo
Bliss	42	5.0	< 0.001	-	0.004	Passive Breathwork > Placebo
Insight	42	3.5	0.002	-	0.1	Passive Breathwork > Placebo
Disembodiment	42	5.4	< 0.001	-	0.002	Passive Breathwork > Placebo
Impaired Control	42	5.1	< 0.001	-	0.003	Passive Breathwork > Placebo
Anxiety	42	4.8	< 0.001	-	0.01	Passive Breathwork > Placebo

Complex Imagery	42	3.3	0.004	-	0.1	Passive Breathwork > Placebo
Simple Imagery	42	4.3	< 0.001	-	0.02	Passive Breathwork > Placebo
Synaesthesia	42	3.3	0.004	-	0.1	Passive Breathwork > Placebo
Changed meaning	42	4.2	< 0.001	-	0.02	Passive Breathwork > Placebo

p) MEQ scores passive-breathwork versus placebo reference scores: t-tests across 11 sub-scales

Outcome metric	df	t	p	Cohen's D	Bf01	Interpretation
Transcendence	7	5.4	0.001	n.a. (see above)	0.02	Passive Breathwork > Placebo
Positive Mood	7	5.4	0.001	-	0.02	Passive Breathwork > Placebo
Ineffability	7	4.1	0.005	-	0.1	Passive Breathwork > Placebo
Mystical Experience	7	5.6	< 0.001	-	0.02	Passive Breathwork > Placebo

q) etCO2 and depth rating linear mixed model

Outcome metric	Coefficient Estimate (b)	95% CI	Std.Error	df	t-value	p-value	Interpretation
Active breath etCO2	-0.0618	[-0.0769, -0.0466]	0.007	246.5	-8.05	< 0.001	Significant negative effect
Active breath Time	0.2163	[0.1466, 0.2853]	0.035	214.7	6.12	< 0.001	Significant positive effect
Passive breath etCO2	-0.01	[-0.0482, 0.0237]	0.018	58.8	0.7	0.51	Non-significant (CI includes zero)
Passive breath Time	0.017	[-0.0827, 0.1183]	0.051	95	0.3	0.73	Non-significant (CI includes zero)

r) QIDS scores pre-post. Paired t-test

Outcome metric	df	t	p	Cohen's D ₄	Bf01	Interpretation
QIDS pre-post (active-breath)	19	4.3	< 0.001	1.03	0.01	QIDS (active, post) < QIDS (active, pre)
QIDS pre-post (passive-breath)	4	0.6	0.61	0.27	2.6	QIDS (passive, post) = QIDS (passive, pre)

s) WEMBWS scores pre-post. Paired t-test

Outcome metric	df	t	p	Cohen's D ₄	Bf01	Interpretation
WEMBWS pre-post (active-breath)	18	3.4	0.003	0.77	0.1	WEMBWS (active, post) > WEMBWS (active, pre)
WEMBWS pre-post (passive-breath)	4	2.0	0.12	1.12	0.9	WEMBWS (passive, post) ≈ WEMBWS (passive, pre)

t) Alpha-amylase scores pre-post in active-breath group. Paired t-test

Outcome metric	df	t	p	Cohen's D₄	Bf01	Interpretation
Amylase pre-post (active-breath)	39	3.3	0.002	0.88	0.1	Amylase (active, post) < Amylase (active, pre)
Amylase pre-post (passive-breath)	14	1.0	0.34	0.35	2.6	Amylase (passive, post) = Amylase (passive, pre)

u) IL-1b scores pre-post in active-breath group. Paired t-test

Outcome metric	df	t	p	Cohen's D₄	Bf01	Interpretation
IL-1b pre-post (active-breath)	39	5.8	< 0.001	1.50	< 0.001	IL1b (active, post) > IL1b (active, pre)
IL-1b pre-post (passive-breath)	14	4.1	0.001	0.92	0.03	IL1b (passive, post) > IL1b (passive, pre)

Supplementary Table S4: Studies included in the database analysis of 11D-ASC scores.

Studies found in Altered States Database (ASDB; <https://alteredstatesdb.org/>; see Prugger et al., 2022)

	Study	Participants	Treatment
Placebo	(Carhart-Harris et al., 2016)	20	Saline
	(Schmidt et al., 2012)	19	Saline + Glucose
	(Murray et al., 2022)	18	Water
Psilocybin	(Carhart-Harris et al., 2018)	20	25 mg
	(Smigielski et al., 2019)	20	0.315mg/kg
	(Madsen et al., 2019)	2	24mg
	(Carbonaro et al., 2018)	20	20mg/70kg
	(Smigielski et al., 2020)	17	0.230mg/kg
LSD	(Carhart-Harris et al., 2016)	20	0.075 mg intravenous
	(Liechti et al., 2017)	24	0.1 mg oral
	(Preller et al., 2017)	22	0.1 mg oral
	(Holze et al., 2020)	28	0.1 mg oral
	(Holze et al., 2021)	16	0.1 mg oral
	(Schmid et al., 2021)	24	0.1 mg oral
MDMA	(Hysek et al., 2012a)	16	0.125 mg oral
	(Hysek et al., 2012b)	16	0.125 mg oral
	(Hysek et al., 2013)	16	0.125 mg oral
	(Schmid et al., 2021)	9	0.125 mg oral
	(Schmid et al., 2021)	18	0.125 mg oral

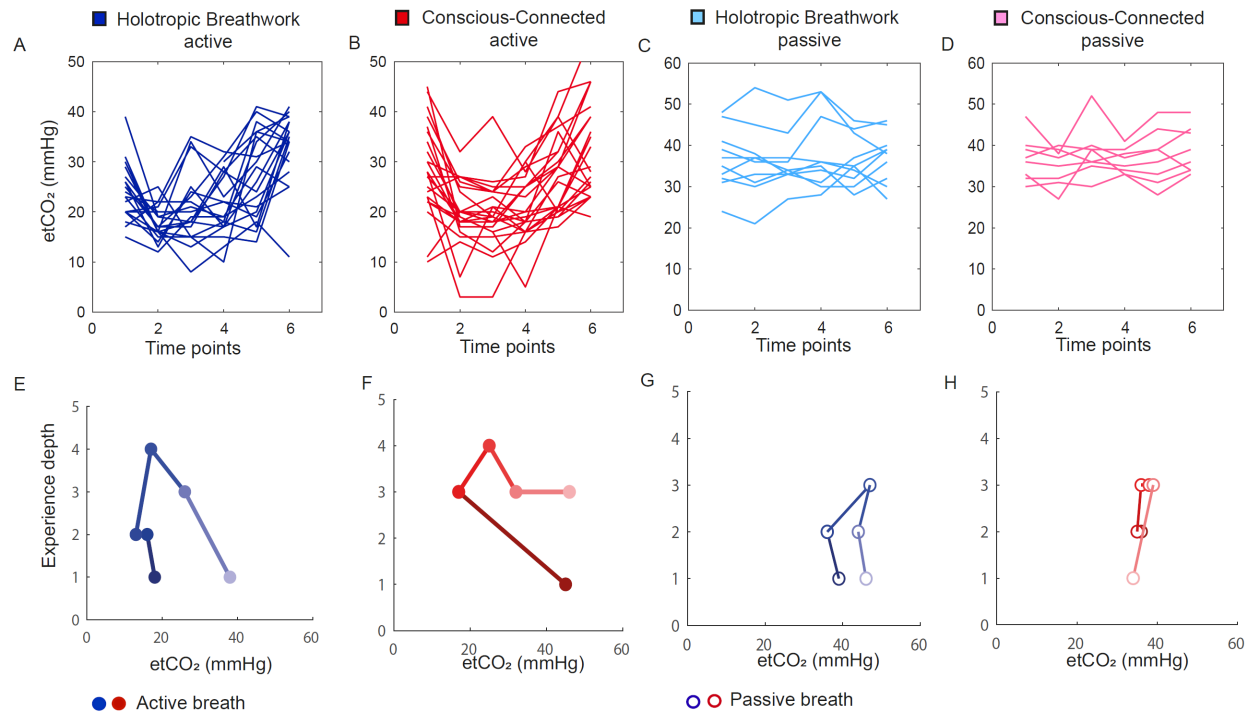
Supplementary Table S5: Studies included in the database analysis of MEQ30 scores.

	Study	Participants	Treatment
Placebo	(Wießner et al., 2023)	24	Alcohol solution
	(Carbonaro et al., 2018)	20	Lactose
Psilocybin	(Barsuglia et al., 2018)	18	20 mg / 70kg
	(Griffiths et al., 2016)	50	0.22-0.3mg/kg
	(Nicholas et al., 2018)	12	0.3mg/kg
	(Carbonaro et al., 2018)	20	20mg/70kg
LSD	(Holze et al., 2020)	28	0.1 mg oral
	(Holze et al., 2021)	16	0.1 mg oral
	(Schmid et al., 2021)	24	0.1 mg oral
	(Schmid et al., 2021)	11	0.1 mg oral
MDMA	(Holze et al., 2020)	28	0.125 mg oral
	(Schmid et al., 2021)	9	0.125 mg oral
	(Schmid et al., 2021)	18	0.125 mg oral

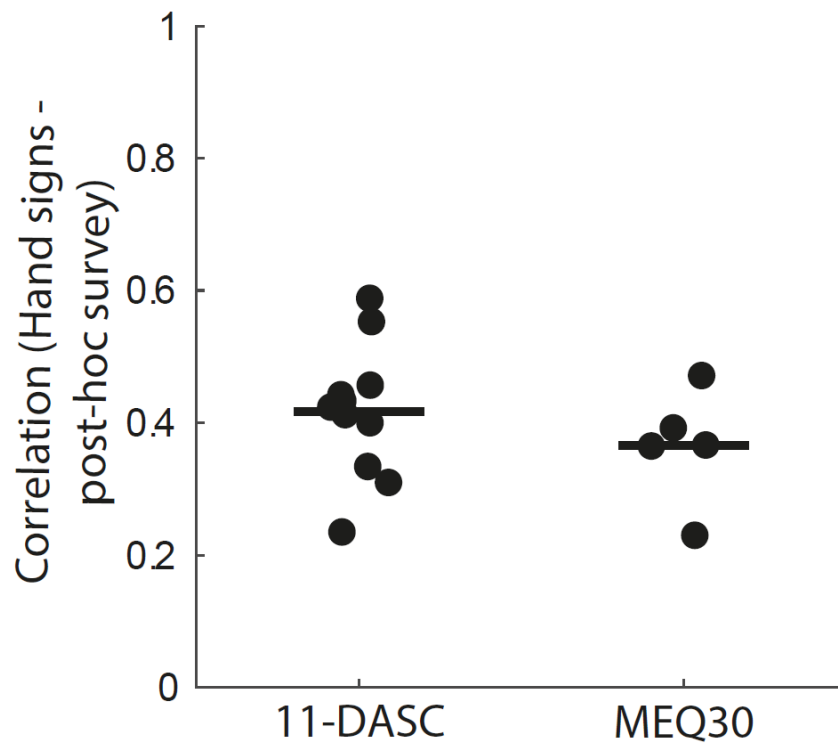
Supplementary Table S6. Comparisons between the sustained effects of Holotropic and Conscious-Connected breathwork.

All comparisons between the sustained effects of Holotropic and Conscious-Connected breathwork were tested with t-tests (ttest2 in MATLAB), taking into account only differences between the two active-breath groups (since this is where sustained effects were initially detected). Note that the only significant difference was found in the change of amylase levels, where Holotropic breathwork triggered a smaller decrease in amylase levels post-session. For all other comparisons, no significant differences were found, and the corresponding bf01 values indicated a robust likelihood that outcomes of holotropic and conscious-connected breathwork sessions came from the same distribution.

Comparison	Means and t-test results
WEMBW's pre-post change	df = 18; t = 1.28; p = 0.21 Mean $\pm$ SD: HB: 7.9 $\pm$ 5.5 ; CCB: 3.3 $\pm$ 9.1; Cohen's D: 0.60 CI (low): 0.25 CI (high): 0.85 Bf01 = 1.49
QIDS-SR16 pre-post change	df = 18; t = 0.95; p = 0.35 Mean $\pm$ SD: HB: -4.2 $\pm$ 3.8 ; CCB: -2.7 $\pm$ 3.1; Cohen's D: 0.4 CI (low): 0.05 CI (high): 0.76 Bf01 = 1.95
α -amylase pre-post change	df = 39; t = 3.20; p < 0.003 Mean $\pm$ SD: HB: -10.5 $\pm$ 43.5 ; CCB: -58.0 $\pm$ 50.4; Cohen's D: 1.0 CI (low): 0.61 CI (high): 1.39 Bf01 = 0.08
IL-1 β pre-post change	df = 39; t = 0.49; p = 0.63 Mean $\pm$ SD: HB: 146.5 $\pm$ 196.5 ; CCB: 122.9 $\pm$ 104.9; Cohen's D: 0.2 CI (low): -0.15 CI (high): 0.54 Bf01 = 3.22

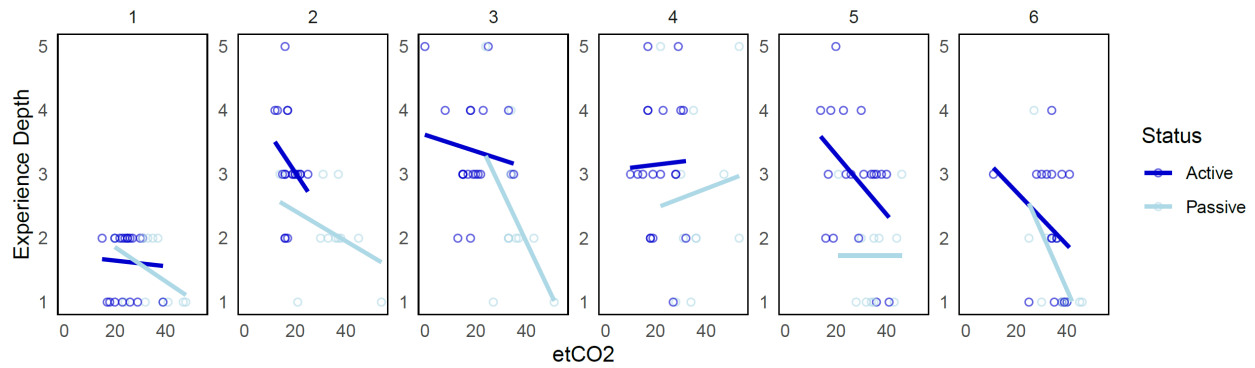


Supplementary Figure S1. Individual examples of end-tidal CO₂ pressure and experience depth ratings. (A) Individual time courses of end-tidal CO₂ pressure (etCO₂) across the six measurement time points of a Holotropic breathwork session. Each line represents one participant in the active-breath group. (B) Same as A for Conscious-Connected breathwork. (C) Same as A but for passive breathers in the Holotropic breathwork sessions. (D) Same as C for Conscious-Connected breathwork. (E) Trajectory of one example participant from the active-breath group in the Holotropic breathwork session (participant ID-11). Trajectories are depicted in the same way as in Figures 3C and D, relating etCO₂ (x axis) and experience depth (y axis) to each other over the six measurement time points of a session. (F) Same as E for the Conscious-Connected breathwork sessions (participant ID-38). (G) Same as E for a participant from the passive-breath group (participant ID-21). (H) Same as G for the Conscious-Connected breathwork sessions (participant ID-48).

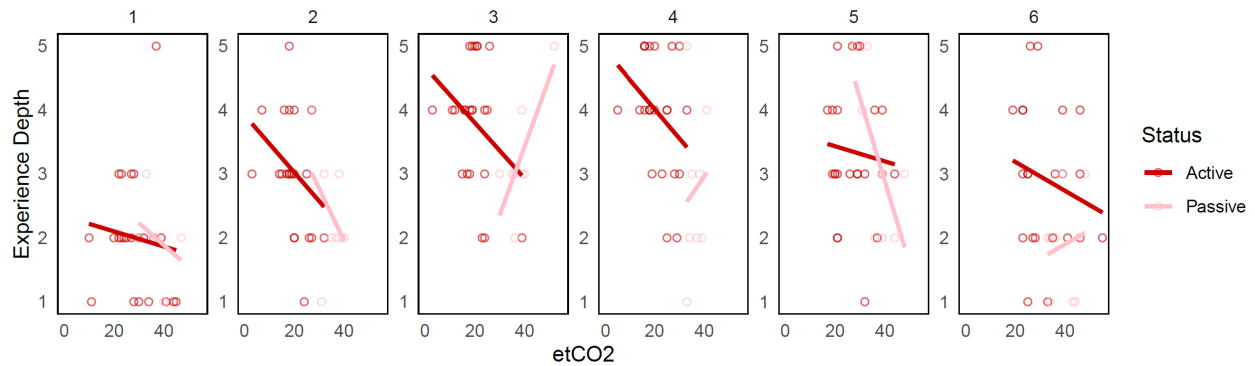


Supplementary Figure S2. Cross-validation of hand sign ratings with post-session ratings of altered states of consciousness. Correlation between average experience depth, as indicated by hand signs during the active part of the session (time points 2-4), and retrospective measures of altered consciousness by 11-Dimensional Altered States of Consciousness (11-DASC) and Mystical Experiences Questionnaire 30 (MEQ30) sub-scales. Left: Correlation coefficients with the 11 sub-scales of the 11DASC. Right: Correlation coefficients with the 4 sub-scales as well as overall score of the MEQ30. Horizontal lines: Average correlation coefficient across all sub-scales per questionnaire. 11-DASC: Mean $r \pm \text{SEM} = 0.42 \pm 0.01$; $p < 0.05$ in 10 of 11 sub-scales based on the family-wise error rate given by the Dunn-Sidak correction for multiple comparisons: MEQ: Mean $r \pm \text{SEM} = 0.37 \pm 0.03$; $p < 0.05$ in 3 of 4 sub-scales based on the family-wise error rate given by the Dunn-Sidak correction.

A Holotropic Breathwork



B Conscious-Connected Breathwork



Supplementary Figure S3. Mixed-model analysis of the relationship between experience depth and etCO2 over time for Holotropic and Conscious-Connected breathwork.

In both breathwork techniques results indicated etCO2 and Time as significant predictors of Experience depth. Holotropic breathwork (A): estimated fixed effects coefficient for etCO2 = -0.050, Std. Error = 0.008, df = 132.741, $t = -5.7$, $p < 0.001$; estimated fixed effects coefficient for Time = 0.106, Std. Error = 0.041, df = 159.437, $t = 2.56$, $p = 0.011$. Conscious-Connected breathwork (B): estimated fixed effects coefficient for etCO2 = -0.052, Std. Error = 0.009, df = 141.816, $t = -5.7$, $p < 0.001$; estimated fixed effects coefficient for Time = 0.184, Std. Error = 0.041, df = 158.137, $t = 4.5$, $p < 0.001$. Each box represents one measurement time point (1 to 6).

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