Long-distance Synchronization of Neural Activity across Cortical Areas Correlates with Conscious Perception

Lucia Melloni
What happens in our brain when we consciously perceive?
What do we see?

What do we not see?
We did not see this!
What do we see?
Once again there was something we missed!
• Some information is processed without awareness (words, faces, pictures, etc).
  – Blindsight, unilateral hemineglect
  – Subliminal priming, attentional blink

• What distinguishes conscious from unconscious processing of information?
A schematic representation of the workspace model

Dehaene, Kerszberg & Changeux, *PNAS*, 1998
inspired by Mesulam, *Brain*, 1998
Neural correlate of consciousness?

SYNCHRONIZATION OF DISTRIBUTED NEURAL ASSEMBLIES

Neural synchrony can be found at different spatial scales. Then, what is the spatial scale that correlates with conscious perception?

Hypothesis

- Conscious integration of information is correlated with long-distance neural synchrony.

- Unconscious integration of information is correlated with local neural synchrony.
Methods

Spectral power (Local Synchrony)

Methods

Phase synchrony (Global Synchrony)

Experimental procedure

• Manipulation of stimulus visibility
  – Visible vs. invisible stimuli

• Electroencephalographic measurements
  – Spectral power ≈ local neural synchrony
  – Phase-synchrony ≈ long-distance neural synchrony
1. Visibility Experiment: Delayed-match to sample task

Same or different word?

CAT  DOG

<table>
<thead>
<tr>
<th>Stimulus Duration [Msec]</th>
<th>Visible word</th>
<th>Invisible word</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>CAT</td>
<td>CAT</td>
</tr>
<tr>
<td>33</td>
<td>CAT</td>
<td>CAT</td>
</tr>
<tr>
<td>200</td>
<td>CAT</td>
<td>CAT</td>
</tr>
<tr>
<td>153</td>
<td>CAT</td>
<td>CAT</td>
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<tr>
<td>67</td>
<td>CAT</td>
<td>CAT</td>
</tr>
<tr>
<td>67</td>
<td>CAT</td>
<td>CAT</td>
</tr>
</tbody>
</table>

N = 15 Subjects
Behavioral measures of word’s visibility

<table>
<thead>
<tr>
<th></th>
<th>Visible</th>
<th>Invisible</th>
<th>Control Visible</th>
<th>Control Invisible</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d'$</td>
<td>3.85</td>
<td>0.16</td>
<td>3.27</td>
<td>2.50</td>
</tr>
<tr>
<td>Hits (%)</td>
<td>94.58</td>
<td>52.25</td>
<td>92.50</td>
<td>86.17</td>
</tr>
</tbody>
</table>
Spectral Power

Visible Condition: Visible – Control Visible
Invisible Condition: Invisible – Control Invisible
Visible Condition: Visible – Control Visible
Invisible Condition: Invisible – Control Invisible
• 50-57 Hz
• 80-130 ms after masked-word presentation
Visible Condition

Invisible Condition
Visible Condition

Invisible Condition
• What distinguishes conscious from unconscious processing of information?

Long-distance synchrony
fast \sim 100ms!

Visible Condition

Invisible Condition
• Long-range neural synchrony could reflect:
  – A specific mechanism associated with awareness or,
  – The depth of processing in the various cortical areas involved in written word processing.

• How to disentangle both hypothesis?
  – Subliminal semantic priming experiment.
    • High-level processing of information WITHOUT awareness
2. Subliminal Semantic Priming Experiment

N=19 subjects
Behavioral measures of subliminal perception

**Subliminal semantic priming**

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>Reaction Time [ms]</th>
<th>Accuracy [%]</th>
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</thead>
<tbody>
<tr>
<td>Congruent</td>
<td>570</td>
<td>50</td>
</tr>
<tr>
<td>Incongruent</td>
<td>575</td>
<td>45</td>
</tr>
<tr>
<td>Blank</td>
<td>580</td>
<td>48</td>
</tr>
</tbody>
</table>

* p<.05

**Prime Visibility**
2. Subliminal Semantic Priming Experiment

Stimulus duration [ms]

- Congruent
- Incongruent
- Blank
Cerebral response to the prime

Spectral Power

- 59-87 Hz
- 131-237ms post prime

* p<.05
* p<.01

Spectral power [arbitrary units]
Cerebral response to the prime

Phase Synchrony

• 59-87 Hz
• 131-237ms post prime
Cerebral response to the target

Spectral Power

- 69-86 Hz
- 312-626 ms post prime

![Spectral Power Chart]

- Congruent
- Incongruent
- Blank

Spectral power [arbitrary units]
Cerebral response to the target

Phase Synchrony

- 69-86 Hz
- 312-626 ms post prime

Phase Synchrony [arbitrary units]
Congruent

Incongruent

Blank
Event-related potential

- ERP’s related to sensory stimulation do not show differences between conditions (P1-N1)

- Thus, the difference in induced gamma oscillation cannot be attributed to a difference in sensory stimulation.
Anterior electrodes

- ---: Congruent
- ----: Incongruent
- ---: Blank

Channel locations

Voltage (µV)

Time (ms)
Anterior electrodes

- ---: Congruent
- ---: Incongruent
- ---: Blank
Posterior electrodes

- ---: Congruent
- ---: Incongruent
- ---: Blank

![Diagram showing voltage changes over time with channel locations marked.]
Posterior electrodes

---: Congruent
----: Incongruent
-----: Blank

Channel locations
Conclusions

• Conscious processing of information correlates with transitory and early increments in long-distance synchronization

• Unconscious processing of information correlates with increments in local synchronization
Interaction between top-down and bottom-up: Hysteresis in conscious perception
Neuronal global workspace theory of Consciousness
Stanislas Dehaene

Bottom-up Stimulus strength

<table>
<thead>
<tr>
<th></th>
<th>Top-Down Attention</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>absent</td>
</tr>
<tr>
<td>Subliminal (unattended)</td>
<td><img src="image1" alt="Subliminal (unattended)" /></td>
</tr>
<tr>
<td>Preconscious</td>
<td><img src="image3" alt="Preconscious" /></td>
</tr>
</tbody>
</table>

- Subliminal: Stimulus strength is below the threshold of perceptual awareness.
- Preconscious: Stimulus strength is at the threshold of perceptual awareness.
- Conscious: Stimulus strength is above the threshold of perceptual awareness.

- Top-Down Attention: Refers to the selective focus of attention that enhances the processing of certain stimuli.

- Subliminal (attended): Stimulus strength increases and is consciously perceived.
- Subliminal (unattended): Stimulus strength remains subliminal and is not consciously perceived.

- Presence of arrows and dots in the brain images indicate the flow of neuronal activity associated with different levels of consciousness.
One example: Attention alters appearance
Marisa Carrasco
Can higher-order representation help in bringing a stimulus into perceptual awareness?
Conscious perception: Interplay between top-down and bottom-up

• How to study a phenomenon where top-down has a clear impact in bottom-up processing?: Hysteresis effect
  – Hysteresis typically occurs in visual perception.
  – In general there seems to be a tendency for something already perceived to continue to be perceived and for something not yet perceived to remain unperceived. This tendency towards perceptual inertia is called **HYSTERESIS**.
  – Hysteresis is a property of systems that do not instantly follow the forces applied to them, but to react slowly, or do not return completely to their original state. That is, systems whose states depend on their immediate history.
EXPERIMENTAL DESIGN

Increase Luminance

Decrease Luminance

Random Between 1000-1500ms

500 ms

Until Subject Response

1 = No Experience
2 = Brief Glimpse
3 = Almost Clear Impression
4 = Clear Impression
Behavioral results: Hysteresis Effect

Scale 2: 1+2: Unseen
        3+4: Seen

N=16 subjects
** : p<.005
Behavioral results: Hysteresis Effect

**Increase Contrast**

- $a = 1.6716$
- $b = 0.0024$
- $f(x) = 3.9669$
- Fit error = 0.0009

**Decrease Contrast**

- $a = 1.4588$
- $b = -0.0154$
- $f(x) = 2.8157$
- Fit error = 0.0007

<table>
<thead>
<tr>
<th></th>
<th>Up</th>
<th>Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>1.6716</td>
<td>1.4588</td>
</tr>
<tr>
<td>$b$</td>
<td>0.0024</td>
<td>-0.0154</td>
</tr>
<tr>
<td>$y$</td>
<td>3.9669</td>
<td>2.8157</td>
</tr>
<tr>
<td>Shift</td>
<td>1.1512</td>
<td></td>
</tr>
</tbody>
</table>

$F(x) = \frac{1}{1+ e^{-a(x-y)}} + b$

*N=16 subjects*
ERPs results: P100

120 ms after stimulus onset
ERPs results: N100

320 ms after stimulus onset
ERPs results: P200

226 ms after stimulus onset
ERP’s results: Hysteresis Effect (P200)
ERPs results: Hysteresis Effect (P200 topography)
ERPs results: Hysteresis Effect (P200 topography)
ERPs results: Hysteresis Effect (P200 topography)
ERPs results: Hysteresis Effect (P200 topography)
ERPs results: Hysteresis Effect
(P200 topography)
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ERPs results: Hysteresis Effect (P200 topography)
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ERPs results: Hysteresis Effect (P200 topography)
ERPs results: Hysteresis Effect

Contrast Increase

Contrast Increase
ERPs results: Hysteresis Effect

Contrast Decrease

Contrast Decrease
Induced Gamma Response: Hysteresis Effect
How can perceptual hysteresis arise?

Higher Order Representations (Top Down) + Visibility = Hysteresis
Can responses in different frequencies explain the hysteresis effect?
Can responses in different frequencies explain the hysteresis effect?

**High Gamma Response**
80 – 94 Hz

**Middle Gamma Response**
55 – 70 Hz
High Gamma response: Top Down

TIME

-3.3764 - 97.973 ms 97.973 - 199.3243 ms 199.3243 - 300.6757 ms 300.6757 - 391.8919 ms 391.8919 - 493.2432 ms

Stim Down

Stim Up
Middle Gamma response: Visibility
Middle Gamma Response: Visibility
Gamma Power

Stim 1

Stim 2

Stim 3

Stim 4

Stim 5

Stim 6
Gamma Power: Shift in the induced gamma response (Hysteresis Effect)
Phase-Locked Synchronization

Stim1

Stim2

Stim3

Stim4

Stim5

Stim6
Phase-Locked Synchronization = Visibility
Hysteresis Control Experiment

Bottom-up

Bottom-up + Top Down

[Diagram of a hysteresis curve with steps labeled A through I, indicating the progression from bottom-up to bottom-up plus top-down.]
Hysteresis Control Experiment

9 ss Behavioral Results

- AVG_gain_Control
- AVG_gain_Expe
- Gain Expe-Gain Control

Stimulus Clarity vs. Hysteresis Effect

Hysteresis Effect

Stimulus Clarity
Hysteresis Control Experiment: Behavioral Results

Control Experiment

Hysteresis Experiment
Conclusions (1)

- Top-down alters the saliency of stimuli making them more visible by a factor of 1 stimulus. (In agreement with Marissa Carrasco’s studies showing that attention alters experience)
Conclusions (2)

- The curve relating the percentage of seen trials to stimulus contrast is well fitted by a sigmoid. Conscious perception seems to follow a nonlinear (sigmoid) function.

Conclusions (3)

- **ERP**: Amplitude modulated by the contrast and visibility of the stimuli. Amplitude modulation shows an hysteresis effect, indicating that top down affects the sensory processing of those stimuli.

- **Gamma Power**: It follows the hysteresis effect.

- **Long-Range Synchrony**: It seems to follow the conscious perception/visibility of the stimulus.
Top-down representations: Not only top-down attention can alter consciousness
Local synchrony ≈ oscillations

Global synchrony ≈ phase-locked synchrony

Dehaene, Kerszberg & Changeux, *PNAS*, 1998
inspired by Mesulam, *Brain*, 1998
Thank you for your attention!

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