Visual Object Recognition
Computational Models and Neurophysiological Mechanisms
Neurobiology 130/230. Harvard College/GSAS 78454

Web site: http://tinyurl.com/visionclass (Class notes, readings, etc)

Location: Biolabs 2062

Time: Mondays 03:30 – 05:30

Lectures:

Faculty: Gabriel Kreiman and invited guests

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Class 1. Sep-12 Introduction to pattern recognition. Why is vision difficult? Visual input. Natural image statistics. The retina.

Class 2. Sep-19 Lesion studies in animal models. Neurological studies of cortical visual deficits in humans.

Class 3. Sep-26 Psychophysics of visual object recognition [Joseph Olson]

Class 4. Oct-03 Introduction to the thalamus and primary visual cortex [Camille Gomez-Laberge]

Oct-10 Columbus Day. No class.

Class 5. Oct-17 Adventures into *terra incognita*. Neurophysiology beyond V1 [Hanlin Tang]

Class 6. Oct-24 First steps into inferior temporal cortex [Carlos Ponce]

Class 7. Oct-31 From the highest echelons of visual processing to cognition [Leyla Isik]

Class 8. Nov-07 Correlation and causality. Electrical stimulation in visual cortex.

Class 9. Nov-14 Theoretical neuroscience. Computational models of neurons and neural networks. [Bill Lotter]

Class 10. Nov-21 Computer vision. Towards artificial intelligence systems for cognition [David Cox]

Class 11. Nov-28 Computational models of visual object recognition. [Kreiman]

Class 12. Dec-05 [Extra class] Towards understanding subjective visual perception. Visual consciousness.

Psychophysics: The study of the dependencies of psychological experiences upon the physical stimuli that generate them

Basic measures:

- Reaction time — The time taken by subjects to perform a task or make a judgment can give an indication (or at least an upper bound) of how long the necessary psychological (and hence neural) processing takes.

- Performance — Often inversely related to reaction time. There are techniques for mitigating response biases.

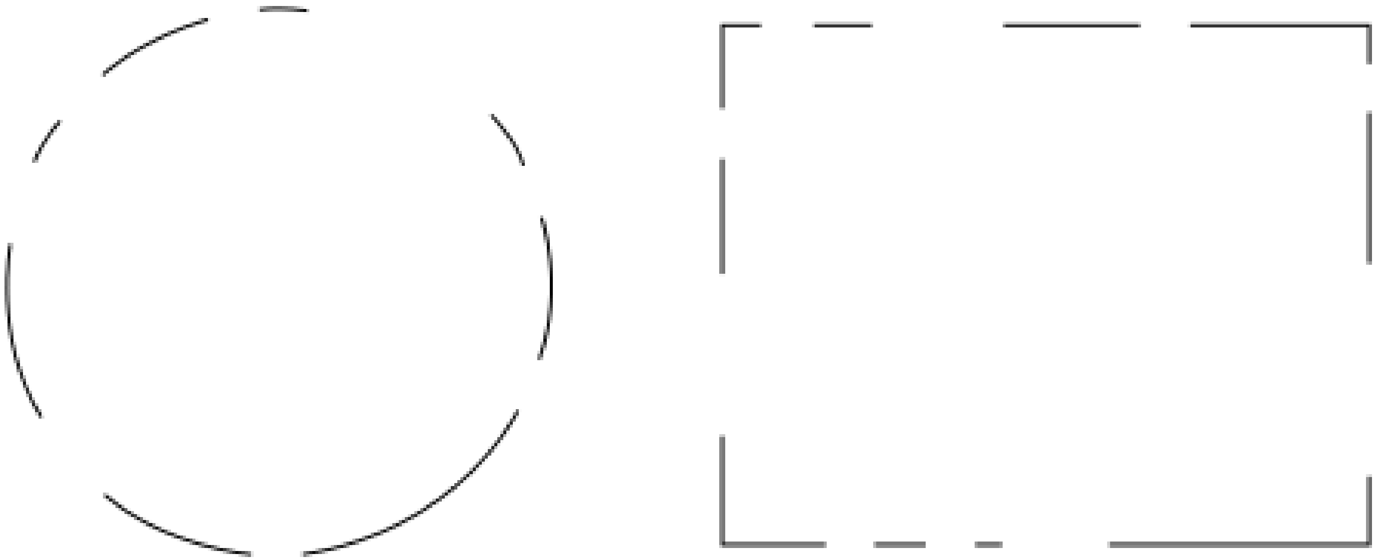
- Threshold — Stimuli can be varied to determine the threshold for detection, discrimination, or some more complex psychological phenomenon.

- What are the theories / evidence / questions driving the motivation behind some psychophysics experiments of visual recognition?
  - Atoms of recognition
  - Gestalt (whole vs sum of the parts)
  - Context
  - Tolerance and Invariance to image transformations
  - Fundamental properties of visual system (e.g. speed)

Gestalt laws of grouping
Basic phenomenological constraints

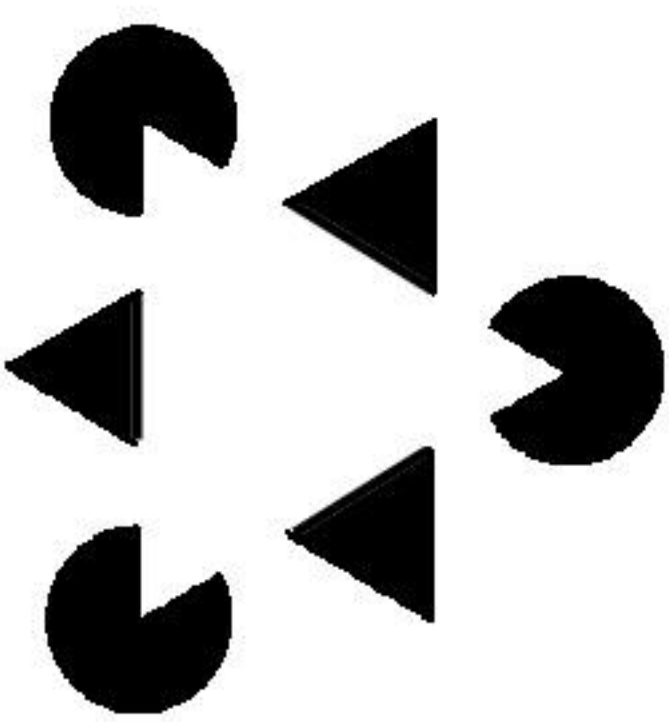
- Law of Closure — The mind may experience elements it does not perceive through sensation, in order to complete a regular figure (that is, to increase regularity).
- Law of Similarity — The mind groups similar elements into collective entities or totalities. This similarity might depend on relationships of form, color, size, or brightness.
- Law of Proximity — Spatial or temporal proximity of elements may induce the mind to perceive a collective or totality.
- Law of Symmetry (Figure ground relationships)— Symmetrical images are perceived collectively, even in spite of distance.
- Law of Continuity — The mind continues visual, auditory, and kinetic patterns.
- Law of Common Fate — Elements with the same moving direction are perceived as a collective or unit.

Law of closure: perceiving objects as whole even if they are not complete



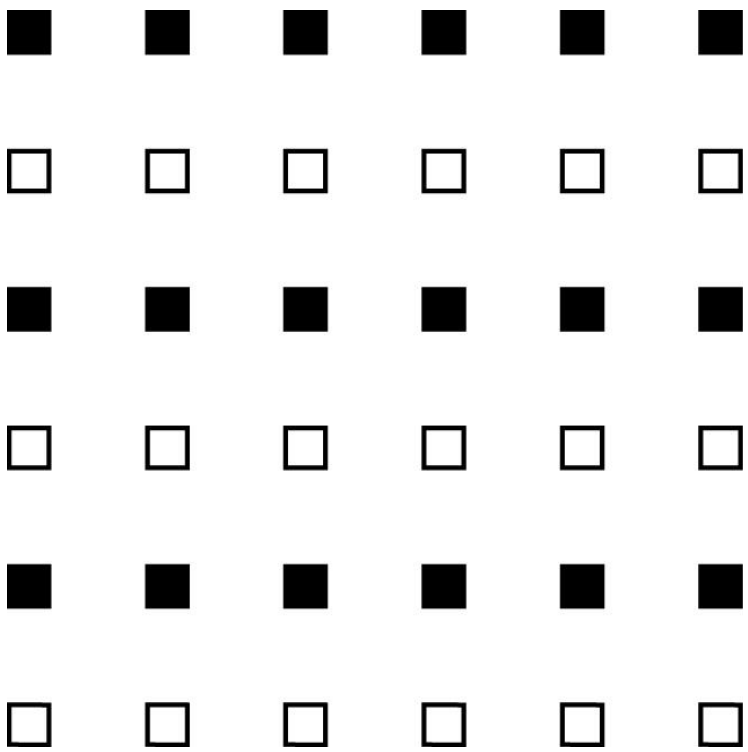
The mind may experience elements it does not perceive through sensation, in order to complete a regular figure (that is, to increase regularity)

Law of closure: perceiving objects as whole even if they are not complete



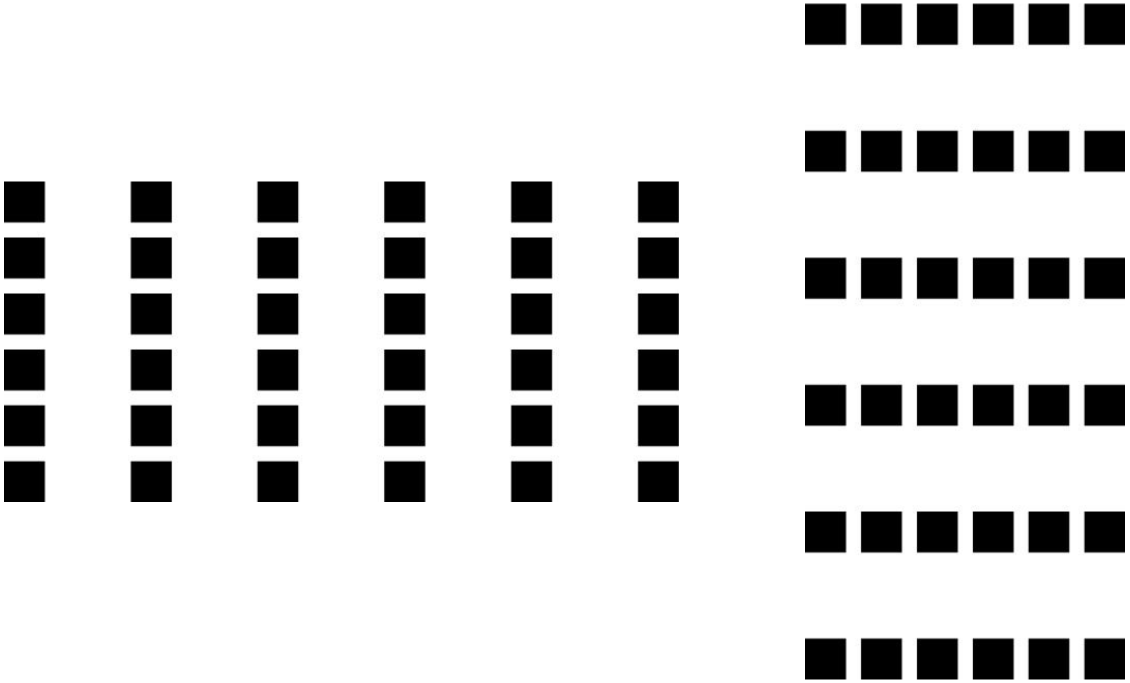
The mind may experience elements it does not perceive through sensation, in order to complete a regular figure (that is, to increase regularity)

Law of similarity



The mind groups similar elements into collective entities or totalities. This similarity might depend on relationships of form, color, size, or brightness

Law of proximity



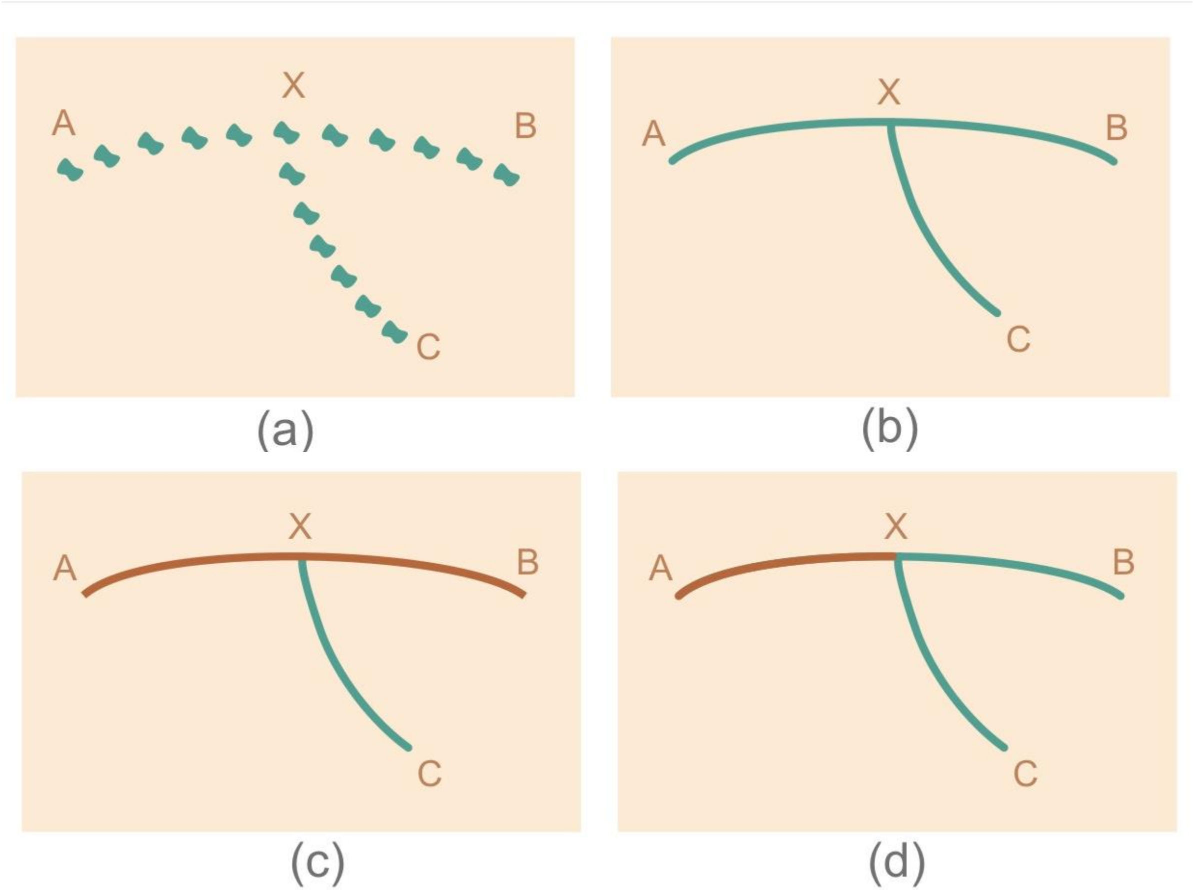
•Spatial or temporal proximity of elements may induce the mind to perceive a collective or totality.

Law of symmetry

http://isle.hanover.edu/Ch05Object/Ch05SymmetryLaw.html

•The **Law of Symmetry** is the **gestalt** grouping **law** that states that elements that are **symmetrical** to each other tend to be perceived as a unified group

Law of continuity

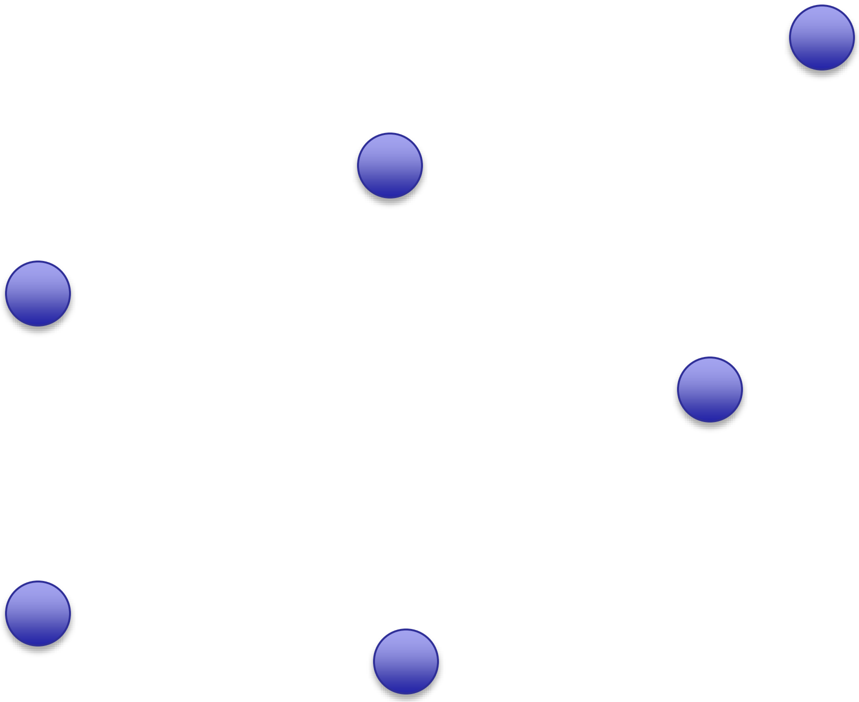


The mind continues visual, auditory,
and kinetic patterns

Law of continuity

The mind continues visual, auditory,
and kinetic patterns

Law of common fate



MIRCs
Minimal Recognizable Configurations

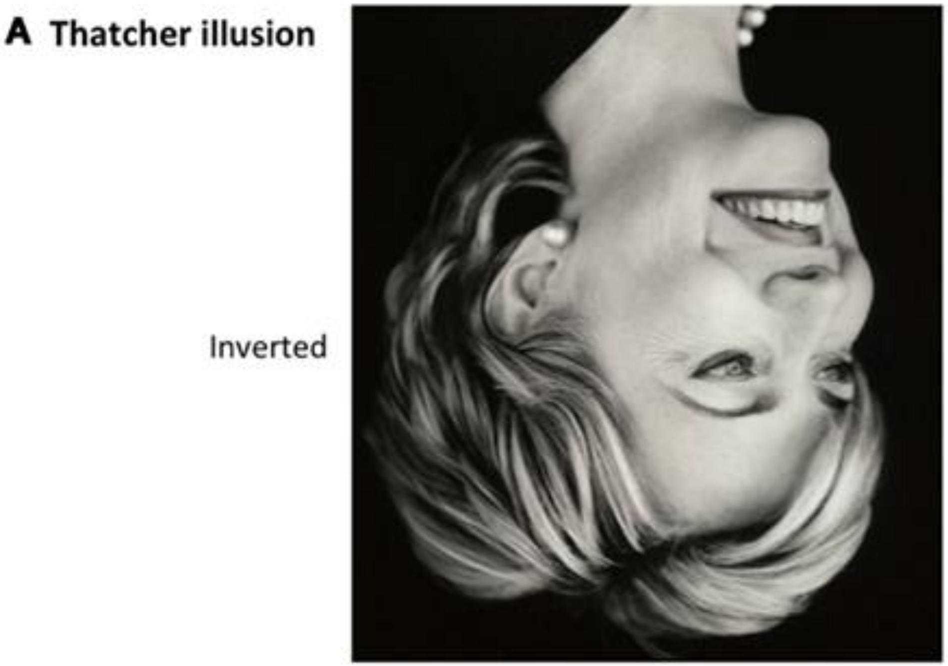
Holistic representation of faces

C **Part-whole illusion**

Upright

McKone et al, Frontiers in Psychology, 2013

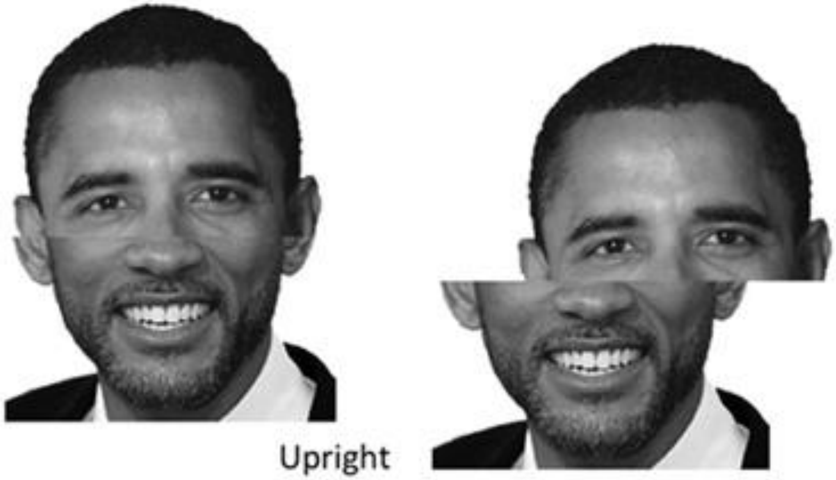
Holistic representation of faces



McKone et al, Frontiers in Psychology, 2013

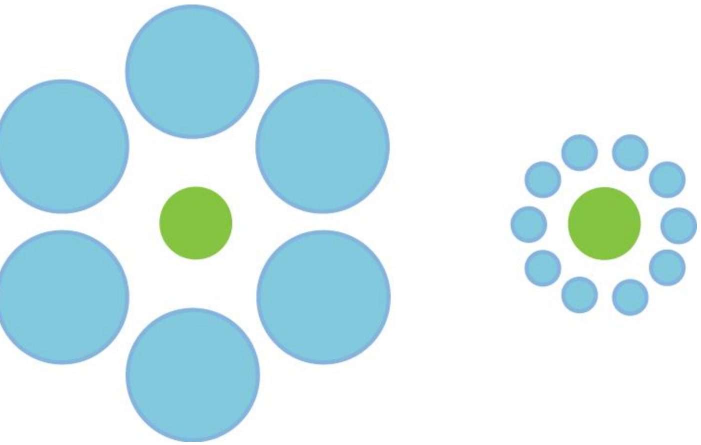
Holistic representation of faces

Composite illusion



McKone et al, Frontiers in Psychology, 2013

Beyond pixels – Context matters



Tolerance to image transformations

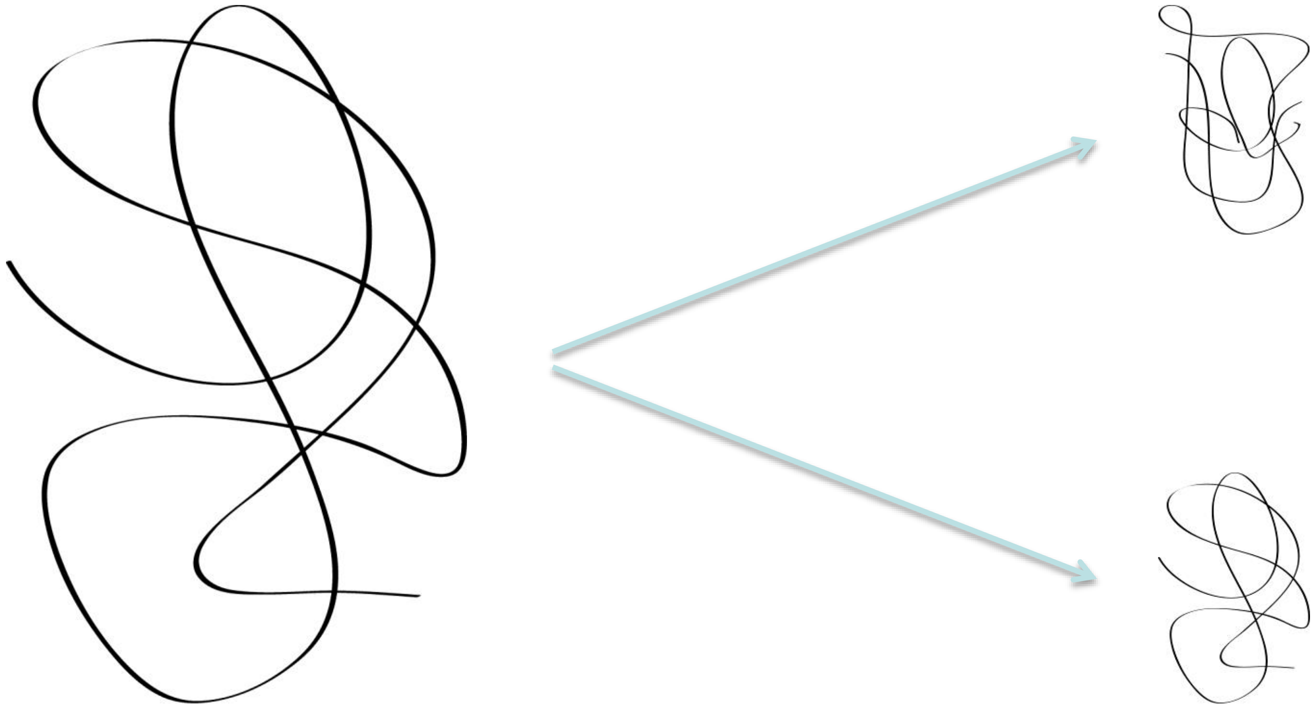
Scale
Position
Rotation (2D)
Rotation (3D) – viewpoint
Color
Illumination
Cues
Clutter
Occlusion
Other non-rigid transformations (aging, expressions, etc)

Scale tolerance

A A A A A A A

One-shot learning for scale tolerance

Which one is it?



Position tolerance

db

bd db

bd

bd

db x

db

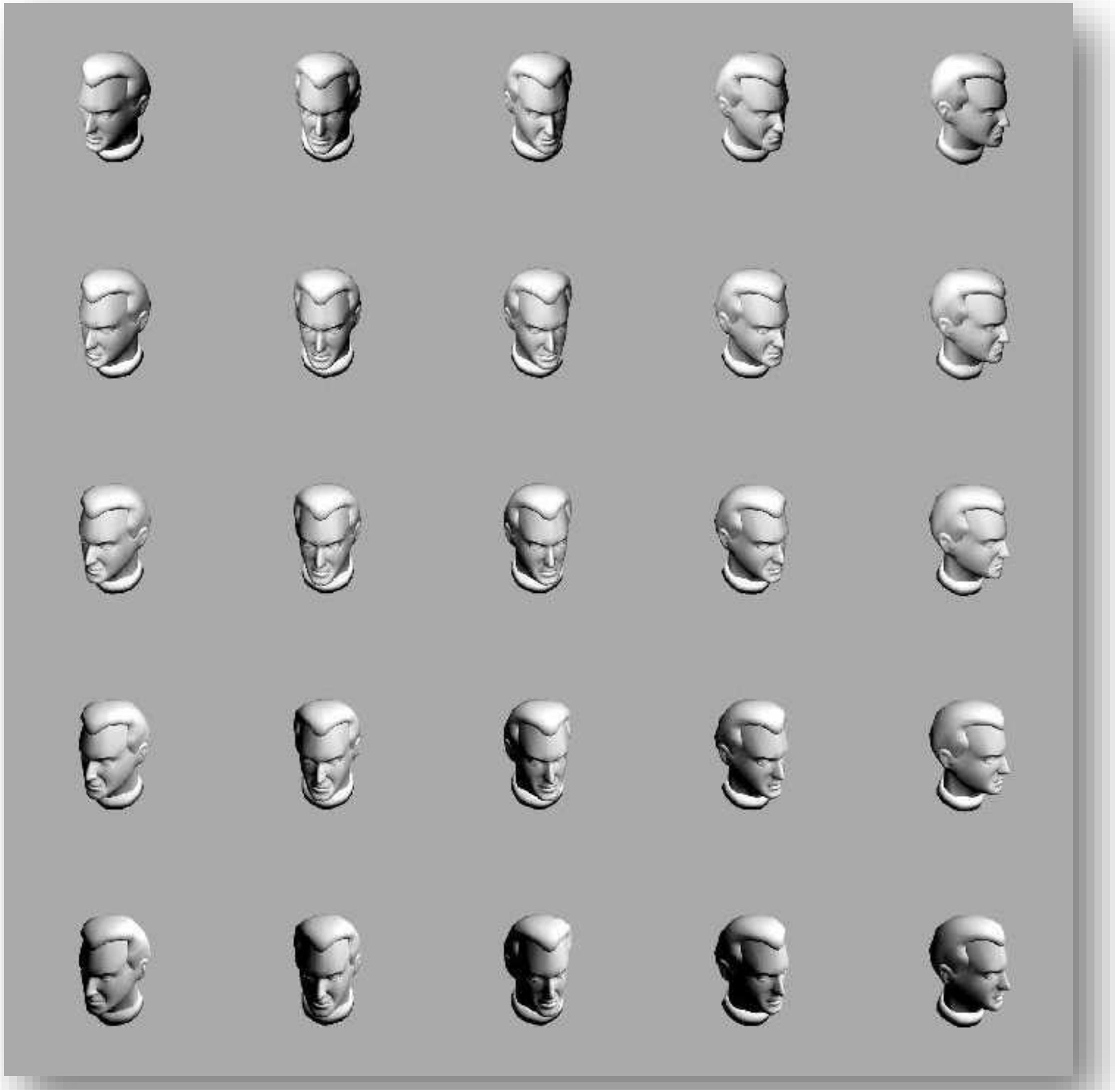
bd

db

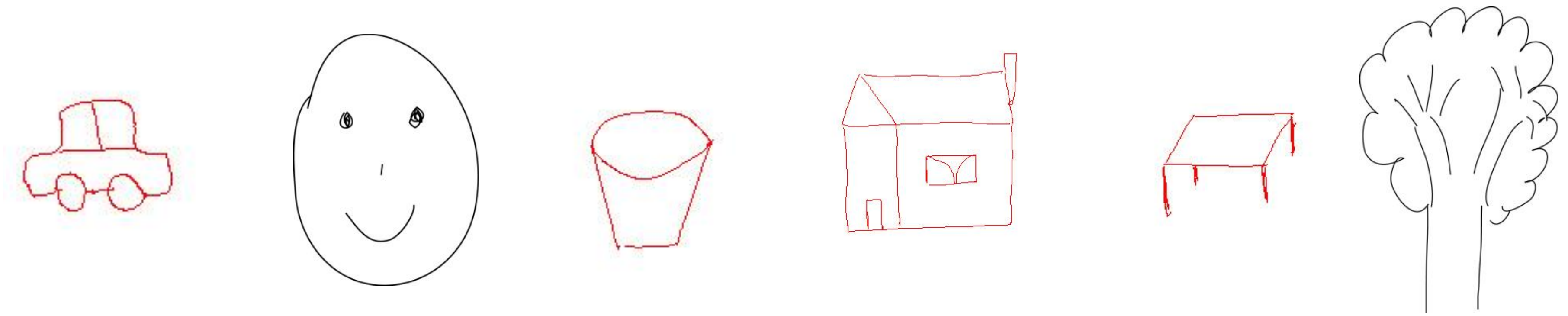
bd

bd

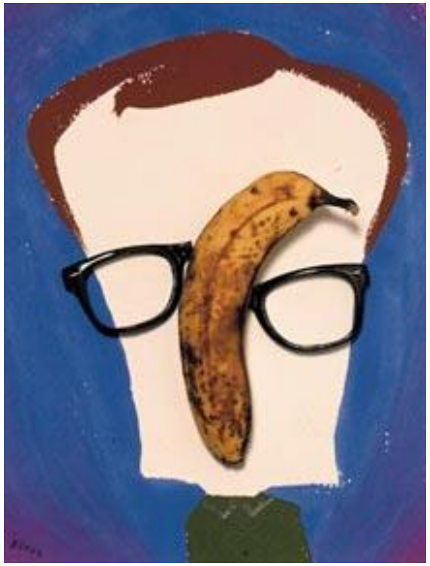
Tolerance to viewpoint and illumination changes

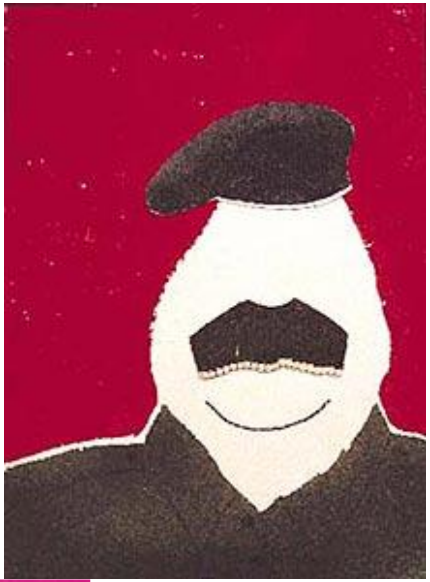


Recognition from minimal features



Recognition of caricatures





Images:
Hanoch Piven

Visual recognition depends on experience

Recognition of images flashed for ~100 ms (demo)

Visual recognition can be extremely fast

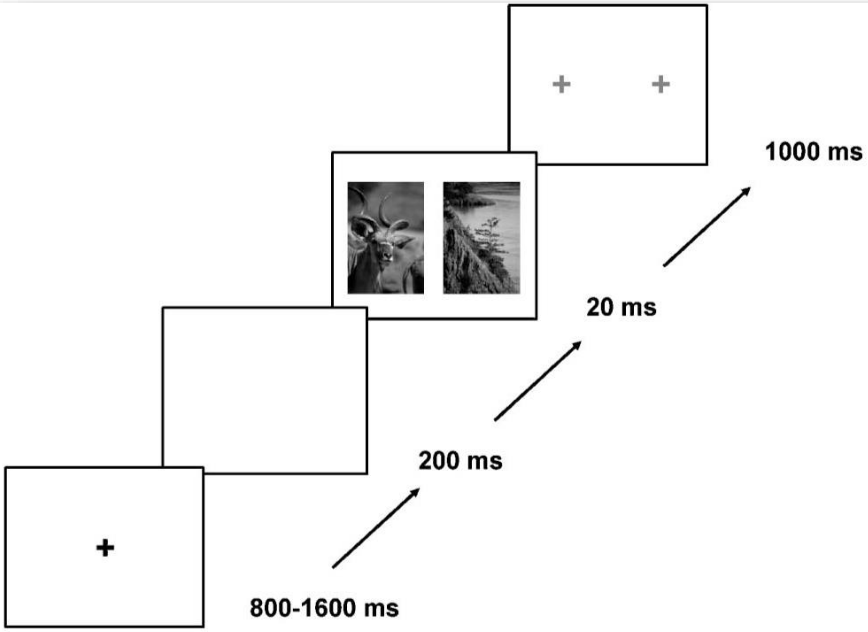


Fig. 1. Choice saccade task. After a pseudo-random fixation period, a blank screen (gap period) for 200 ms preceded the simultaneous presentation of two natural scenes in the left and right hemifields (20 ms). The images were followed by two grey fixation crosses indicating the saccade landing positions.

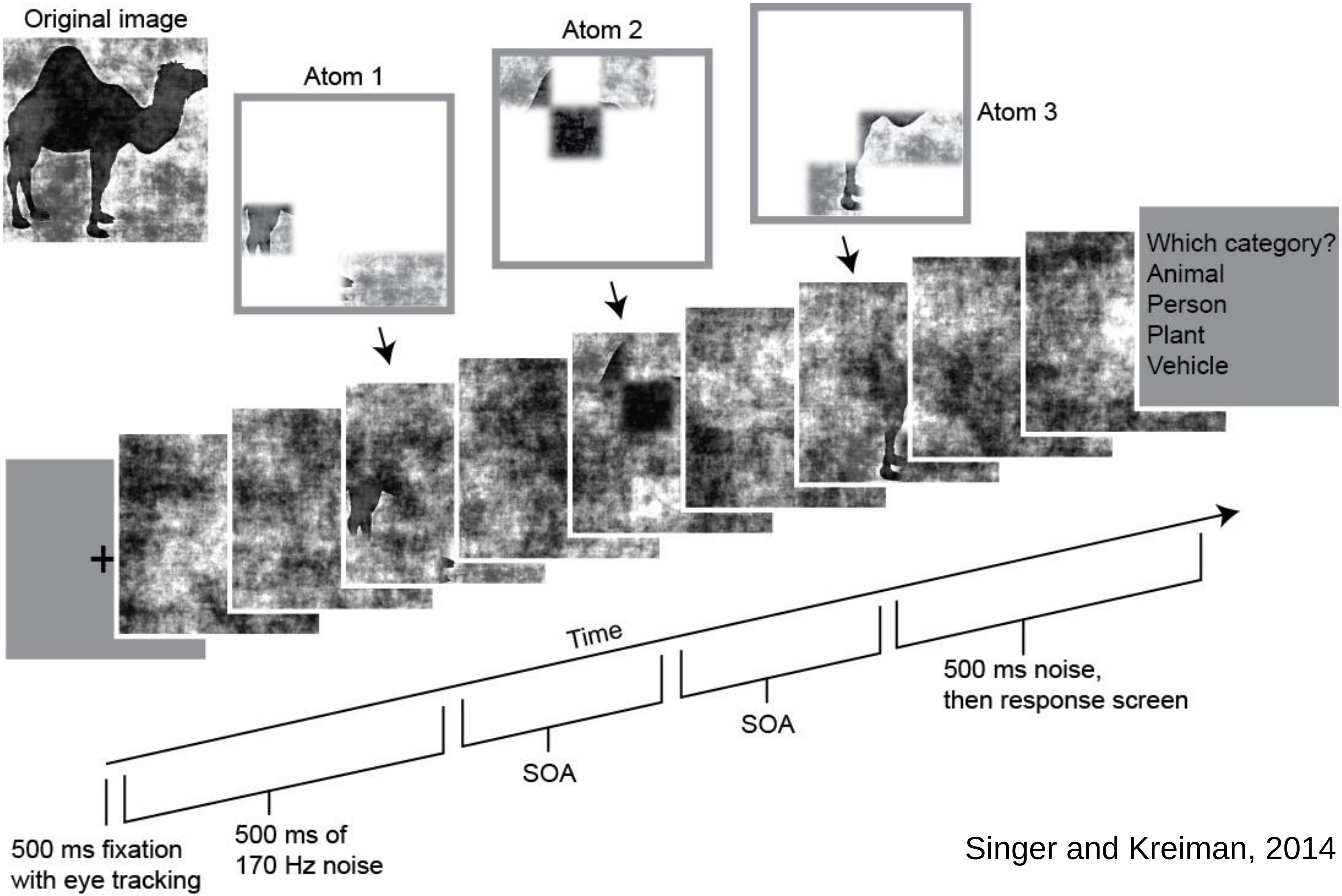
Table 1
Summary of behavioural results. Participant numbers correspond to those in Fig. 4

Subject	*N*	Accuracy (%)	Median RT (ms)	Min RT (ms)	Mean start (ms)
1	682	96.3	227	130	143
2	774	93.3	200	130	136
3	726	81.8	201	130	129
4	563	80.1	191	120	126
5	672	86.6	159	130	133
6	675	86.1	224	150	143
7	574	90.2	204	140	129
8	653	94.0	213	150	147
9	694	96.7	251	180	200
10	534	89.7	236	180	124
11	739	90.0	253	190	205
12	652	96.6	276	200	235
13	703	95.0	238	160	173
14	769	98.7	301	230	251
15	529	77.1	233	160	235
All	8998	90.1	228	120	140

The second column of this table indicates the total number of trials per participant (see Section 2 for details). Columns 3–5 give the mean accuracy, median and minimum reaction time values for each participant shown in Figs. 3B and C. The last column indicates the onset latency of the mean eye trace for each participant (see Fig. 5).

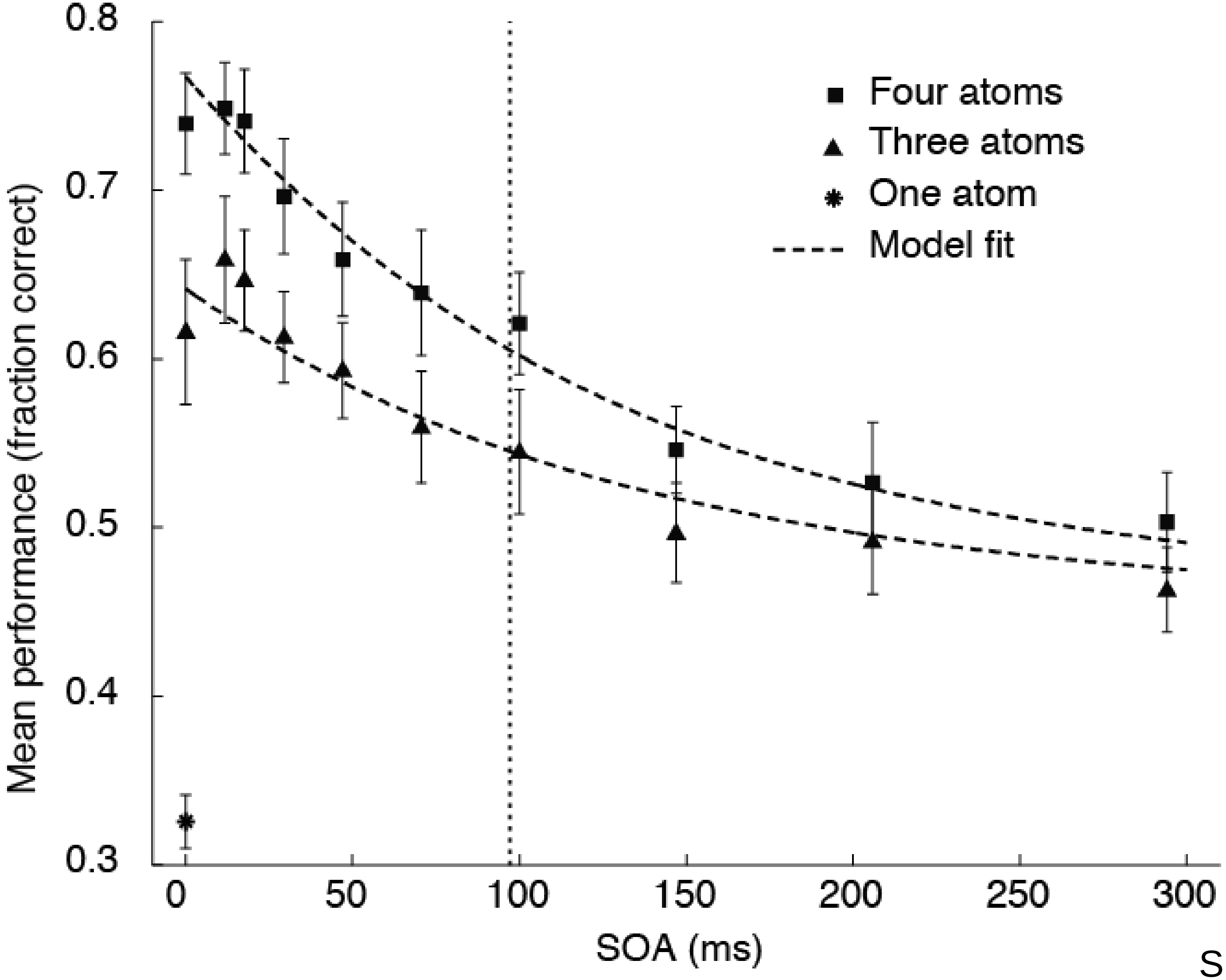
Kirchner, H., & Thorpe, S. J. (2006). Ultra-rapid object detection with saccadic eye movements: visual processing speed revisited. Vision Res, 46(11), 1762-1776.

Is information integrated over time?



Singer and Kreiman, 2014

Rapid decay in recognition of asynchronously presented object parts

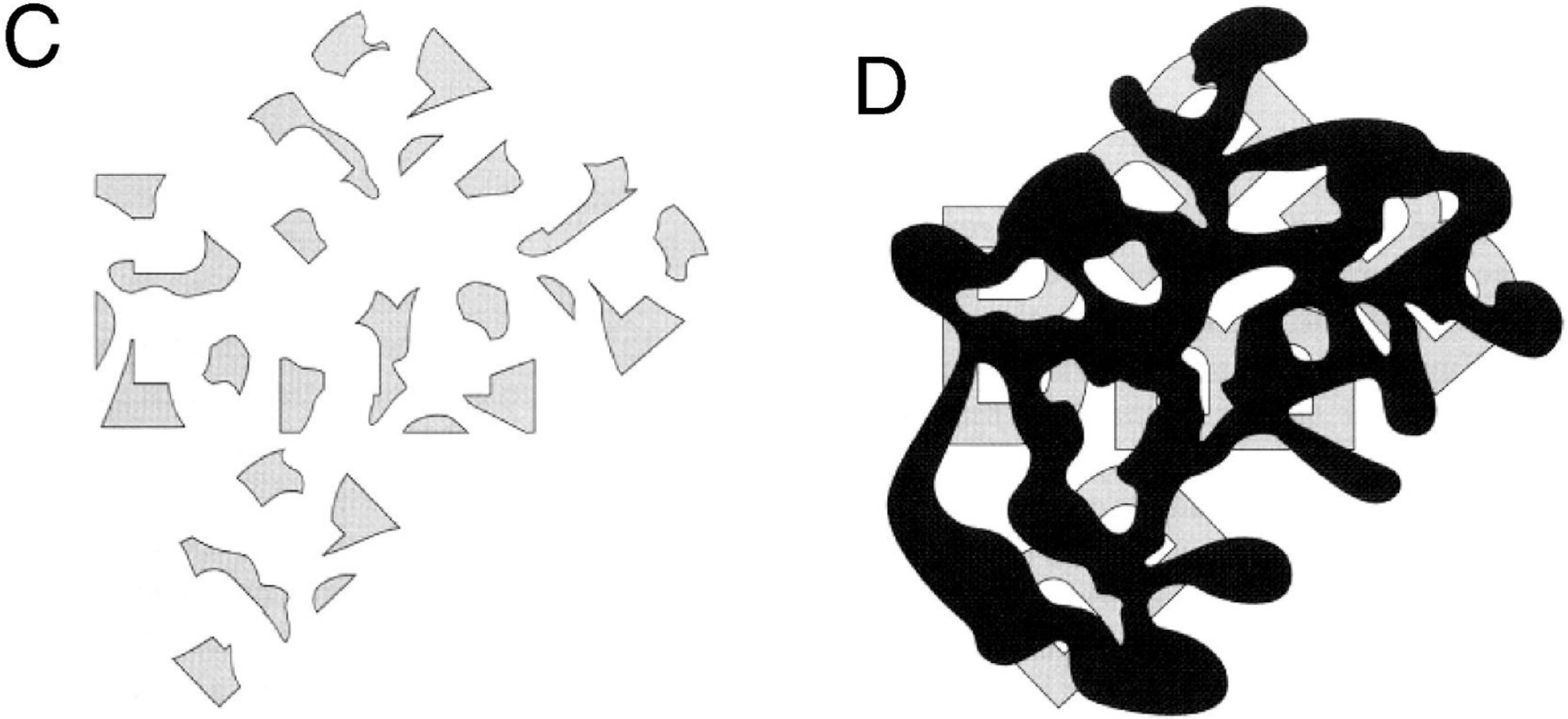


Brief asynchronies disrupt object recognition

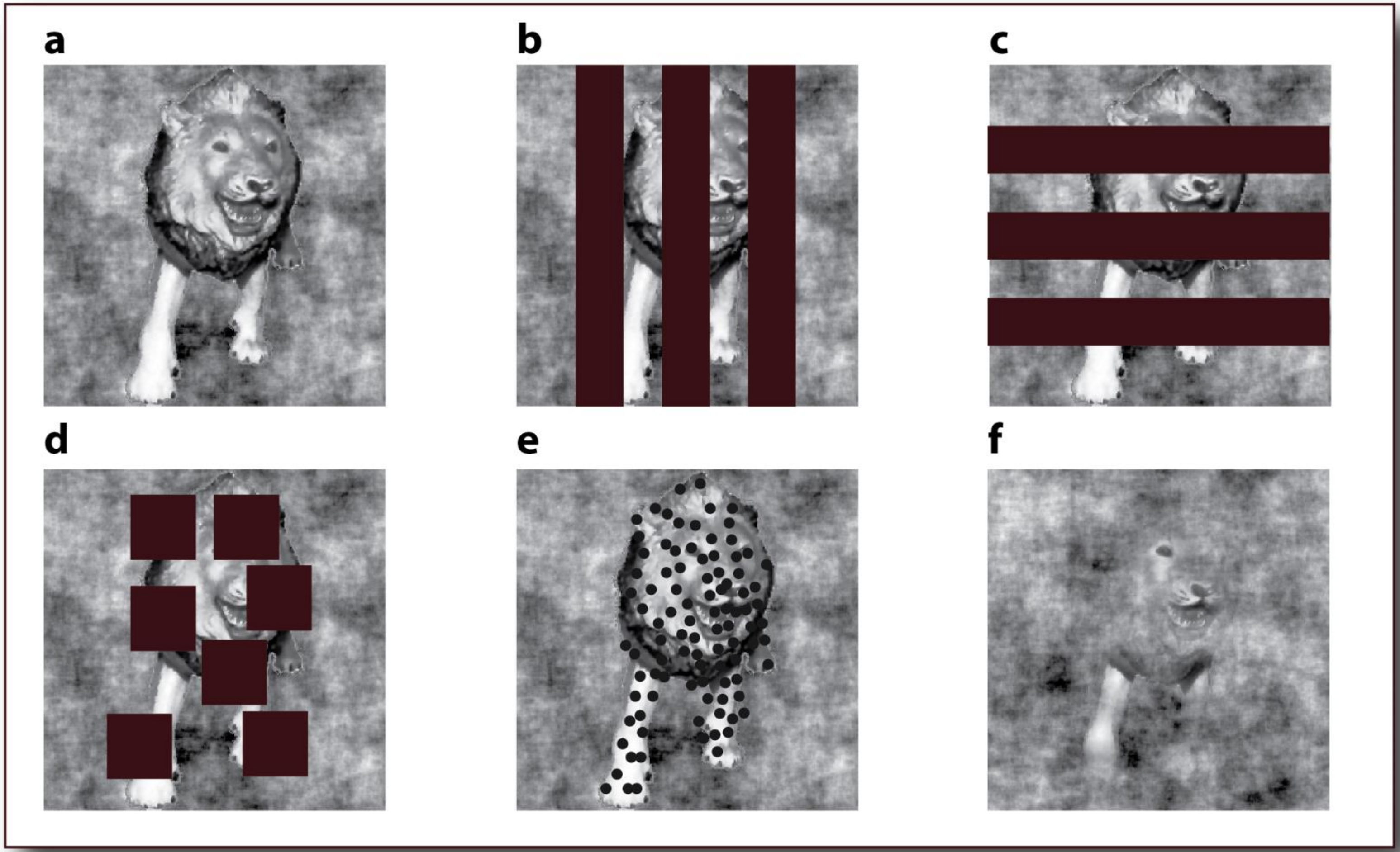
Singer and Kreiman, 2014

The visual system has a very large capacity

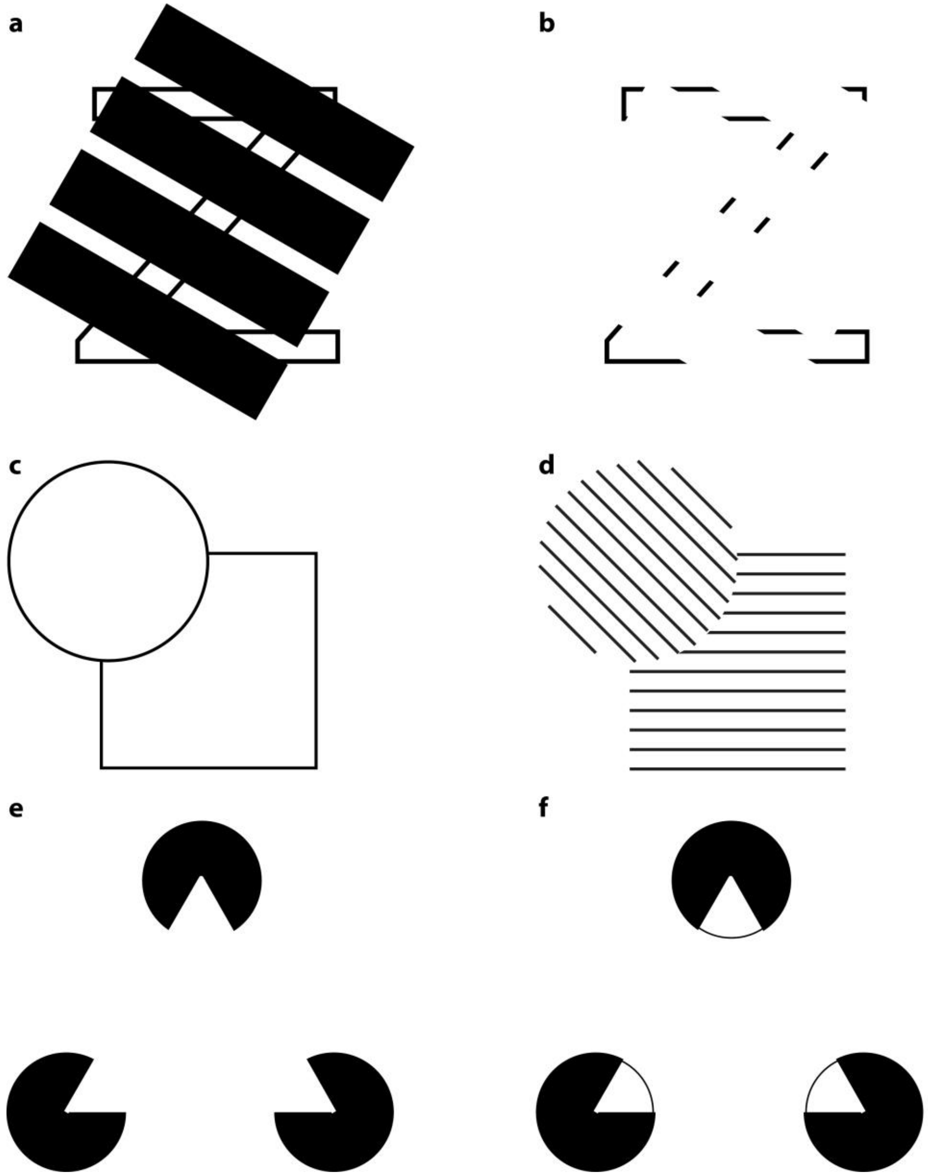
Occlusion



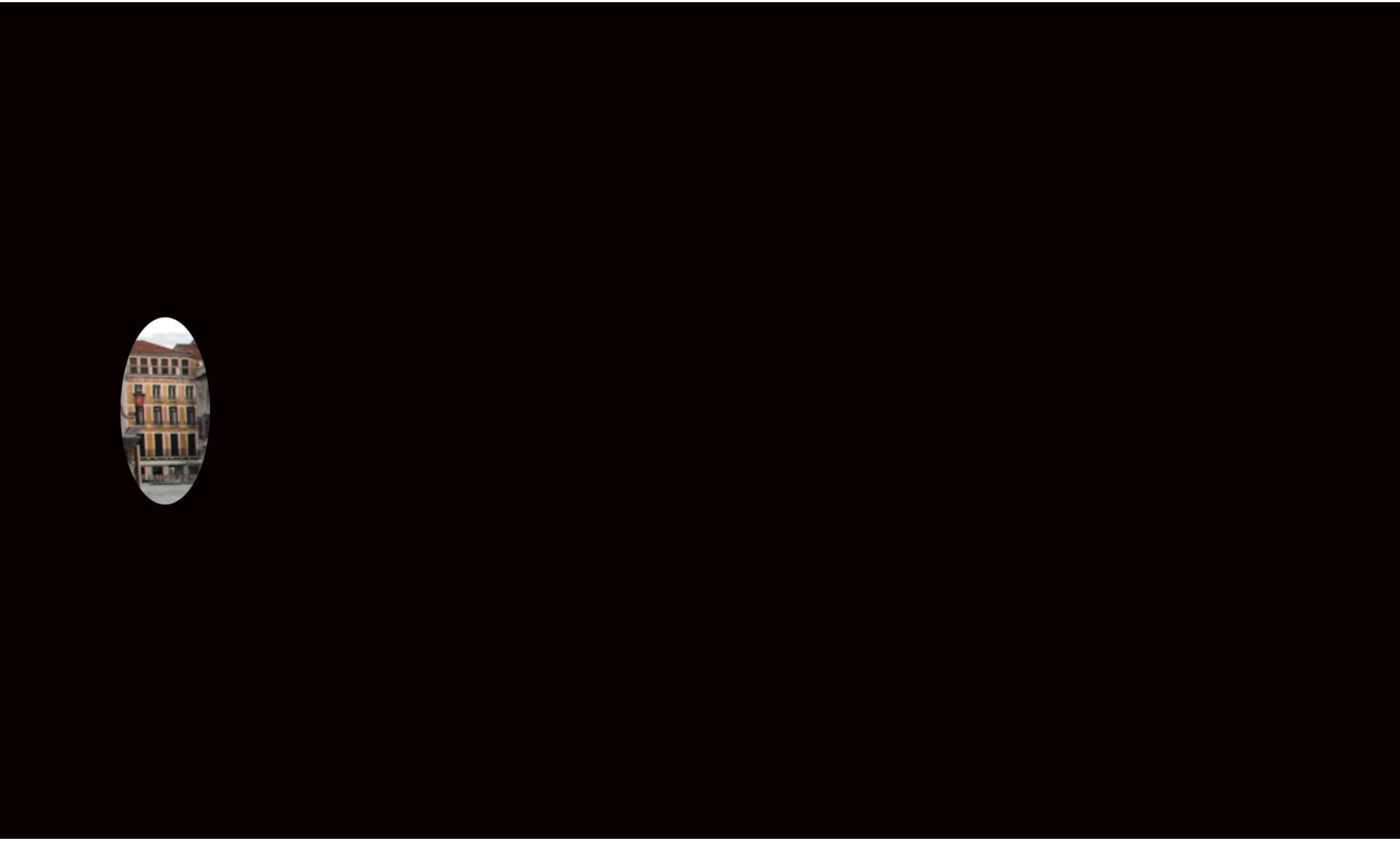
Pattern completion: Objects can be recognized from partial information



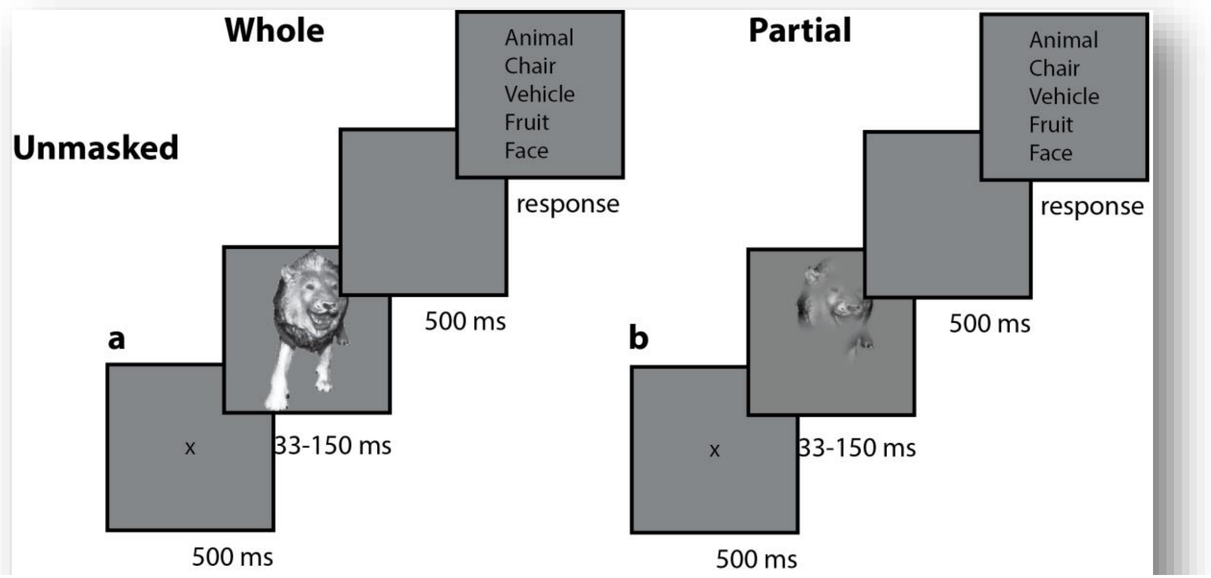
Amodal completion



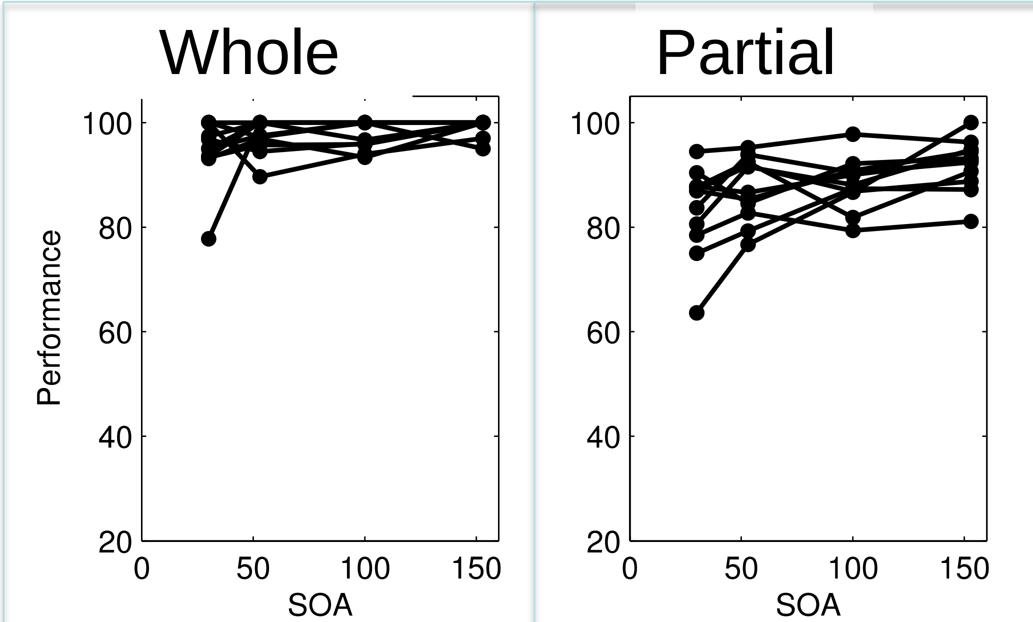
Object recognition from partial information

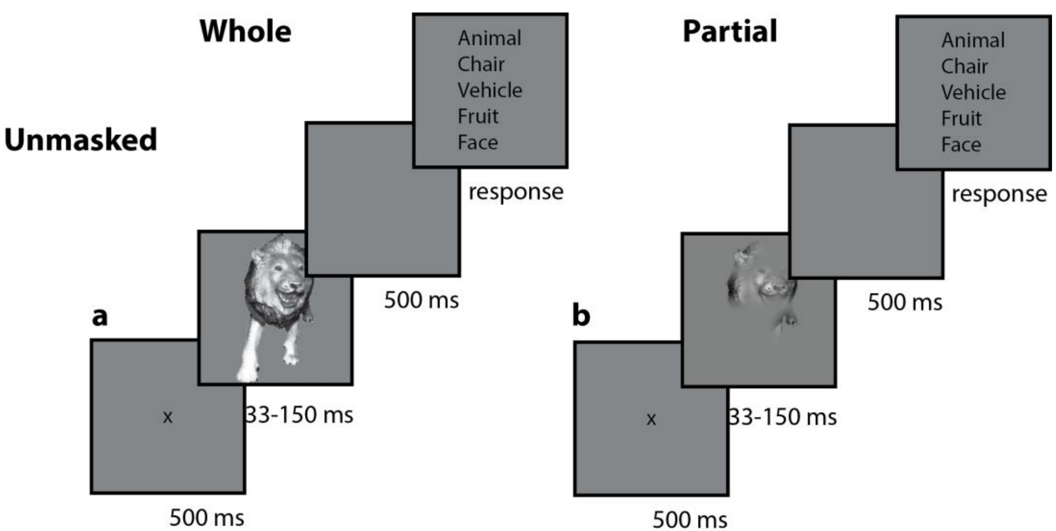


Object completion task

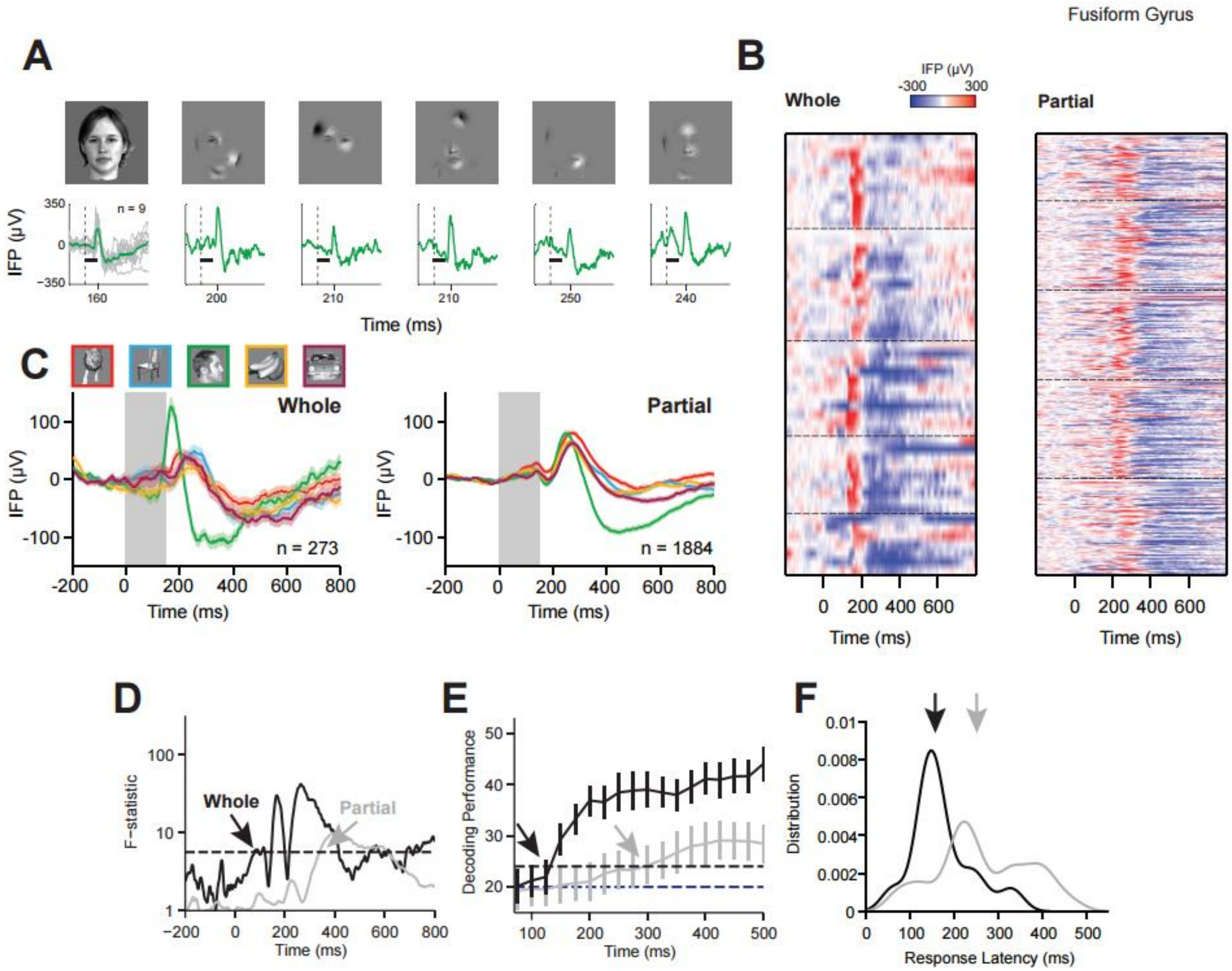


Object completion (unmasked condition)

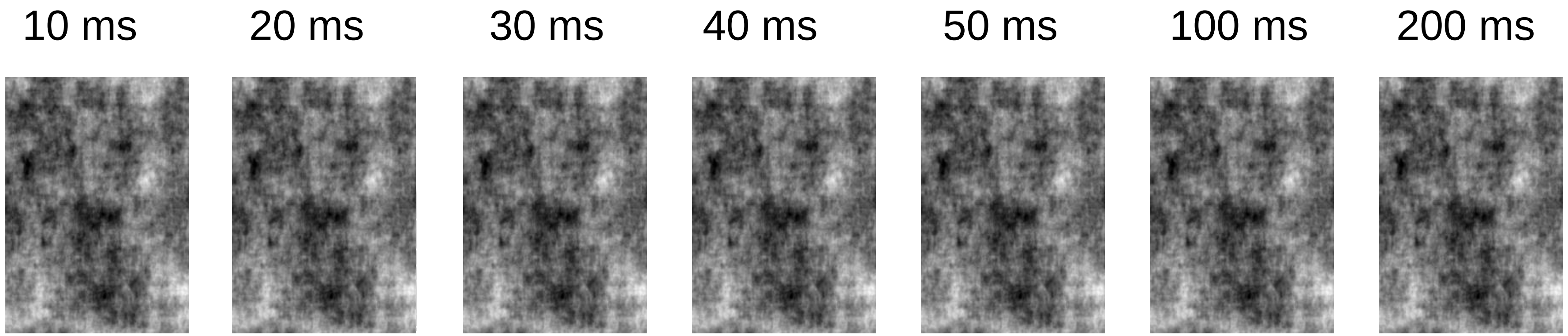


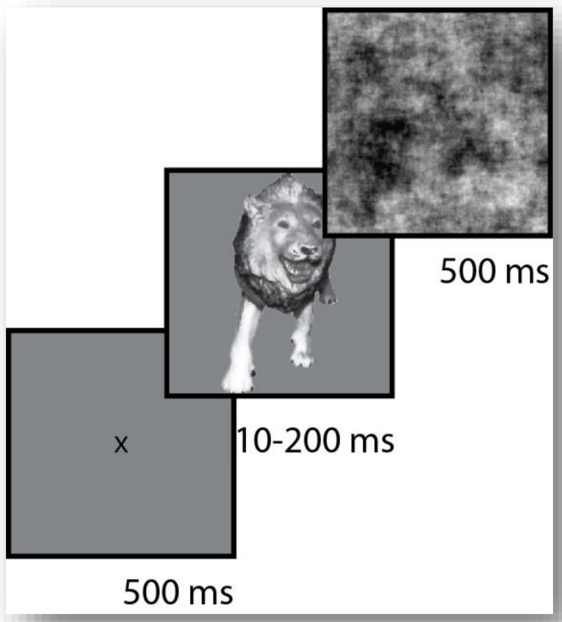


Partial Information induces latencies



Backward masking





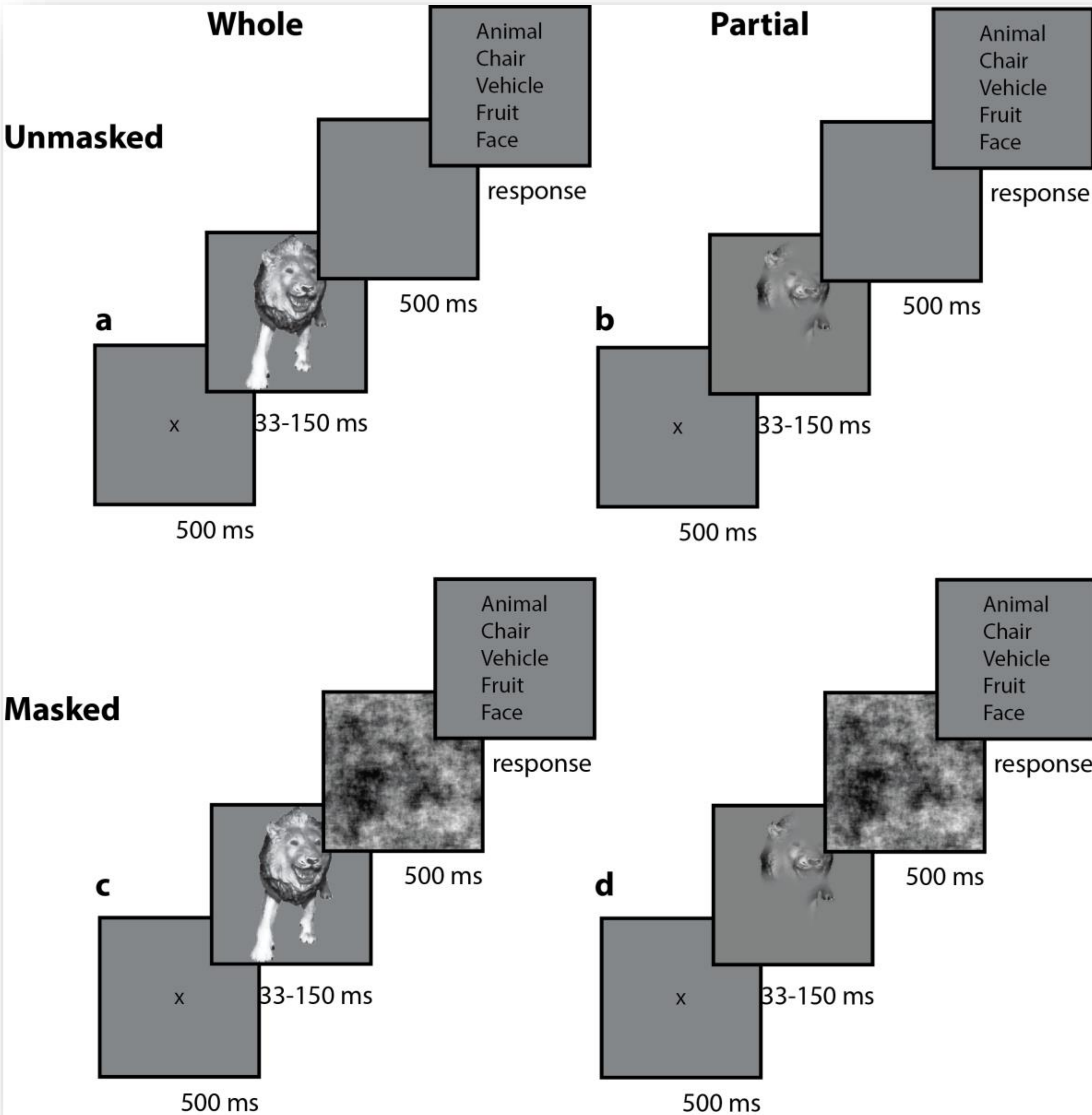
Doubles?

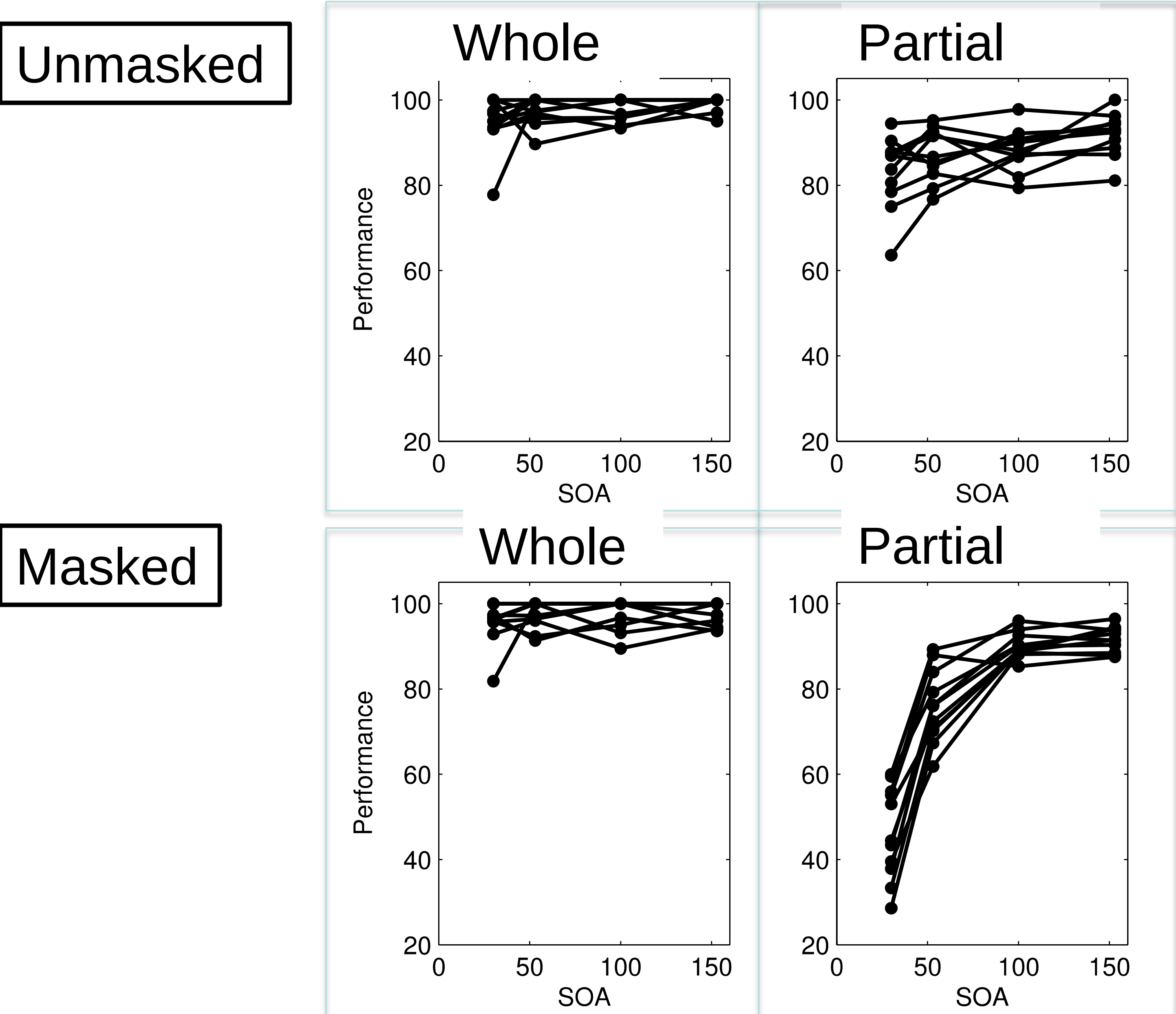
http://www.francoisbrunelle.com/

Francois Brunelle

Object completion task (masking)



Object completion (unmasked condition)



Further reading

- Regan, D. Human Perception of Objects (2000). Sinauer Associates. Sunderland, Massachusets.
- Frisby, JP and Stone JV. Seeing (2010). MIT Press. Cambridge, Massachusetts.

Original articles cited in class (see lecture notes for complete list)

- Potter, MC (1969) Recognition memory for a rapid sequence of pictures. Journal of Experimental Psychology 81:10-15.
- Kirchner, H., & Thorpe, S. J. (2006). Ultra-rapid object detection with saccadic eye movements: visual processing speed revisited. Vision Res, 46(11), 1762-1776.
- Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. Proc Natl Acad Sci U S A, 105(38), 14325-14329
- Mooney CM. (1957). Age in the development of closure ability in children. Canadian Journal of Psychology 11: 219-226
- McKone et al, Frontiers in Psychology, 2013
- Singer and Kreiman (2014). Short temporal asynchrony disrupts visual object recognition. Journal of Vision 12:14.
- Tang, H., et al. (2014). "Spatiotemporal dynamics underlying object completion in human ventral visual cortex." Neuron **83**: 736-748.
- Tang, H., et al. (2014). "A role for recurrent processing in object completion: neurophysiological, psychophysical and computational evidence." CBMM Memo(9).