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Arousal & awareness

Consciousness | Neural correlates | Diagnosis | Prognosis | Treatment | Ethics

Conscious Wakefulness
Locked-in syndrome
Drowsiness

Minimally Responsive
- command following MCS+
- non-reflex movements MCS-

"Vegetative" unresponsive
Epilepsy
Sleepwalking

Content of Consciousness: Awareness

Level of Consciousness: Wakefulness

Lucid Dreaming
REM Sleep
St I-II Sleep
St III-IV Sleep
General Anesthesia
Coma

Arousal & awareness = necessary but not sufficient

Laureys, Trends in Cognitive Sciences, 2005
Laureys et al, Nature Clinical Medicine, 2008
Measuring awareness

Boly et al, Ann NY Acad Sci, 2009
Vanhaudenhuyse & Demertzi et al, J Cogn Neurosci, 2011
Measuring brain activity

Altered states of consciousness
- Pathological: coma
- Pharmacological: anesthesia
- Physiological: hypnosis
Consciousness and global brain function

Stender et al, Current Biology, 2016
“Global workspace” of consciousness

Thibaut et al, J Rehabil Med, 2012
Vanhaudenhuyse, Demertzi et al, J Cogn Neurosci 2010
Consciousness ≈ top-down

“VEGETATIVE” UNRESPONSIVE

MINIMALLY RESPONSIVE

Temporal dynamics of EEG measures

EEG ultradian rhythmicity differences in disorders of consciousness during wakefulness

Andrea Piarulli¹,² • Massimo Bergamasco² • Aurore Thibaut¹ • Victor Cologan³ • Olivia Gossières¹,⁴ • Steven Laureys¹

SPECTRAL ENTROPY

MCS VS/UWS
Diagnostic error after coma

n=103 post-comatose patients
- 45 clinical consensus diagnosis ‘vegetative state’
- 18 signs of awareness (Coma Recovery Scale)

30-40% potential misdiagnosis

Schnakers et al, BMC Neurology, 2009
Stender et al, Lancet, 2014
fMRI-based communication

Imagine **Tennis** to answer 'YES'
Imagine **Navigating** to answer 'NO'

Is your father's name Alexander?

Is your father's name Thomas?

Brain Computer Interfaces

“MOVE YOUR FOOT”

“MOVE YOUR HAND”

CONTROL SUBJECT

“VEGETATIVE” UNRESPONSIVE PATIENT

Noirhomme et al NeuroImage 2015
Lesenfants, Habbal et al J Neural Engineering 2014
Cruse et al Lancet, 2011, also see Goldfine et al, Lancet, 2013
Measuring consciousness

MCS+

MCS-

VEGETATIVE/UNRESPONSIVE

COMA

MINIMALLY CONSCIOUS STATE +

EMERGENCE

MINIMALLY CONSCIOUS STATE -

appropriate smiling/crying
localization to noxious stimulation
visual pursuit

reflex movements
eye opening

command following

functional communication and object use

Bruno et al, J Neurology, 2012
Classifying “resting” fMRI

Intrinsic functional connectivity differentiates minimally conscious from unresponsive patients

Vanhaudenhuyse et al, *Brain*, 2010
Pathological hyper-connectivity

EEG-TMS Perturbational Complexity Index

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EEG-TMS Perturbational Complexity Index

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130 patients (29/y)  
4 excluded (3%)  
81 MCS  
41 VS/UWS  
4 LIS  
110 chronic (87%)  
78 non-trauma (62%)  

35% clinical misdiagnosis  
32% CRS-R misdiagnosis  

Stender & Gossessies et al, Lancet, 2014
Consciousness ≈ thalamo-cortical

Intralaminar nuclei "reconnections" in spontaneous recovery from "vegetative“ unresponsive state

Intralaminar nuclei stimulation induces "recovery" from minimally responsive state


Intralaminar nuclei “reconnections” in spontaneous recovery from “vegetative” unresponsive state

Transcranial direct current stimulation (tDCS)

Laureys et al, Lancet 2000

Thibaut et al, Neurology 2014
Ethical framework

Target Article  The American Journal of Bioethics, 8(9): 3–12, 2008

Neuroimaging and Disorders of Consciousness: Envisioning an Ethical Research Agenda

Joseph J. Fins, Weill Medical College of Cornell University*  
Judy Illes, University of British Columbia*  
James L. Bernat, Dartmouth Medical School**  
Joy Hirsch, Columbia University**  
Steven Laureys, University of Liege**  
Emily Murphy, Stanford Law School**

*Co-lead authors.  
**Equal authors in alphabetical order.
Pain in minimally conscious state


http://neurology.thelancet.com
Quality of life

A survey on self-assessed well-being in a cohort of chronic locked-in syndrome patients: happy majority, miserable minority

Marie-Aurélie Bruno,1 Jan L Bernheim,2 Didier Ledoux,1 Frédéric Pellas,3 Athena Demertzi,1 Steven Laureys1

Bruno et al, BMJ Open, 2011
Paradigms (re)framed by neuroimaging

transcranial Direct Current Stimulation

mesocircuit fronto-parietal model

amantadine

Deep brain stimulation

zolpidem

Scientific
- Neural correlates

Medical
- Diagnosis
- Prognosis
- Treatment

Ethical

Laureys & Schiff, *NeuroImage*, 2012
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