

# ASSESSING THE RELATIONSHIP BETWEEN NEURAL ENTRAINMENT AND ALTERED STATES OF CONSCIOUSNESS INDUCED BY ELECTRONIC MUSIC

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## INTRODUCTION

- In electronic dance music festivals, the **highly rhythmic** and repetitive beat of electronic music seems to be used to produce **altered states of consciousness** and facilitate the life-shaping experiences that the attendees crave [1]. This observation has evoked comparison to the **absorptive continuous drumming** used in shamanic rituals to go into spiritual journeys [2].
- From a neuroscientific standpoint, several neural mechanisms have been suggested to explain how exposure to repetitive sounds might induce altered states of consciousness. The one that has received the most attention is **entrainment**, the natural synchronization of brainwaves to the phase of periodic external stimuli [3].
- However, the relationship between entrainment and ASCs has not been systematically explored before. To shed light on this relationship, we drew upon the finding that the rate at which repetitive sounds are presented modulate the magnitude of entrainment, **reaching a peak at around 2 Hz** [4].

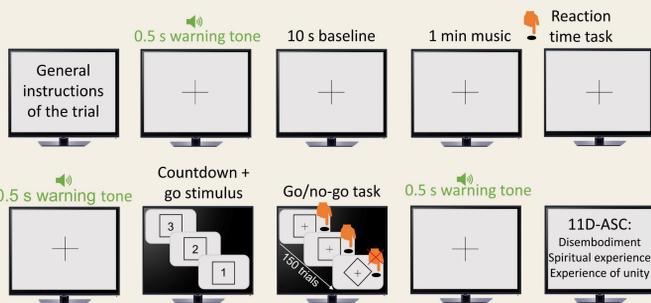
### AIM OF THE STUDY:

To shed light on the relationship between neural entrainment and altered states of consciousness for the first time by using naturalistic electronic music.

## METHODS

### PROCEDURE

- N = 19 volunteers.**
- We measured brain responses **with electroencephalography (EEG)** to 6 electronic songs with a salient beat at **1.65 Hz**, **2.25 Hz** and **2.85 Hz** (2 songs / condition). Each song was played 3 times.
- We acquired **objective** (executive function and reaction time) and **subjective** (self-rating questionnaire about phenomenological experience) **measures of cognition** after being stimulated by each song.

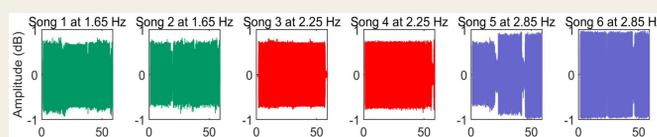


### EEG RECORDING

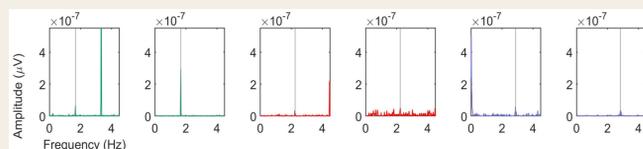
- Continuous EEG recording from 36 electrodes.
- Offline re-reference: Average electrodes.
- Filter: [0.5 45] Hz.
- Epoching: [+1 +58] ms from music onset.
- Sampling rate: 1 kHz.

### SOUND PATTERN & EEG ANALYSIS

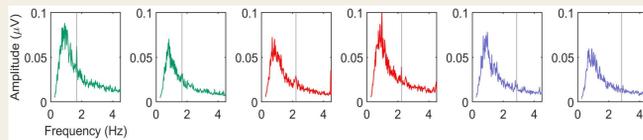
#### Waveforms of each song



#### Fast-Fourier transforms of the waveforms

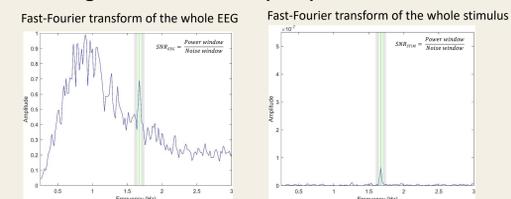


#### Fast-Fourier transforms of the averaged EEG responses



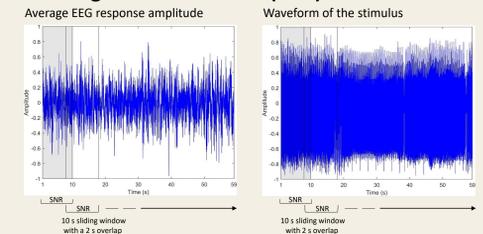
### ENTRAINMENT AS SIGNAL-TO-NOISE RATIO

#### Global signal-to-noise ratio (SNR) and normalization



$$SNR_{GLOBAL} = \frac{SNR_{EEG}}{SNR_{STIM}}$$

#### Across time signal-to-noise ratio (SNR) and normalization



### DATA ANALYSIS

One-way repeated measures Analysis of Variance (**ANOVA**).

- Within-subjects factor:
  - Tempo (3 levels).

**Post-hoc** pairwise comparisons using t-tests:

- Comparisons between the 3 levels of the factor tempo.

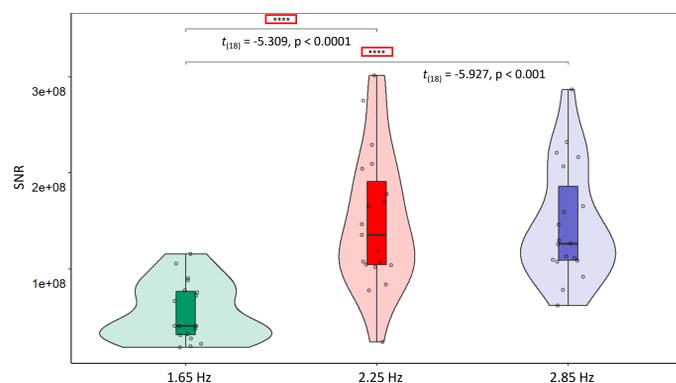
**Correlation analyses:**

- Between entrainment and the objective and subjective measures.

## RESULTS

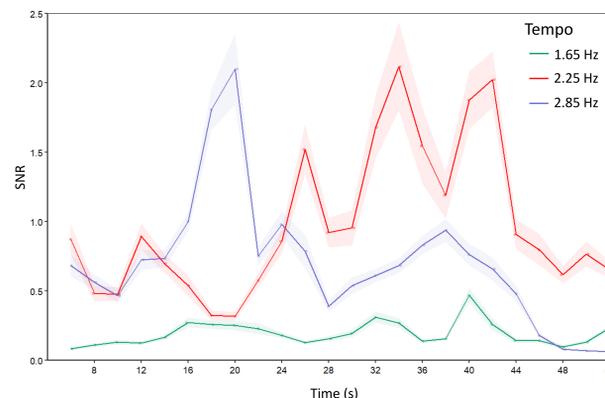
### GLOBAL ENTRAINMENT

ANOVA:  $F_{(2,36)} = 19.069, p < 0.05, \eta^2 = 0.394$



### ENTRAINMENT ACROSS TIME

ANOVA: Main effect of tempo in all timepoints.



### CORRELATIONS ENTRAINMENT - BEHAVIOR

Table 1. Correlations between disembodiment (DIS) and entrainment (SNR)

Variable	1	2	3	4	5	6
1. DIS at 1.65 Hz						
2. DIS at 2.25 Hz	0.847*					
3. DIS at 2.85 Hz	0.749*	0.928*				
4. corrected SNR at 1.65 Hz	<b>-0.478*</b>	-0.401*	-0.372*			
5. corrected SNR at 2.25 Hz	-0.103	0.137	0.069	-0.036		
6. corrected SNR at 2.85 Hz	-0.126	-0.115	-0.053	-0.034	0.208*	

Table 2. Correlations between spiritual experience and entrainment (SNR)

Variable	1	2	3	4	5	6
1. SPI at 1.65 Hz						
2. SPI at 2.25 Hz	0.865*					
3. SPI at 2.85 Hz	0.942*	0.924*				
4. corrected SNR at 1.65 Hz	<b>-0.531*</b>	-0.583*	-0.621*			
5. corrected SNR at 2.25 Hz	-0.238*	-0.102	-0.269*	-0.036		
6. corrected SNR at 2.85 Hz	0.072	0.099	0.073	-0.034	0.208*	

Table 3. Correlations between experience of unity (UNI) and entrainment (SNR)

Variable	1	2	3	4	5	6
1. UNI at 1.65 Hz						
2. UNI at 2.25 Hz	0.945*					
3. UNI at 2.85 Hz	0.869*	0.916*				
4. corrected SNR at 1.65 Hz	<b>-0.550*</b>	-0.489*	-0.373			
5. corrected SNR at 2.25 Hz	-0.060	0.078	0.058	-0.036		
6. corrected SNR at 2.85 Hz	-0.011	0.047	0.146	-0.034	0.208*	

## DISCUSSION

- Our research systematically explores for the first time the long-held assumption that entrainment to repetitive auditory stimuli is related to altered states of consciousness.
  - Specifically, **sounds at 2.25 Hz yield more entrainment compared to slower and faster rates.**
  - Critically, a **significant correlation was found between the phenomenological aspects of ASCs and entrainment at 99 bpm.**
- Our results elucidate on why rhythmic stimuli is used in some human ritualistic settings. Additionally, our findings add on the notion that entrainment engages endogenous brain activity, ultimately affecting cognitive processes, and challenge the view that entrainment only reflects steady-state evoke potentials.
- We highlight the importance of taking into consideration the temporal evolution of entrainment in future research on the field when working with numerous stimulation rates.

## REFERENCES

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