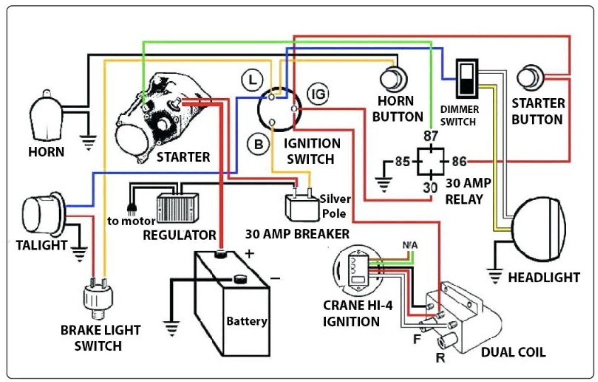
Introduction to Cognitive Science

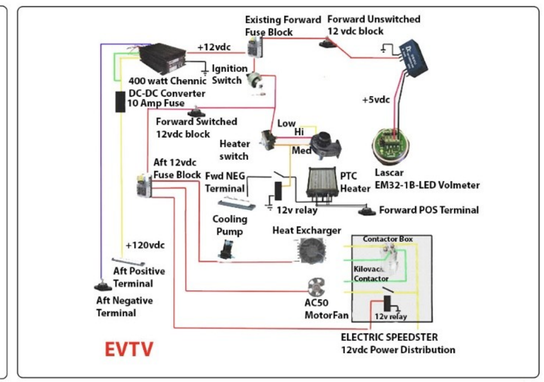
(10: Brain Mapping)

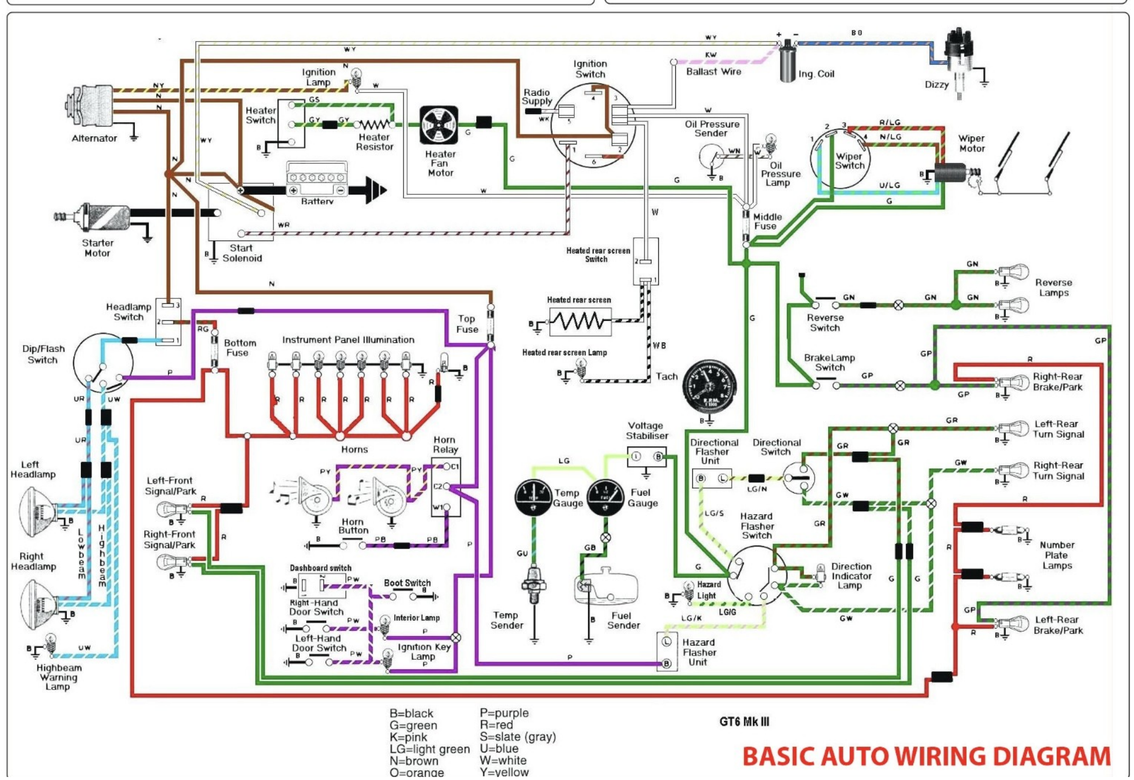
(Ch. 9)

What would a wiring diagram look like?
Brain=Neuroanatomy, mind=CogSci

CAR WIRING DIAGRAM







Problem

- Cognitive functions rarely map cleanly to brain regions
- Localization techniques:

  EEG (measuring ERP, event-related potentials)

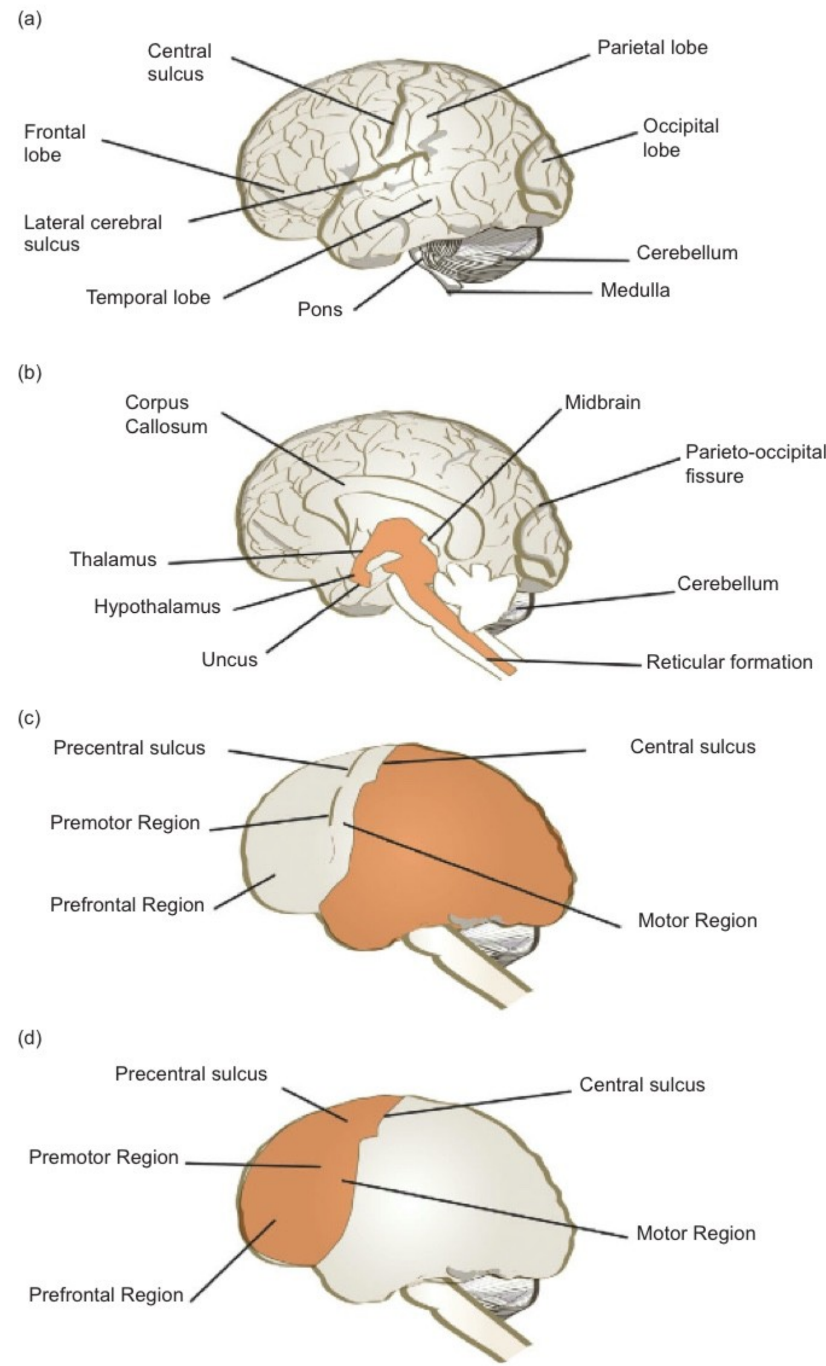
  PET

  fMRI

Structure of the brain

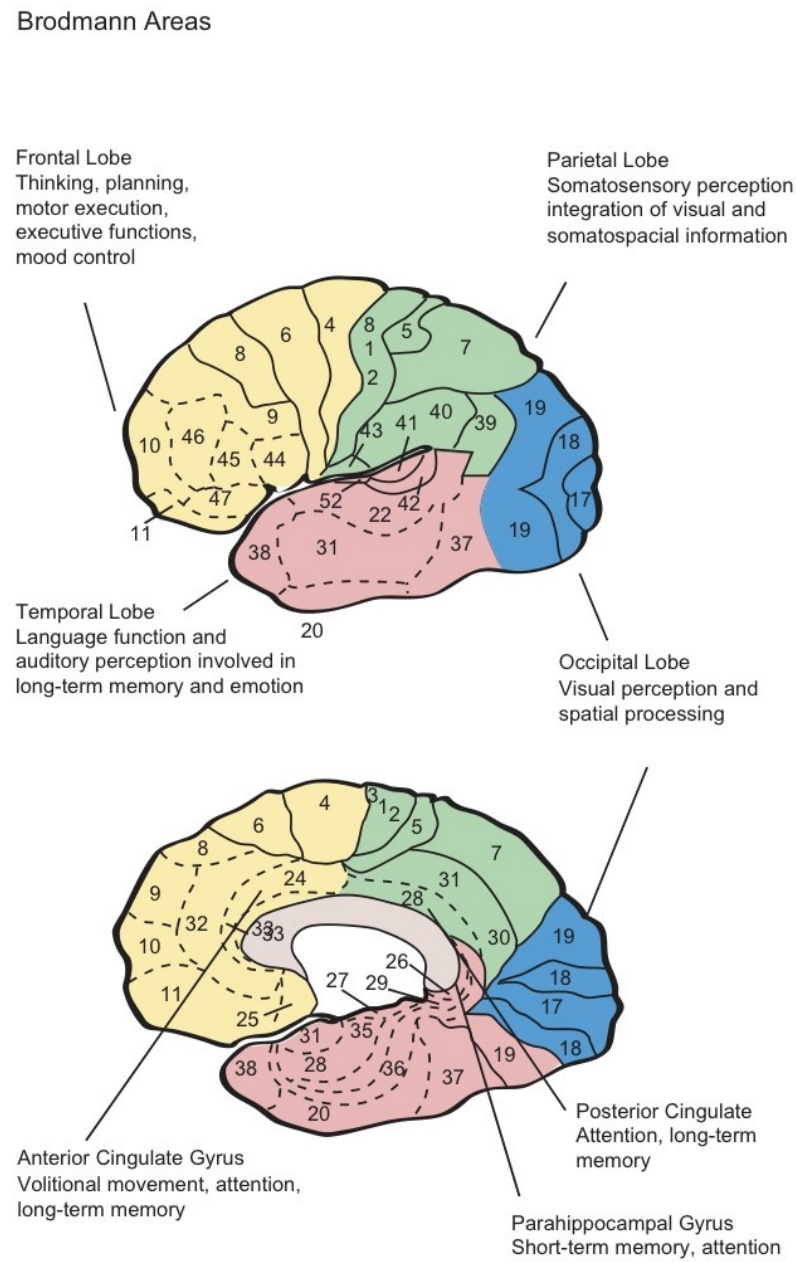
Gyri (bumps)

Sulci (grooves)



Exploring anatomical connectivity

- Brodmann identified over fifty different cortical regions
- Primary visual cortex, V1 is the point of arrival for retina info (Brodmann 17)
- Primary motor cortex (Brodmann 4)
- Tract tracing: invasive technique (injecting chemical marker in brain region)

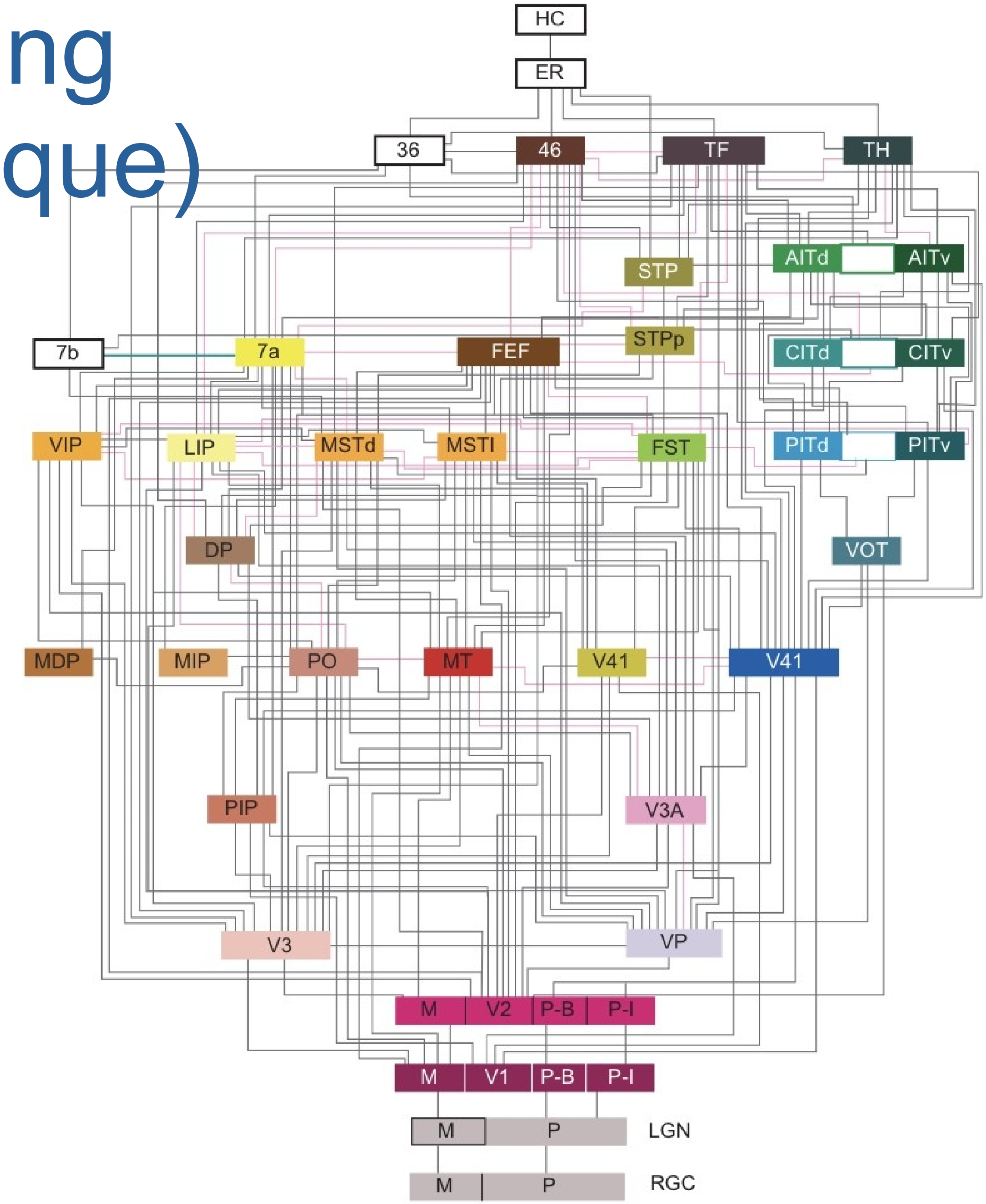


Tract tracing results (macaque)

	V1	V2	V3	VP	V3A	V4	VOT	V4T	MT	FST	PITd	PIT	PITv	CITd	CIT	CITv	AITd	AITv	STPp	STP	STPa	TF	TH	MSTd	MSTl	PO	PP	LP	VIP	MIP	MDP	DP	7a	FEF	46
V1		1	1	0	1	1	0	0	1	0	0		0	0		0	0	0	0		0	0	0	0		1	1	0	0	0	0	0	0	0	0
V2	1		1	1	1	1	1	1	1	1	0		0	0		0	0	0	0		0	0	0	1	1	1	1	0	1	0	0	0	0		0
V3	1	1			1	1	0	1	1	1	0		0	0		0	0	0	0		0	1	0	1	0	1	1	1	1	0	0		0		0
VP	0	1	1		1	1	1	0	1	1	0		0	0		0	0	0	0		0	1	0	1	0	1	1		1	0	0		0		0
V3A	1	1	1	1		1			1	1	0		0	0		0	0	0	0		0	0	0	1	1	1				0	0	1	0		0
V4	1	1	1	1	1			1	1	1	1		1	1		1	0	1	0		0	1	1	0	0	0	1	1	0	0	0	1	0		1
VOT	0	1	0	1		1					1		1																						
V4t	1		1	0		1			1	1														0	1	1									
MT	1	1	1	1	1	1		1		1	0		0	0		0	0	0	0		0	0	0	1	1		1	1	1	0	0	0	0	1	
FST	0	0	1	0	1	1		1	1			1		0		0	0	0	1			1		1	1	0	0	1	1				1	1	0
PITd	0	0	0	0	0	1			0							1	1	1							0	0	0	0	0				0		
PIT										1														1										1	1
PITv	0	0	0	0	0	1			0							1		1							0	0	0		0				0		
CITd	0	0	0	0	0	1			0				1				1	1						0	0	0	0	0	0				0		
CIT																																		1	1
CITv	0	0	0	0	0	1			0				1				1	1						0	0	0	0	0	0				0		
AITd	0	0	0	0	0	0			0	0			1			1								0	0	0	0	0	0	0	0		1	1	1
AITv	0	0	0	0	0	1			0	0			1			1					0	1	1	0	0	0	0	0	0	0	0				
STPp	0	0	0	0	0	0			0	1					1		0				1	1	1	1	1	0	0	0	0	0	0			1	1
STP																																	1		
STPa	0	0	0	0	0	0			0								1	0	1			1	1			0	0	0	0	0	0				1
TF	0	0	1	1	0	1			0	1			1			1	1	1	1		1			1		0	0		0	0	0		1		1
TH	0	0	0	0	0	1			0				1		1		1	1	1		1			0	0	0	0	0	0	0	0		1		1
MSTd	0	1	1	1	1	0		1	1	1		1		0		0	0	0	1							1		1	1			1	1	1	
MST1	0	1	0	0	1	0		0	1	1	0	0	0	0		0	0	0	1							1	0		1			0	0	1	
PO	1					0			1	0	0		0	0		0	0	0	0		0	0	0	1	1			1	1			1	1		
PIP	1		1	1		1			1		0		0	0		0	0	0	0		0					1						1	1		
LIP	0		1	1	1	1			1	1	0		1	0		0	0	0				1	0	1	1	1			1			1	1	1	1
VIP	0		1						1	1	0		0	0		0	0	0						1	1	1		1					1	1	
MIP	0	0	0	0	0	0			0	0	0		0	0		0	0	0						0	0	1							1		
MDP	0	0	0	0	0	0			0	0	0		0	0		0	0	0						0	0	1							1		
DP	0	0	0	0	1	1			0	1	0		0	0		0	0	0	0		0	0	0	1	1	1	1	1					1		1
7a	0	0	0	0	0	0			0		0		0	0		0	1			1		1	1	1		1		1				1		1	1
FEF	0									1					1		1		1					1	1	1		1	1			1	1		1
46	0	0	0	0	0					0					1		1		1		1	1	1	0								1	1	1	

Figure 9.3 A connectivity matrix for the visual system of the macaque monkey. (Adapted from Felleman and Van Essen 1991)

Anatomical wiring diagram (macaque)



What about cognitive wiring?

Techniques for studying human anatomical connectivity in vivo such as diffusion tomography are still in their infancy

HW: develop, for next week, a technique for imaging anatomical connections of the brian in vivo

But so far, anatomical and cognitive connectivity are studied in a wholly different way

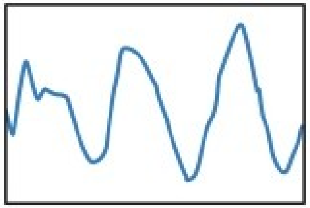
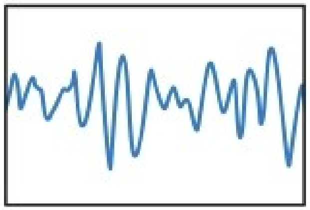
Functional vs effective connectivity

- Effective connectivity is the name for how neural systems actually interact
- More often than not, we can only measure correlation of active areas (aka functional connectivity)
- One way around this is to design a set of experiments to force out the response
- We seen this in Sect. 3.4, how Petersen drew conclusions about lexical processing from a series of PET experiments using the paired subtraction paradigm

EEG

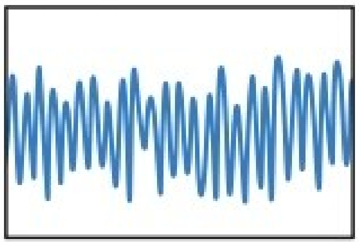
- Electrodes, sensitive to thousands of neurons
  - These coordinated actions of groups of neurons can be seen as waves in the EEG
- EEGs are important because the can measure ERPs (event-related potentials)
  - ERP=electrical activity provoked by a certan stimulus
- MEG (magnetoencephalography): similar to EEG but measures the magnetic field

EEG

Name and example	Description
Delta 	Delta is the slow wave characteristic of deep, unconscious sleep. It is less than 4 Hz, and similar EEG frequencies appear in epileptic seizures and loss of consciousness, as well as some comatose states. It is therefore thought to reflect the brain of an unconscious person. The delta frequency tends to have the highest amplitude and the slowest frequency. Delta waves increase with decreasing awareness of the physical world.
Theta 	Theta activity has a frequency of 3.5 to 7.5 Hz. Theta waves are thought to involve many neurons firing synchronously. Theta rhythms are observed during some sleep states, and in states of quiet focus, for example meditation. They are also manifested during some short-term memory tasks, and during memory retrieval. Theta waves seem to communicate between the hippocampus and neocortex in memory encoding and retrieval.
Alpha 	Alpha waves range between 7.5 and 13 Hz and arise from synchronous (in-phase) electrical activity of large groups of neurons. They are also called Berger's waves in memory of the founder of EEG. Alpha waves are predominantly found in scalp recordings over the occipital lobe during periods of relaxation, with eyes closed but still awake. Conversely alpha waves are attenuated with open eyes as well as by drowsiness and sleep.

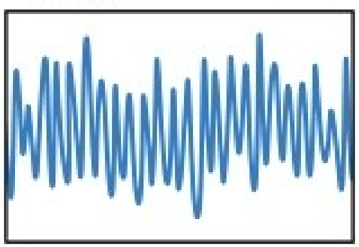
EEG

Beta



Beta activity is 'fast' irregular activity, at low voltage (12–25 Hz).
Beta waves are associated with normal waking consciousness, often active, busy, or anxious thinking and active concentration.
Beta is usually seen on both sides of the brain in symmetrical distribution and is most evident frontally. It may be absent or reduced in areas of cortical damage.

Gamma



Gamma generally ranges between 26 and 70 Hz, centered around 40 Hz.
Gamma waves are thought to signal active exchange of information between cortical and other regions. They are seen during the conscious state and in REM dreams (Rapid Eye Movement Sleep). Note that gamma and beta activity may overlap in their typical frequency ranges, because there is still disagreement on the exact boundaries between these frequency bands.

Figure 9.6 Typical patterns of EEG waves, together with where/when they are typically found.
(From Baars and Gage 2012)

PET and fMRI

Sensitive to spatial but not temporal variation

Cognitive tasks of a certain kind like those exploiting short term memory do not require temporal variation

For all techniques: spatial resolution should be fine enough to map cognitive processes to anatomical areas of the brain

No technique for studying groups has high/high

TABLE 9.1 Comparing techniques for studying connectivity in the brain

	DIRECTLY MEASURES	TEMPORAL RESOLUTION	SPATIAL RESOLUTION
Single-unit recording	Potentials in individual neurons and very small populations of neurons	High	High
EEG (electroencephalography)	Electrical activity of larger populations of neurons	High	Low
MEG (magnetoencephalography)	Magnetic fields produced by electrical activity of larger populations of neurons	High	Low
PET (positron emission tomography)	Cerebral blood flow in particular brain regions	Low	High
fMRI (functional magnetic resonance imaging)	Levels of blood oxygen in particular brain regions	Low	High

Locus of selection problem

- How do we select perceptual info?
  - This selectivity is attention
  - Broadbent model of attention, ch. 1
    - Early selection model (attention comes early in the cognitive process sequence)
- Late selection models:
  - Important parts of perceptual processing are done BEFORE attention comes into play
- Locus of selection problem: is attention an early or late selection phenomenon?

EEG/ERPs and Single Unit recording

- EEG is the general method
  - ERP is what the technique actually measures (similar to BOLD for PET)
- ERP graphs: y axis, negative above, positive below
- Time elapsed between a stimulus and the wave is called latency
- Earliest component is the C1. It is a negative component that appears 50-90ms after the stimulus

Components

P1 is the first positive component

Vs

P300 is the positive component @300ms

P300 typically occurs after a novel stimulus and it is taken to be a sign of higher cognitive processing

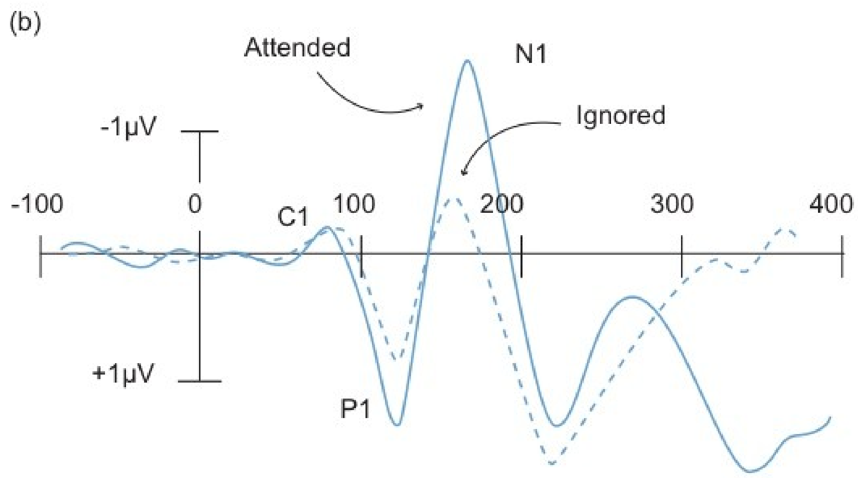
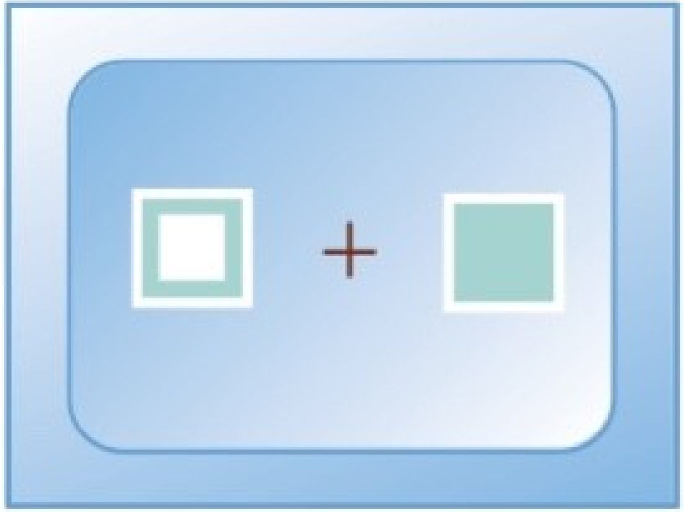


Figure 9.7b Example of the occipital ERPs recorded in a paradigm of this nature. Note that the C1 wave (generated in area V1) shows no attention effect, whereas the P1 and the N1 waves (generated in extrastriate cortex) are larger for the attended stimuli. (Courtesy Stephen J. Luck and Michelle A. Ford)

Typical attention experiment

Stimuli are presented at various places in the screen and ERPs are measured both for the case the stimulus is in the box or if it is not

(a)

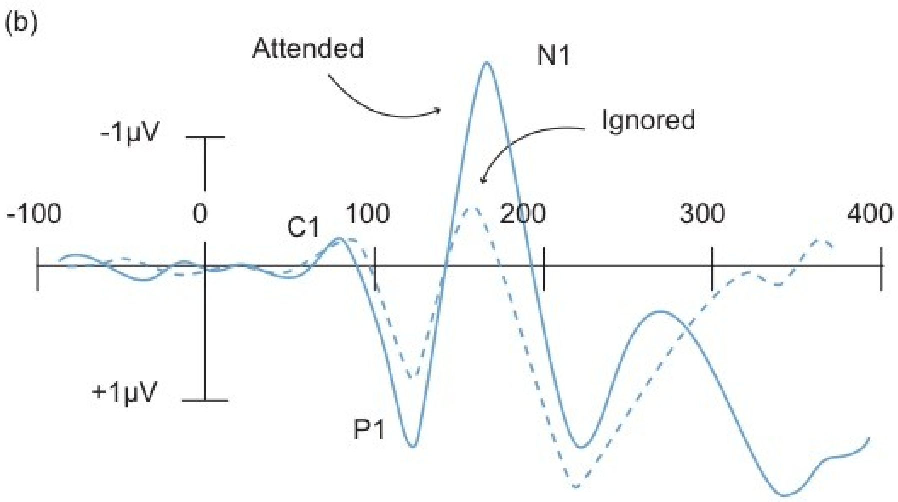


Attention

Two bursts @100 and 200ms after attention is used

How does it help in the early/late discussion?

All info proc (sect 3.2.) in V1, V2, V4 is done befor the visual sys processeses repr of objects



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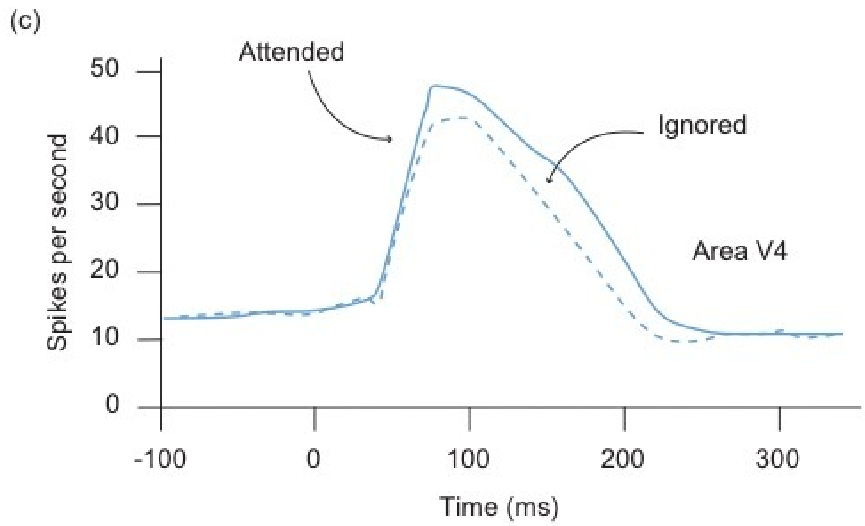

Figure 9.7c Single-unit responses from area V4 in a similar paradigm. Note that the response is larger for attended compared with ignored stimuli. (Courtesy Stephen J. Luck and Michelle A. Ford)

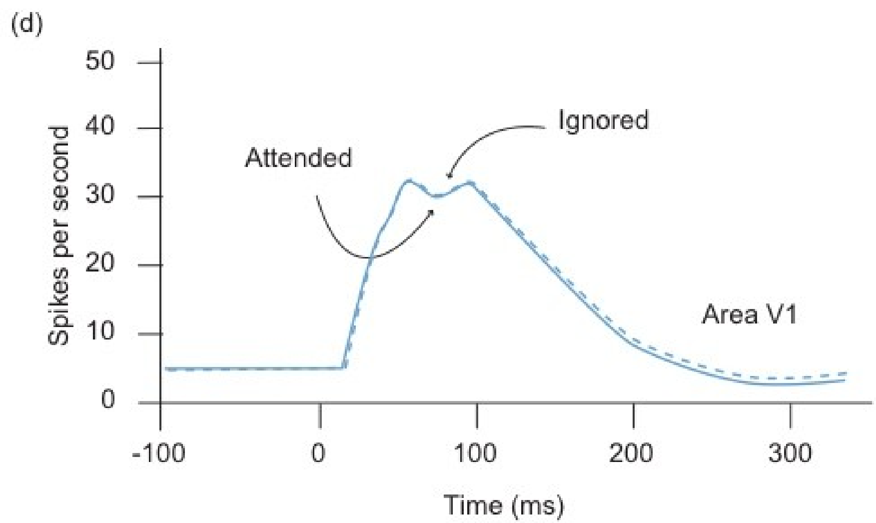

Figure 9.7d Single-unit responses from area V1 showing no effect of attention. (Courtesy Stephen J. Luck and Michelle A. Ford)

Early or late selection?

Attention is late IF it comes into play after the visual system has generated repr of objects

Any evidence that attention is in play before repr is evidence for attention as early s.p.

Therefore, EARLY!

Other questions

Locus selection leaves a couple of interesting questions (see Bermudez for a partial answer):

- Which brain areas are involved in attention?
- How is attention related to other cognitive processes, such as memory and action planning?
- How does the brain direct attention to particular objects and particular places?
- There are different kinds of attention

Neuroimaging: PET, fMRI

Some technical considerations

Neuroimaging

Neuroimaging is not a direct picture of cognitive activity

FMRI measures the BOLD signal, PET measures celebral blood flow

Very little is known how what we observe directly (e.g. BOLD) is connected to what we are trying to measure (info processing in the brain)

fMRI

- Neuroimaging's greatest strenght is spatial resolution (in contrast to temporal resolution)
  - Even this has issues...
- Resolution: voxels (volume+pixels)
  - Basic unit of data is the BOLD in each voxel
  - The smaller the voxel, the higher the spatial resolution
  - But! The smaller the voxel the lower the signal strenght

Voxel size

- For some experiments, mainly dealing with perception, the BOLD signal is powerful enough event with small voxels
  - But, for more complex experiments it might be too faint to be reliably measurable
- Then the only option is to increase the voxel size. But, this brings new problems
- Increasing voxel size means that voxels are not as homogenous, and this can distort the signal
  - Neuroimaging data is standardly interpreted as having homogenous voxels (even though this is rarely the case)

Normalization

If we want to be precise, the fMRI data needs to be normalized

- The data from each subject and each voxel needs to be reinterpreted with a brain atlas that has coordinates
  - This mapping is called a stereotactic map
  - There are several standard atlases and this make comparing experiments difficult