A hierarchy of temporal receptive windows in human cortex

Uri Hasson, Nava Rubin, David Heeger, Ignacio Vallines, Eunice Yang

Psychology department and the Neuroscience Institute, Princeton University
Real-world events unfold at different time scales, and therefore cognitive and neuronal processes must likewise occur at different time scales.
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**The speed of sight**

150mesc  

1000mesc  

7000mesc

The visual system is optimized for rapidly processing the momentary visuospatial properties of the stimuli.
Temporal scale of processing

Real-world events unfold at different time scales, and therefore cognitive and neuronal processes must likewise occur at different time scales.

Real life temporal scales

150mesc  1000mesc  7000mesc

The visual system is optimized for rapidly processing the momentary visuospatial properties of the stimuli
Things unfold over time

The desperate

The savior

Intervention

Turning point

Time (seconds)

0

10

36

57
Things unfold over time

Fine temporal granularity (Frame–by-Frame)

Short temporal granularity (~2-5 sec)

Mid temporal granularity (~15-20 sec)

Long temporal granularity (~40 sec – the entire movie ...)

The desperate

The savior

Intervention

Turning point

Time (seconds)

0 10 36 57
Parametric variation of the temporal structure of a movie sequence

**Single event 14**

**Single event 15**

**Single event 16**

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**Piecewise Scrambling**

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**At short temporal scales (≈4 +/- 1sec)**

**At mid temporal scales (≈12 +/- 3sec)**

**At long temporal scales (≈36 +/- 4sec)**
Shot vs. juxtaposition of shots

**Short temporal granularity**
(~4 +/- 1sec)

**Mid temporal granularity**
(~12 +/- 3sec)

**Long temporal granularity**
(~36 +/- 4sec)

Correlation
Short1:Short2

Correlation
Mid1:Mid2

Correlation
Long1:Long2

Correlation Director’s cut
Forward1:Forward2
Reliability of cortical activity during natural stimulation

- Correlation
  - Short1:Short2
  - Mid1:Mid2
  - Long1:Long2
  - Director’s cut
    - Forward1:Forward2
Reliability of cortical activity during natural stimulation

Predictions

Higher order areas (e.g. reasoning)
Integration over long time scales - plot

Mid order processing areas (e.g. FFA, PPA)
Integration over few sec -montage

Early visual areas (e.g. V1, MT+)
Frame by frame analysis of single shots

Inter-subject correlations for the original movie
Effect of scrambling at different time scales

Hasson et al. J Neuroscience
Parametric variation of the temporal structure of a movie sequence

Forward $x 2 (F_1, F_2)$

Backward $x 2 (B_1, B_2)$
Correlation coefficient: Forward vs. Backward
(Lower bound)

Forward x 2 (F1, F2)

fMRI response

Corr_{F1:B1} = 0.04

Correlation between the backward and forward TC
Internal assessment of noise

Backward x 2 (B1, B2)
Moment to Moment responses

Forward x 2 (F1, F2)

- Reversing the backward TC
- Shift TC: Correct for Hemodynamic delay

Corr_{B1:F1} = 0.71

Reversed Backward time course

Backward x 2 (B1, B2)
Strong correlation between the *reversed backward* and *forward* Time courses. Moment to moment response profile within short time intervals. No dependency on the direction of time.
While regions in which the response pattern dependent on the temporal sequences should differ in their response profile to the forward and reversed backward movies.

\[ \text{Corr}_{B1:F1} = 0.01 \]
MT+/V5 motion-related area
MT+/V5 motion-related area

$\text{Corr}_{F1:F2} = 0.68$

$\text{Corr}_{F:B} = 0.05$

$N = 8$
What was the correlation between the reversed backward and forward time courses?

$\text{Corr}_{F1:F2} = 0.68$

$\text{Corr}_{B1:B21} = 0.61$
MT+/V5 motion-related area
Forward - Left to right movement

On average homogeneous populations of left and right movement

Similar mean activation

No skewed representation towards the forward movies

Backward - Right to left movement

MT neurons

Left to right movement

Right to left movement

MT Voxel
Thus, we can conclude that the moment-to-moment response profile in MT+ is similar in the backward and forward movies.
Voxel-by-voxel inter correlation analysis

Source Brain
Target Brain

Talairach coordinates

Forward
Reversed Backward
Cortical activity independent of temporal order

Reversed backward vs. Forward
Cortical activity dependent of temporal order

\[(CrB1:F1 < \frac{1}{2} CF1:F2)\]
The reduction in the reliability of the response patterns for the unstructured movies cannot be attributed to reduction in the responsiveness in these regions.
Response amplitude vs. correlation-based analysis

![Graph showing response amplitude vs. correlation-based analysis.](image)

- **FEF**
  - fMRI response
  - Time (sec)

- **Dynamic range** (SD % change in image intensity)

  - **MT+**
  - **STS**
  - **FEF**
  - **LS-TPJ**
  - **Precuneus**

- **Colors**:
  - Red: Forward film
  - Blue: Long (36 +/- 4 sec)
  - Green: Mid (12 +/- 3 sec)
  - Black: Short (4 +/- 1 sec)
  - Grey: Backward film
Response amplitude vs. correlation-based analysis

Epoch based: Short movie clips

MT+
Response amplitude vs. correlation-based analysis

Response amplitude

MT+. STS. LS-TPJ. Precuneus

Reproducibility of response patterns

<table>
<thead>
<tr>
<th>MT+</th>
<th>STS</th>
<th>LS-TPJ</th>
<th>Precuneus</th>
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The reduction in correlations for the unstructured movies cannot be attributed to differences in eye movements.
Eye Movements

A: $C_{F1:F2}$

B: $C_{B1:B2}$

C: $C_{rB:F}$

D: $C_{B:F}$

Correlation vs. Time lag (sec)

Horizontal eye position: blue line
Vertical eye position: red line

N=4
Conclusion

The results demonstrate that the activation in some brain areas depends on the moment-to-moment sensory inputs while the activation in other areas depends on the past context over a variety of temporal scales.
A hierarchy of temporal receptive windows

Temporal receptive windows

Spatial receptive fields

TPJ-LS

FEF

FFA, PPA

STS, Precuneus

V1, MT

High level

Mid level

Low level
Temporal Receptive Window (TRW)\nOpen questions

1. How do neurons accumulate information over long time scales? Is it an emerging property of the network?

2. What are the functional properties of a TRW
   a) Refresh rate
   b) Variability of rate
   c) Attentional modulation

3. Can we find a similar hierarchy of temporal receptive windows in other modalities, beside the visual cortex?
The end