Human consciousness

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Group Meeting Literature Review
September 22nd, 2021
“Brain in a vat” in different cultures across the world

The material world is an illusion ("Maya") over the soul
Hinduism (1200 BC)

“Suddenly he woke up … but he didn't know if he was Zhuang Zhou who had dreamt he was a butterfly, or a butterfly dreaming that he was Zhuang Zhou”
Taoist philosophy (300 BC)

An evil demon of “the utmost power … to deceive me”
Descartes (1641)
Cartesian philosophy

The Allegory of the Cave
Plato (514 AD)

“If real is what you can feel, smell, taste and see, then 'real' is simply electrical signals interpreted by your brain”
The Matrix (2001)
Consciousness is our only interface with the world.

“I think, therefore I am”

René Descartes (1637)

“Brain in a vat” in different cultures across the world

An evil demon of “the utmost power … to deceive me”

Descartes (1641)

Cartesian philosophy
The “easy problem”

*How* the brain gives rise to
- Perception
- Cognition
- Learning
- Behavior

The “hard problem”

Why and how does this relate to consciousness?

The study of **human consciousness** may appear untenable at a glance.

The "hard problem"

The "easy problem"

How the brain gives rise to
- Perception
- Cognition
- Learning
- Behavior

Why and how does this relate to consciousness?

The real problem

How to account for various properties of consciousness in terms of biological mechanisms

Without pretending it doesn’t exist

Without worrying about explaining its ultimate origin

Historic parallels with the study of life

George Louis Leclerc (1749)
Hypothetical material units called “organic molecules”

René Descartes (1637)
“I think, therefore I am”

Neither is “one thing”, but they have many potentially separable aspects

Encyclopedia Britannica (2020)
Life is defined as any system capable of performing functions such as eating, metabolizing, excreting, breathing, moving, growing, reproducing, and responding to external stimuli.

Modern studies of consciousness

Tirard, S.; Morange, M.; Lazcano, A. Astrobiology 2010, 10 (10), 1003.
Outline

**Conscious level**

e.g. vividly awake vs. dreamless sleep

**Conscious content**

What populates your experience when you are awake

- sights, sounds, smells
- emotions, thoughts, beliefs

**Conscious self**

specific experiences of *being you*
Outline

Conscious level

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- What populates your experience when you are awake
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Conscious self

- specific experiences of being you
Conscious level

What are the fundamental brain mechanisms that underlie our ability to be conscious at all?

It is NOT…

- simply being awake
  (consider dreaming, or dream/wake cycles in vegetative states)

- the number of neurons
  (the cerebellum has 4X neurons as the rest of the brain, while barely involved in maintaining consciousness)
Conscious level

What are the fundamental brain mechanisms that underlie our ability to be conscious at all?

It is NOT…

- the overall level of neural activity

Energy use during non-rapid eye movement sleep is ~85% of that during waking state
Conscious level

What are the fundamental brain mechanisms that underlie our ability to be conscious at all?

It is NOT…

- the overall level of neural activity

Energy use during non-rapid eye movement sleep is ~85% of that during waking state

Representative PET images across different patients

[18F]-fluorodeoxyglucose

UWS: unresponsive wakefulness syndrome
MCS: minimally conscious state
EMCS: emerging from MCS

Conscious level

What are the fundamental brain mechanisms that underlie our ability to be conscious at all?

It is NOT…

- the overall level of neural activity

Consciousness can be sustained <42% of the energy in healthy conscious individuals.

UWS: unresponsive wakefulness syndrome
MCS: minimally conscious state
EMCS: emerging from MCS

Conscious level

What are the fundamental brain mechanisms that underlie our ability to be conscious at all?

It is NOT…

- the overall level of neural activity

Unconsciousness induced by anesthetics does not correlate with brain metabolism.

-Halothane
-Isoflurane
-Propofol

-decreases metabolism

-Induces unconsciousness

-(±) Ketamine

-increases metabolism

Conscious level reflected by crosstalk between different sections of the brain

Pioneered by Giulio Tononi (University of Wisconsin, Madison) and Marcello Massimini (University of Milan)

Photo credit: g.tec medical engineering GmbH Austria
Napolitani, M. Brain Inj. 2014, 28, 1180.
Conscious level reflected by crosstalk between different sections of the brain

Transcranial magnetic stimulation (TMS)

Magnetic pulses

Secondary ionic currents in neurons

Localized depolarization

Cascaded ion movements across neurons propagate to the scalp in the form of a wave, then detected by electrodes.

Pioneered by Giulio Tononi (University of Wisconsin, Madison) and Marcello Massimini (University of Milan)

Photo credit: g.tec medical engineering GmbH Austria

Napolitani, M. Brain Inj. 2014, 28, 1180.
Conscious level reflected by crosstalk between different sections of the brain

EEG signal at location of TMS stimulus
EEG signal other areas of the brain

Conscious
Complex resonances across the brain
Wakefulness

MCS: minimally conscious state

Napolitani, M. Brain Inj. 2014, 28, 1180.
Conscious level reflected by crosstalk between different sections of the brain

EEG signal at location of TMS stimulus

EEG signal other areas of the brain

**Conscious**
Complex resonances across the brain

**Wakefulness**

**Unconscious**
Simple echo to stimulus

**UWS**: unresponsive wakefulness syndrome

Conscious level reflected by crosstalk between different sections of the brain

Wakefulness
REM: rapid eye movement (dreaming)

NREM sleep: non-rapid eye movement (not dreaming)
Anesthesia
UWS: unresponsive wakefulness syndrome

Unconscious
simple echo to stimulus

MCS: minimally conscious state

Napolitani, M. Brain Inj. 2014, 28, 1180.
There is a clinical need to reliably and objectively assess the level of consciousness of patients. (e.g. locked-in syndrome)

How can we quantify consciousness level?

“In physical science the first essential step in the learning of any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it.”

–Lord Kelvin, on the development of accurate thermometers
Two key attributes to quantifying consciousness

Key theoretical insight:
consciousness requires an optimal balance of functional integration and functional differentiation
Perturbational complexity index (PCI) to quantify conscious level

Key theoretical insight:
consciousness requires an optimal balance of **functional integration** and **functional differentiation**

quantified by how “compressible” they are, similar to how digital photos are compressed

Transcranial magnetic stimulation (TMS)

Electroencephalography (EEG) signal across 60 electrodes

Perturbational complexity index (PCI) to quantify conscious level

Perturbational complexity index (PCI) to quantify conscious level

Mathematical manipulations to arrive at a binary distribution
*(weighted minimum norm inverse solution and nonparametric bootstrap-based statistical procedure)*

Electroencephalography (EEG) signal across 60 electrodes

Perturbational complexity index (PCI) to quantify conscious level

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Perturbational complexity index (PCI) to quantify conscious level

Mathematical manipulations to arrive at a binary distribution
(weighted minimum norm inverse solution and nonparametric bootstrap-based statistical procedure)

PCI is independent stimulus strength

High complexity

PCI is expected to be low if:
- reduced interaction among cortical areas (integration)
- perturbations all behave in a stereotypical way (differentiation)

Low complexity regardless of the extent of response to TMS

PCI is independent stimulus location

32 healthy subjects, 152 measurements ("sessions")

PCI is sensitive to gradient changes in consciousness

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Responds readily to name spoken in normal tone</td>
</tr>
<tr>
<td>4</td>
<td>Lethargic response to name spoken in normal tone</td>
</tr>
<tr>
<td>3</td>
<td>Responds only after name is called loudly and/or repeatedly</td>
</tr>
<tr>
<td>2</td>
<td>Responds only after mild prodding or shaking</td>
</tr>
<tr>
<td>1</td>
<td>Responds only after painful trapezius squeeze</td>
</tr>
<tr>
<td>0</td>
<td>No response after painful trapezius squeeze</td>
</tr>
</tbody>
</table>


Modified Observer's Alertness/Sedation scale (MOAA/S)

Clear distinction between “intermediate” (2–3) and “deep” (0–1) anesthesia

REM: rapid eye movement (dreaming)
NREM: non-rapid eye movement (not dreaming)
PCI useful for brain-injured patients

Unconscious: VS/UWS: vegetative state/unresponsive wakefulness syndrome
MCS: minimally conscious state
EMCS: emerging from MCS
LIS: Locked-in syndrome

Conscious

Statistical significance evaluated by a linear mixed model

\[ *P = 0.002, \; **P = 0.0001, \; ***P = 2 \times 10^{-5}, \; ****P = 8 \times 10^{-7} \]

Large improvement over measuring energy consumption

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Conscious self
specific experiences of being you
Neural correlates of consciousness (NCC)

NCC: the minimum neural mechanisms sufficient for any one specific conscious percept

Francis Crick
1996–2004

Christof Koch
1956–present

**Neural correlates of consciousness (NCC)**

*NCC: the *minimum* neural mechanisms sufficient for any one specific conscious percept*

*Aims to specifically identify the regions of the brain that are responsible for different aspects of consciousness*
The posterior cortex “hot zone”

Consciousness remains despite absence of cerebellum

24 year-old women, who walked into a hospital complaining of dizziness, leading to her diagnosis

Cerebellum
- contains 50% of the brain’s neurons (69 billion!)
- controls balance, motor actions, speech, etc.

Healthy brain

Cerebellum contains highly parallel circuitry

- Feed forward system, with no complex feedback loop
- Each unit operates in parallel, with distinct inputs and outputs

Binocular Rivalry as an example to investigate NCC

Photo credit: “One Weird Visual Illusion Explained” BrainCraft (Youtube, 2016)
Binocular Rivalry as an example to investigate NCC

The combination of **unchanging physical stimulation** and **varying awareness** allows a comparison of neural events between moments that differ specifically with regard to conscious state.

Photo credit: “One Weird Visual Illusion Explained” BrainCraft (Youtube, 2016)
The combination of **unchanging physical stimulation** and **varying awareness** allows a comparison of neural events between moments that differ specifically with regard to conscious state.


*The thought: “it’s a red apple”*
The combination of **unchanging physical stimulation** and **varying awareness** allows a comparison of neural events between moments that differ specifically with regard to conscious state.

*Binocular Rivalry as an example to investigate NCC*

*The thought: “it’s a red apple”*

Binocular Rivalry: frontal activity relates to report, not perception

Optokinetic nystagmus (OKN): left or right movement of the pupil

Replaces subject report of perception with an objective measure.

Pupil reflex: constriction or dilation of the pupil

Binocular Rivalry: frontal activity relates to report, not perception

Blood oxygen level dependent signal (BOLD)

With active report of perception change

Without active report of perception change

### No-report paradigms toward “true” NCC

<table>
<thead>
<tr>
<th>Possible underestimation of the NCC</th>
<th>Traditional, Report-Based Paradigm</th>
<th>No-Report Paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conscious, but forgotten (inattentional amnesia). Conscious, but not reportable (e.g., aphasia, minimally conscious state). Conscious, but below decision criterion. Experience without access.</td>
<td>Some percepts may be experienced only when report is attempted. Contrast of conditions (e.g., not reported percept A vs B) may heavily rely on subsequent memory-based trial categorizations (e.g., later reports of A vs B).</td>
<td></td>
</tr>
</tbody>
</table>

| Possible overestimation of the NCC | Inclusion of post-perceptual processes (e.g., executive processes, self-monitoring, report, access). Inclusion of pre-perceptual processes (e.g., prior exposure, attention). | Inclusion of non-conscious processing. |

| Advantages | Ambiguous stimuli and threshold stimuli can remove stimulus-related confounds. | Can be applied to situations where reports are difficult to obtain (patients, babies, animals, anesthesia, and sleep). |
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**Conscious self**
specific experiences of *being you*
Different aspects of the conscious self

The bodily self
The experience of being in a body and having a body

The volitional self
Experiences of intention and agency

The social self
Self-experience refracted through the perceived minds of others
The “rubber hand illusion” as an example of bodily selfhood

The “rubber hand illusion” as an example of bodily selfhood

During the experiment there were times when:

- It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched.
- It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand.
- I felt as if the rubber hand were my hand.
- It felt as if my [real] hand were drifting towards the right (towards the rubber hand).
- It seemed as if I might have more than one left hand or arm.
- It seemed as if the touch I was feeling came from somewhere between my own hand and the rubber hand.
- It felt as if my [real] hand were turning ‘rubbery’.
- It appeared [visually] as if the rubber hand were drifting towards the left (towards my hand).
- The rubber hand began to resemble my own [real] hand, in terms of shape, skin tone, freckles or some other visual feature.

The “rubber hand illusion” as an example of bodily selfhood

“With eyes closed, the right index finger was drawn along a straight edge below the table until it was judged to be in alignment with the index finger of the left hand, which rested on the table in the same position as during the exposure period.”

Volitional selfhood closely related to consciousness

What is voluntary action?

- neurophysiologically: arises from internal generation, not external triggering

Voluntary

reaching for a drink

“I want a drink”

Involuntary

recoiling from a burning tea kettle

heat = sensory stimulus
Volitional selfhood closely related to consciousness

What is voluntary action?

- **neurophysiologically**: arises from internal generation, not external triggering
- **neuroanatomically**: a voluntary motor pathway on the central motor cortex

Electrical stimulation to different parts of the brain during awake brain surgery resulted in different voluntary response

Different aspects of the conscious self

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The experience of being in a body and having a body

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YOU
Bereitschaftspotential (BP), or readiness potential

“Readiness potential”: a brain signal linked to voluntary movement

slowly increasing surface-negative cortical potential of 10–15 μV

Kornhuber, H.H.; Deeke, L. Pflugers Arch. 1965, 284, 1.
A notorious argument against free will


Measurement precision is ±50 ms

readiness potential preceding W-time (“urge to act”) indicates that decision for action was initiated before subject is aware
Non-classical interpretation of readiness potential

**Late decision account:** RP reflects neural activity antecedent to the decision to move, rather than the outcome of a decision to move.


Different aspects of the conscious self

The bodily self
The experience of being in a body and having a body

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YOU
Many neuromechanisms underly social interactions

Learning through observing others
- Reward learning
- Gaze following
  - Mirroring

Learning about other minds
- Taking account of others
- Reputation and gossip effects
  - Tracking false beliefs

Metacognition (“thinking about thinking”)
- Reflective discussions
- Justification of action changes behavior

Gaze-following

- ubiquitous in typical human social development
- failure to respond to gaze cues is associated with pathological social development

Neuromechanisms of gaze-following in social interactions

Healthy subjects were asked to identify angry, neutral, or happy faces with direct or averted gazes while in a fMRI machine.

Neuromechanisms of gaze-following in social interactions

**Happy expression:** identical brain activity between averted and direct gaze

![Happy expression (direct and averted gaze)](image)

**Angry expression:** different brain activity between averted and direct gaze

![Angry expression with averted gaze](image)

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Final thoughts

The boundaries of human consciousness is continuously morphed

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“Only concepts can be defined, others have history” – Nietzsche