C-LAB

CENTRE
FOR BRAIN
RESEARCH JU

# Neural correlates of conscious content

Marcin Koculak

Under supervision of
prof. Michał Wierzchoń

PSA

# Self-paced defence

## WERSJA PO POLSKU!

https://tinyurl.com/polskiphd

## ENGLISH SLIDES

https://tinyurl.com/slajdypdf

# Dichotomy of Consciousness Science

## State

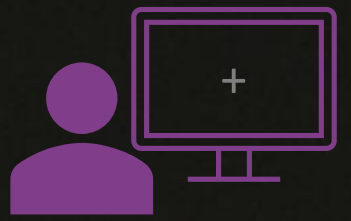
Clearly distinguishable

Reliable candidate measures: complexity

Mixed with arousal et al.

Experimentally difficult

My research



## Content

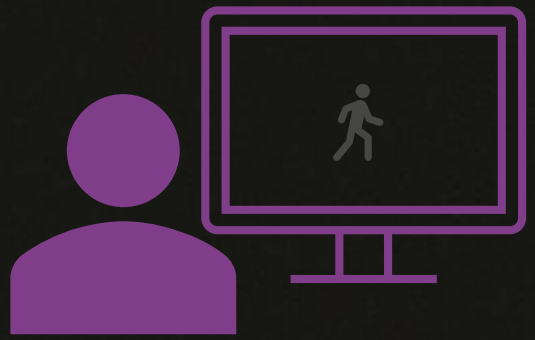
Difficult to track

Many competing correlate candidates

Mixed with cognition

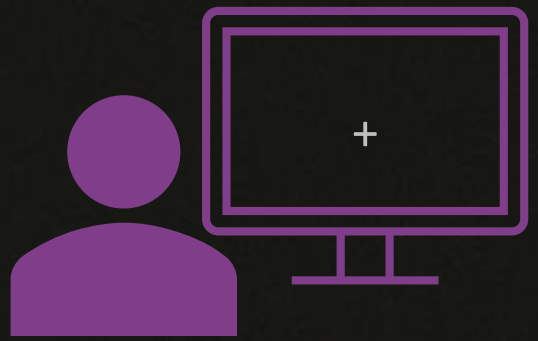
Experimentally easy

# Extent of conscious content



GOING FROM NO STIMULATION

TO NATURALISTIC SETTING




GOING FROM NO INFORMATION


TO EXPERIENCE SAMPLING

# Redesigning Resting-state

EEG

ECG

ARSQ

SHORT MOVIES

+

MUSIC

WALK

+

EYES CLOSED

+

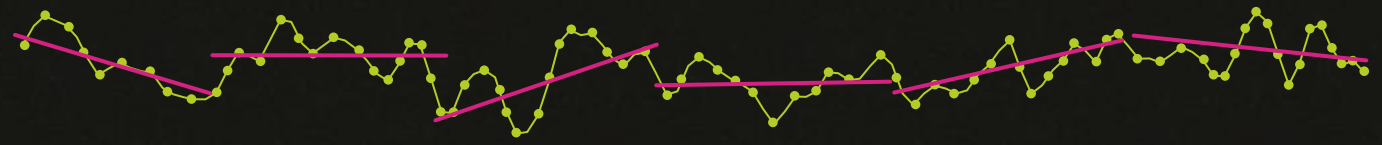
EYES OPENED

STATIONARY VIDEO

# Flavours of complexity

MSE

DFA



LZc

# TRACKING CONSCIOUS CONTENT

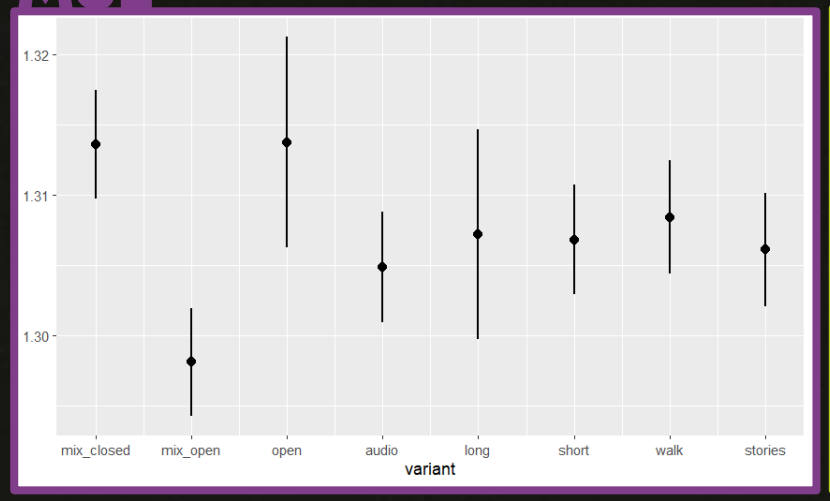
**PARTICIPANTS**

WOMEN - 357
MEN - 266

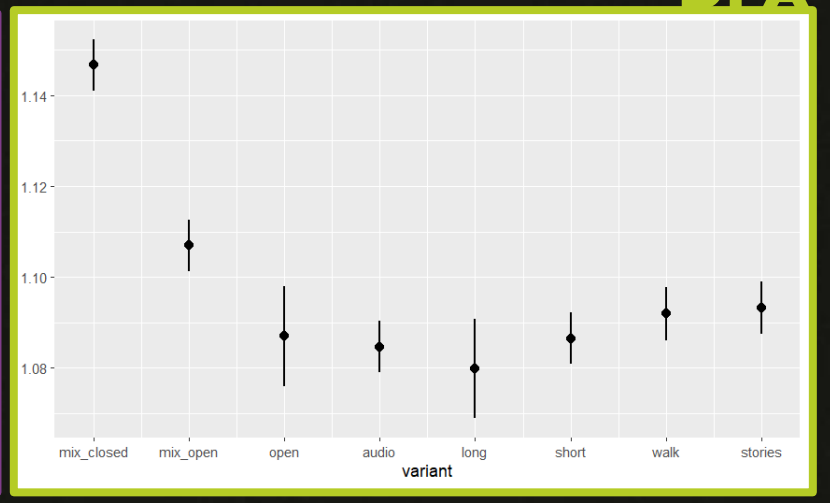
MIX-CLOSED - 570
MIX-OPEN - 570
OPEN - 107
AUDIO - 252
LONG - 112
SHORT - 337
WALK - 163
STORIES - 166

**RECORDINGS**

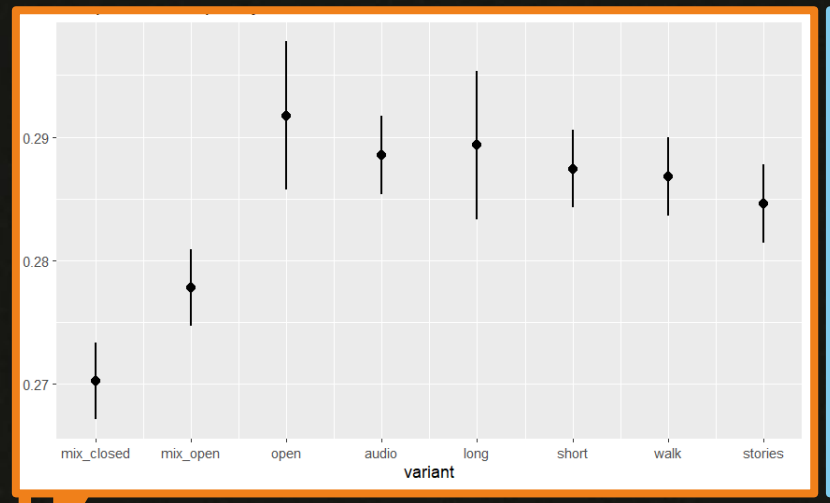
MSE



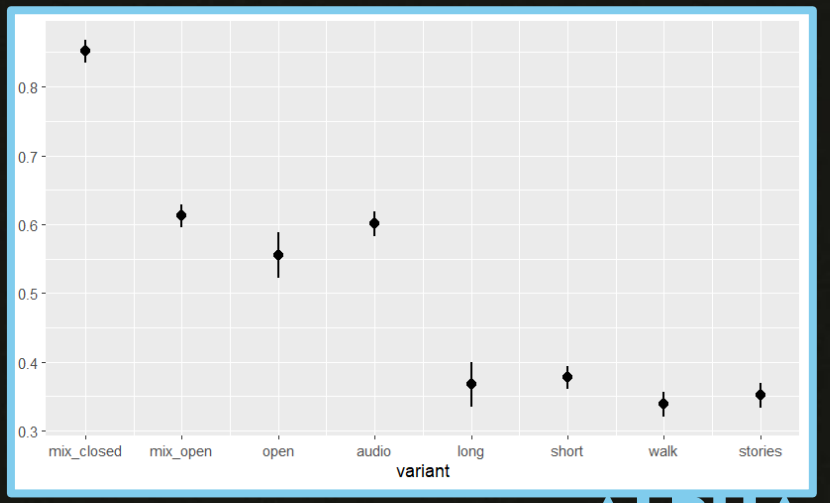

DFA



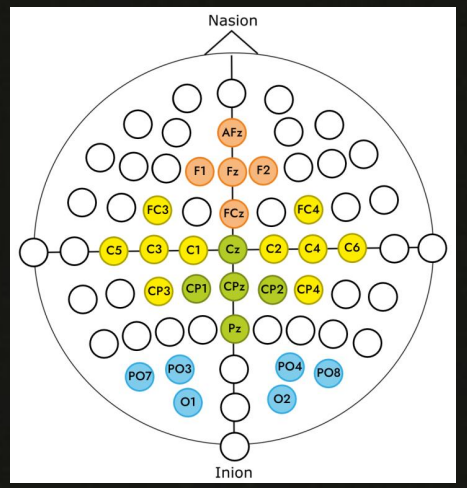

LZc



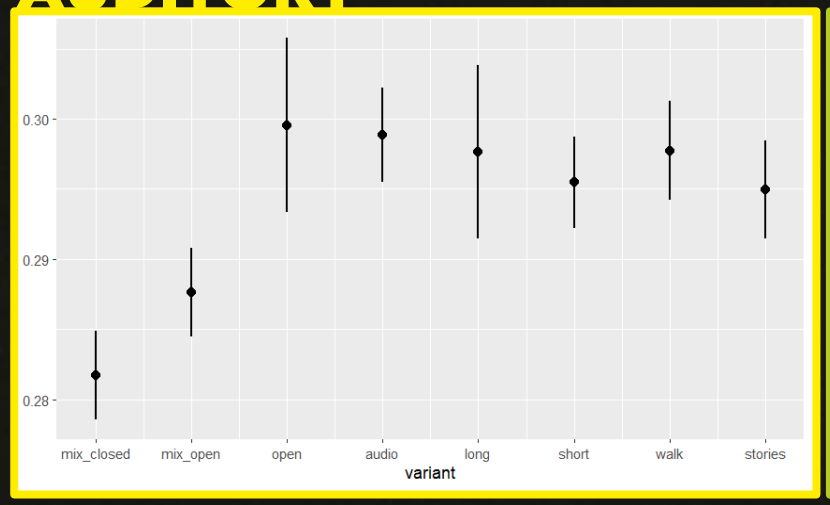

ALPHA



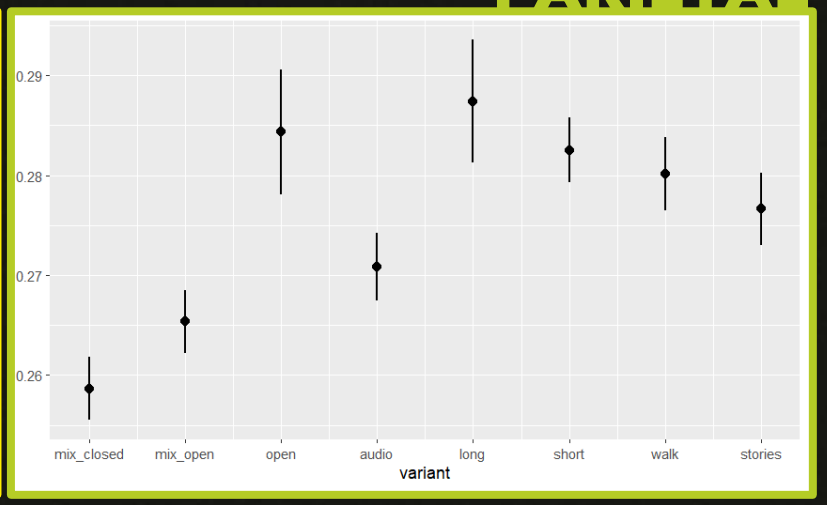
# "LOCALIZING" THE EFFECTS



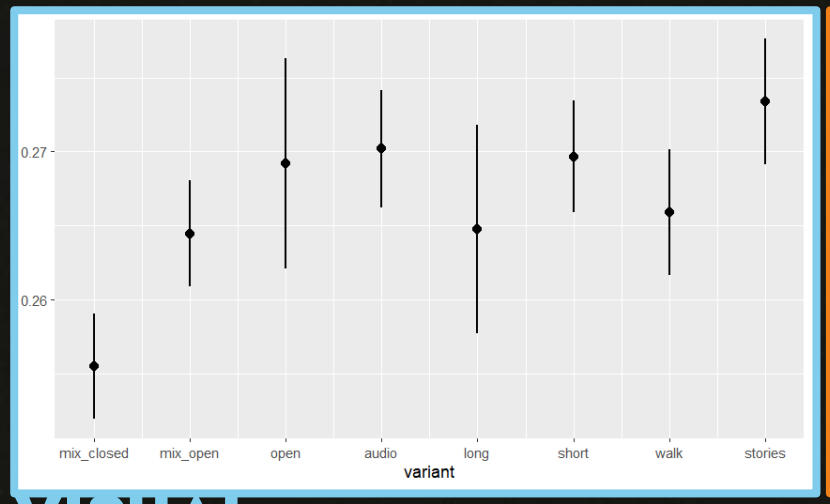

## AUDITORY



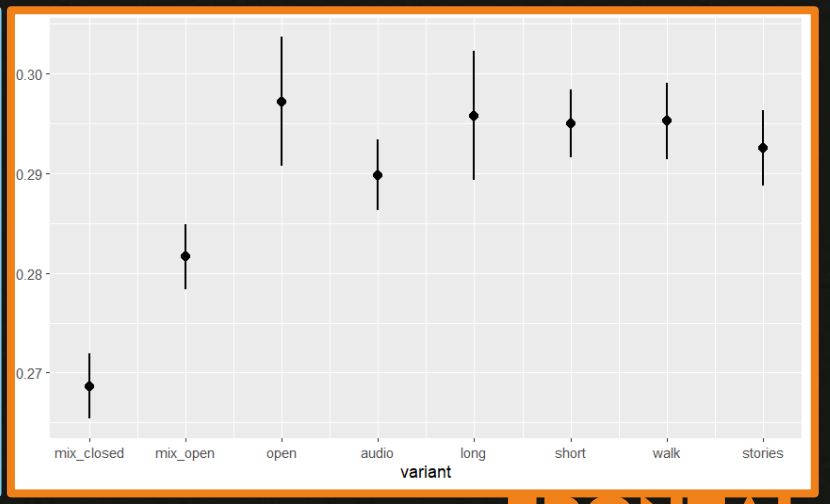

## PARIETAL




## VISUAL

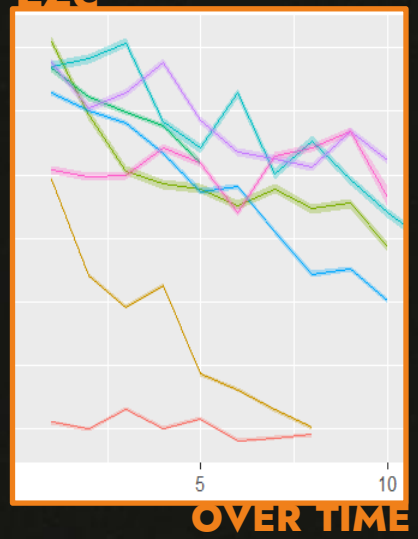



## FRONTAL



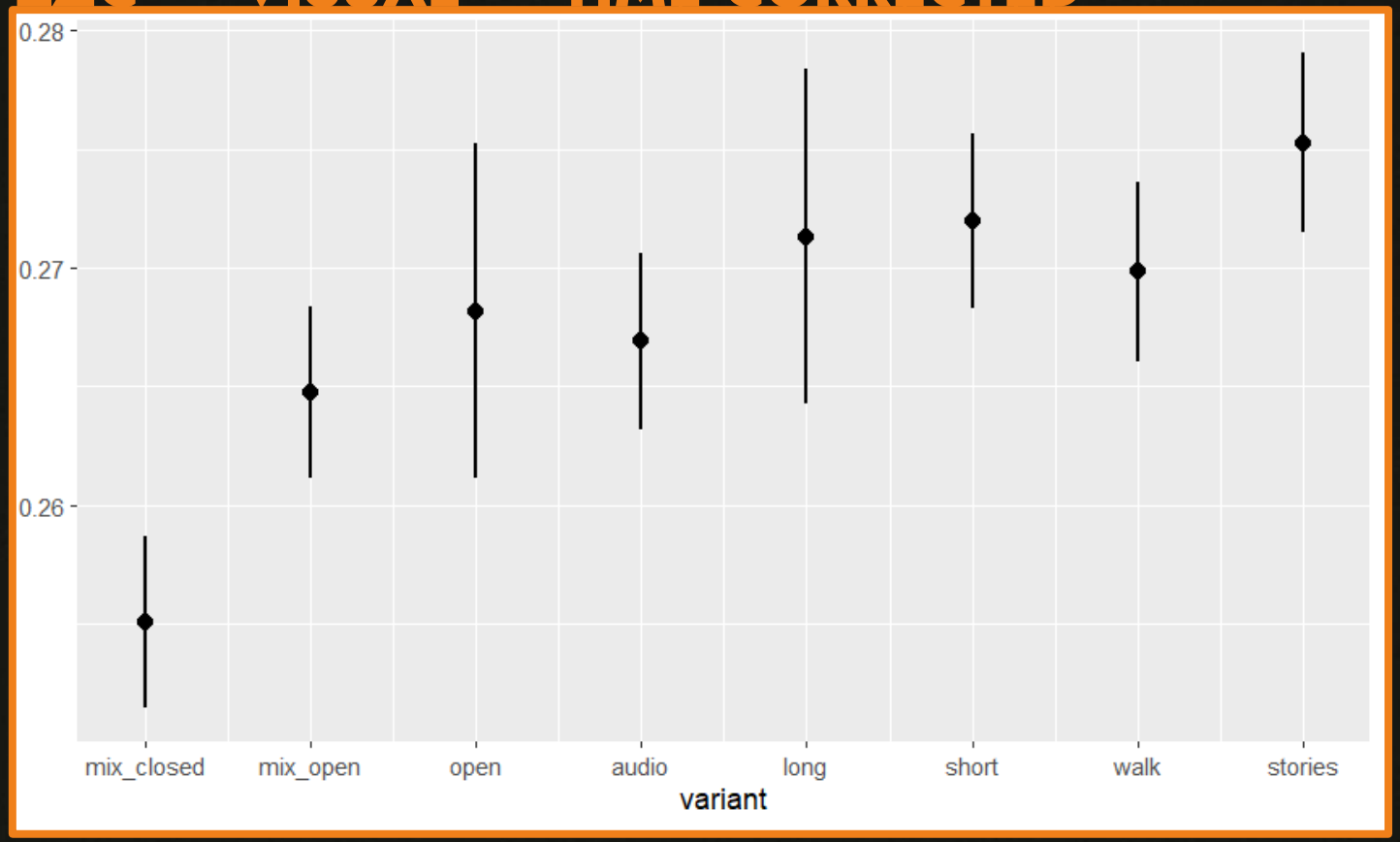
# Tracking the dynamics

## LZc



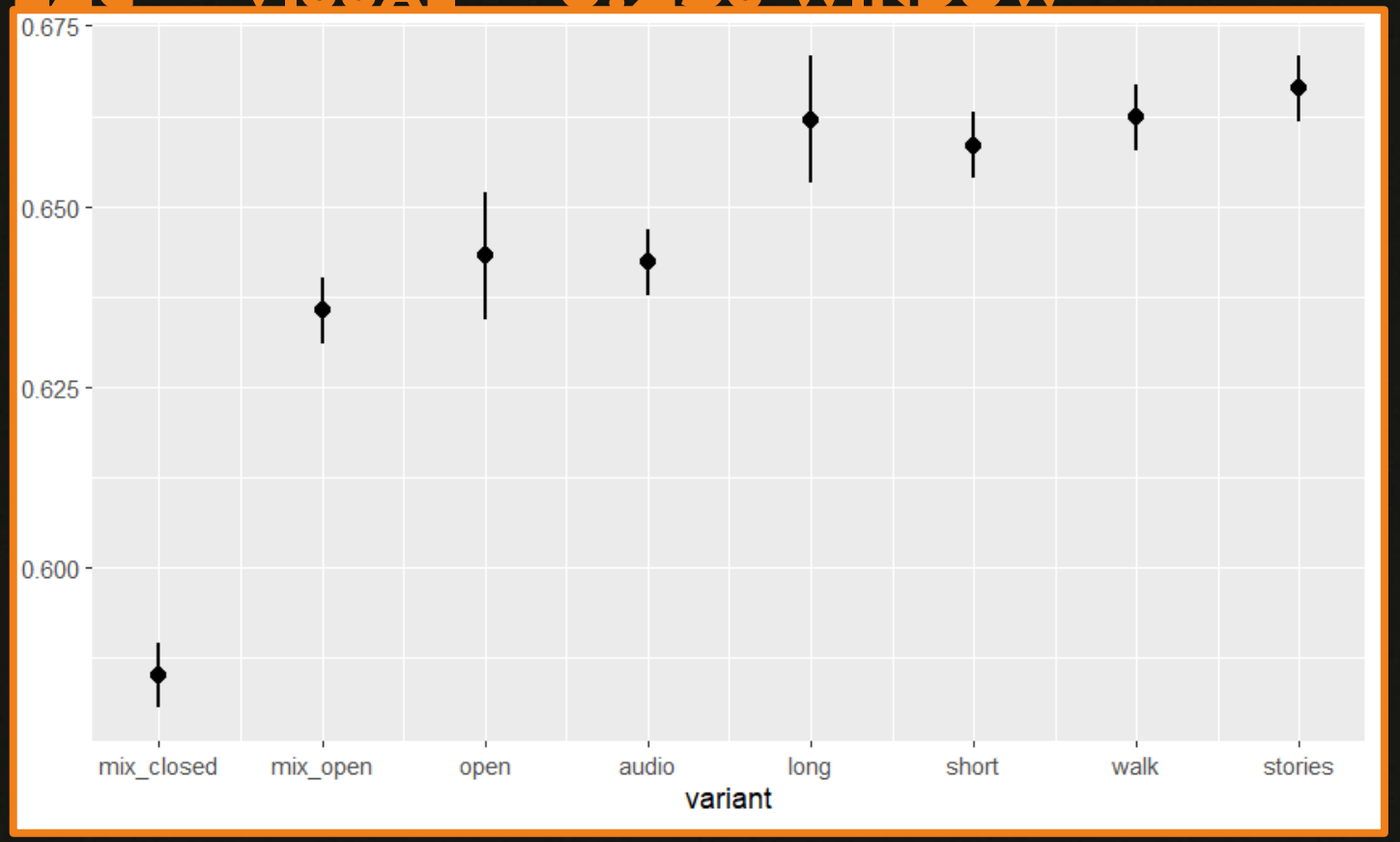

over time

## LZc — visual — time corrected



# Tracking the dynamics II

## LZc — visual — 0.25s window



# Complex = conscious?

- Complexity measures (LZc) can track conscious content
- It is not a viable option for typical experiments
  (sample size, localization issues)

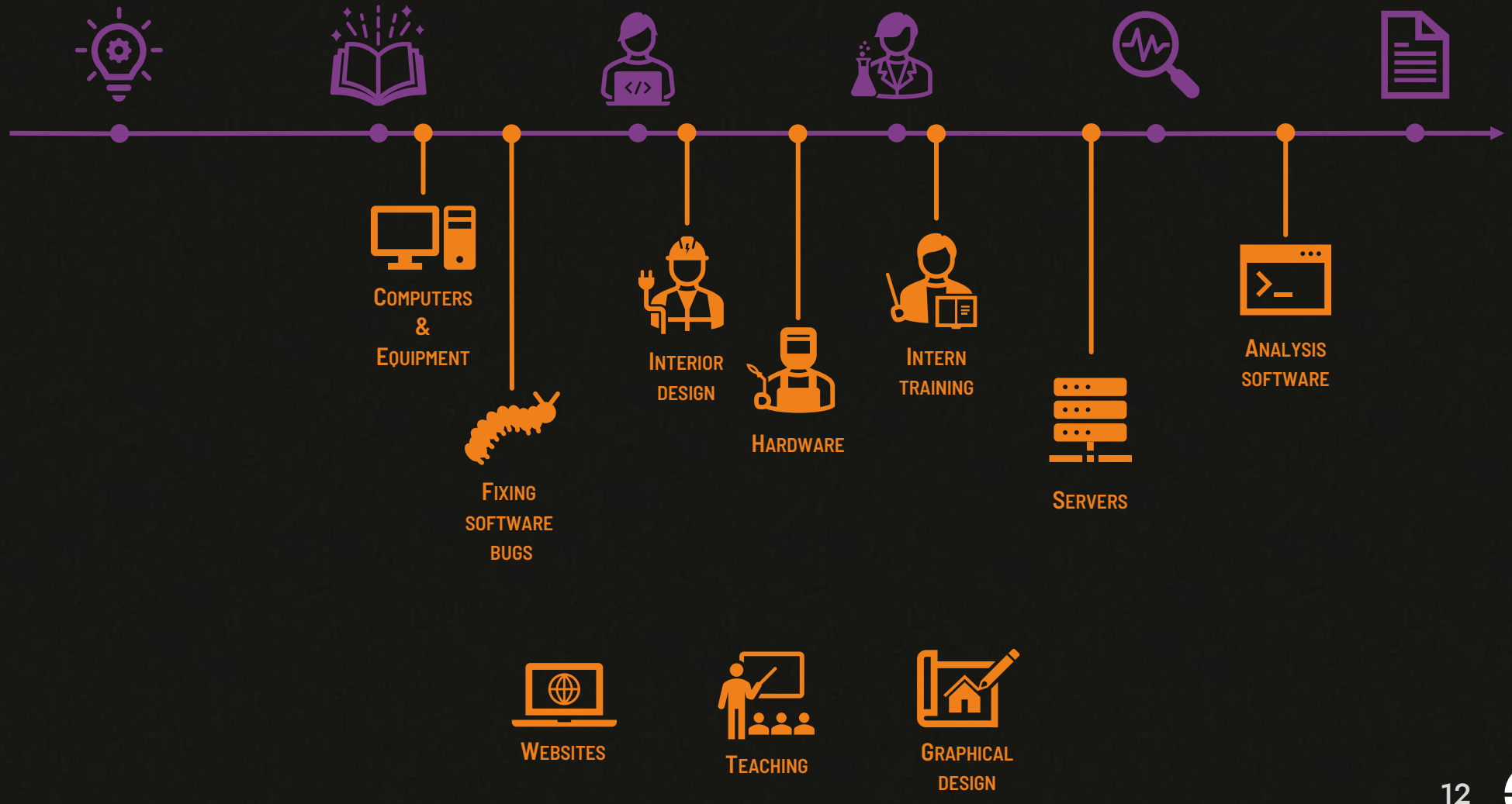
- New resting state paradigms work
- Database, paradigms, and code will be public

- More research needed



Supplementary materials

# PhD wrapped/rewind



# Collaborators

Michał Wierzchoń

Michał Bola

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Dominika Drążyk

Tomasz M. Rutkowski

Aleksander Zębrowski

Laura Łępa

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## Thank You for attention!

# Responses to reviews


# Why all of this?

## Main goal

Investigate if complexity is a useful measure outside of state research

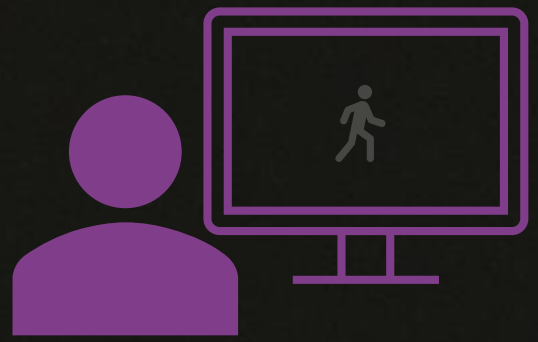
## Subgoals

1. Identifying a viable experimental approach – resting state
2. Maximizing the chances for meaningful results – C-REST database
3. Formalising experimental strategy – "atheoretical" complexity
4. Exploring the collected data – complexity analyses



Subgoal 1

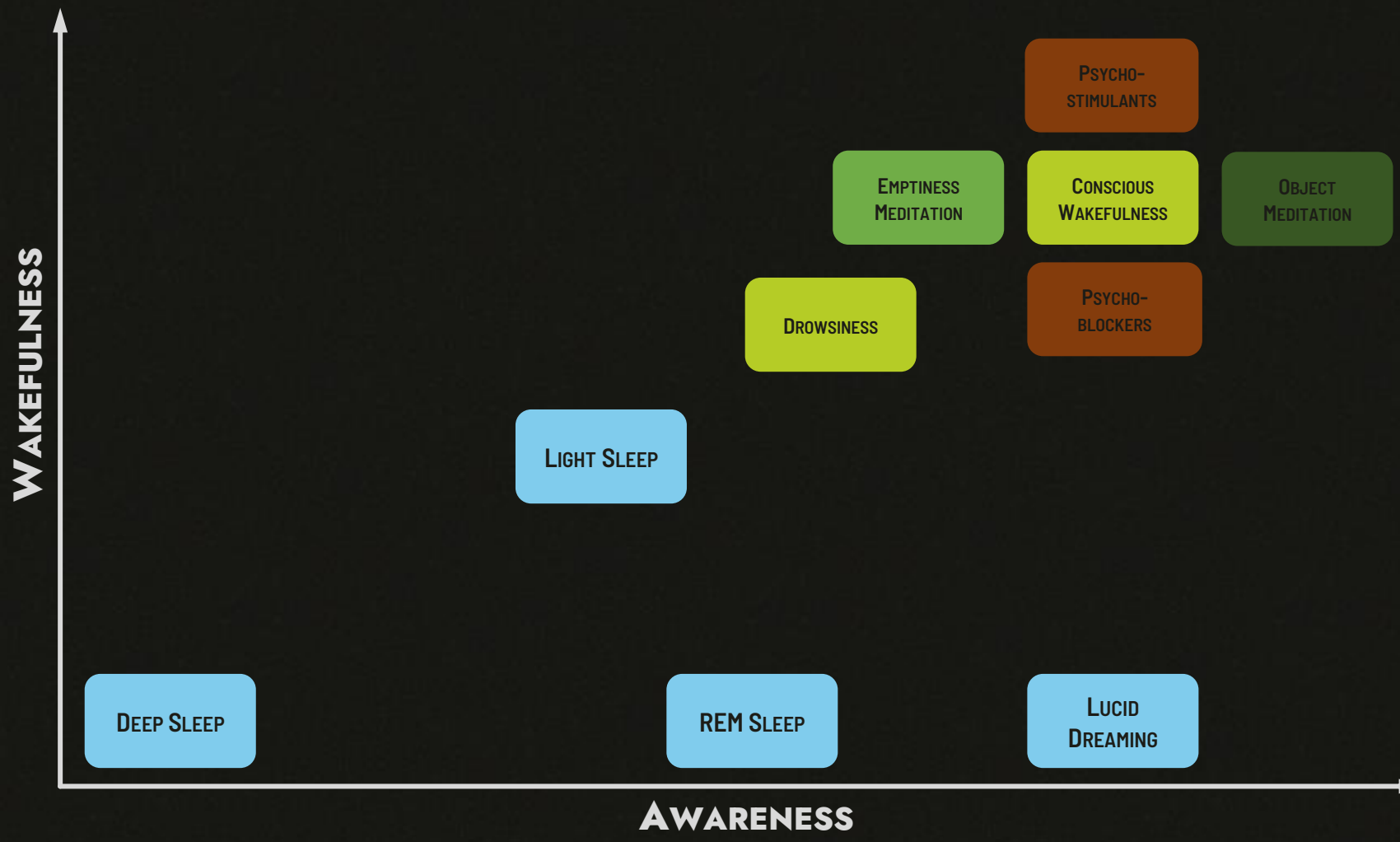
# Defining consciousness in research



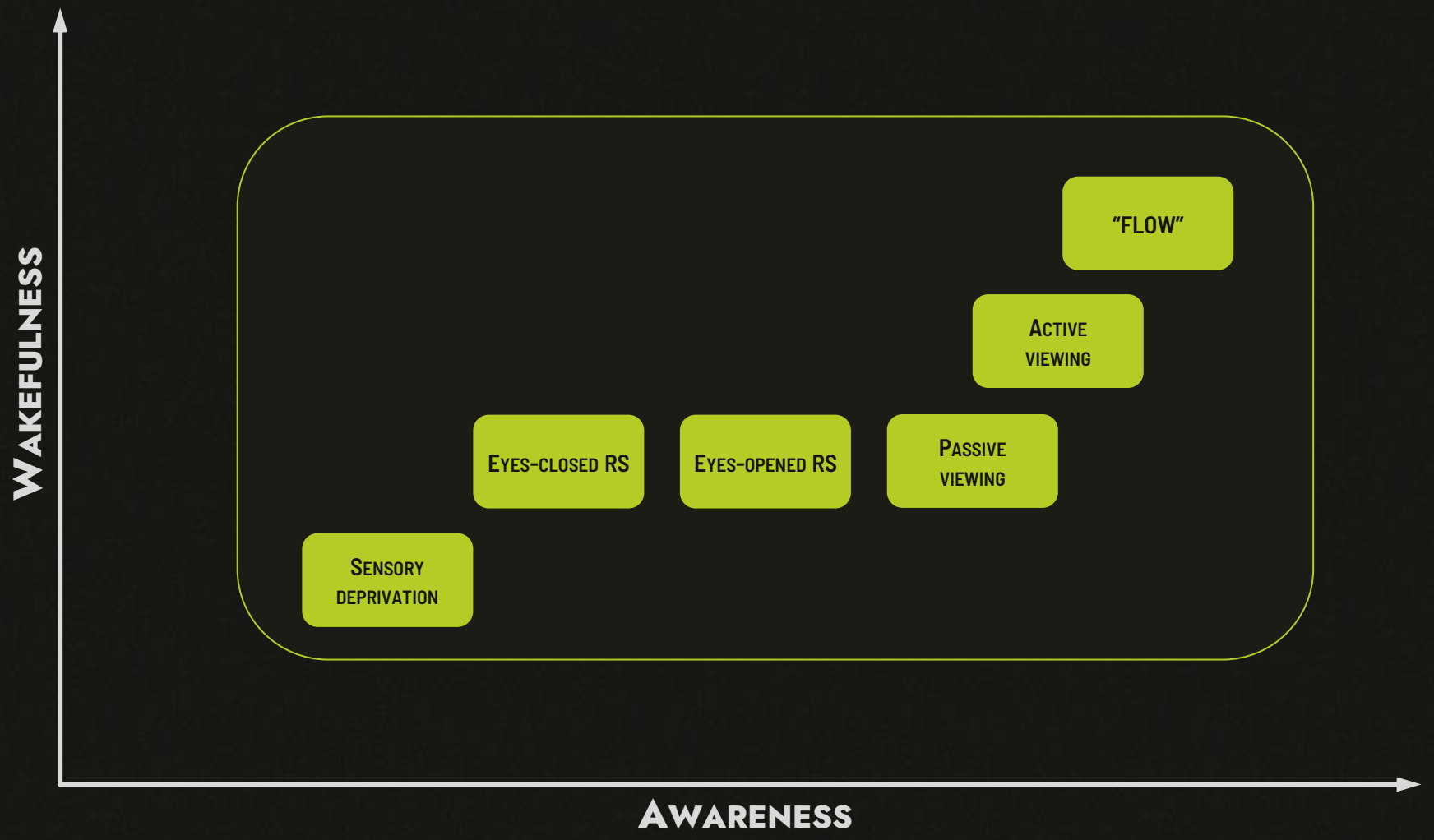
Subgoal 1

# Background consciousness

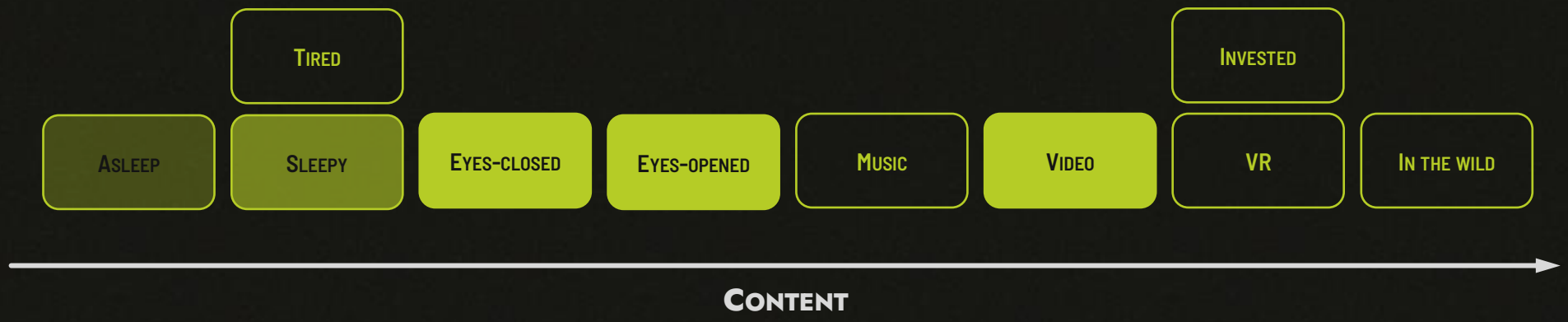
# State vs Content Dichotomy



# State vs Content Dichotomy

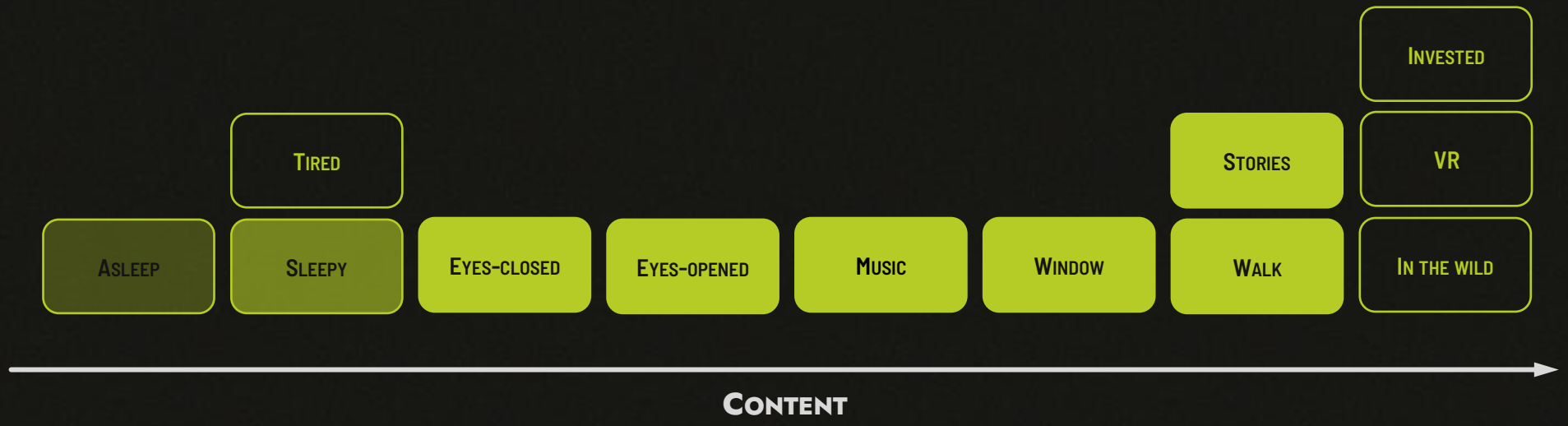


# State vs Content Dichotomy



## Subgoal 1

# State vs Content Dichotomy



## Subgoal 2

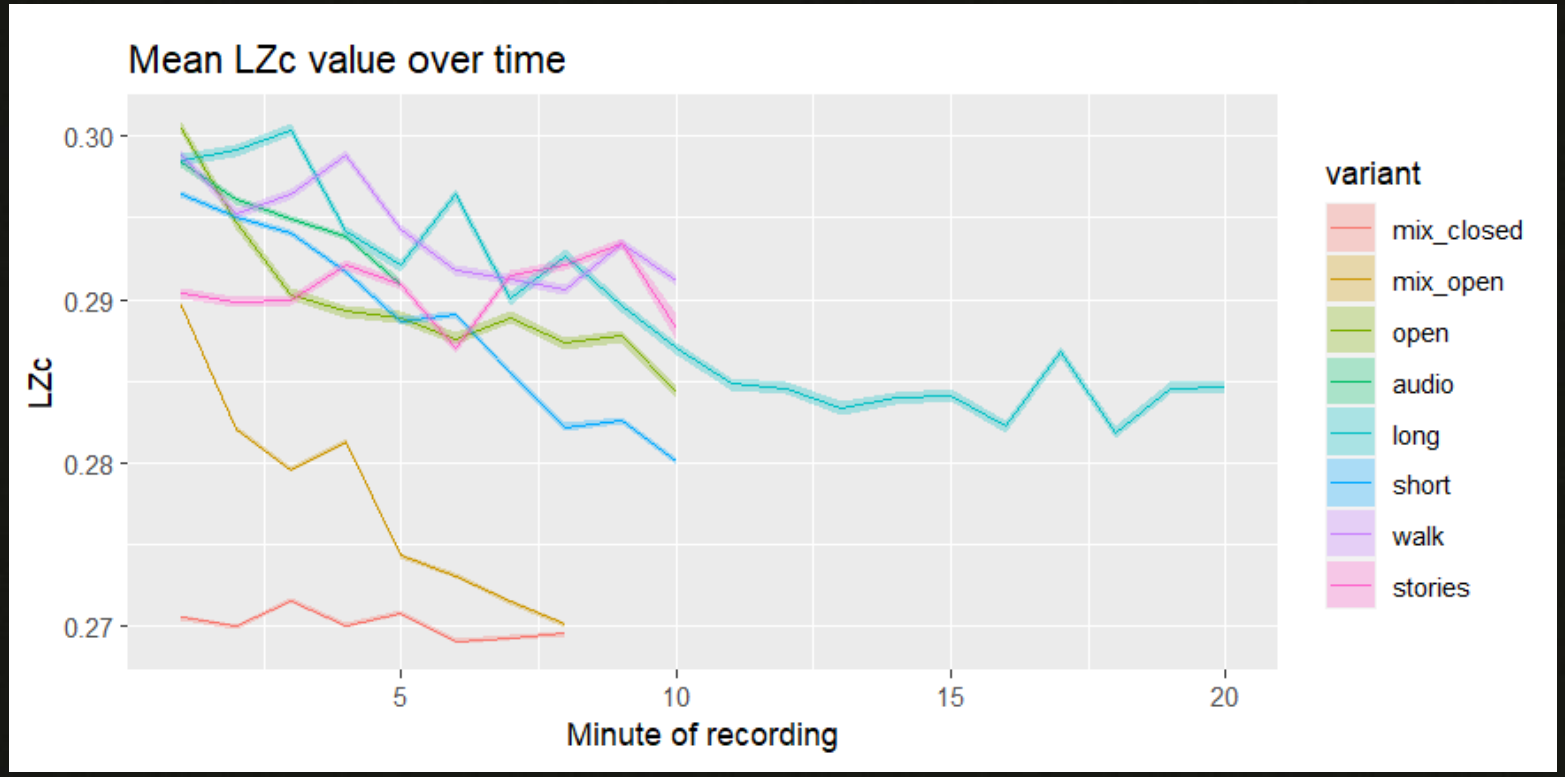
# Dataset condition matrices

| AUDIO | MIX | OPEN | LONG | SHORT | STORIES | WALK |
|---|---|---|---|---|---|---|
| 225 | 210 | | | 165 | 141 | 135 |
| | 402 | | | 289 | 140 | 138 |
| | | 107 | 103 | | | |
| | | | 112 | | | |
| | | | | 310 | 110 | 107 |
| | | | | | 156 | 137 |
| | | | | | | 150 |

| | RUNS | |
|---|---|---|
| | 2 | 3 |
| AUDIO | 25 | 1 |
| MIX | 152 | 8 |
| OPEN | | |
| LONG | | |
| SHORT | 23 | 2 |
| STORIES | 10 | |
| WALK | 13 | |

Subgoal 2

# Temporal dynamics of complexity



## Subgoal 3

# Universal complexity

Complexity measures capture general system properties

- Detachment from theoretical framework of IIT
- Proposal for simpler but testable underlying mechanisms

Data-driven exploration of relations between complexity and consciousness

- Utilising available data
- Focus on generalizability
- Understanding parameter space of the measure

New hybrid approaches



Subgoal 4

# Proof of (complex) concept

## Hypothesis

Lempel-Ziv complexity will track conscious content
as operationalized between resting-state conditions.

## Baselines

Selectivity for conscious content – alpha (arousal/perceptual confounds)

Specificity of complexity variant – MSE, DFA

Robustness of estimation – ROI, temporal dynamics, window size



# Was it worth it?

## Outcomes

Important contribution to resting-state modernization movement

Unique resting-state database for general purpose research

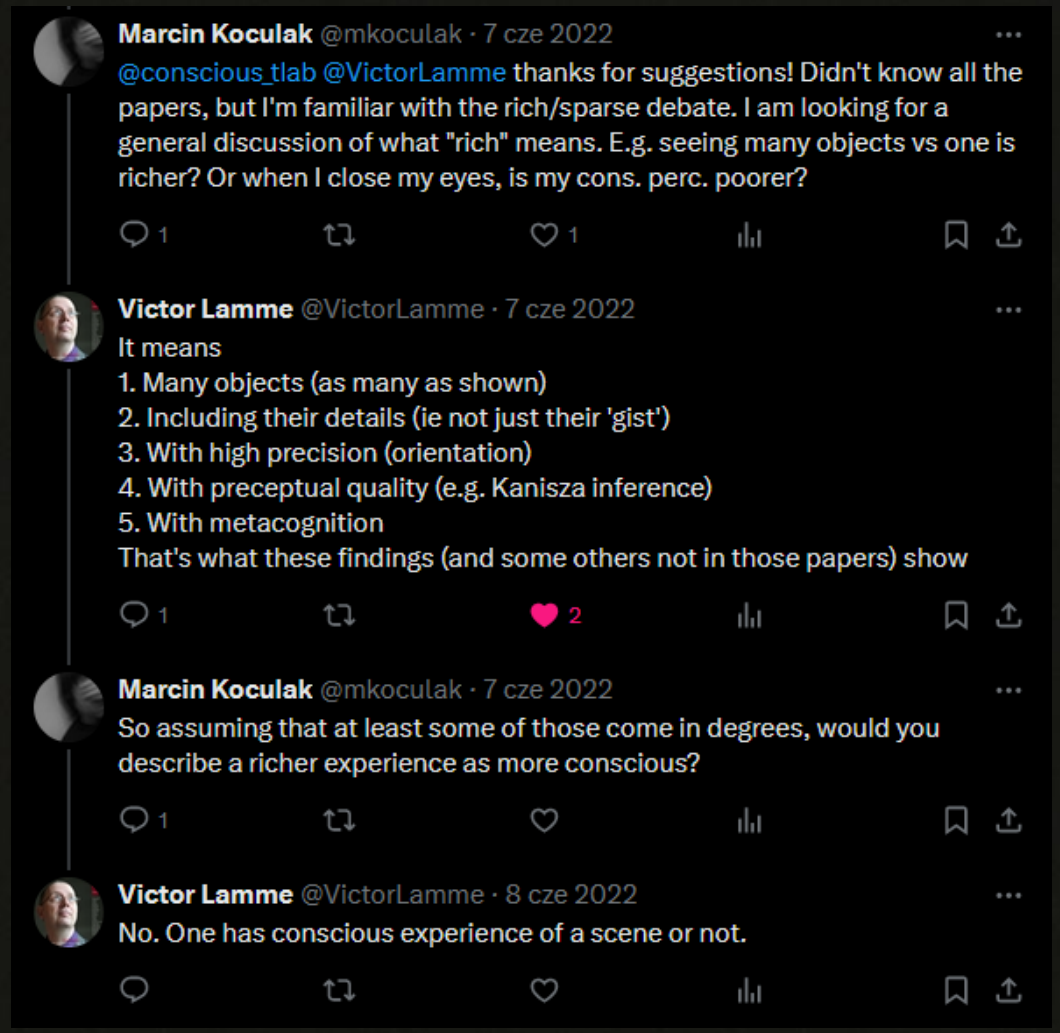
Proposal for data-driven content/qualia research paradigm

Proof-of-concept application of the paradigm to data



# Qualia or quantia?

# Qualia or quantia?



**Marcin Koculak** @mkoculak · 7 cze 2022

@conscious_tlab @VictorLamme thanks for suggestions! Didn't know all the papers, but I'm familiar with the rich/sparse debate. I am looking for a general discussion of what "rich" means. E.g. seeing many objects vs one is richer? Or when I close my eyes, is my cons. perc. poorer?

1 · 1

**Victor Lamme** @VictorLamme · 7 cze 2022

It means
1. Many objects (as many as shown)
2. Including their details (ie not just their 'gist')
3. With high precision (orientation)
4. With preceptual quality (e.g. Kanisza inference)
5. With metacognition

That's what these findings (and some others not in those papers) show

1 · 2

**Marcin Koculak** @mkoculak · 7 cze 2022

So assuming that at least some of those come in degrees, would you describe a richer experience as more conscious?

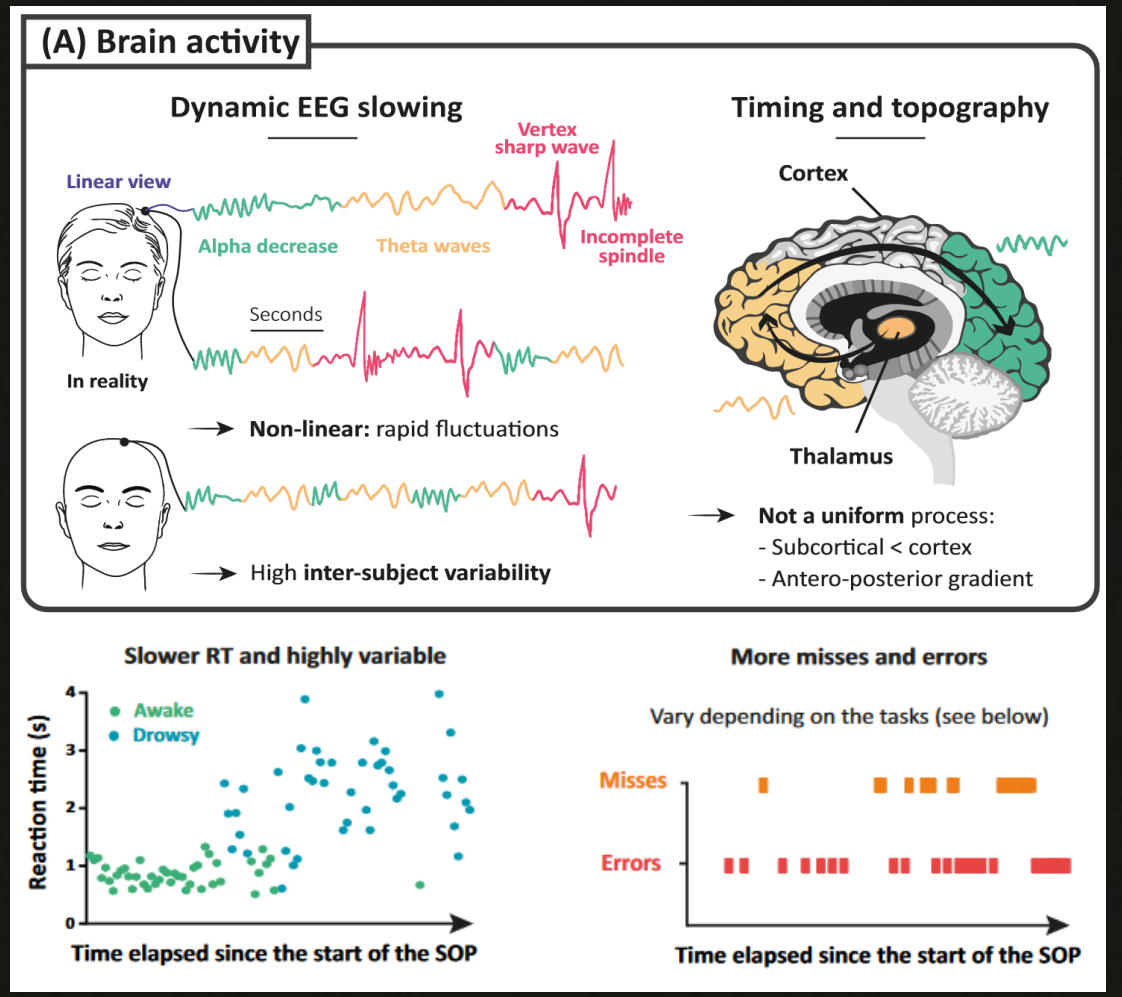
1

**Victor Lamme** @VictorLamme · 8 cze 2022

No. One has conscious experience of a scene or not.

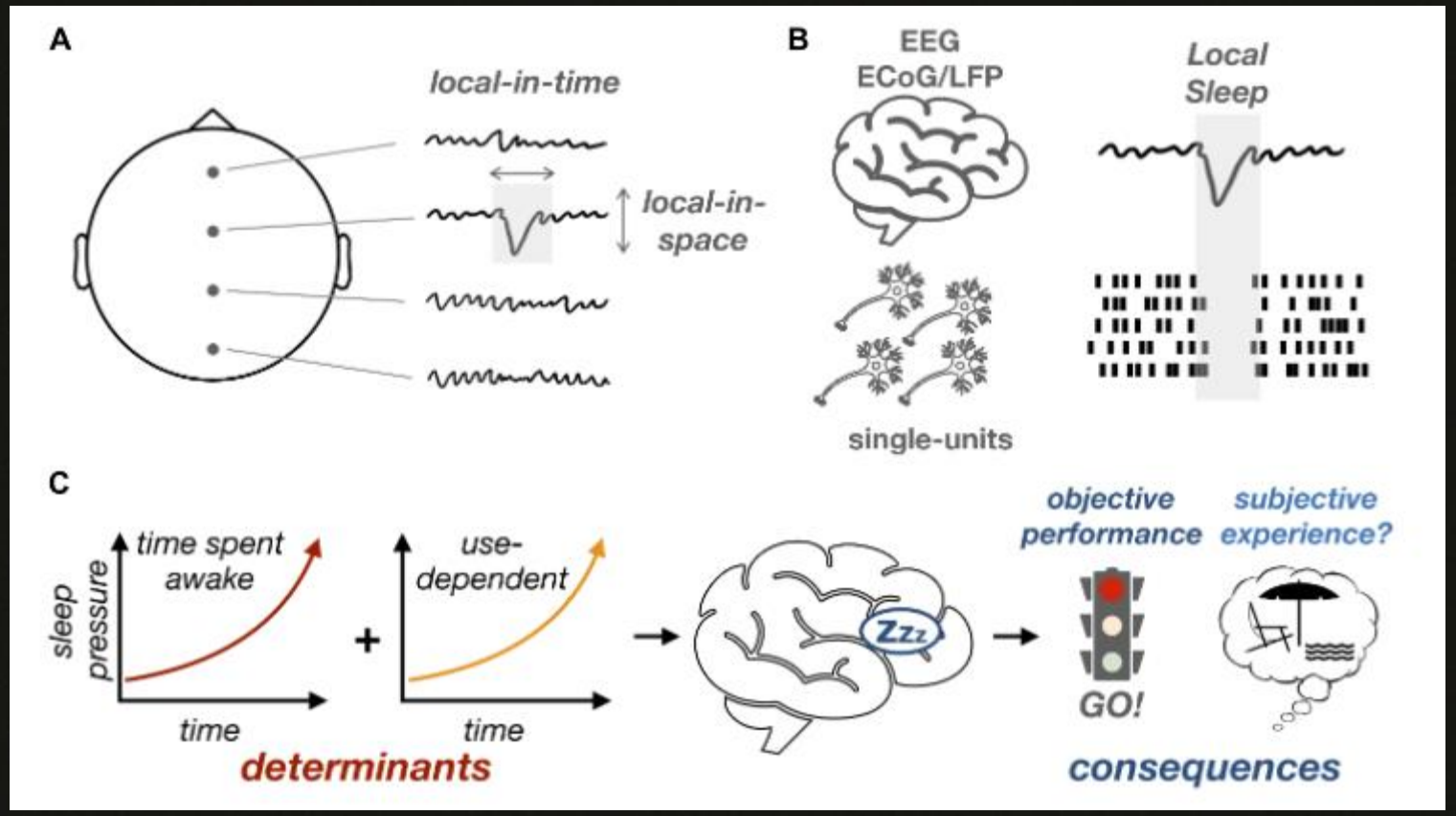
# Combined paradigms

Lacaux, C., Strauss, M., **Bekinschtein, T. A.**, & Oudiette, D. (2024). **Embracing sleep-onset complexity**. Trends in Neurosciences, 47(4), 273–288. https://doi.org/10.1016/j.tins.2024.02.002



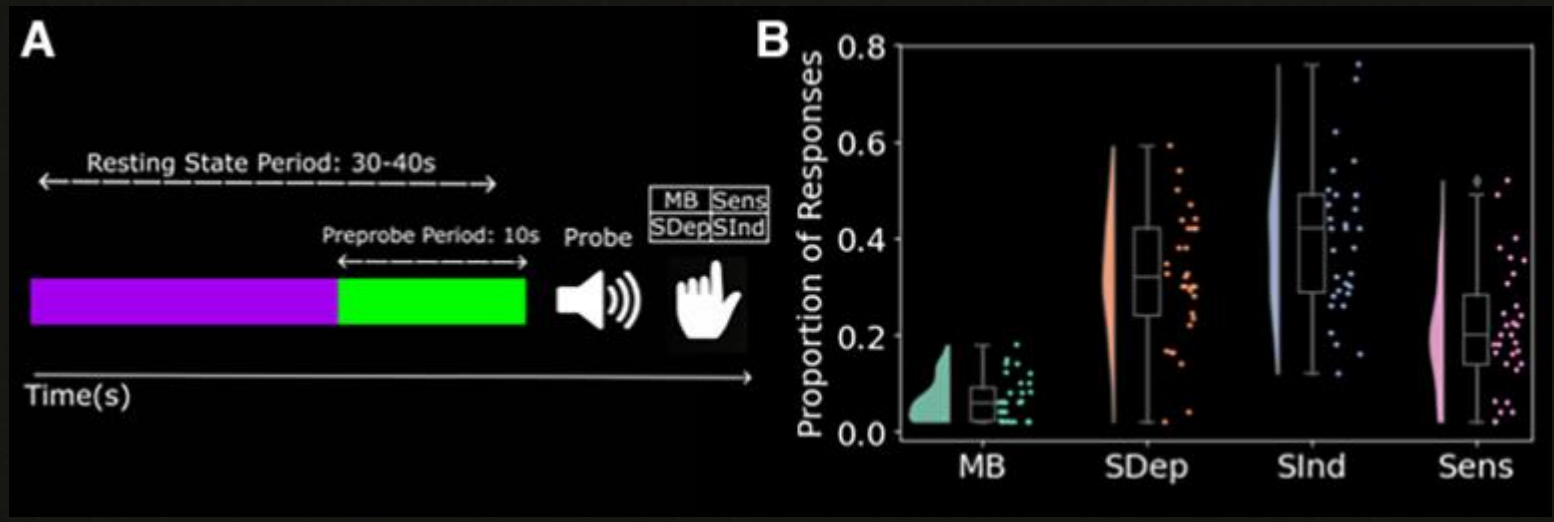
# Combined paradigms

Andrillon, T., Windt, J., Silk, T., Drummond, S. P. A., Bellgrove, M. A., & Tsuchiya, N. (2019). **Does the Mind Wander When the Brain Takes a Break? Local Sleep in Wakefulness, Attentional Lapses and Mind-Wandering.** Frontiers in Neuroscience, 13, 949. https://doi.org/10.3389/fnins.2019.00949



# Combined paradigms

Boulakis, P. A., Mortaheb, S., Calster, L. van, Majerus, S., & Demertzi, A. (2023). **Whole-Brain Deactivations Precede Uninduced Mind-Blanking Reports.** Journal of Neuroscience, 43(40), 6807–6815. https://doi.org/10.1523/JNEUROSCI.0696-23.2023



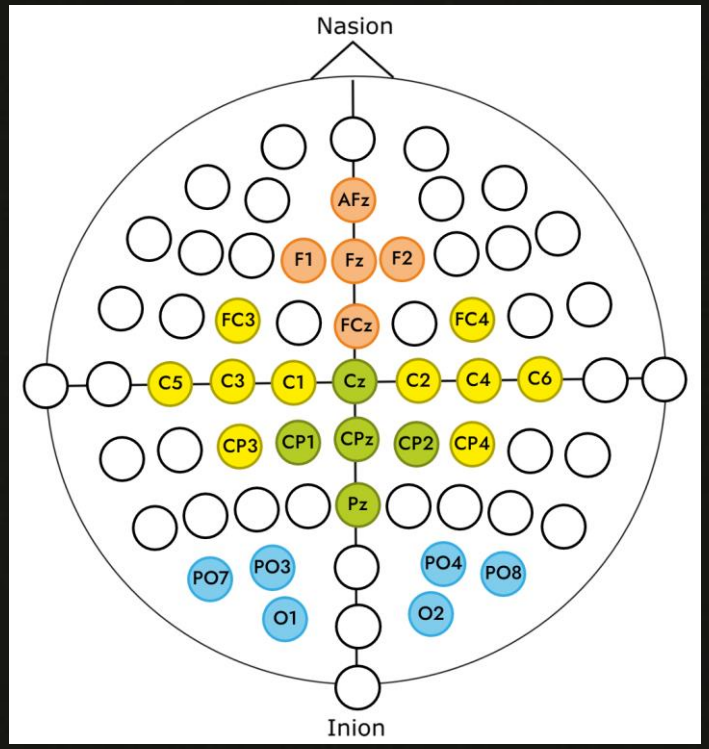
# "Localization" issues

**"AUDITORY"**

Reported in literature as locations for early auditory correlates (e.g. AAN)

**"VISUAL"**

Early correlates of conscious visual perception (e.g. VAN)




**"CENTRO-FRONTAL"**

Added as non-sensory baseline region for comparison purpose.

**"CENTRO-PARIETAL"**

Late correlates of conscious visual perception (e.g. P300)

# Why these measures?

Nilsen, A. S., Juel, B., Thürer, B., & Storm, J. F. (2020). **Proposed EEG measures of consciousness: a systematic, comparative review.** https://doi.org/10.31234/osf.io/sjm4a

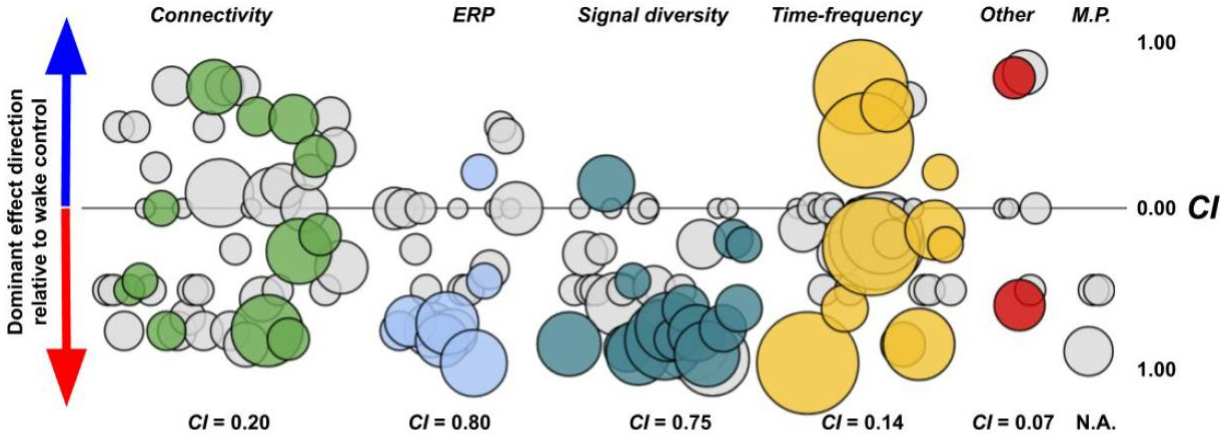



**Figure 2. Overview of measures and categories.** Each bubble represents a single measure with size determined by the number of results registered and position by *CI* and dominant effect direction relative to wake control (increase or decrease). Light grey bubbles represent measures that were removed in the filtering process (see Suppl. 1) with *CI* determined at filtering step S1.2. Colored bubbles are measures that remained after the filtering process, with *CI* determined at filtering step S1.6. *CI* for categories, presented as numbers along the bottom of the figure, is determined at S1.6. The category *multi-parameter* (*M.P.*) had no measures surviving the filtering process, and therefore has no estimate of consistency available.

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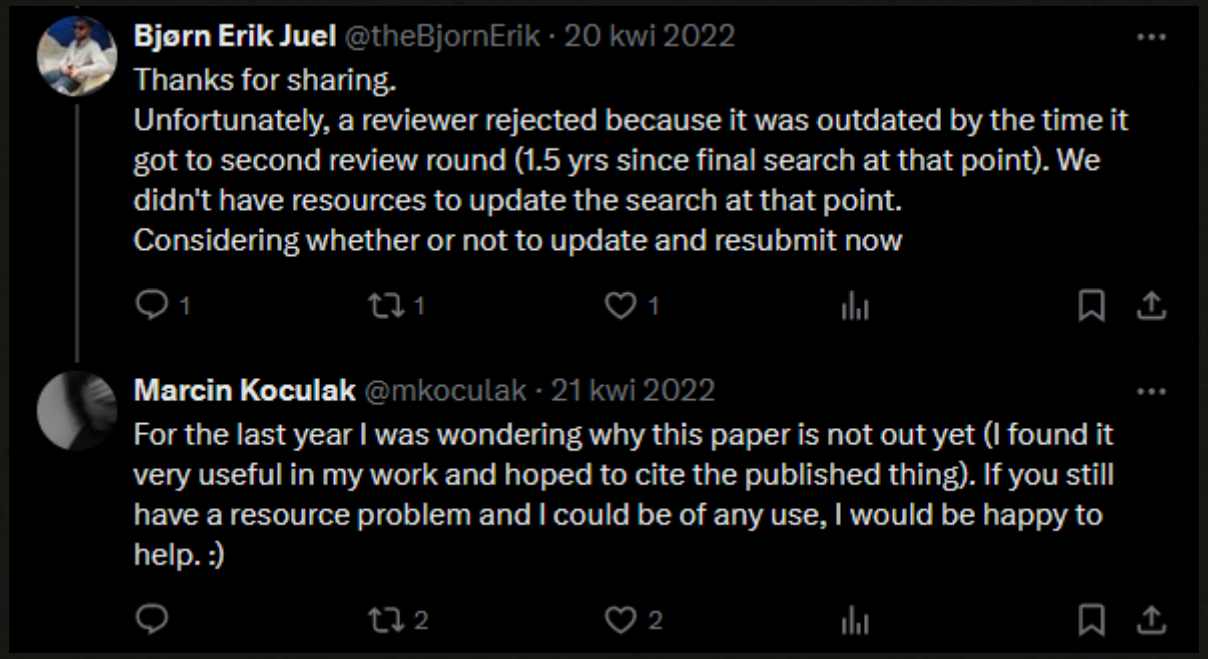
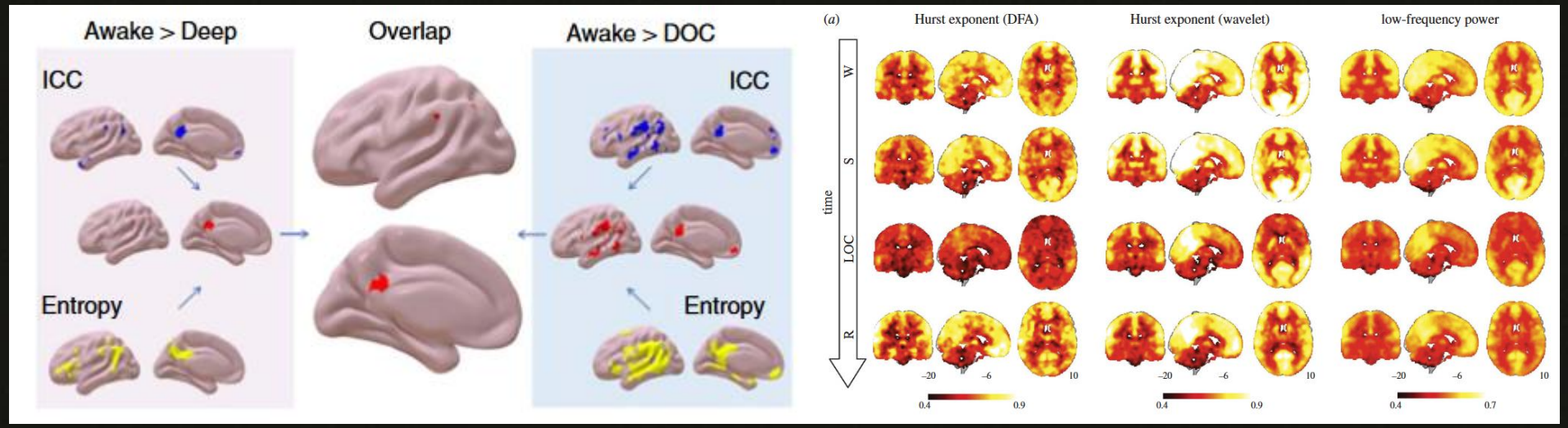
Nilsen, A. S., Juel, B., Thürer, B., & Storm, J. F. (2020). **Proposed EEG measures of consciousness: a systematic, comparative review.** https://doi.org/10.31234/osf.io/sjm4a



# Why these measures?

**Luppi, A. I.**, Craig, M. M., Pappas, I., Finoia, P., Williams, G. B., Allanson, J., Pickard, J. D., Owen, A. M., Naci, L., Menon, D. K., & Stamatakis, E. A. (2019). **Consciousness-specific dynamic interactions of brain integration and functional diversity**. Nature Communications, 10(1), 4616. https://doi.org/10.1038/s41467-019-12658-9

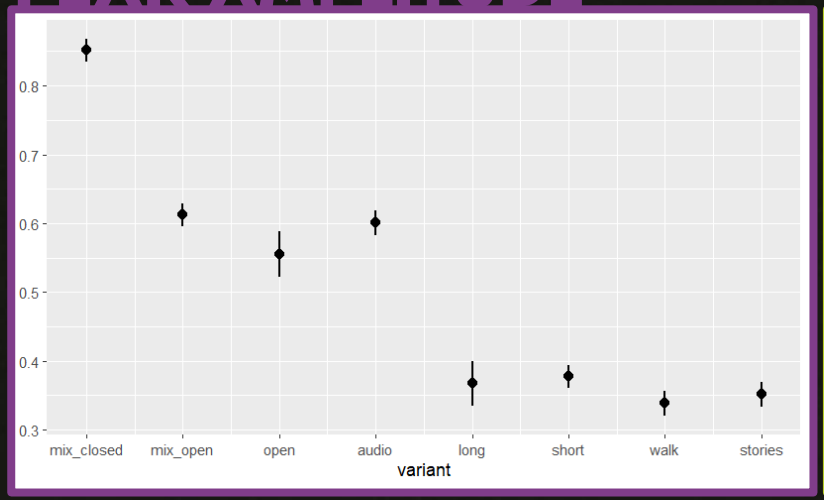
**Tagliazucchi, E.**, Chialvo, D. R., Siniatchkin, M., Amico, E., Brichant, J.-F., Bonhomme, V., Noirhomme, Q., Laufs, H., & Laureys, S. (2016). **Large-scale signatures of unconsciousness are consistent with a departure from critical dynamics.** Journal of The Royal Society Interface, 13(114), 20151027. https://doi.org/10.1098/rsif.2015.1027



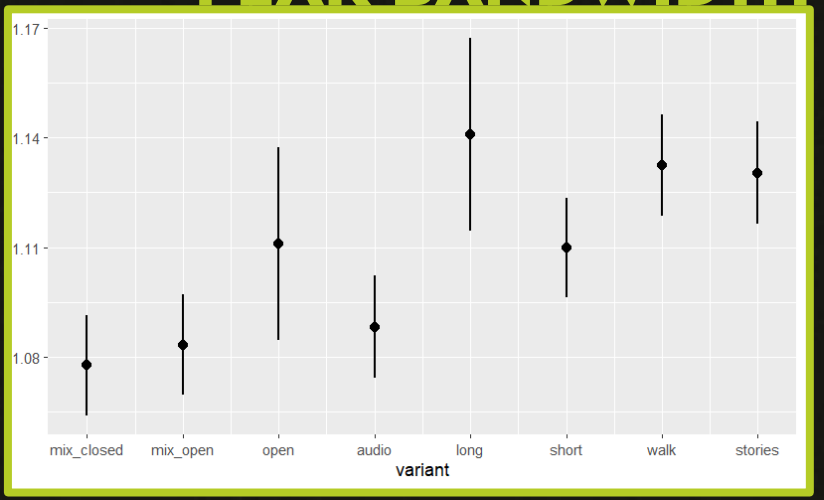
# Why these measures?

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Clarke, A. R. (2020). **Natural alpha frequency components in resting EEG and their relation to arousal.** Clinical Neurophysiology, 131(1), 205–212. https://doi.org/10.1016/j.clinph.2019.10.018

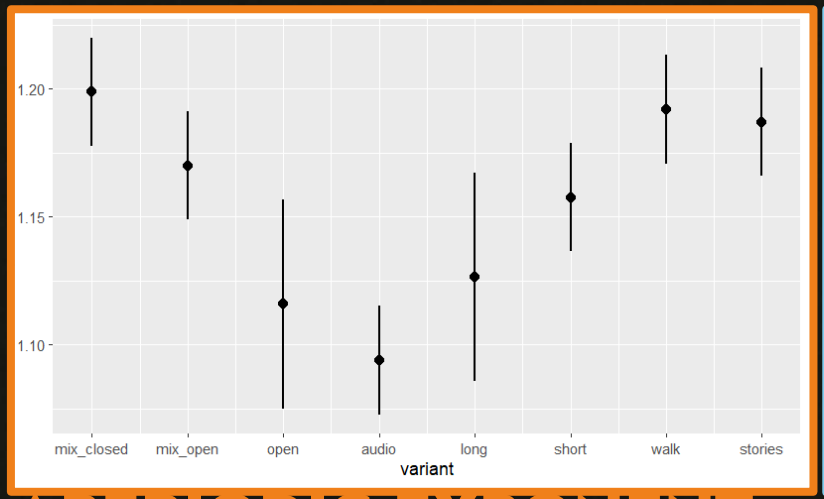
## Peak Amplitude



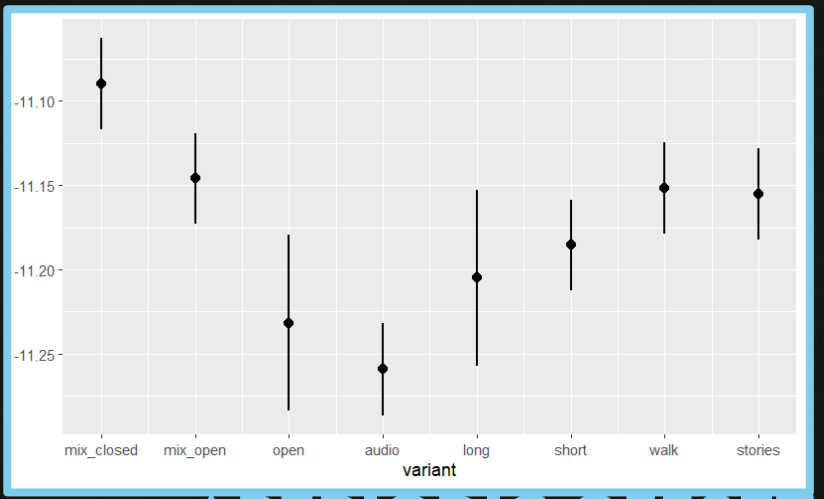

## Peak Bandwidth



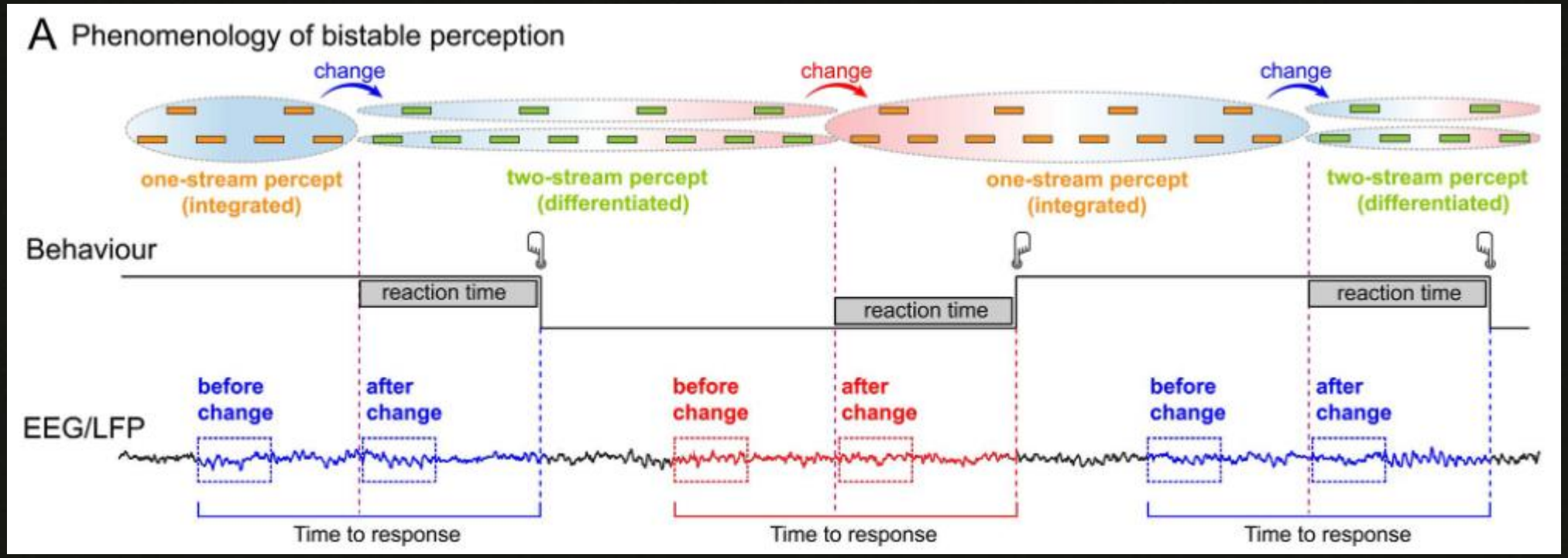

## Aperiodic Exponent




## Aperiodic Offset



# Other measures




Canales-Johnson, A., Billig, A. J., Olivares, F., Gonzalez, A., Garcia, M. D. C., Silva, W., Vaucheret, E., Ciraolo, C., Mikulan, E., Ibanez, A., Huepe, D., Noreika, V., Chennu, S., & Bekinschtein, T. A. (2020). **Dissociable Neural Information Dynamics of Perceptual Integration and Differentiation during Bistable Perception.** Cerebral Cortex, 30(8), 4563–4580. https://doi.org/10.1093/cercor/bhaa058

Other

# Good to have

- Raincloud plots
- Bayesian multilevel mixed modelling