Attention, please!

Attention, please!

Or

How to select sensory information intelligently

And

How to treat it right in the brain

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Contents

1) Why study attention? Definition, Motivation *(What is selective attention, and why do we have it)*

2) Psychophysical evidence

3) The "Where" pathway and the saliency map: Model and experimental test

4) The "What" pathway and temporal tagging: Model and experimental tests, in monkey and human

Function of Selective Attention

- "Everyone knows what attention is. It is the taking possession by the mind...of one out of what seem several simultaneously possible objects or thoughts...It implies withdrawal from some things in order to deal effectively with others.

  William James, 1890

Why we need attention

- Functional reason: cope with complexity

VISUAL SELECTIVE ATTENTION

Complex visual world

- Overwhelming amount of sensory information

VISUAL SELECTIVE ATTENTION

Complex visual world

Limited processing resources

- Unable to fully process all visual information simultaneously

VISUAL SELECTIVE ATTENTION

Complex visual world

Limited processing resources

Selection of the *most relevant* visual information for detailed processing

VISUAL SELECTIVE ATTENTION

Complex visual world

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Selection of the most relevant visual information for detailed processing

Why *model* (and *implement*) attention?

- Important cognitive/perceptual function
- Observable at many levels, in many systems (drosophila, ...):
  - single cells (electrophysiology)
  - whole system (psychology)
  - intermediate levels (imaging: PET, fMRI, EEG,...)
- Use *quantitative* models to combine data from different disciplines
- Will be important for machine intelligence (e.g. Mark Tilden: “The cocktail party problem costs me money”)

The problem to solve: Information overload

Organisms need many sensors at *some* time

- e.g. Vision: 100 Mbits/sec/eye
- somatosensory system comparable

� 10^9 bits/sec, times 10^9 seconds in lifetime

� Number of synapses in cortex: 10^15 (and not exactly all are available for storing sensory information!)

� THUS: Not all available information can be processed (or stored) at all times

� Solution: Select important part of available information, suppress all other
==> "Selective Attention"

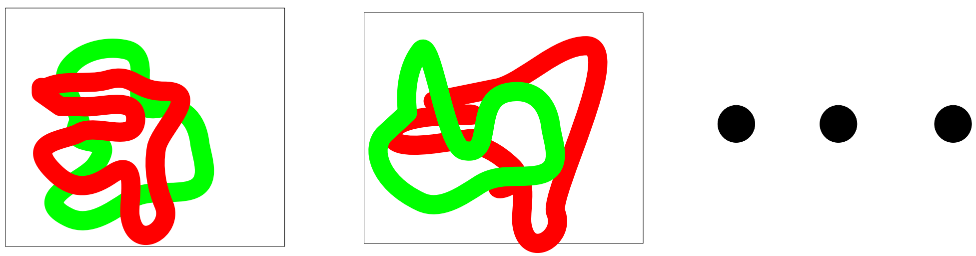
100bits/sec/axon: Rate or Capacity?

-
  Results supporting "Rate:"
  - Brenner,..., RdRvS (1999): fly, 100s bps
  - Reinagel & Reid (2000): cat LGN, 15 - 100 bps
  - Reich, ... Victor (2000): primate cortex, 5-30 bps
-

Attention: Gateway to Perception

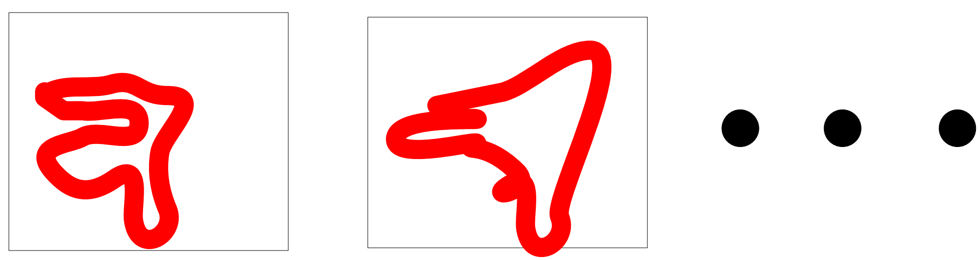
Rock and Gutman 1981:

1) "Score green figures for aesthetical appeal"



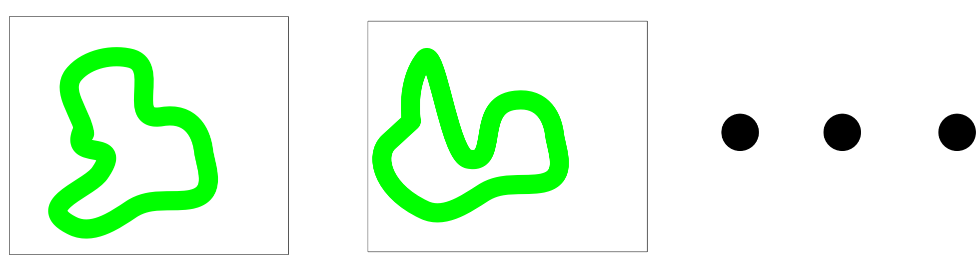
2) Immediately following: "Have you seen this figure before?"

Unattended:



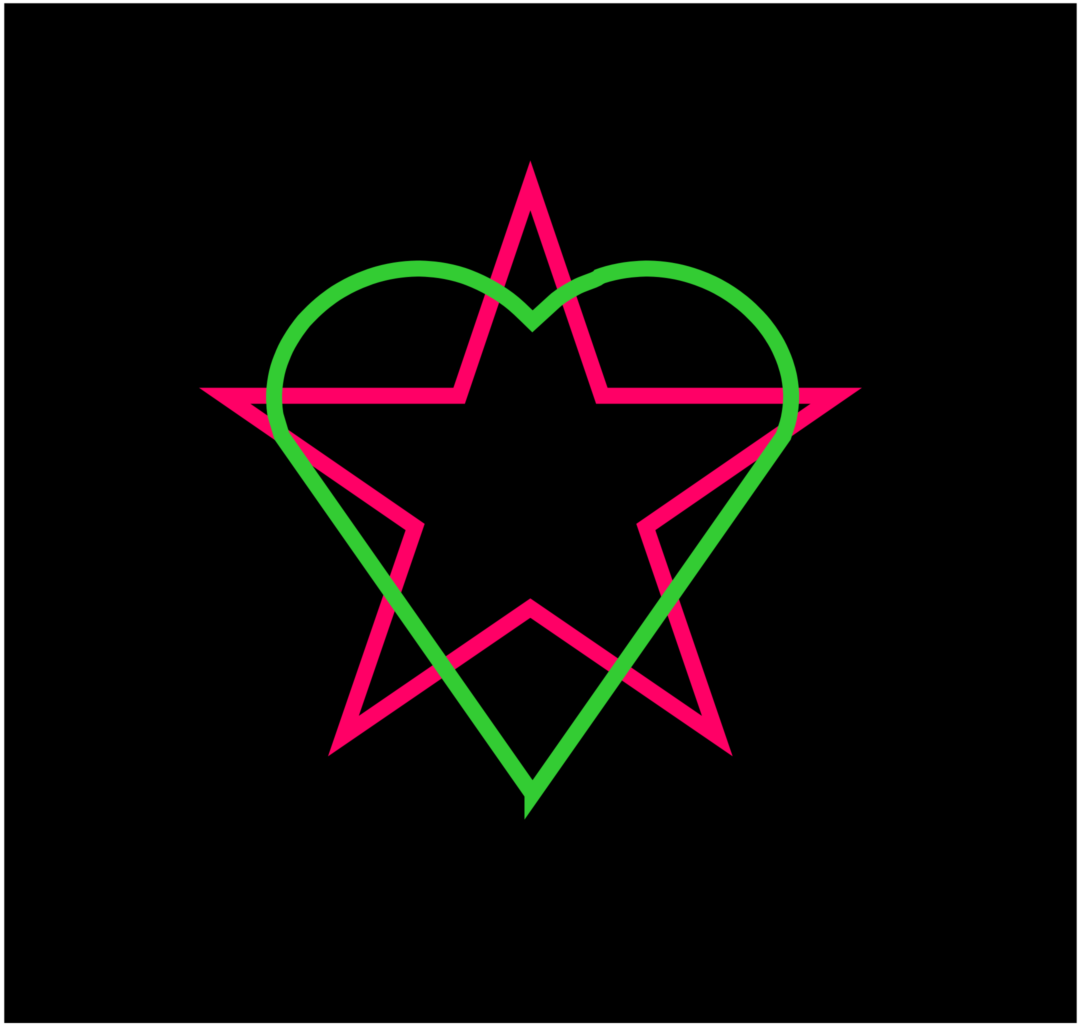
No!

Attended:



Yes!

Rock and Gutman (1981)



Not **all** features are lost. Available:

•Color (duh!)

•Size

•Line type (full or dashed)

•Open vs. closed

But **not** rectilinear vs. curved!

Another example showing attentional selection: Change Blindness

- Originally: during saccades (McConkie, 1970s)
- Rensink 1997: flicker paradigm
- Many other paradigms work:
  - Mud splashes
  - Very slow motion
  - Direct attention by instructions (top-down)
  - Real life changes (change of person)

Demos

- kaffeine ~/dwplayer/awareness
- www.usd.edu/psyc301/Rensink.htm
- kaffeine ~/dwplayer/personswap
- And many many more...

  e.g. http://www.cs.ubc.ca/~rensink/flicker/download/index.html

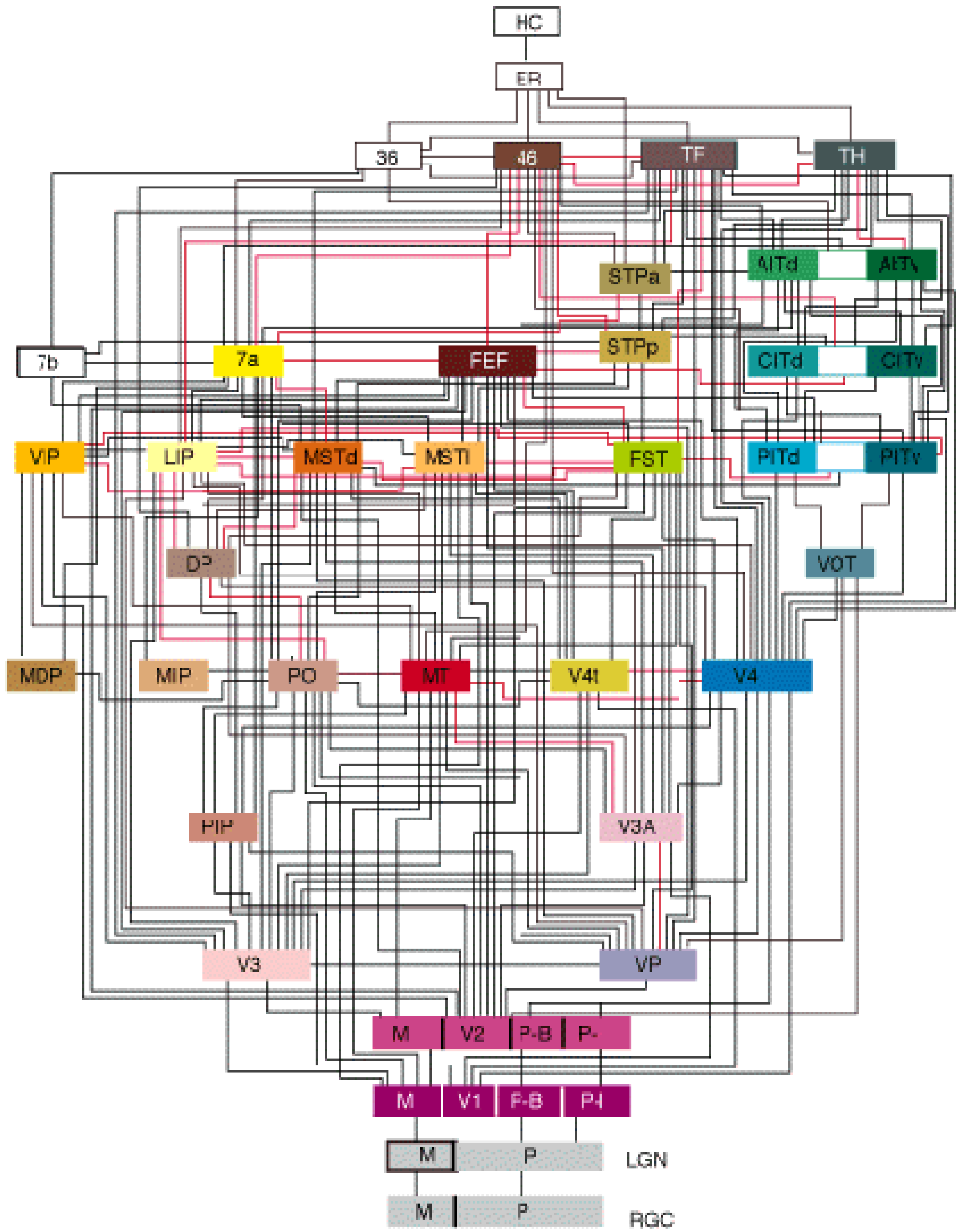
  http://viscog.beckman.uiuc.edu/djs_lab/demos.html

Function of Selective Attention: Beyond William James and psychology

- The information processing view
  - � Limited computational resources ==>
    - filter out unimportant inputs
    - detailed processing only of parts of sensory input
    - treat larger data sets serially

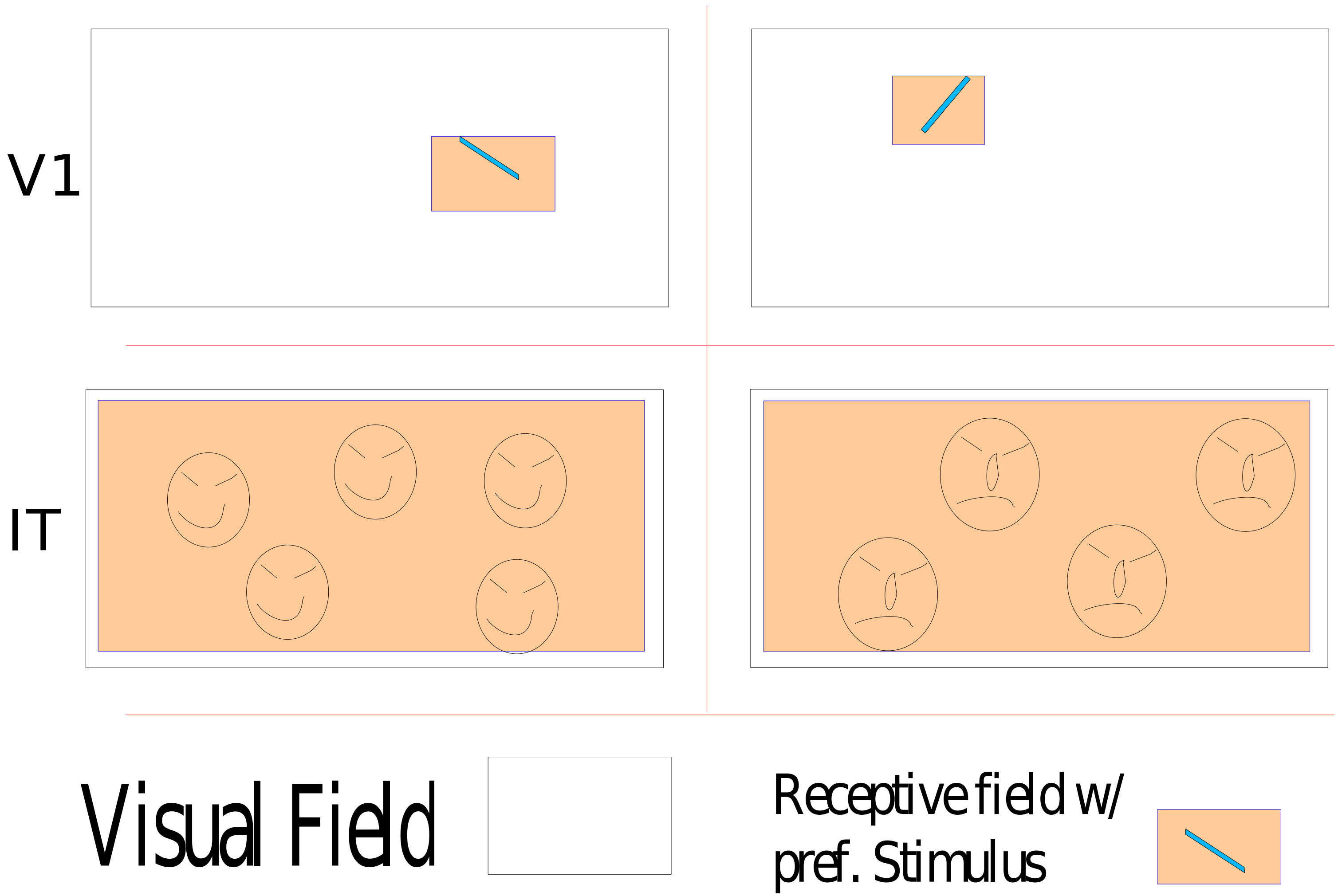
- The neurobiological view
  - � Receptive fields increase when going up in cortical hierarchy ==> "to which stimulus do IT neurons respond?" (Nicole!)

Distributed Processing



from Felleman, D. J. and Van Essen, D. C. (1991) *Cerebral Cortex* 1:1-47.

Hierarchical Processing



Roles of attention

- Provide a bottleneck: only admit as much information as can be processed at one time
- Serialize processing to present selected portions to specialized processors
- Explore sensory space faster than in 'hardware' E.g: "scouting hypothesis" in for eye movements

But: Hierarchical view is oversimplified!

Feedforward filter theory (even with some feedback) unlikely to be true

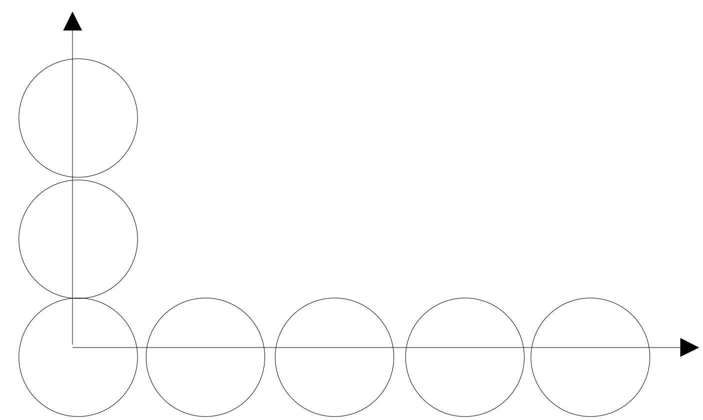
Our hypothesis:

- *All* areas are used to represent different features of sensory input.
- Many “perceptual hypotheses” are represented simultaneously in all areas and they are competing all the time. Attention modulates this competition (Usher & Niebur, 1995).
- This is consistent with Nicole's result that the 'activity fraction' is the same in all areas: because *all* areas are used!

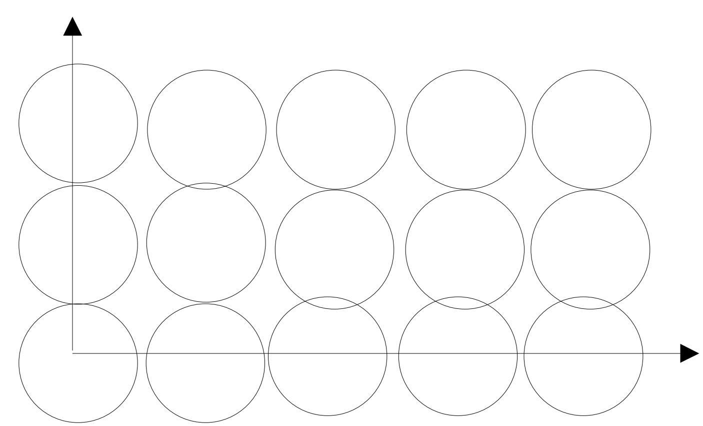
Why *What* and *Where*…

Any object can appear essentially
in any location of the visual field ==>
reduce complexity by processing

{Object identity}+{location}



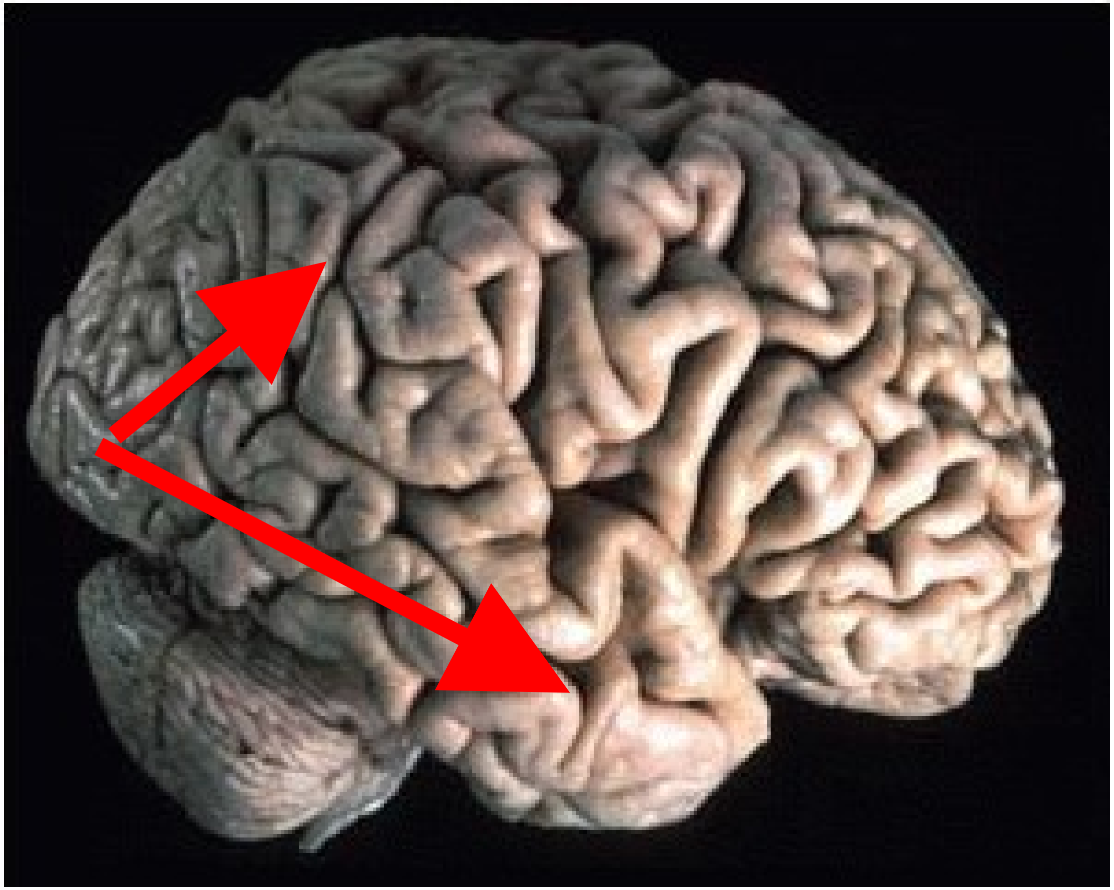
{Object identity}x{location}



Why *What* and *Where*... and How: Separate Pathways

- *What*: ventral; occipital-temporal
- *Where*: dorsal; occipital-parietal

Why *What* and *Where*... and How: Separate Pathways



- *What*: ventral; occipital-temporal
- *Where*: dorsal; occipital-parietal

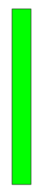
Current State of Neuromorphic Engineering: "Reflexes"

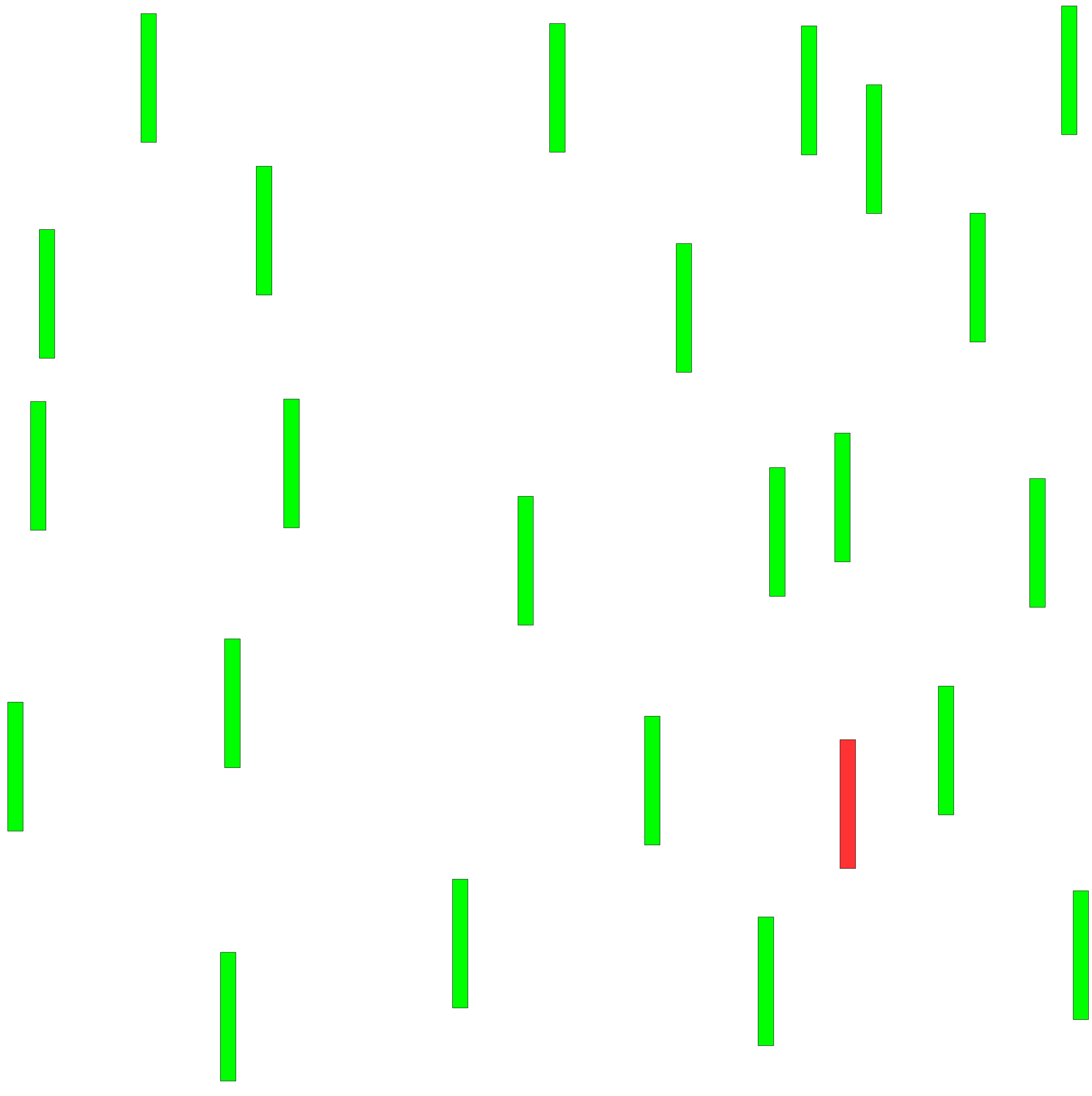
- Current work: neuronal periphery
  - � design, improvement of (mainly) sensors and (some) actuators
- System level work <==> reflexes
- Little need for selection of information
  - � Typically, machines are single-purpose
- Will change with increasing complexity
  ==> selective attention required

2.) Psychophysical Evidence

Quantitative Assessment of Attention: Visual Search Task

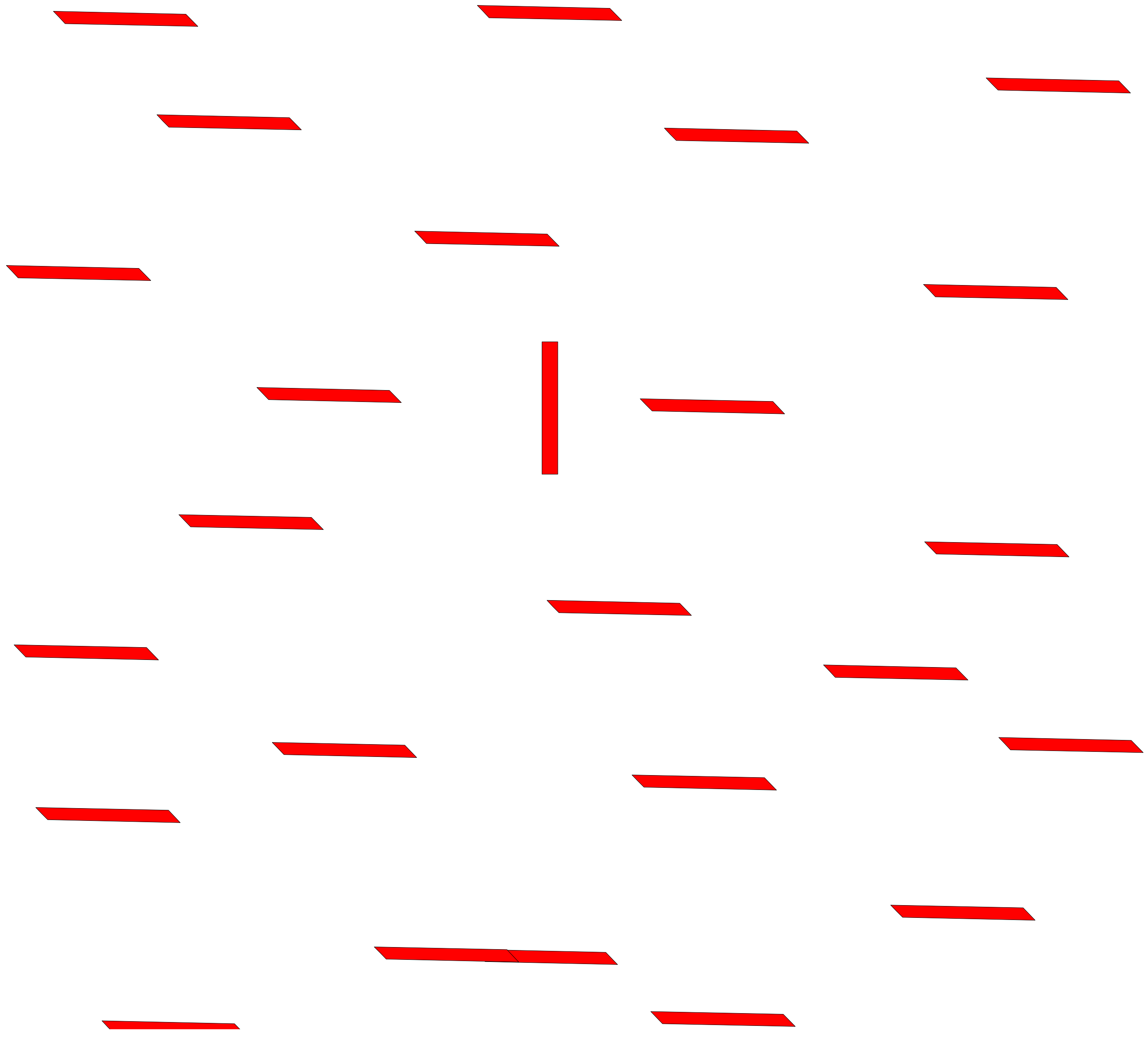
- Target: 

- Distracters: 



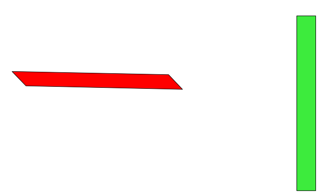
Visual Search Task II

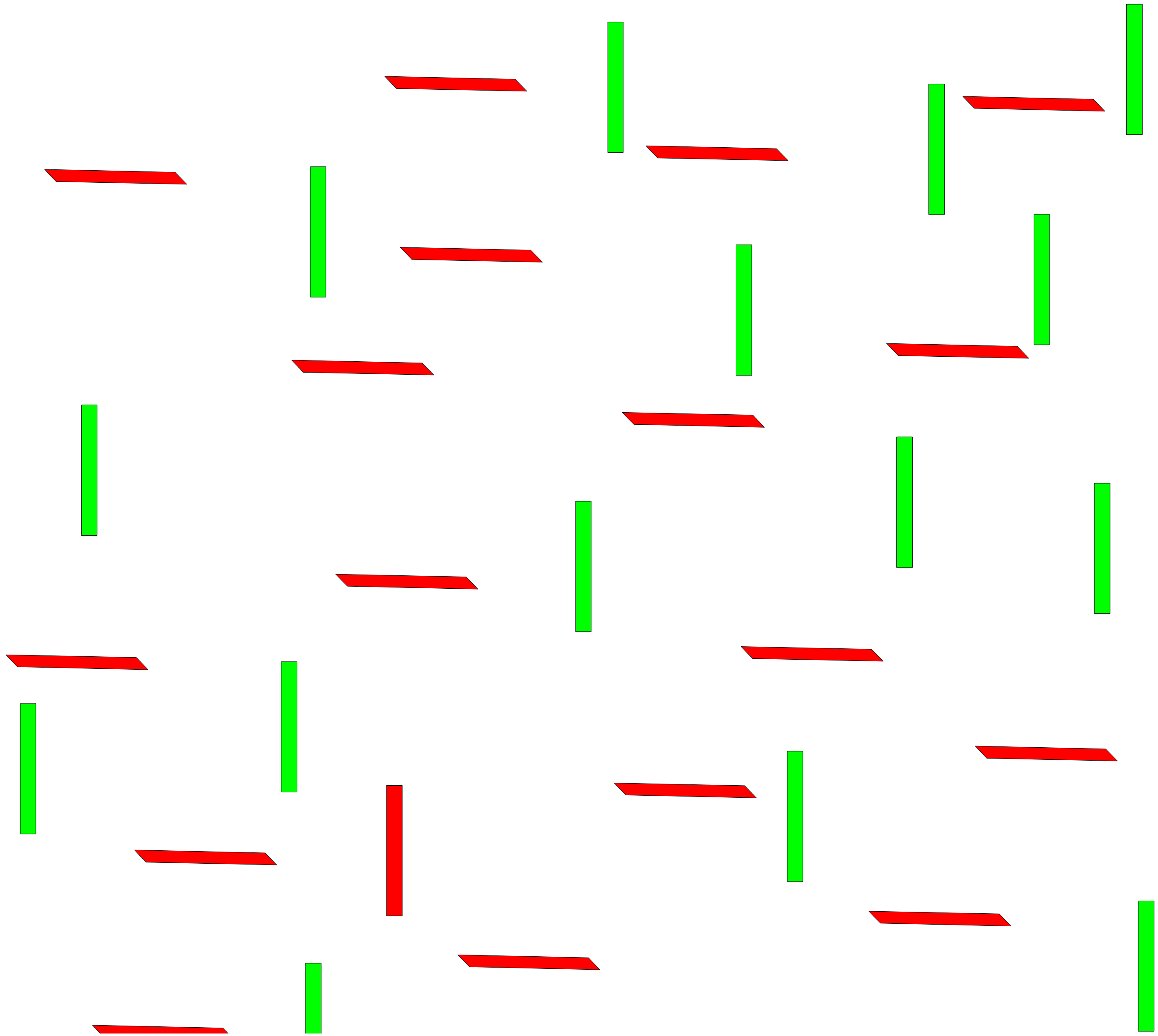
- Target: 
- Distracters: 



Visual Search Task III

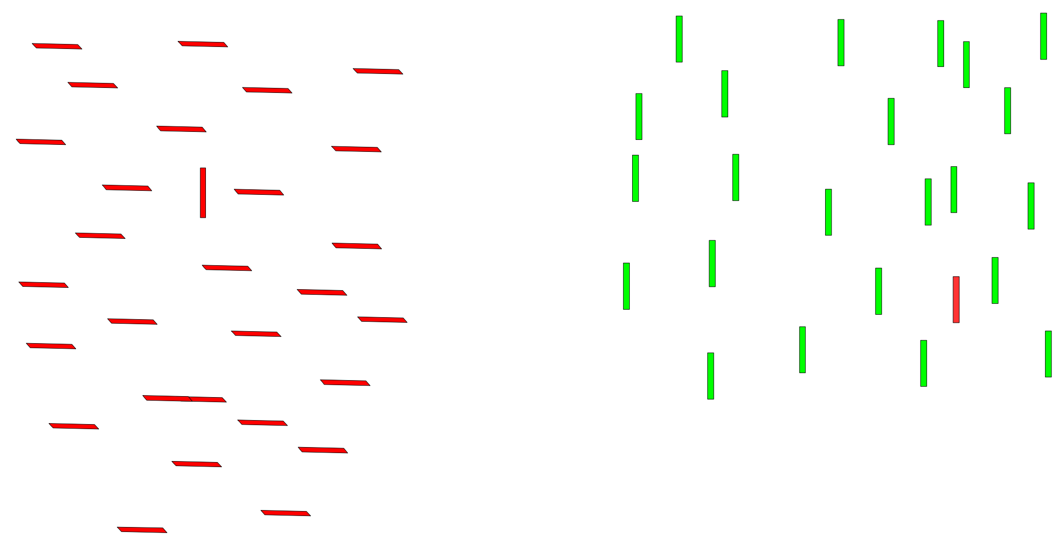
- Target: 

- Distracters: 



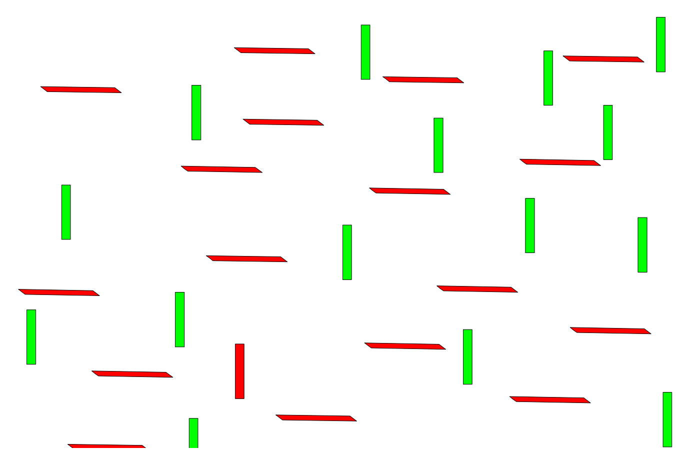
Why the difference?

- Feature (singleton) search: *pop-out*



vs.

- Conjunction search



(Treisman, 1980)

Quantitative Measurement of Covert Attention

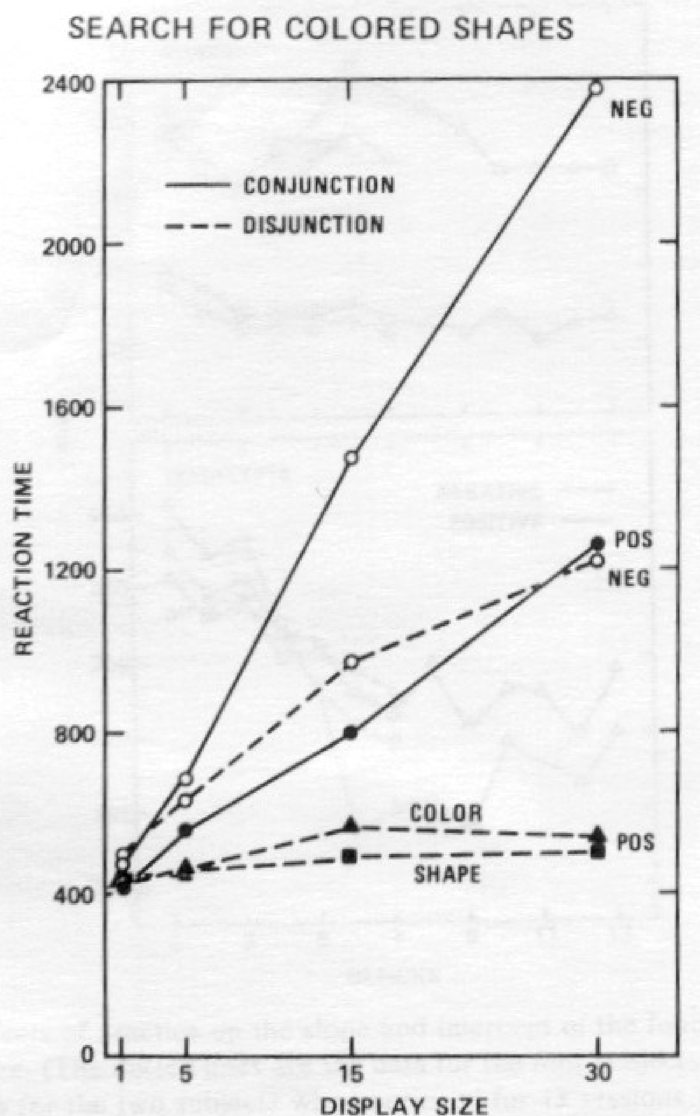


FIG. 1. Search times in Experiment I.

(Treisman and Gelade, 1980)

Conjunctive:
Target absent
80ms/item

Conjunctive:
Target present
40ms/item

Feature task:
Target absent or present:
No dependence on # of distr.

==> Self-Terminating Search Task, 80ms/item

Interpretation

- Feature search can be done in parallel (local differences in dedicated feature maps)
- Conjunction search requires resources which are not available at all locations
  => sequential search: Attention!
- Attention moves at 40ms/item

To Understand

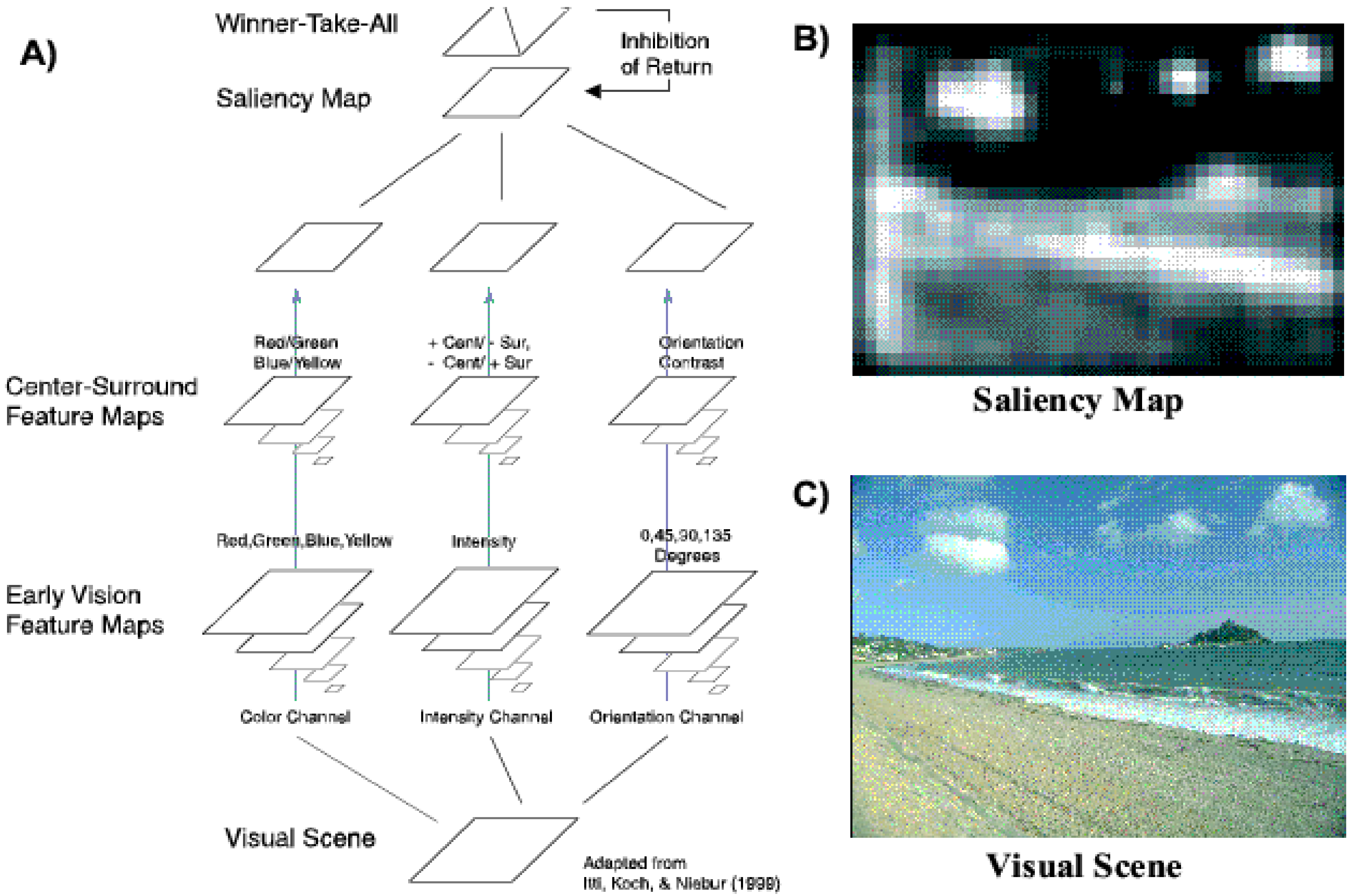
- How does the brain select the stimuli to be attended? Next section
- Given that the selection has been made, how does the fact that a stimulus is attended modify its represenation ? Final section

3.) The *Where* pathway & the saliency map: Model and experimental test

Modeling the *Where* Pathway

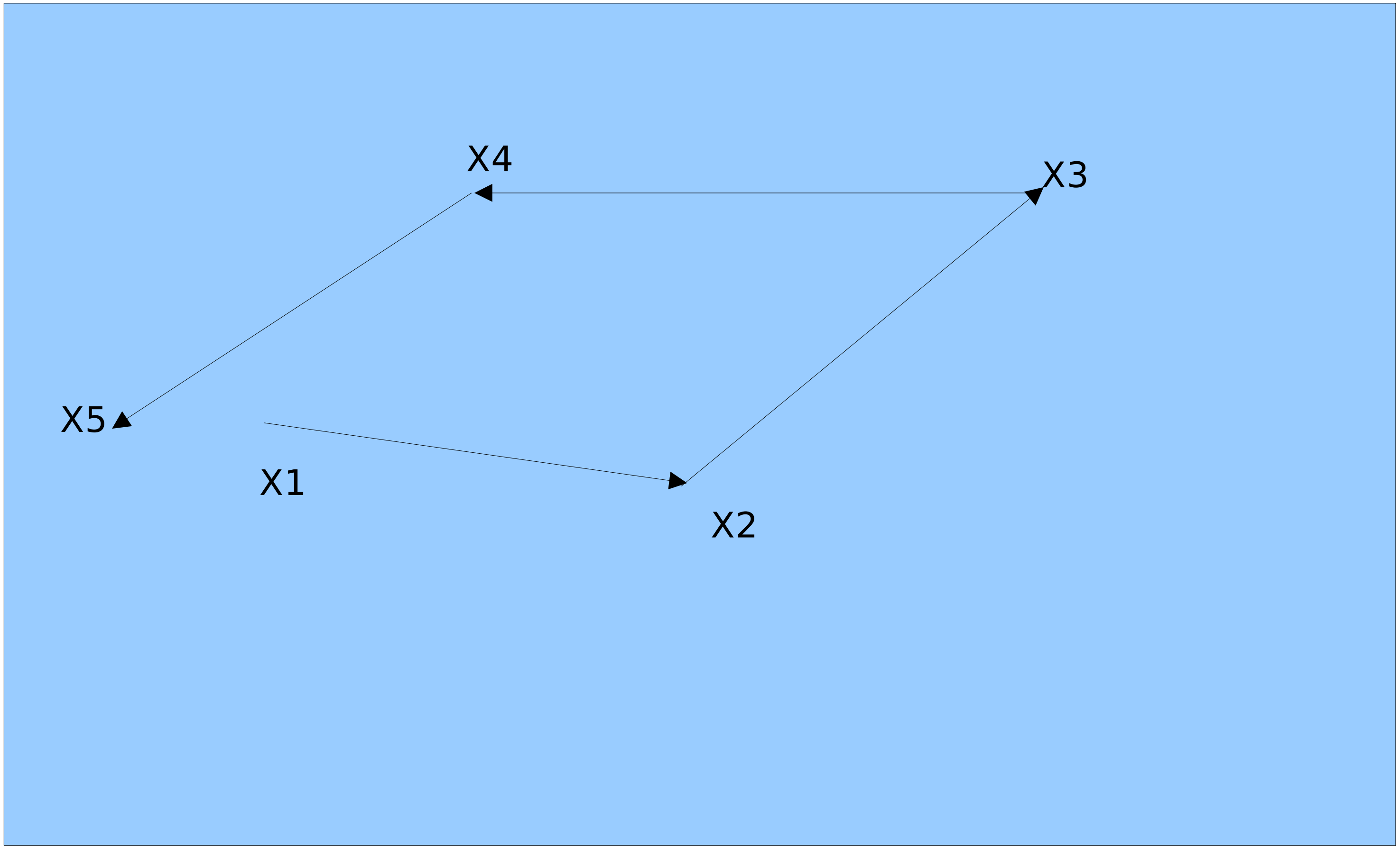
- Attentional Control through Saliency Map (bottom-up *only*!)
  - Concept proposed: Koch & Ullman (1985)
  - Computational implementation: Niebur & Koch (1996)
  - Open-source implementation: Itti, Koch & Niebur (1998); ilab.usc.edu
- Input at different spatial scales (Pyramids):
  - orientation
  - intensity
  - Color
  - motion
- Center-surround architecture
- Maximum determines Focus of Attention
- Scanning through Inhibition of Return

Saliency Map

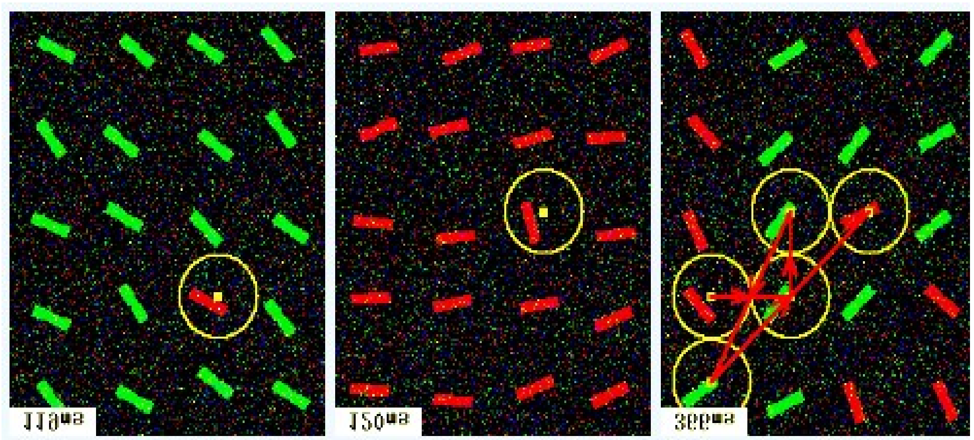


Trajectory of Focus of Attention

- Scanning the image sequentially
- Spike output only at the instantaneously attended location
- x_i=location of FoA at time t_i
- $(t_i - t_{i-1}) = 50$ ms



Selection sequencies from Saliency Map



Simple psychophysical stimuli (Niebur & Koch 96)

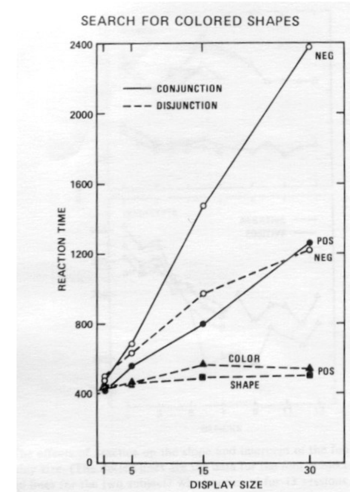
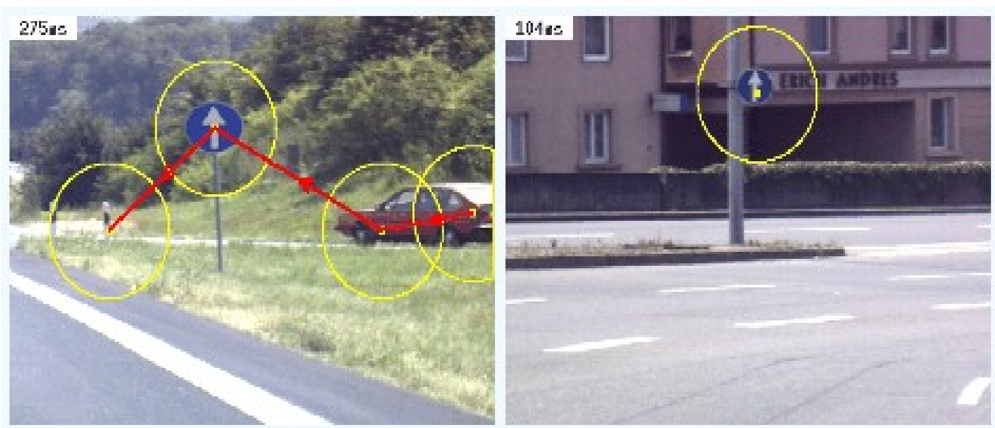


FIG. 1. Search times in Experiment I.



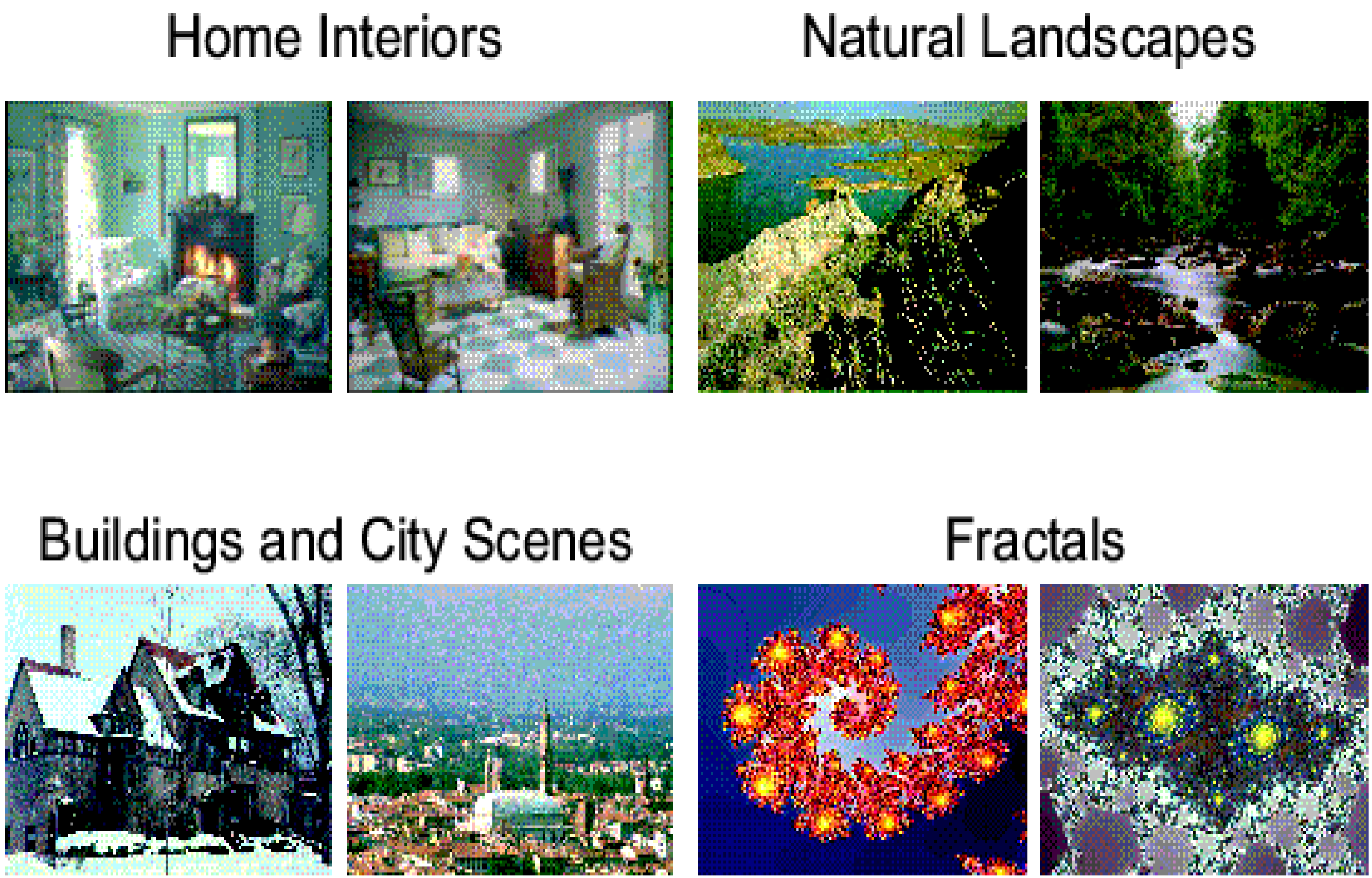
Traffic signs (Niebur & Koch 96)

Large variety of scenes
(from Itti implementation; ilab.usc.edu)

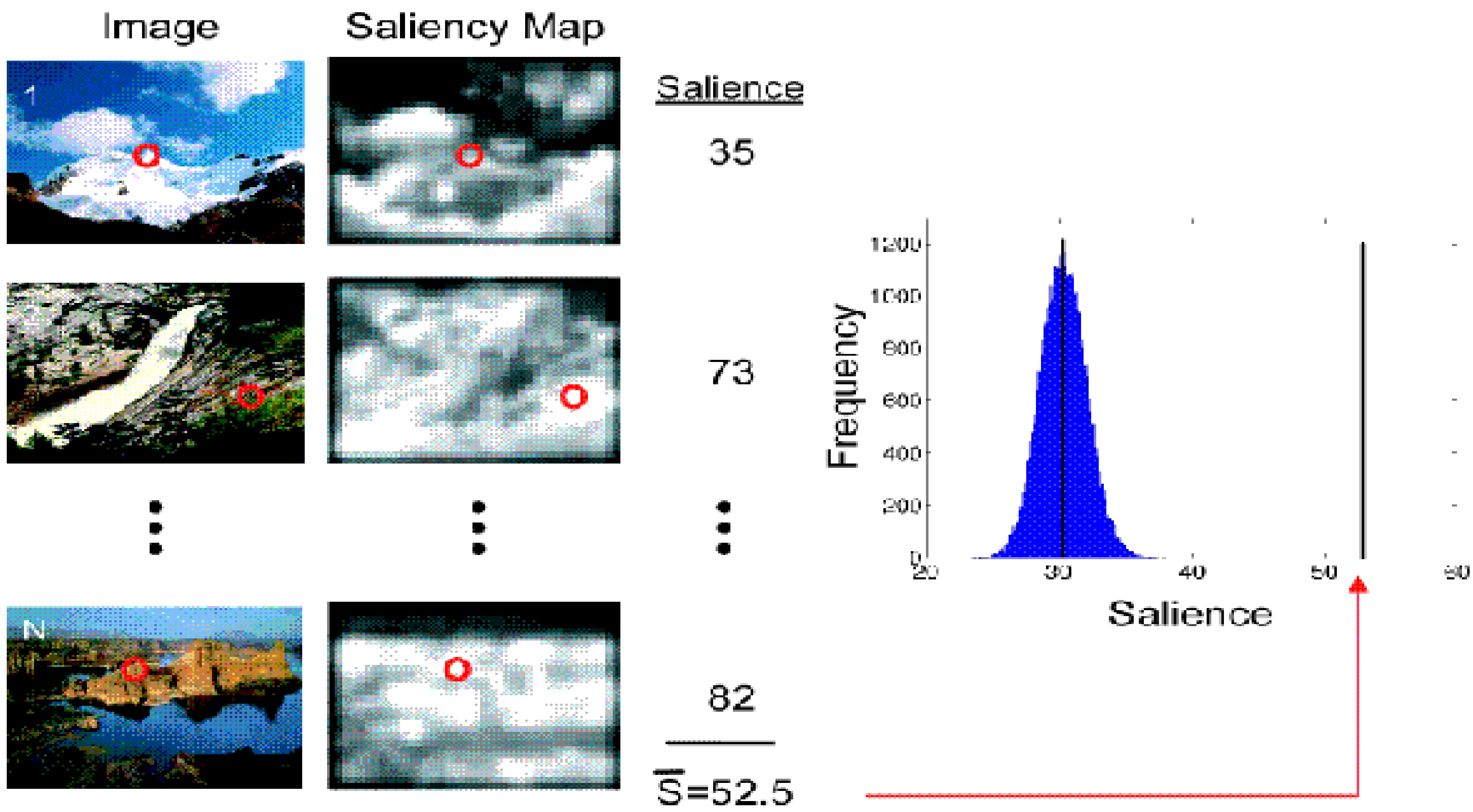
Experimental Test of Predictions for Eye Movements

- Hypothesis: Covert attention is related to overt attention
- First fixations of observers should be predicted by attention model
- Prediction for later fixations expected to be worse because of top-down effects

Free-Viewing Human Observers: Four Databases of Images

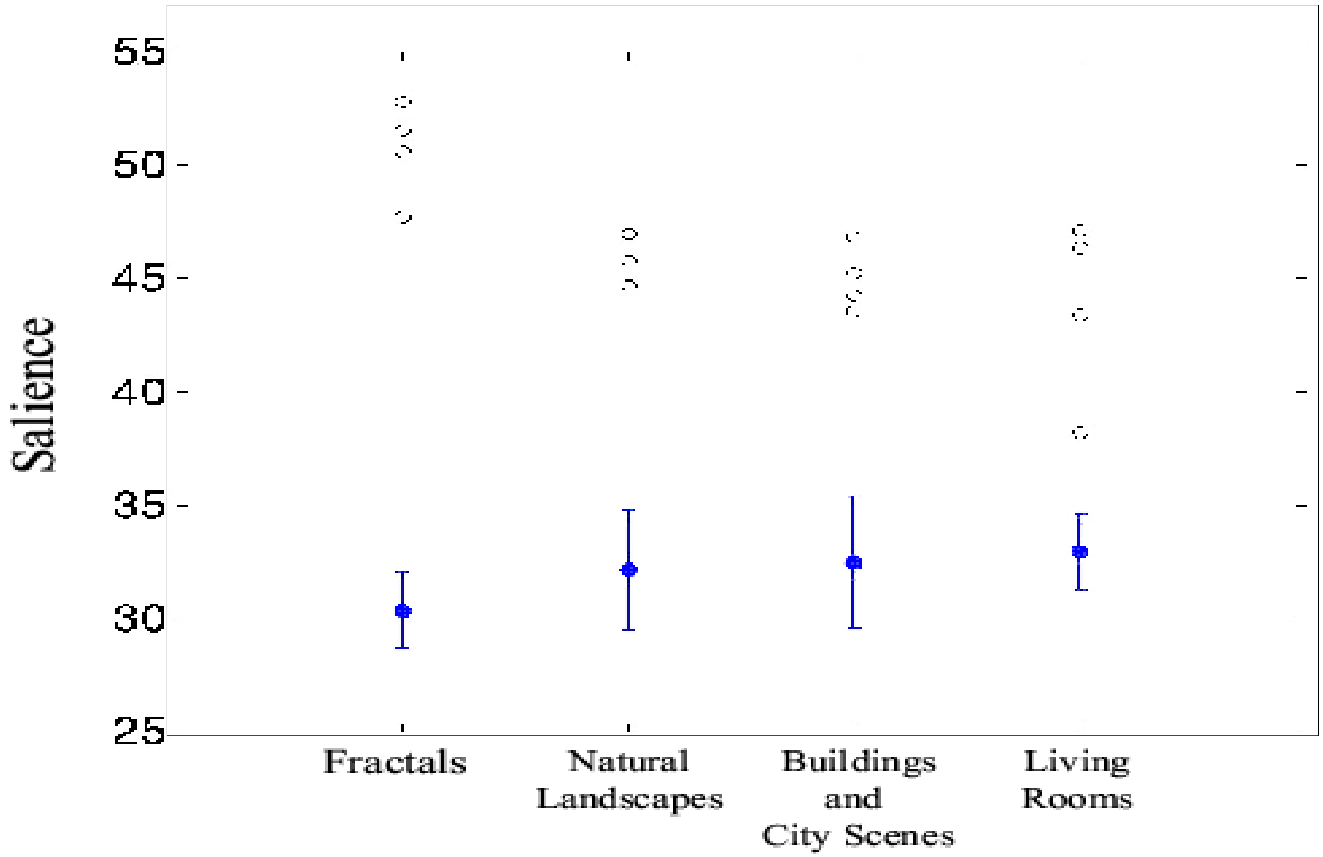


Salience Controls Human Saccades



Very significantly different from chance!

Salience at first fixation



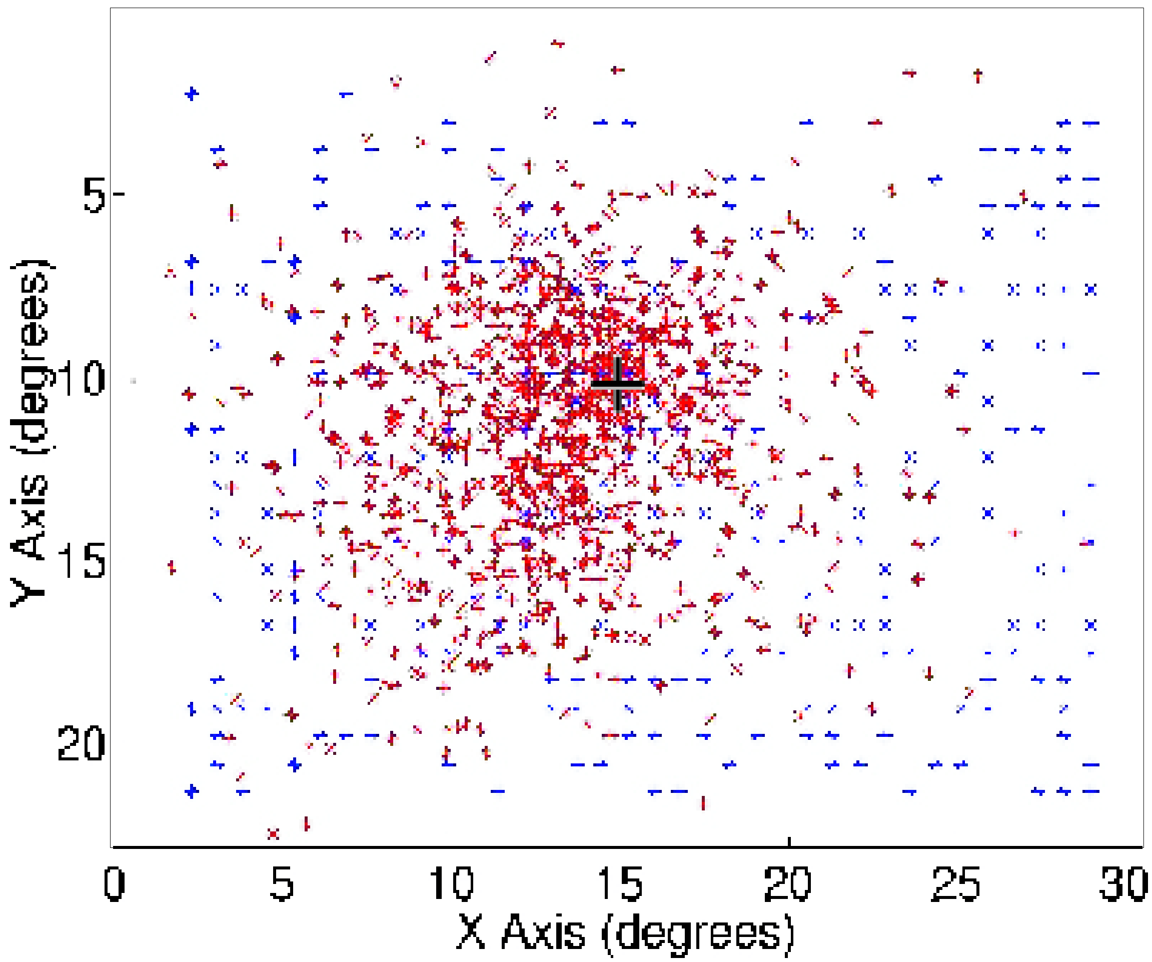
Model

Chance

Performance decreases in subsequent fixations (but is always *way* above chance)

Parkhurst et al 2003

Fixations Bias Towards Center



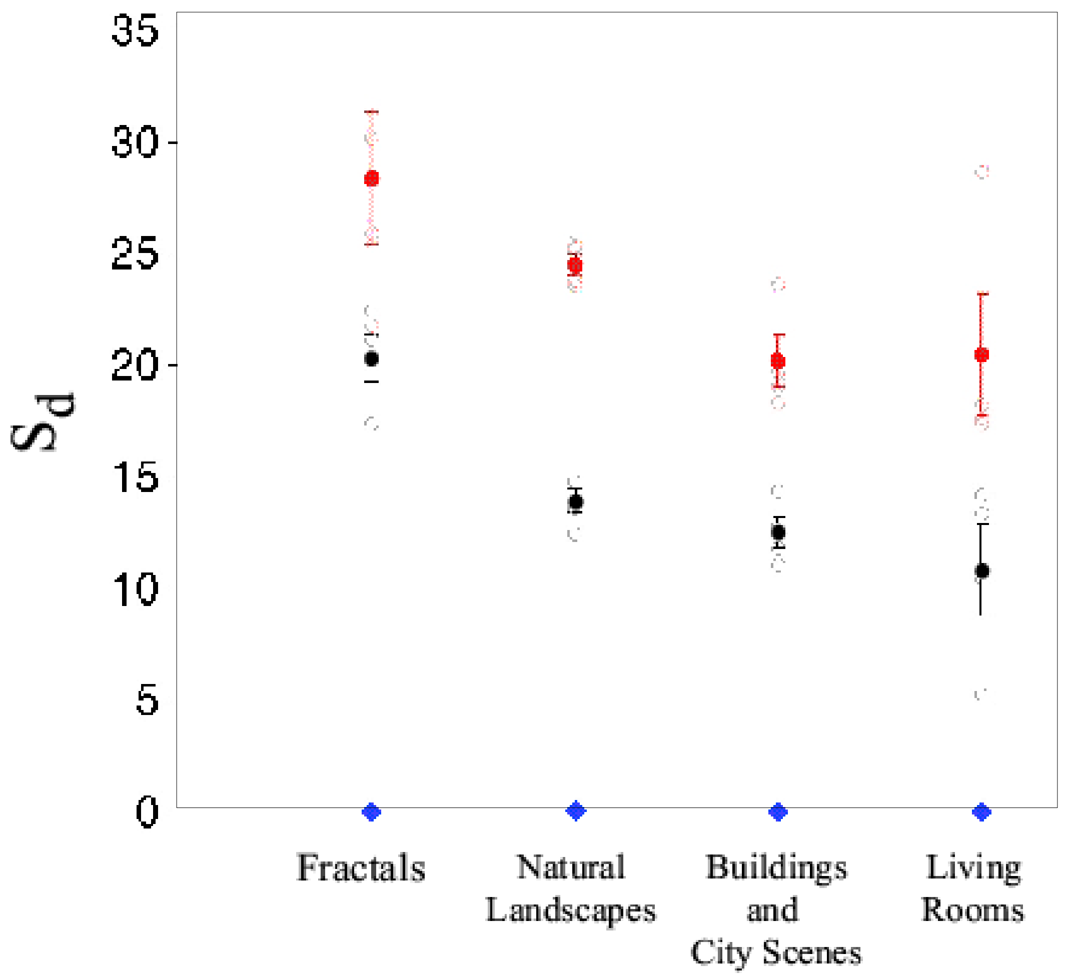
Human

Model

Parkhurst et al 2003

Performance with Differential Center Weighting

Convolve Saliency Map with Gaussian around center:



Non-uniform model

Uniform model

Chance

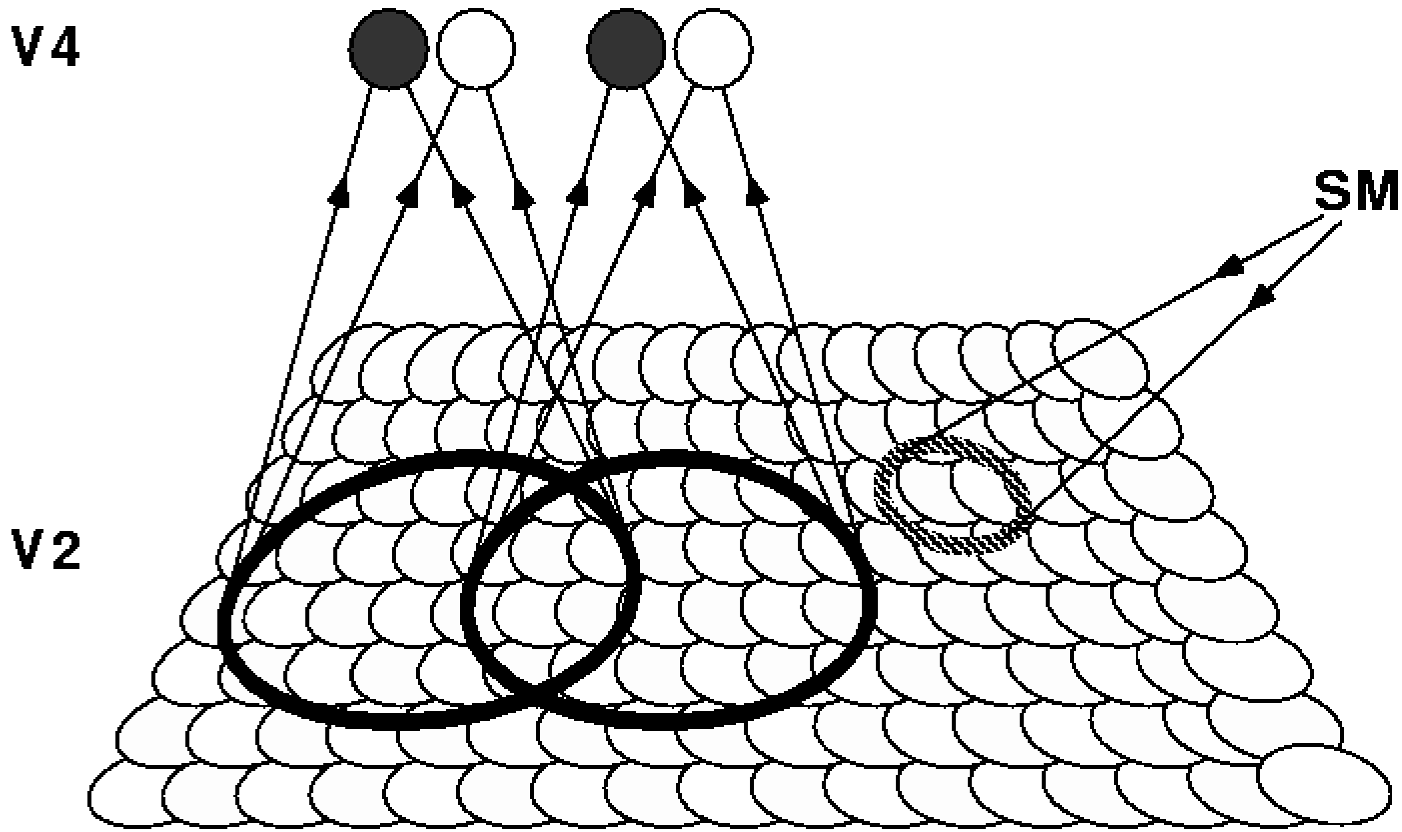
Parkhurst et al 2003

4.) The "What" pathway and temporal tagging: The model and 2 experimental tests

Modeling the *What* Pathway

- Assume attentional selection has been made in *Where* pathway: How to tell the What pathway?
- What is the representation of attention?
- Hypothesis: Synchrony structure of spike trains (quasi-orthogonal to rate)
- "*Temporal Tagging*"

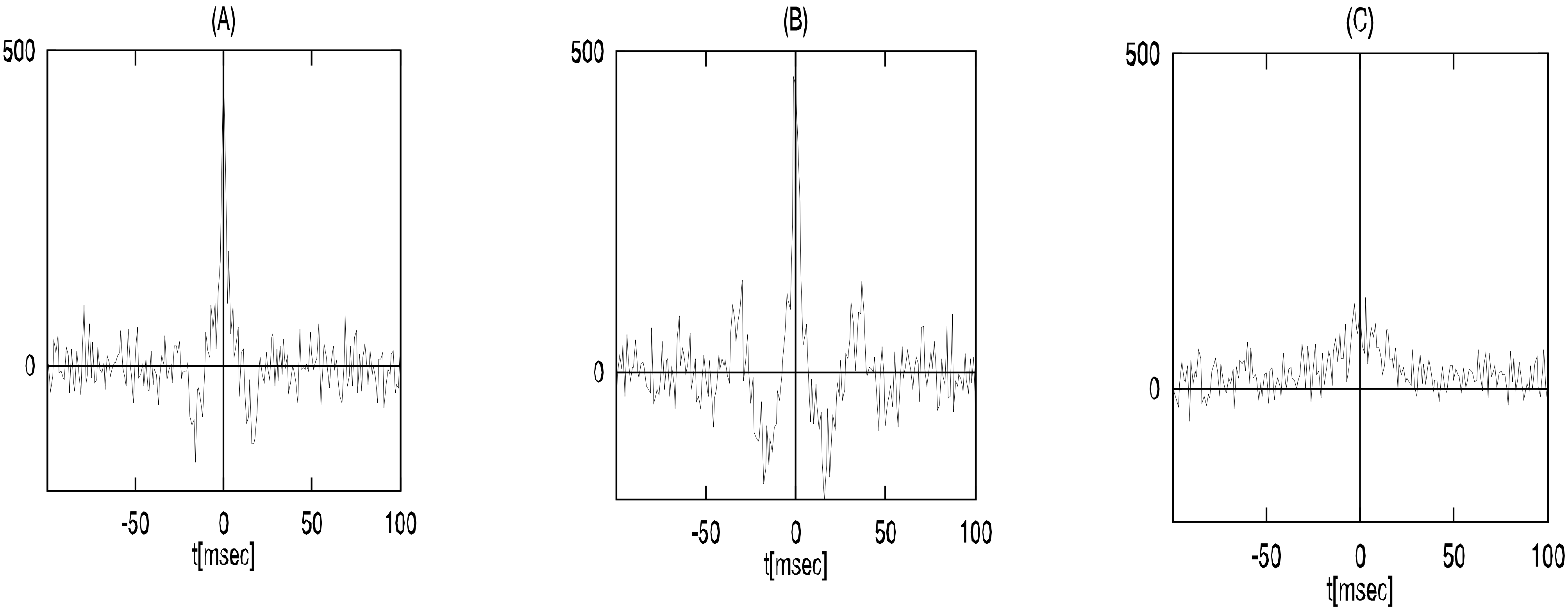
Temporal Tagging



V2: Modulation of temporal structure
V4: Coincidence detection

Predictions

- Peak in spike-spike crosscorrelation between attended stimuli
- No peaks in cc. between unattended stimuli
  (Niebur & Koch, JCNS 1(1), 1994)



V2 Attended | V4 Attended | V4 Unattended

Experimental Test in monkeys

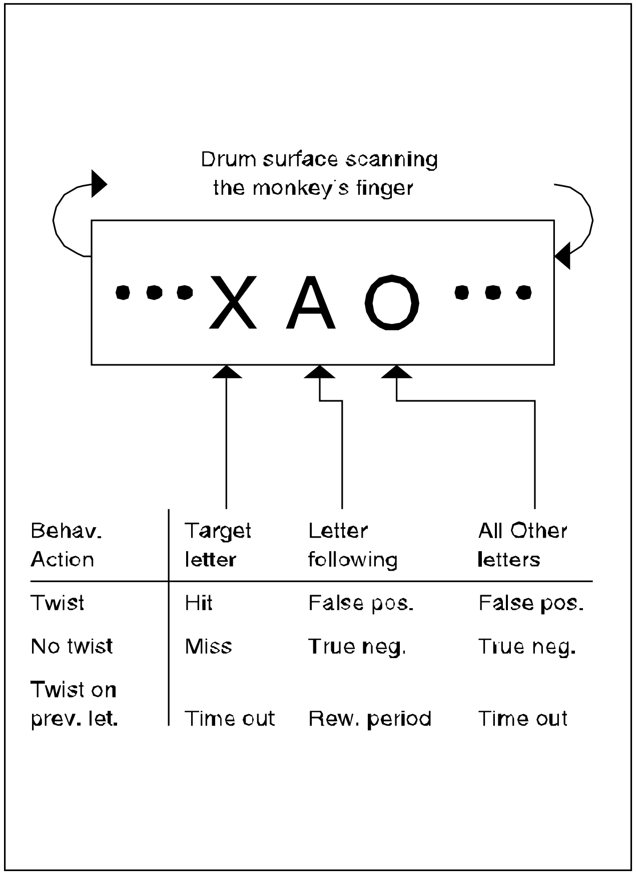
Experimental Paradigm:

- Monkey (*macaque*) receives simultaneous visual and tactile stimulation
- Attention switched between visual and tactile task
- Performance approx. 90% correct
- Tactile input *identical* during both tasks
- Record in SII cortex
- Analyze temporal structure and correlation with attentional state

Task Monkeys 1&2

- Complex patterns (letters) scanned across finger pad
- Twist lever when target pattern appears
- Blocked with visual task (dimming detection)

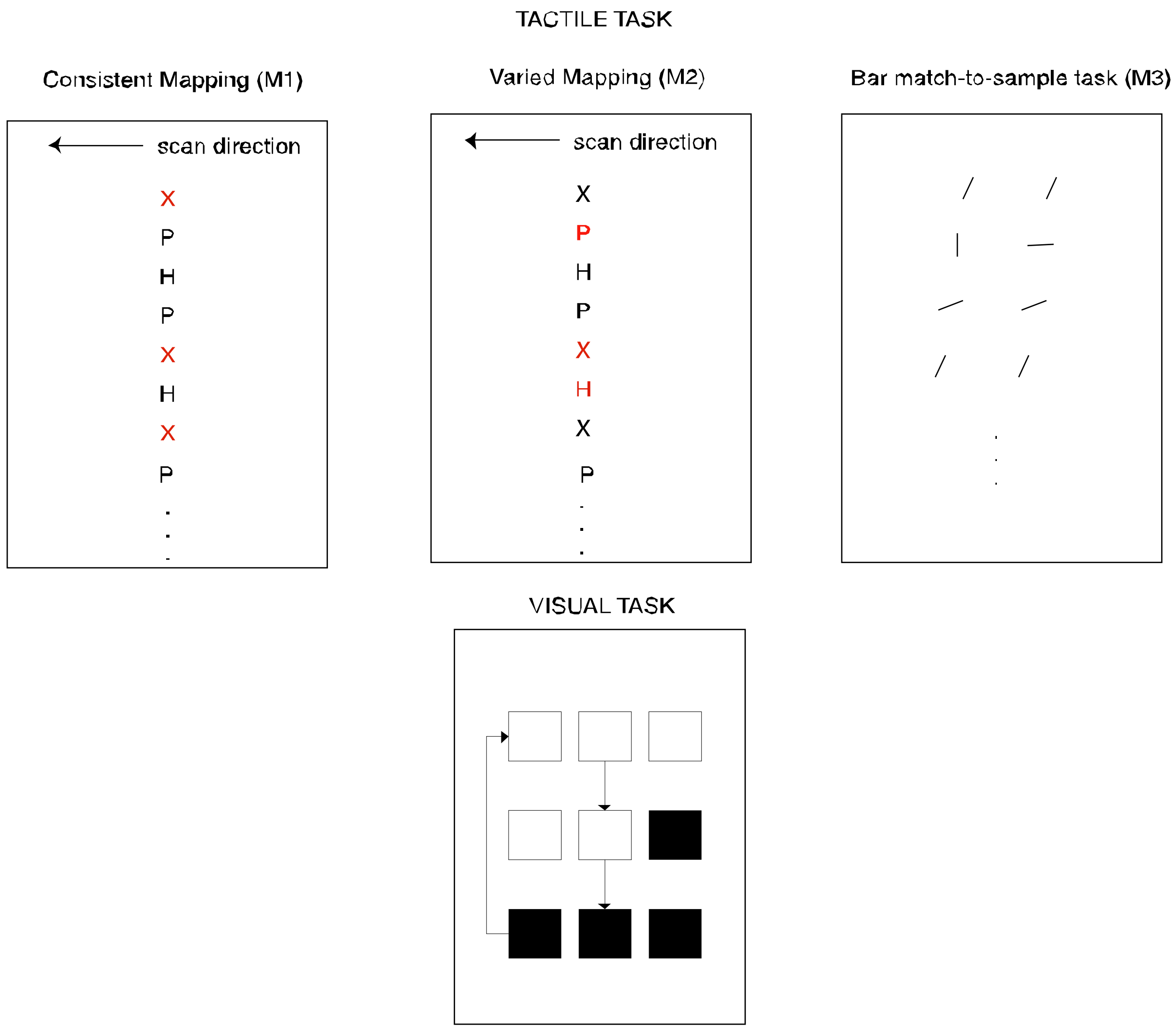
TACTILE TASK



Task Monkey 3

- Tactile task: Delayed match to sample of orientation
- Visual task: Detect dimming
(as for M1 & M2)

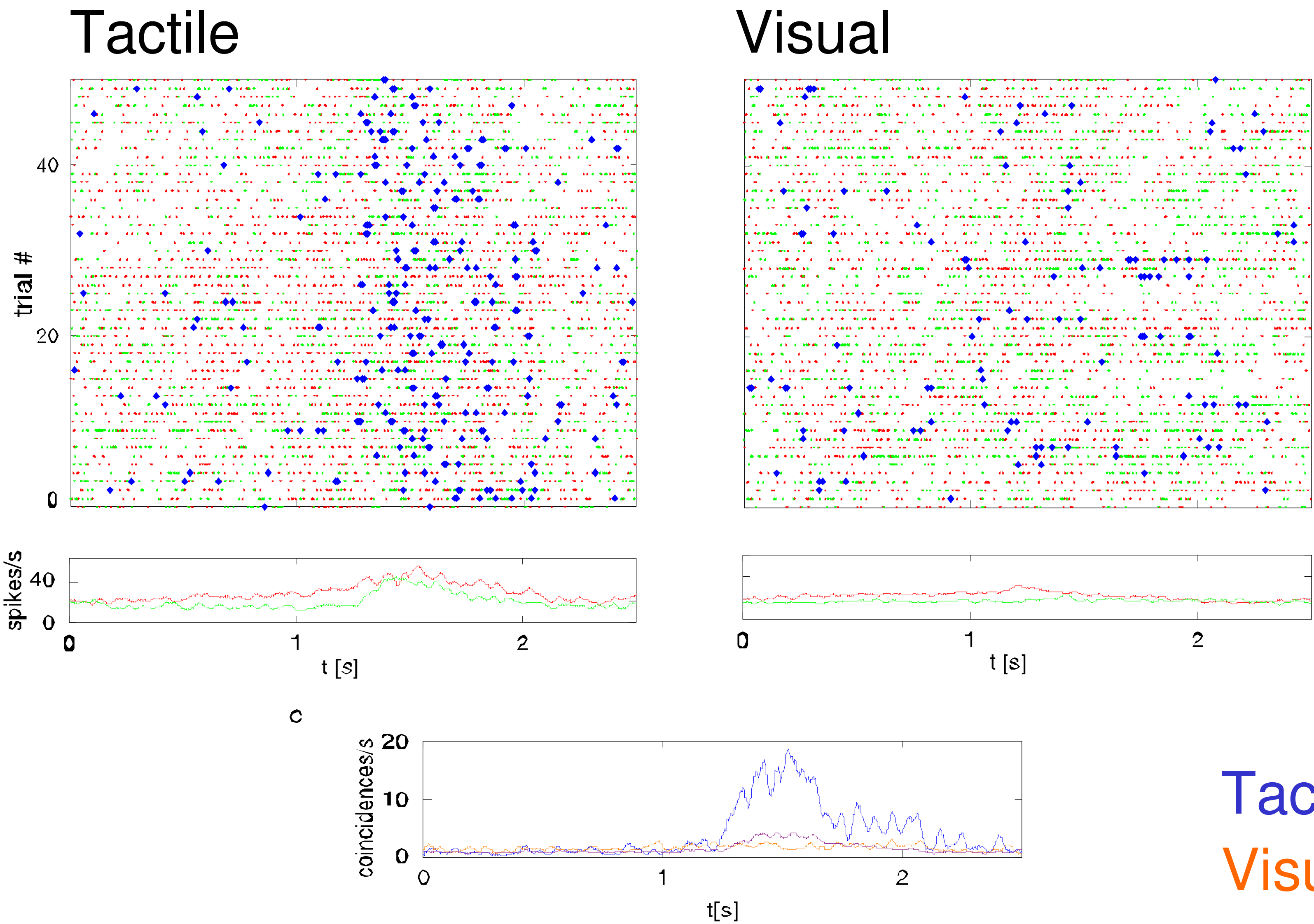
Overview: Tasks



Data Set

- Up to 7 electrodes
- 436 SII cells in 4 hemispheres of 3 monkeys.
- 648 cell pairs analyzed.
- Cells in pair had overlapping fields on the hands.
- Cells in pair recorded on separate electrodes, average distance 1 mm, minimum 400 μm.

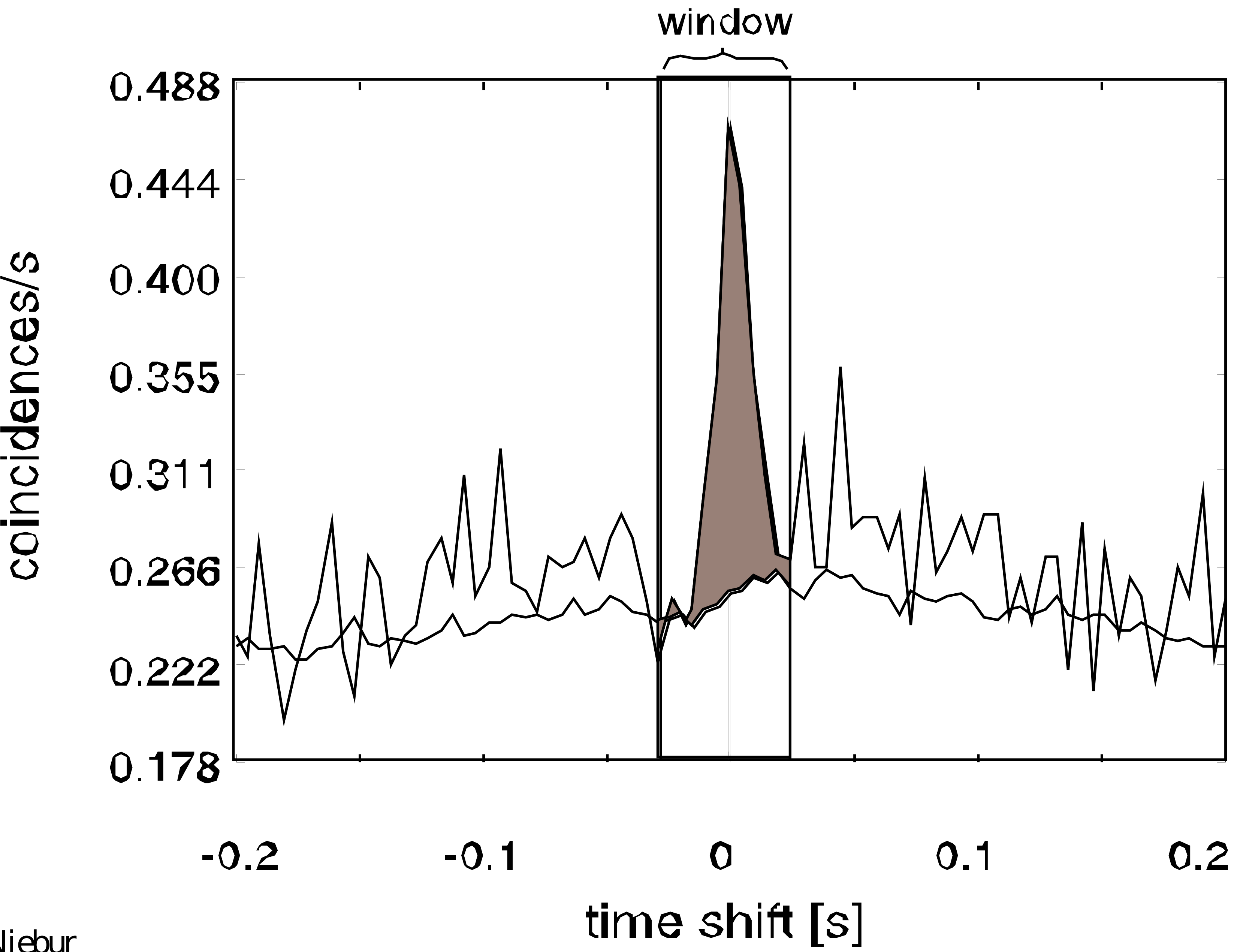
Responses of a neural pair



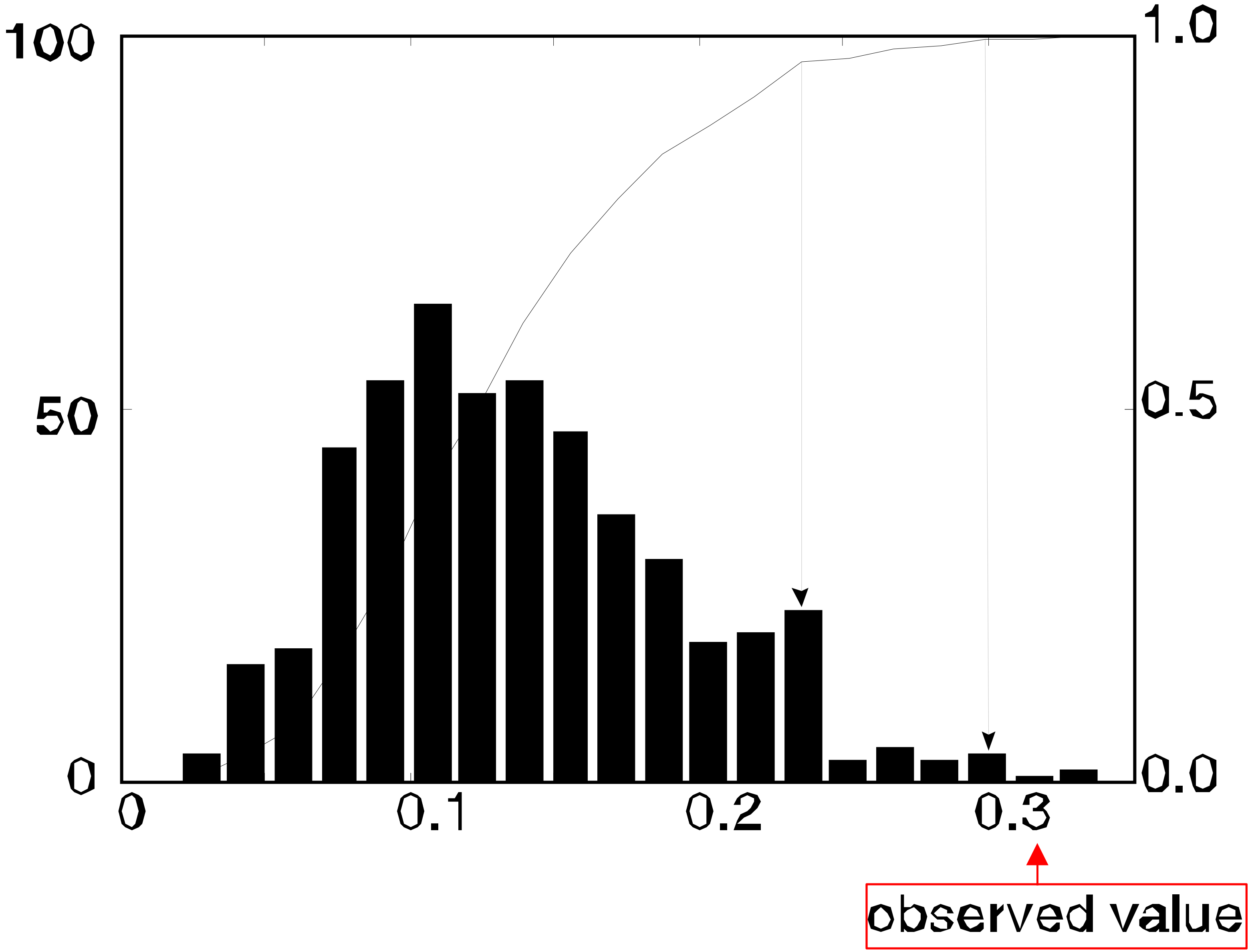
Tactile
Visual
Expected

Steinmetz et al (2000)

Measure of Synchrony: Deviation from shift-predictor



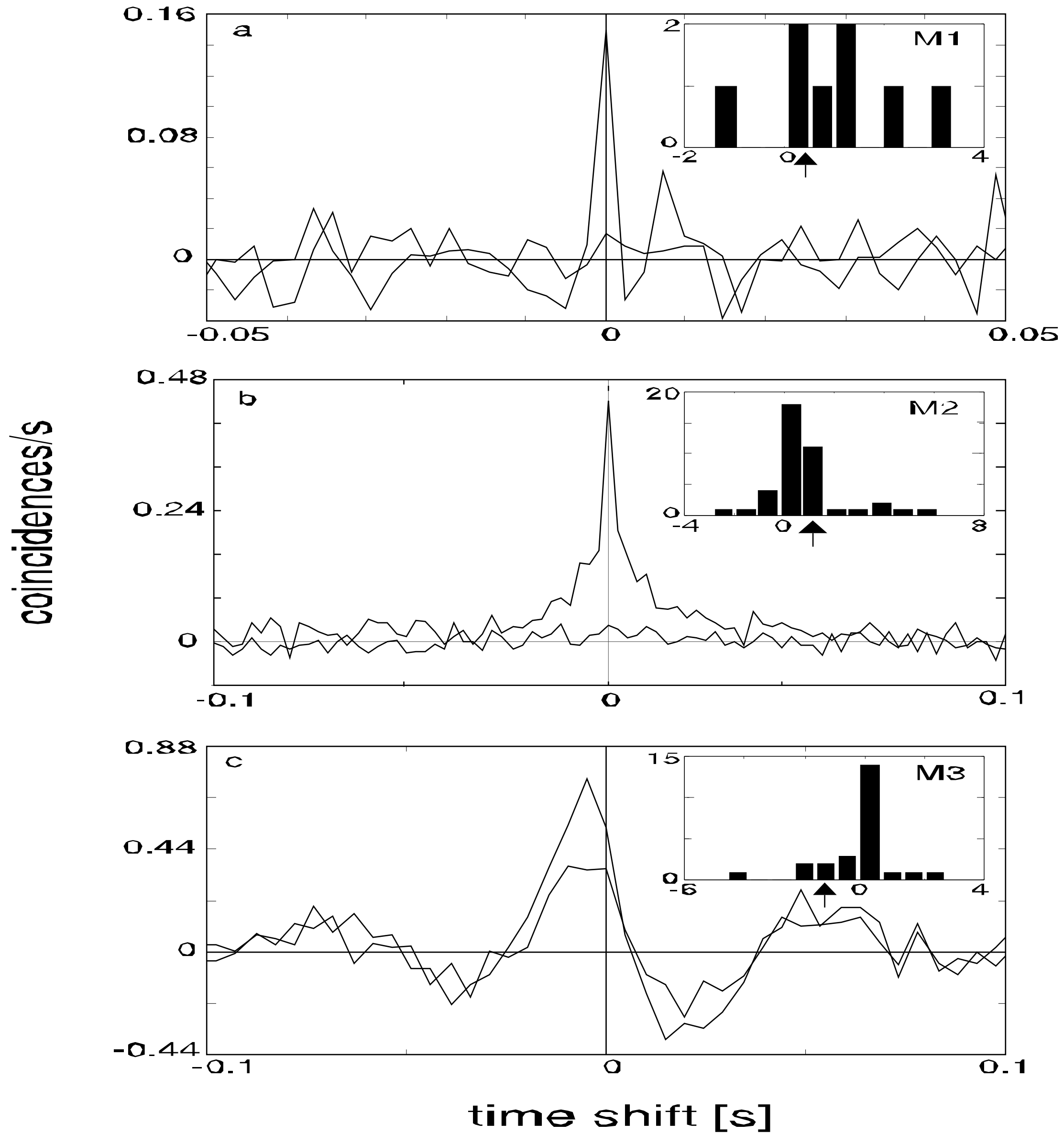
Significance testing by bootstrap



Pairs with synchrony

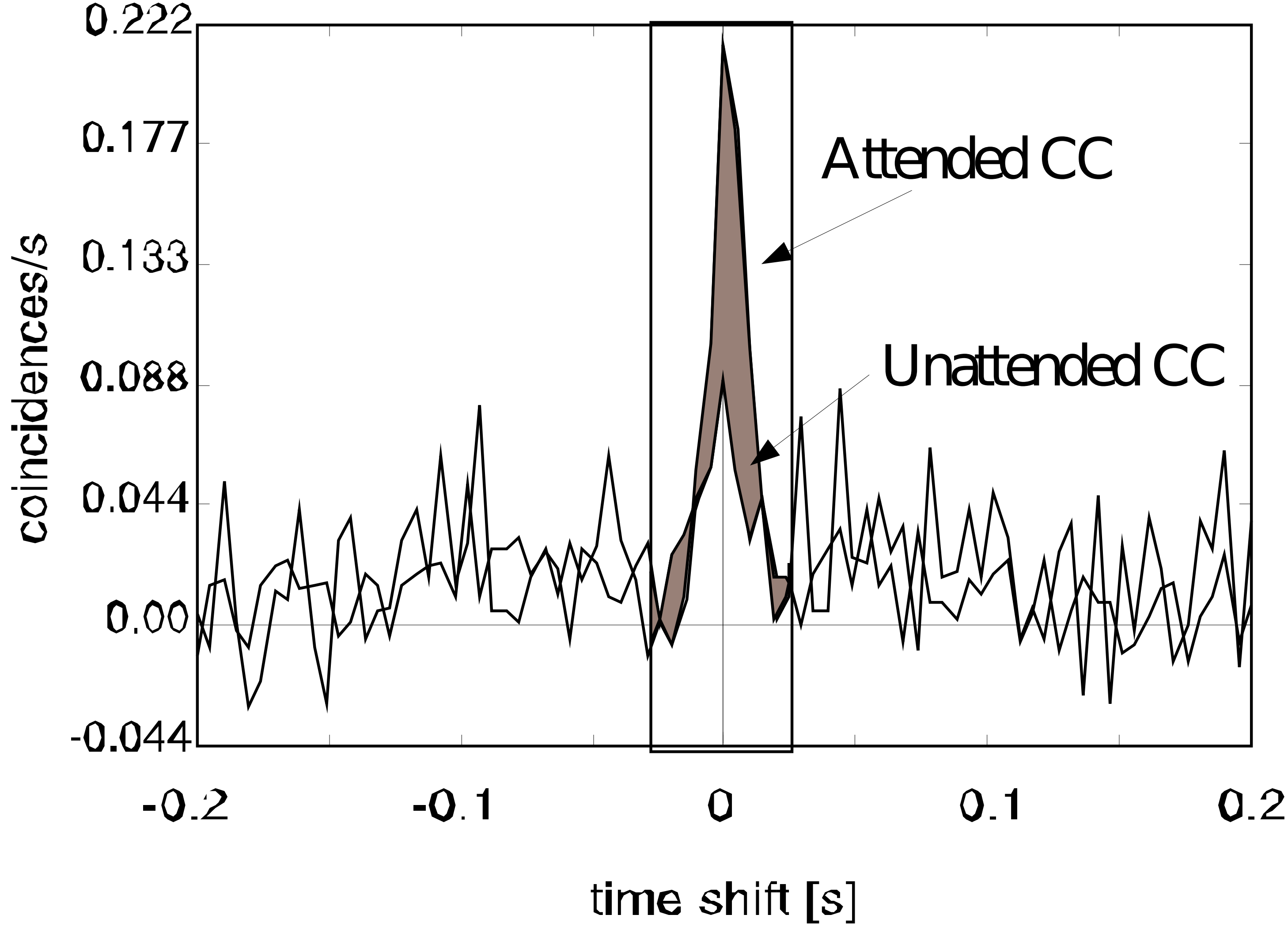
Monkey	Synchrony
M1:constant target letter	50/95 (53%)
M2: varying target letter	113/145 (78%)
M3: orientation DMS	264/408 (65%)

Synchrony changes with attentional state



(remember the predictions...)

Quantification of difference



Again: Significance testing by bootstrap

Pairs with synchrony change

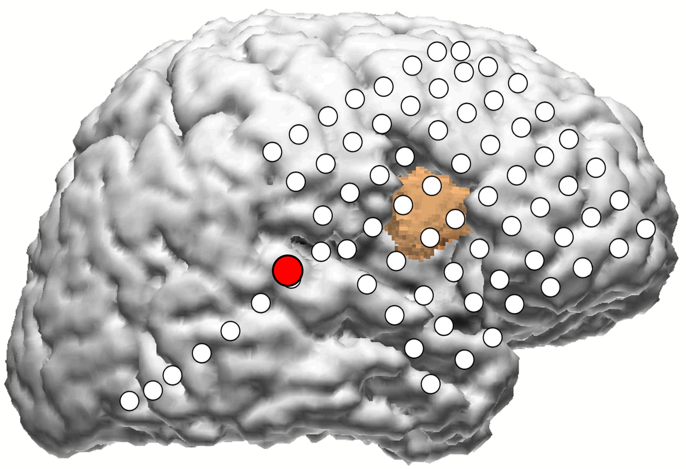
Monkey	Change	Increase
M1: const. Letter	8/50 (16%)	7/8 (87%)
M2: var. letter	41/116 (35%)	35/41 (85%)
M3: orient. DMS	24/264 (9%)	17/24 (68%)

Summary of Experimental Test in Monkeys

- Synchrony present in 66% of neuron pairs in SII
- Synchrony changes with attentional state in 17% of those pairs
- Stronger effect with controlled attention than with automatic attention
- Synchrony increases with attention in most cases (80%)
- Evidence for mixed rate/temporal code, in agreement with model predictions

Effects of attention on ECoG high-gamma activity in humans

Recordings from grids of subdural electrodes implanted in human patients with untractable epilepsy in preparation for surgical resection of putative epileptical foci.

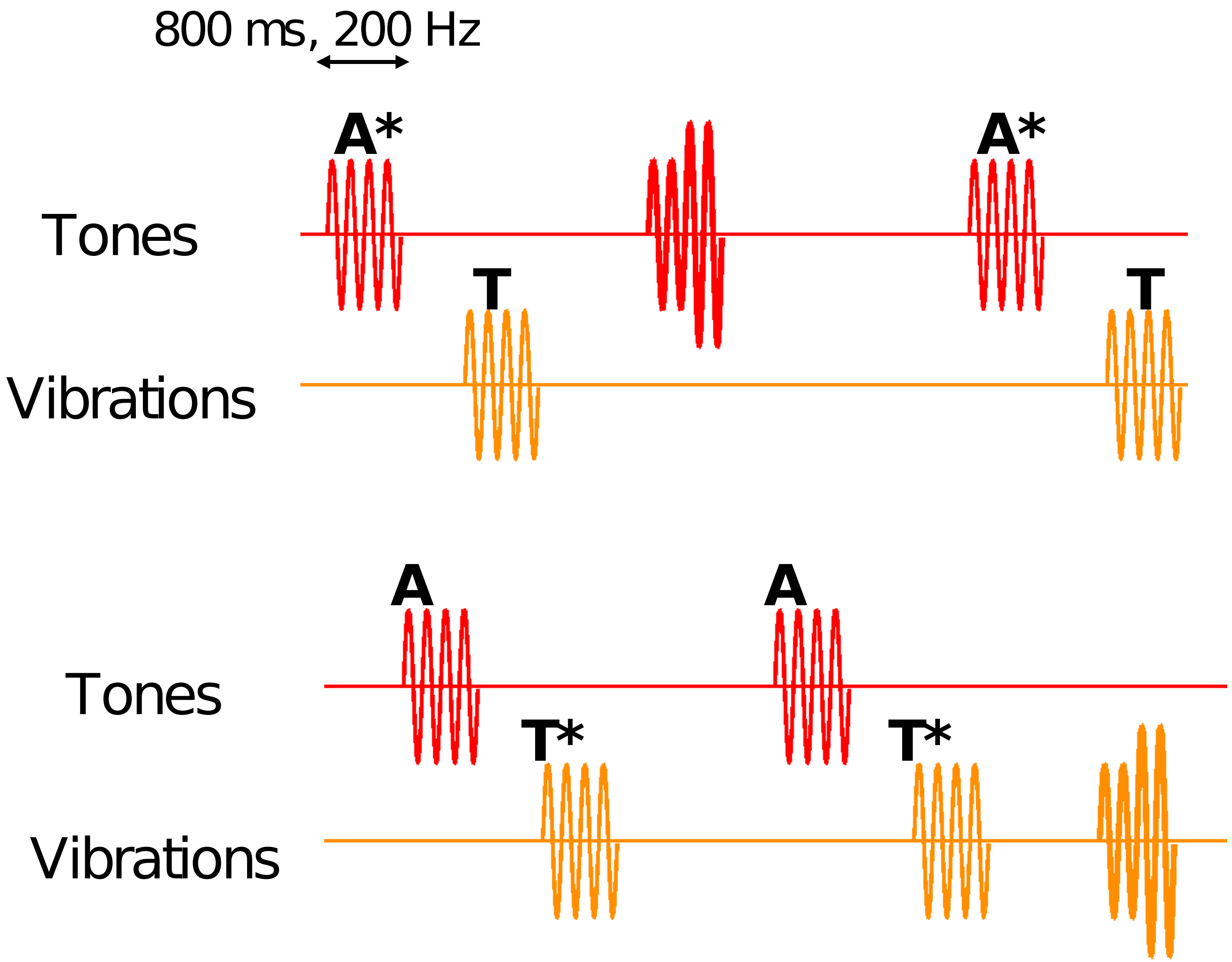


Behavioral task

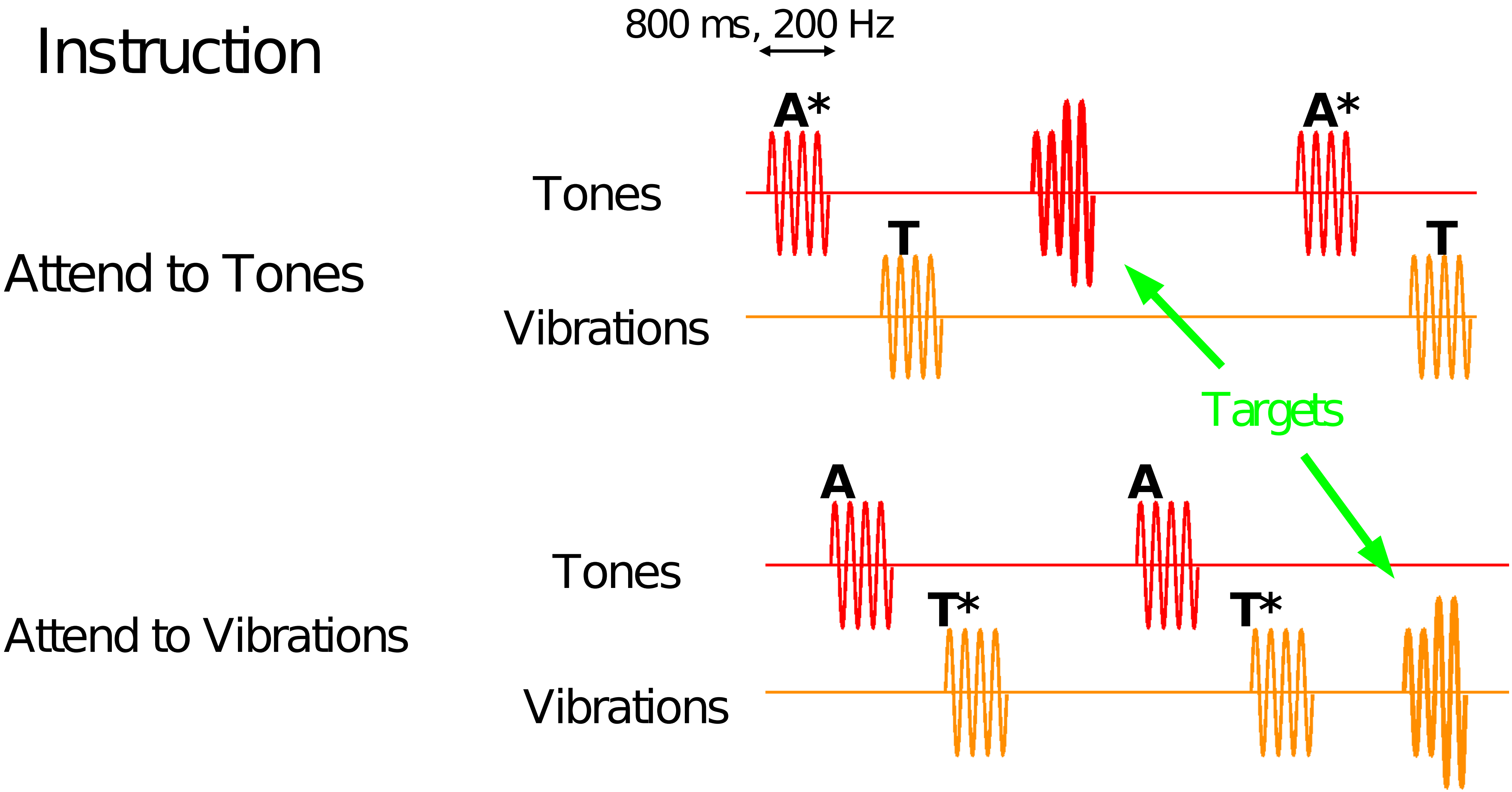
Instruction

Attend to Tones

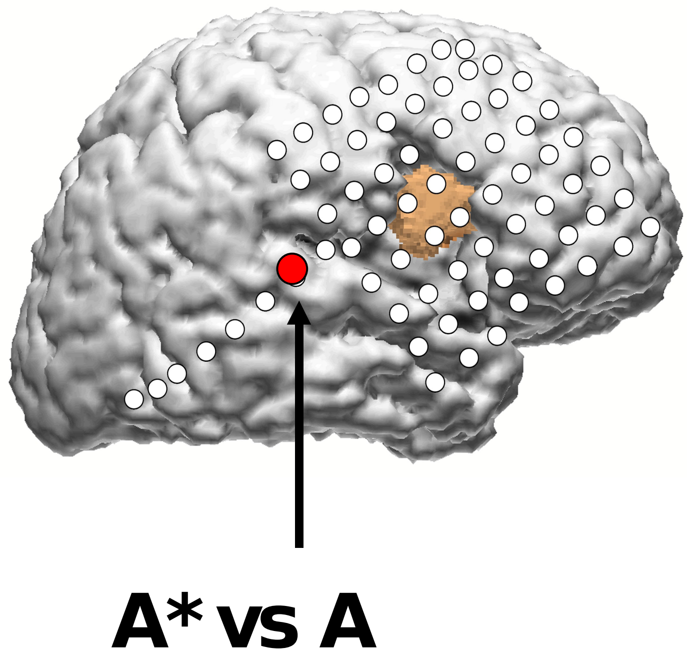
Attend to Vibrations

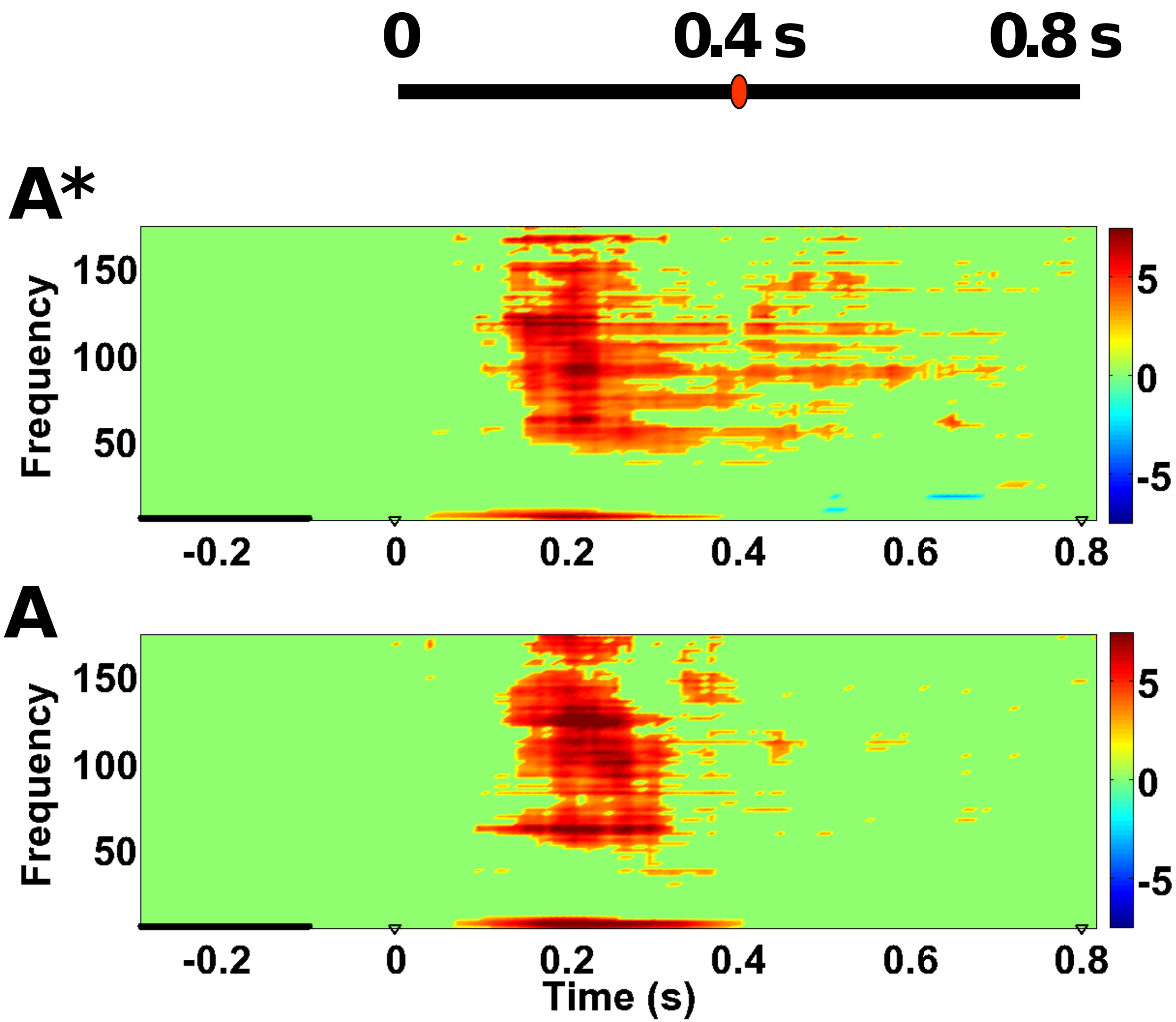


Behavioral task

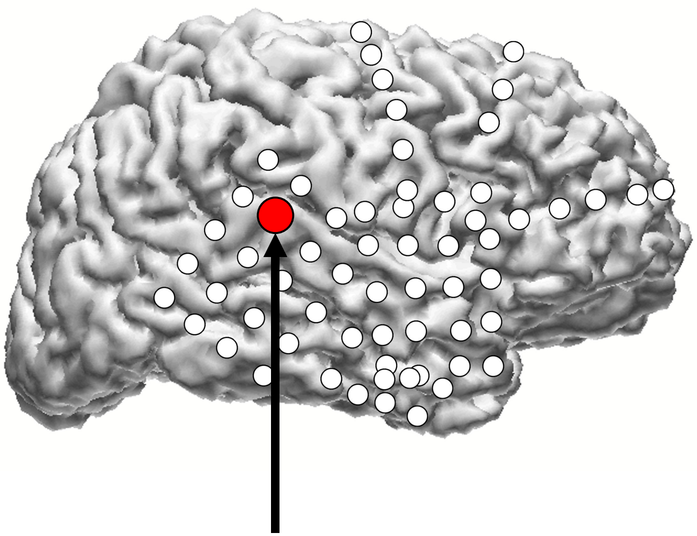


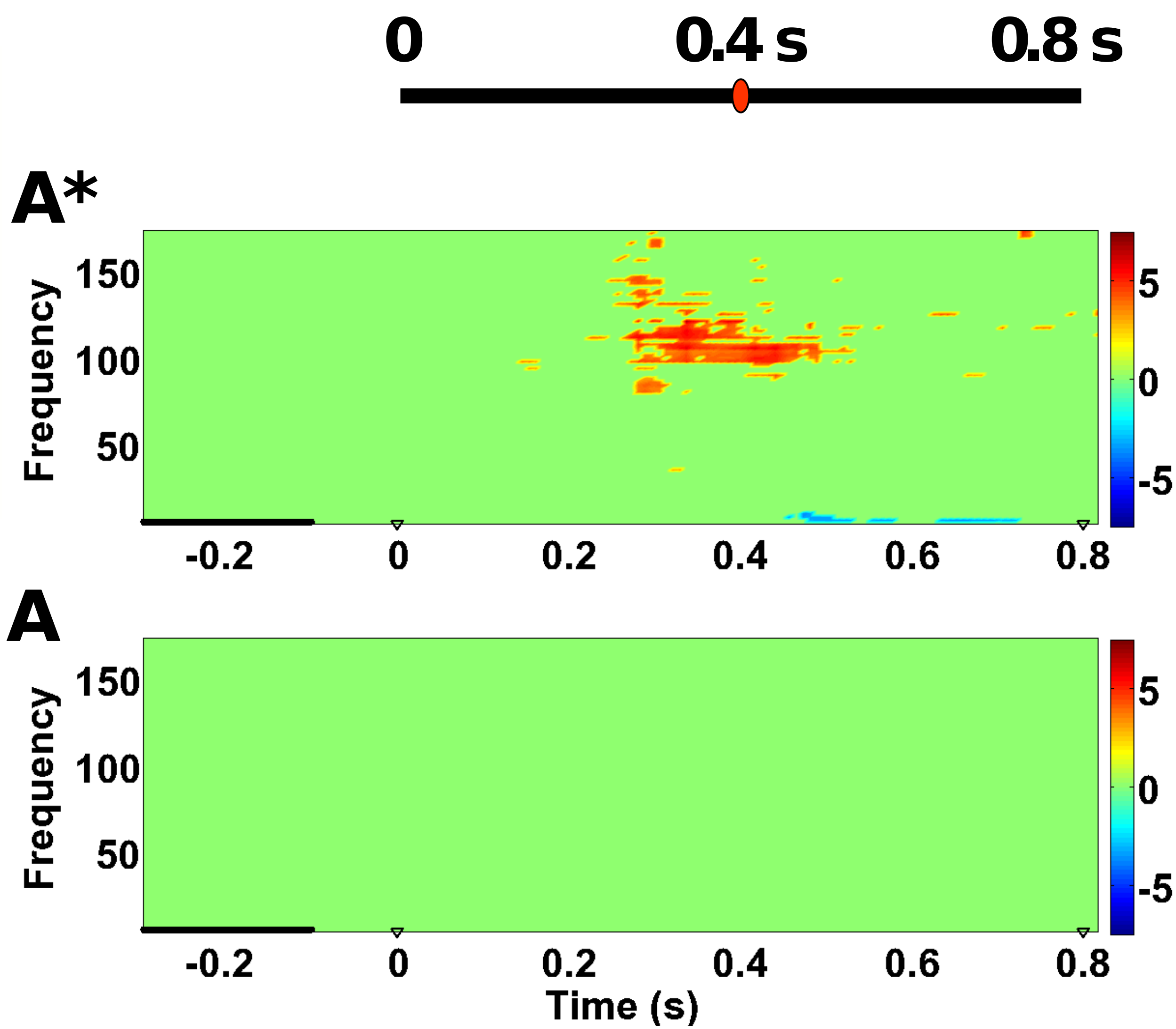
Results: Auditory cortex



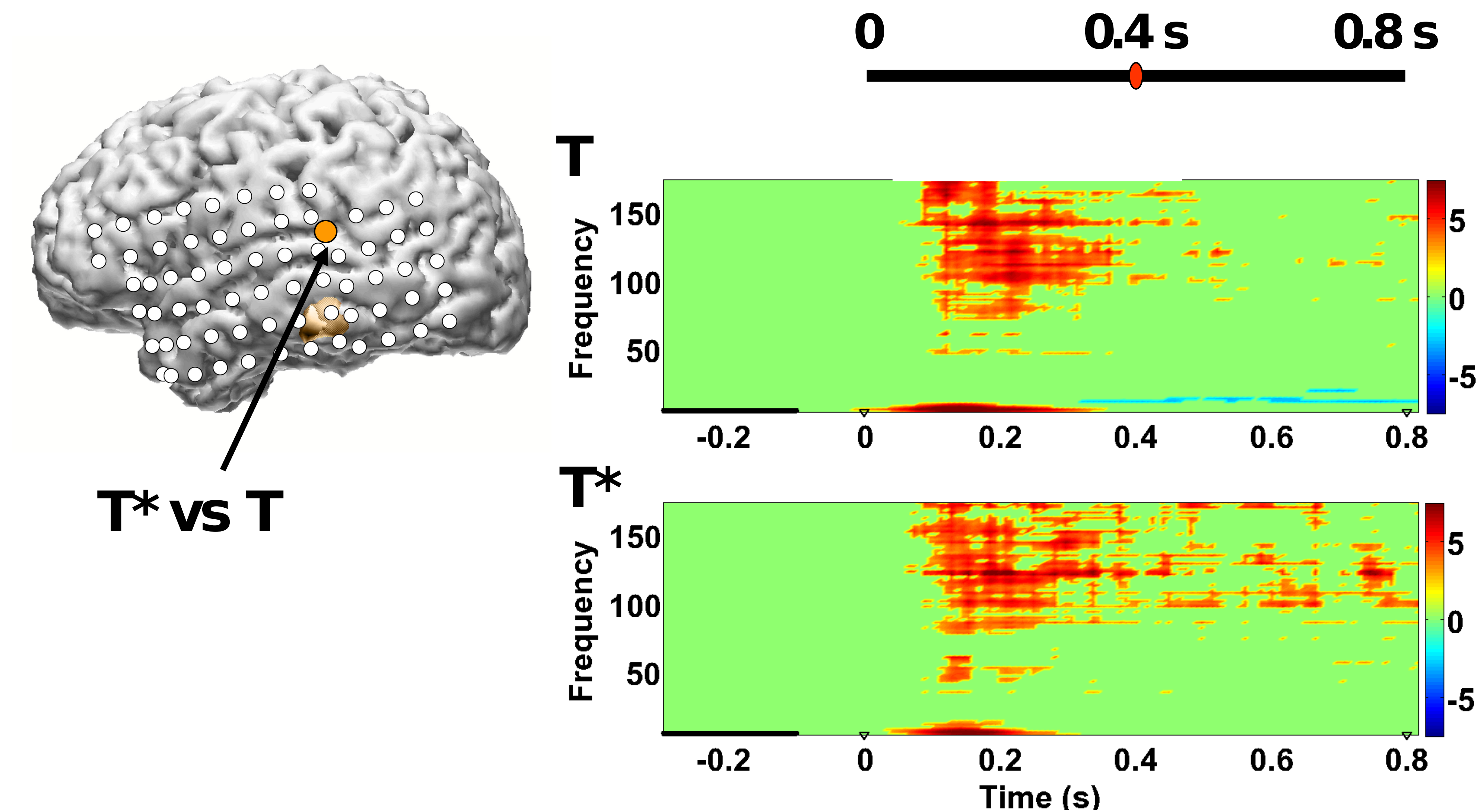


Results: Auditory cortex

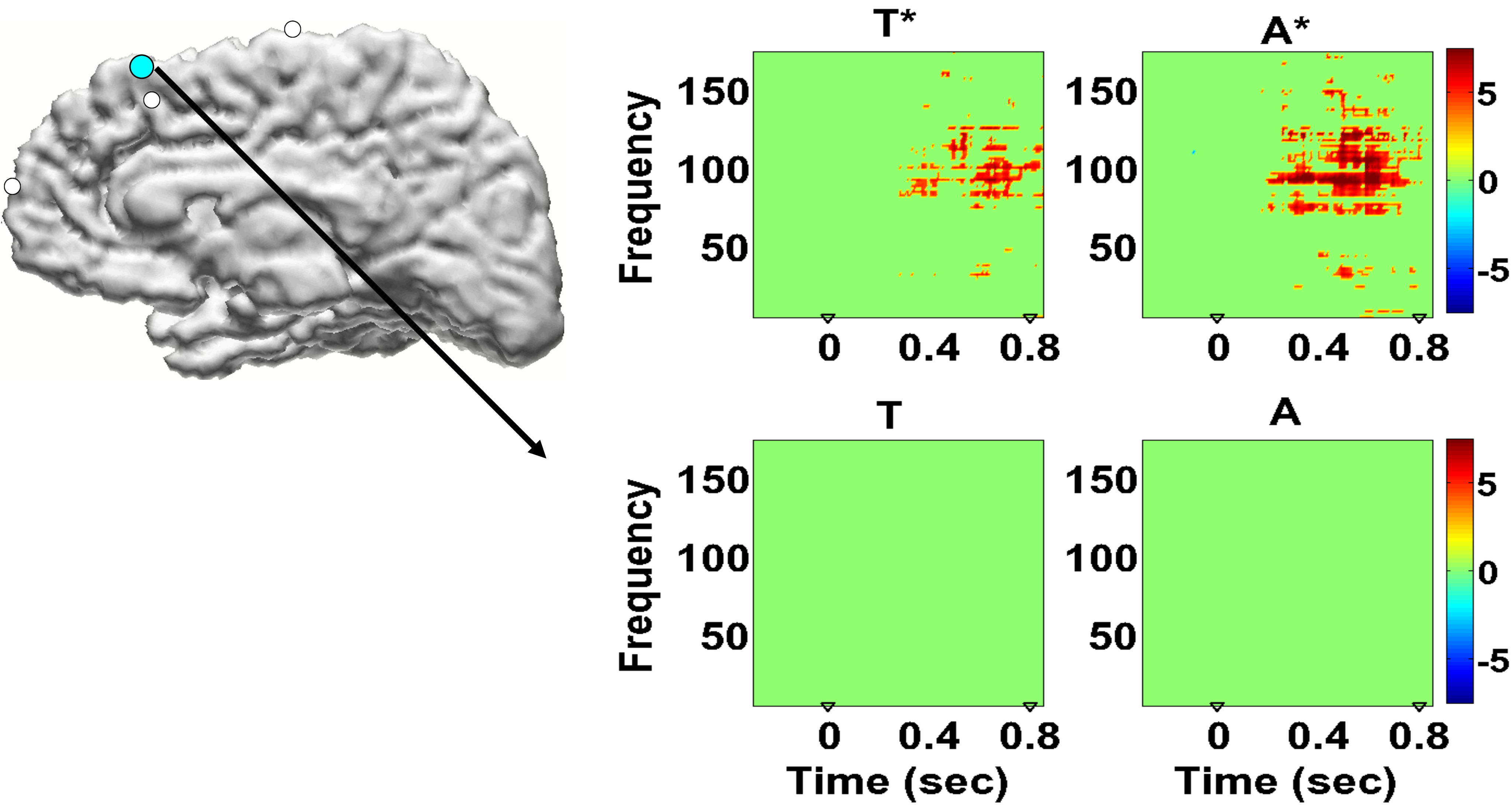




Results: Somatosensory cortex



Frontal cortex



Summary of Experimental Test in Humans

- High-gamma oscillations increase with attention
- (Not shown:) High-gamma oscillations are likely due to synchronous spiking (Ray et al, J. Neuroscience, in press)
- Again: Evidence for mixed rate/temporal code, in agreement with model predictions

General Conclusion

- Attention/Selection is indispensable for intelligent processing of complex sensory input
- Model for selection algorithm based on saliency map, agrees with eye movements
- Model for neuronal implementation based on temporal tagging confirmed in somatosensory cortex of monkey, and consistent with human data
- Technical implementations in infancy

(two more slides to come...)

Collaborators

- *Saliency map:* Christof Koch, Laurent Itti
- *Synchrony model:* Christof Koch
- *Overt attention:* Derrick Parkhurst
- *Somatosensory attention (monkey):* Arup Roy, Peter Steinmetz, Steven Hsiao, Ken Johnson
- *ECog (humans):* Supratim Ray, Nathan Crone

The Telluride Compromise

(staying friends with Malcolm *and* with John)

- Every bit (of sensory information) is *not* sacred
    - we need to throw away most of them to focus on the relevant ones

But

- Every spike (in the nervous system) *is* sacred
    - because it represents one of the selected, thus important, bits in a hybrid/temporal code

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