Promising EEG-based markers of consciousness

BCI Meeting

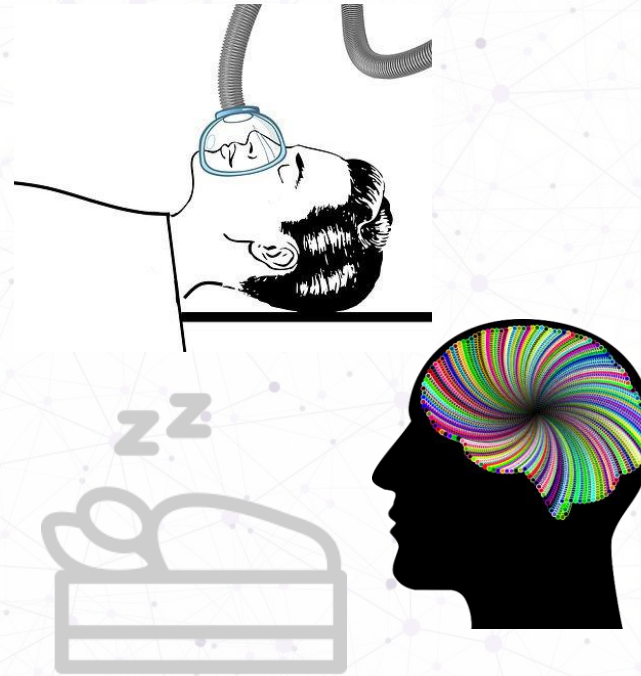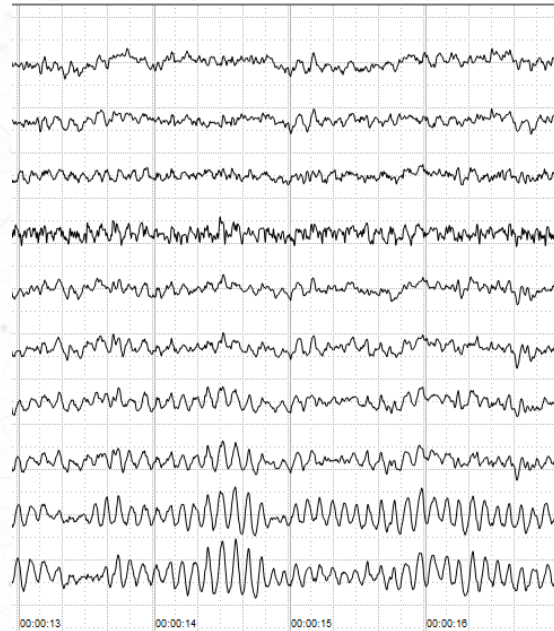Banff 2025

Bjørn Erik Juel

EEG-based marker of consciousness

Measurable signatures in the electrical brain activity
that are **always apparent** when some individual **is conscious**
and is **never there** when their **consciousness is gone**.

An example strategy for finding an EEG-based markers of consciousness
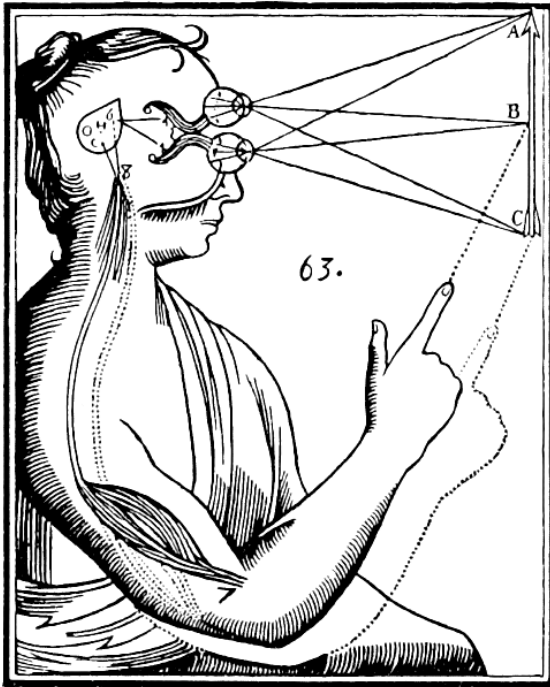
Measure brain signals from individuals ...

... and check if your marker of reliably tracks changes in consciousness!

... in different states ...

Why do we want markers of consciousness?

Approaching a fundamental understanding of consciousness

www.wikipedia.com/consciousness

Developing tools to aid clinicians in monitoring conciousness in patients

www.covidien.com

Electrophysiological Markers of Consciousness:

Measures of connectivity, complexity, and signal diversity in EEG for distinguishing between conscious and unconscious brain states

Thesis for the degree of Philosophiae Doctor (PhD) by

Bjørn Erik Juel

Institute of Basic Medical Sciences

Faculty of Medicine

University of Oslo

2018

Some examples of Electrophysiological markers of consciousness?

Strong feedback

High spectral edge frequ

High (xyz) entro

High fracta

Low slow-wave acti

transfer entropy

w spectral exponent

ecific
nts

High mutual information

world connectivity

w delta power

Proposed EEG measures of consciousness: a systematic, comparative review

André Sevenius Nilsen*, Bjørn Erik Juel, Benjamin Thürer, Johan Frederik Storm*

Brain Signalling Group, Department of Molecular Medicine, Institute of Basic Medical Sciences, University of Oslo (UiO), 0372 Oslo, Norway
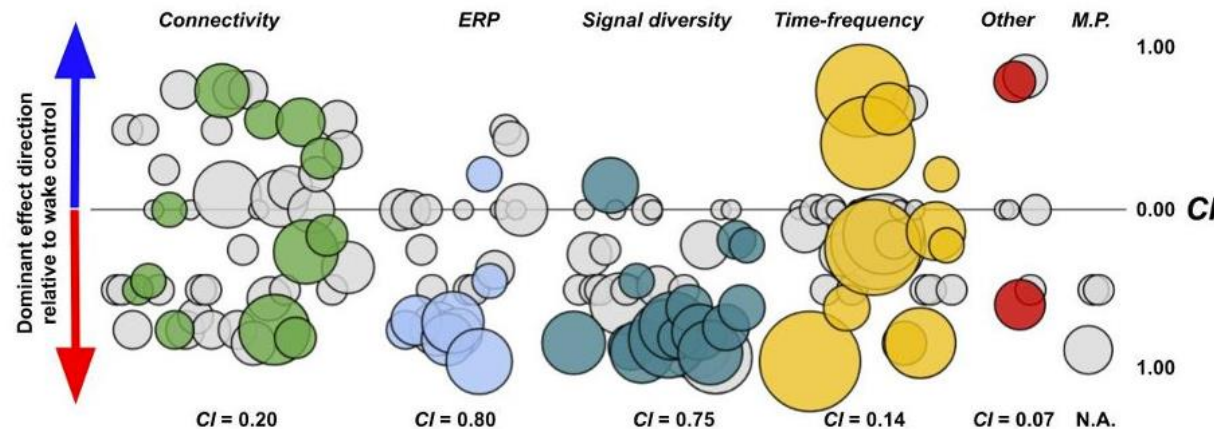
Limitations

Most measures

- … are tested without explicit control of conscious experience

- … are tested in between state paradigms

- … have no clear theoretical grounding

- … fail crucial tests (see next presentation).

Kinds of EEG markers of consciousness
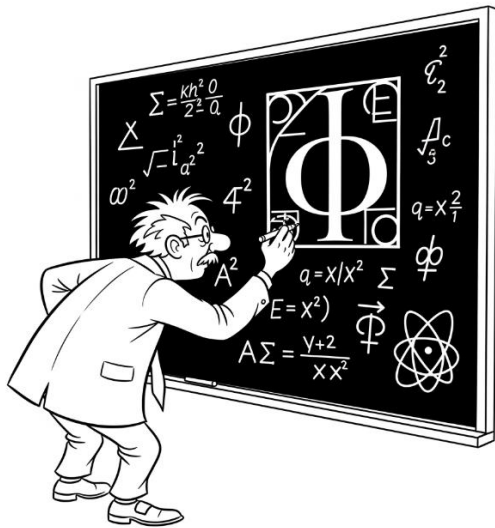
Theory vs. data driven

State vs. content based

Resting state vs. Evoked activity

Kinds of EEG markers of consciousness

Theory vs. data driven

State vs. content based
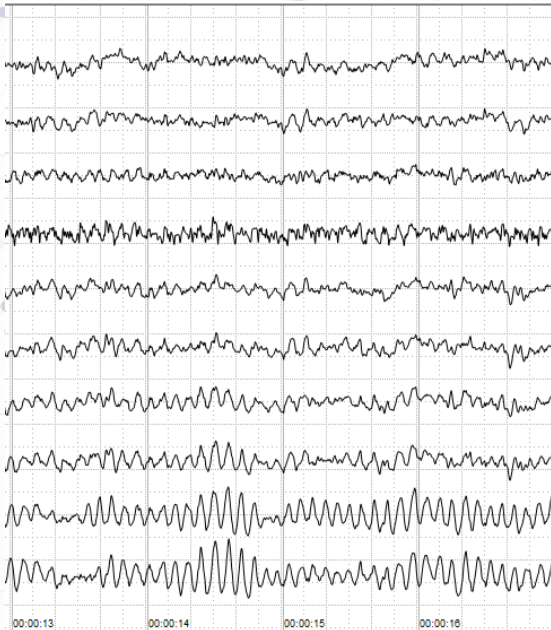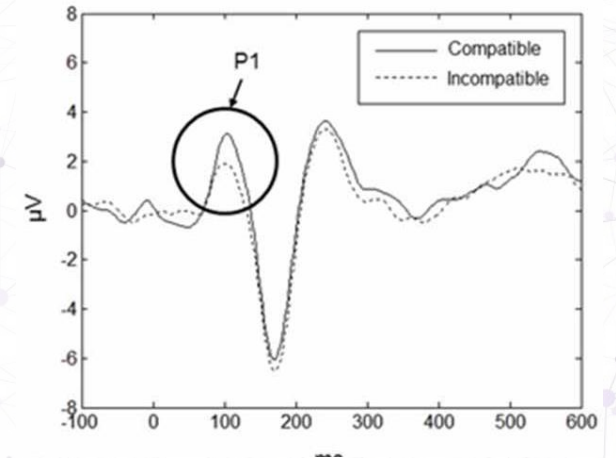
Resting state vs. Evoked activity

Kinds of EEG markers of consciousness
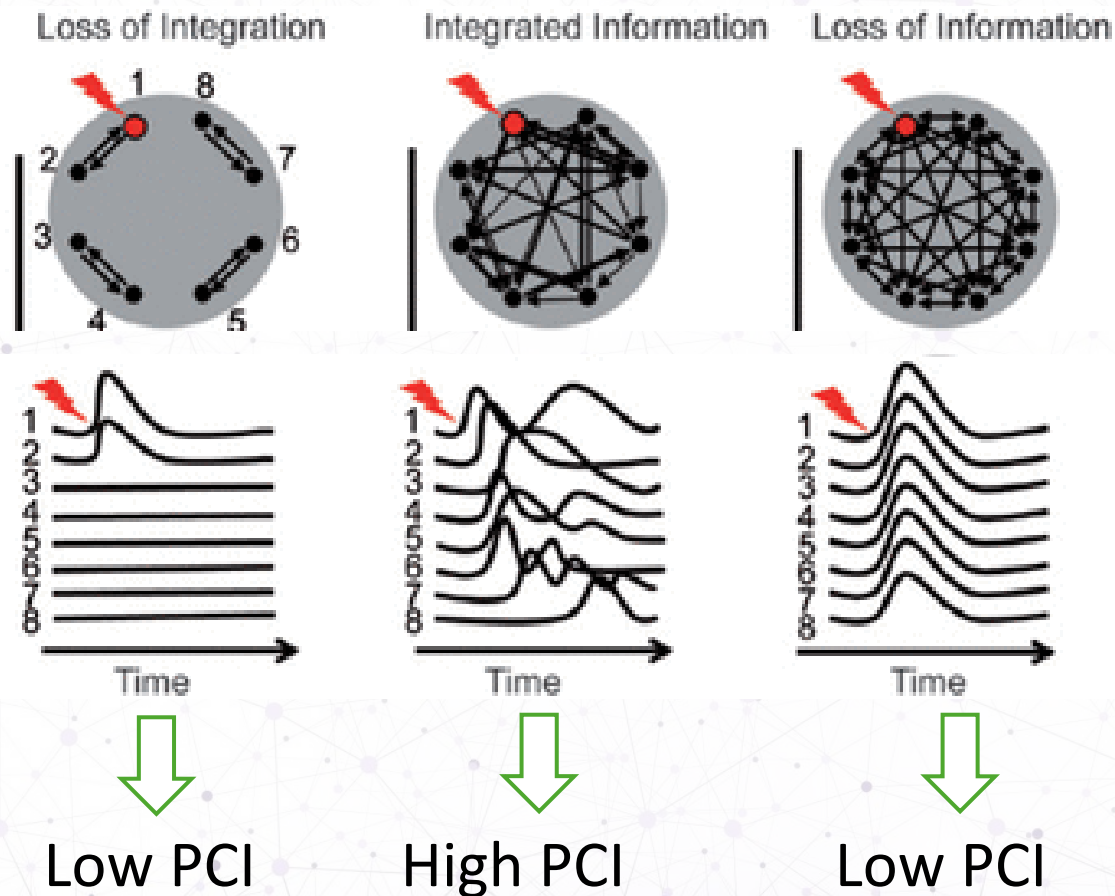
Theory vs. data driven
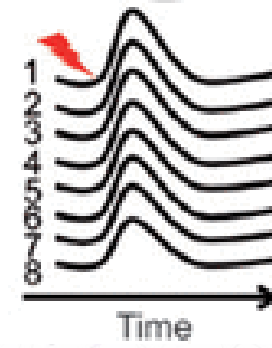
State vs. content based

Resting state vs. Evoked activity

One example of a proposed marker: Perturbational complexity index (PCI)

Massimini

Tononi

Theory vs. data driven

State vs. content based

Resting state vs. Evoked activity
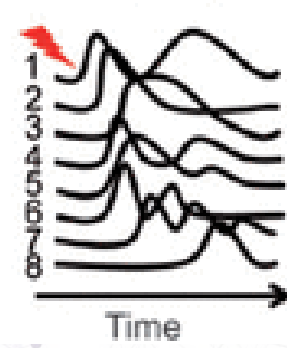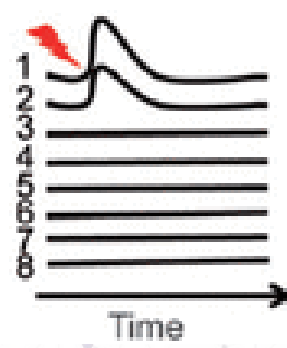
Casali et al 2013, Sci Transl Med

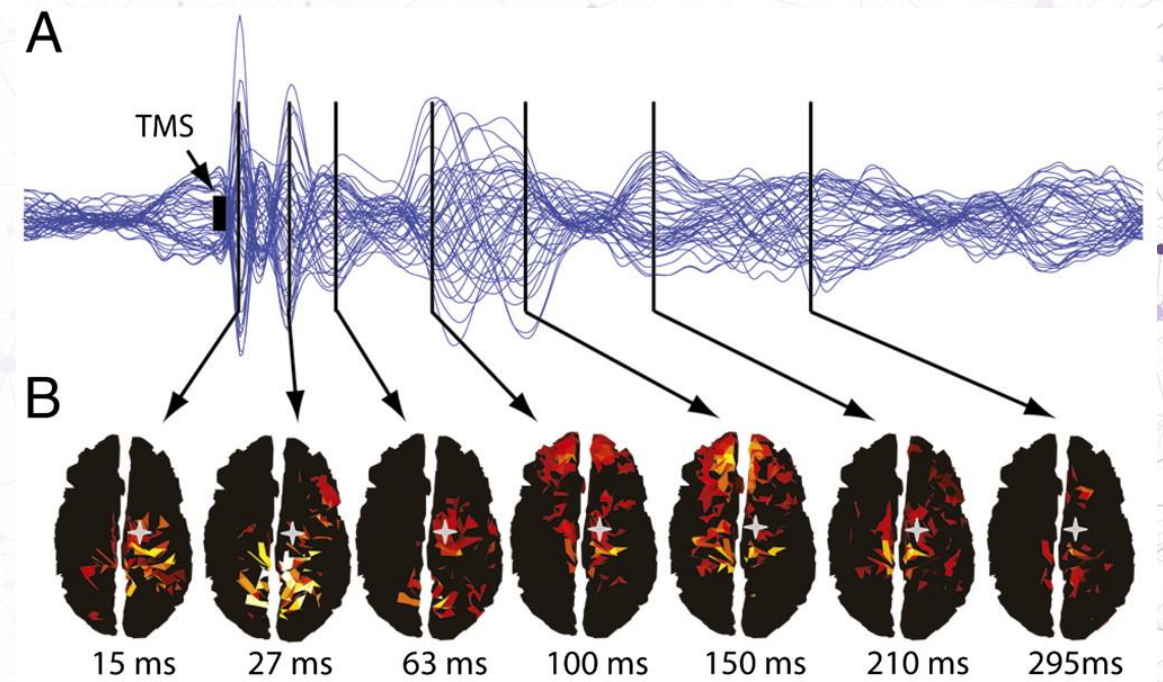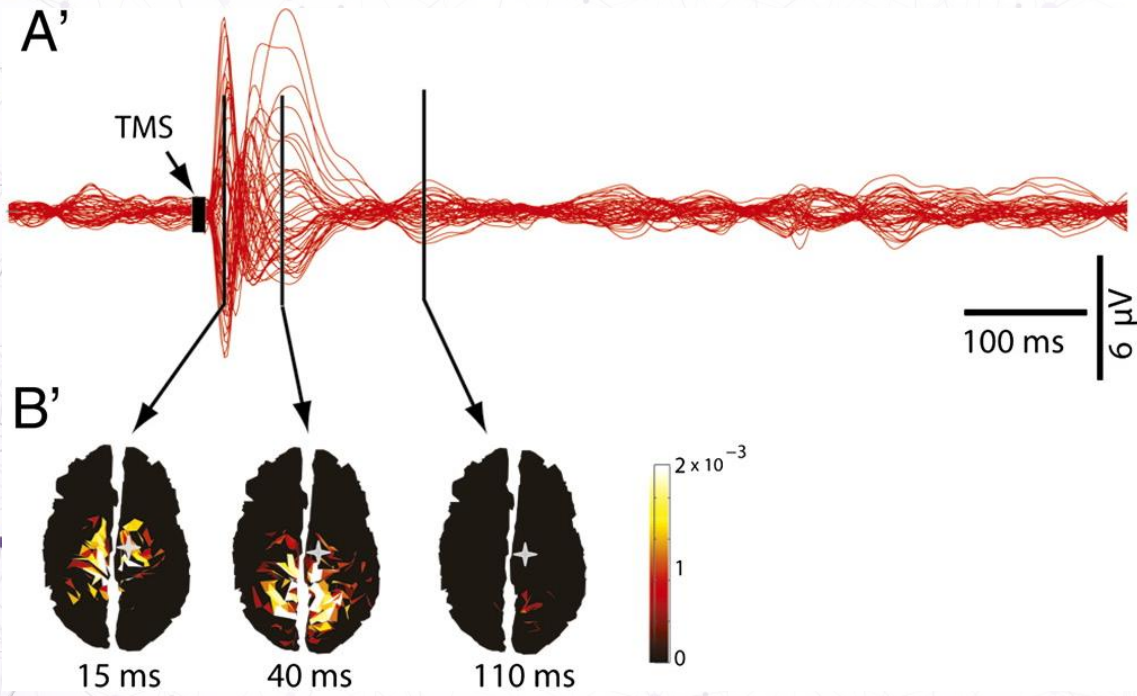# One example of a proposed marker: Perturbational complexity index (PCI)

Propofol anesthesia

Awake control subject

A' TMS 100 ms 6 μV

B' 15 ms 40 ms 110 ms

A TMS

B 15 ms 27 ms 63 ms 100 ms 150 ms 210 ms 295ms

Ferrarelli et al 2010, PNAS

Perturbational complexity index

Koch et al. 2016

Nature Reviews | Neuroscience
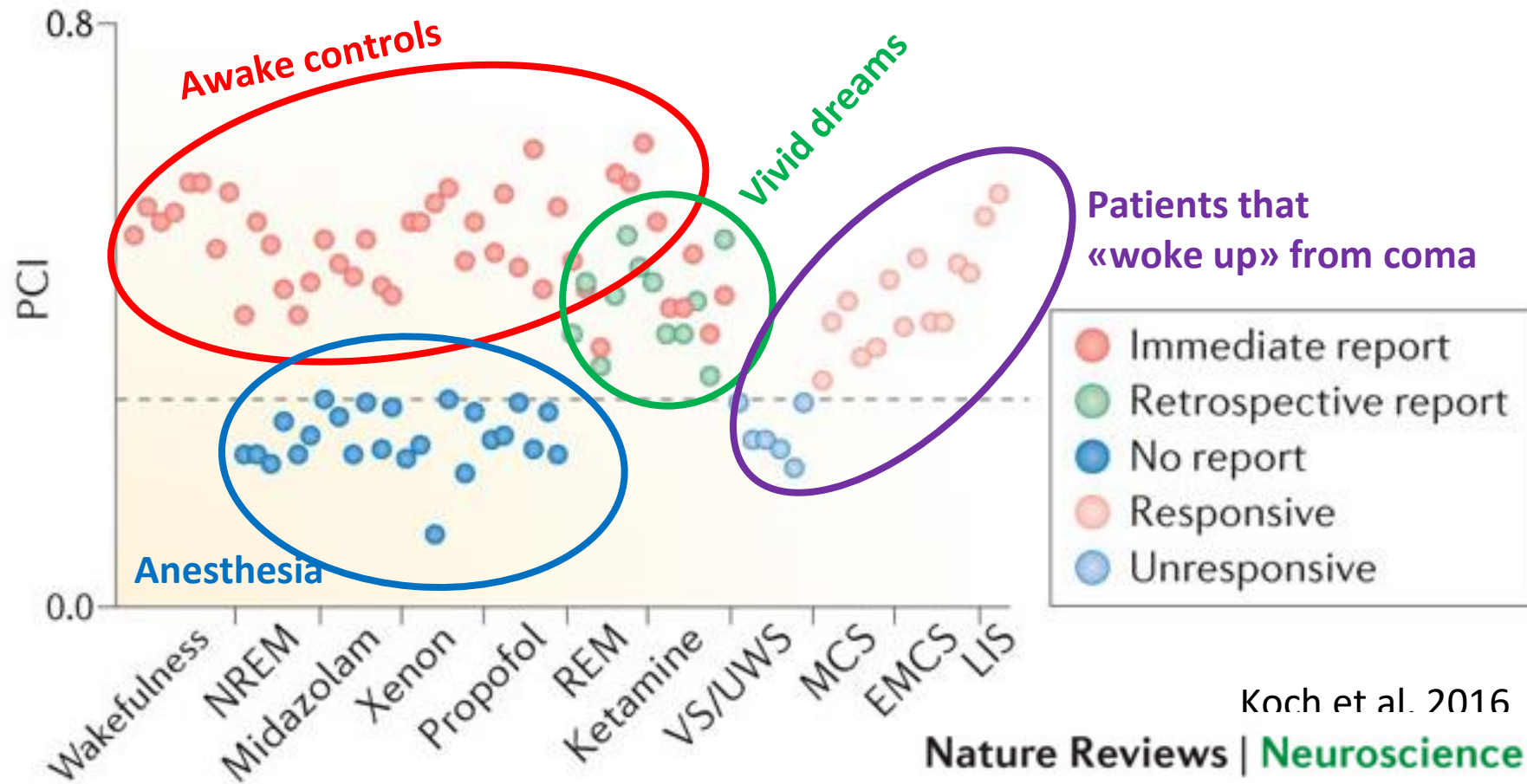
So what are
promising EEG-based markers of consciousness?

It depends! ☹

- An (opinionated) list of characteristics:
  - Independent of behavioral and physiological state
  - Theoretically grounded
  - Practically applicable
  - Indicative of the structure (content) of the experience