fMRI Block Design and Data Analysis

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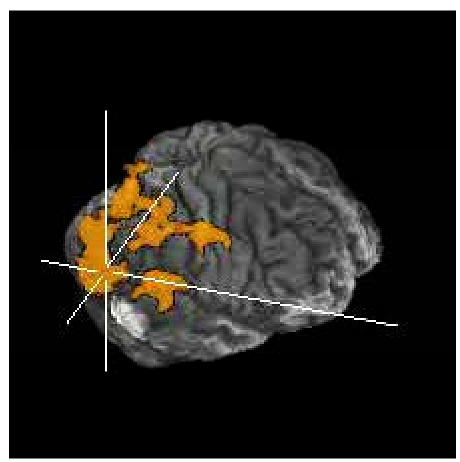
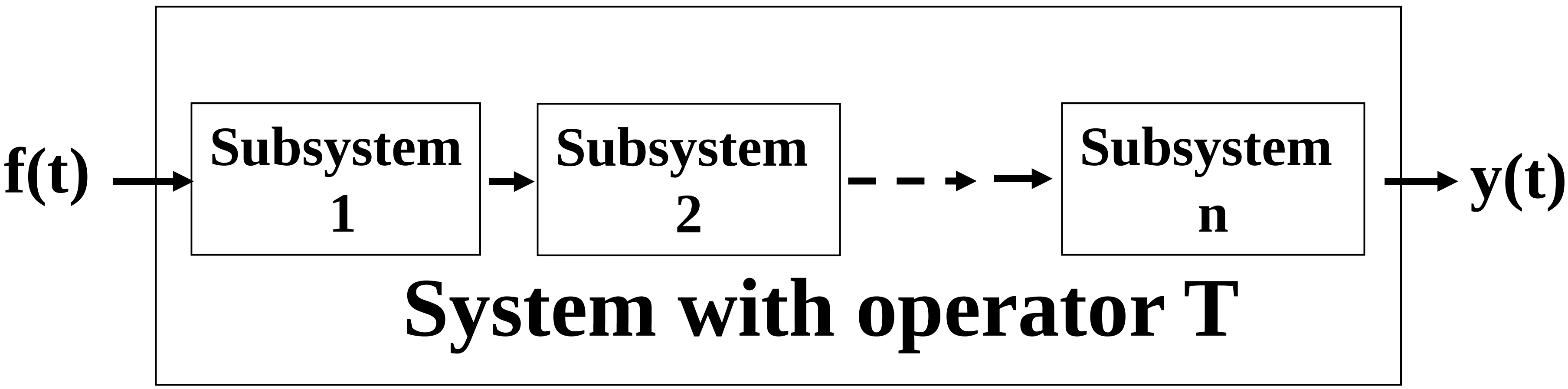


Reading materials

Henderson JM, Larson CL, Zhu DC. Cortical activation to indoor versus outdoor scenes: an fMRI study. Exp Brain Res. 2007;179:75-84.

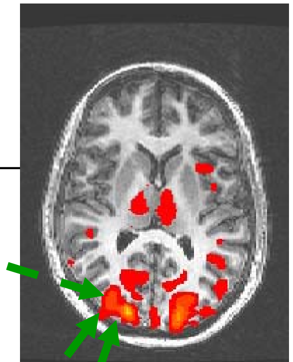


$$y(t) = T\{f(t)\}$$

(1) Find T => Event-related design

(2) Assume T' = T based on some model
Find expected y'(t) = T'{f(t)}
Compare y(t) and y'(t)
=> Block related design

Linear System



$f(t)$ → System → $y(t)$

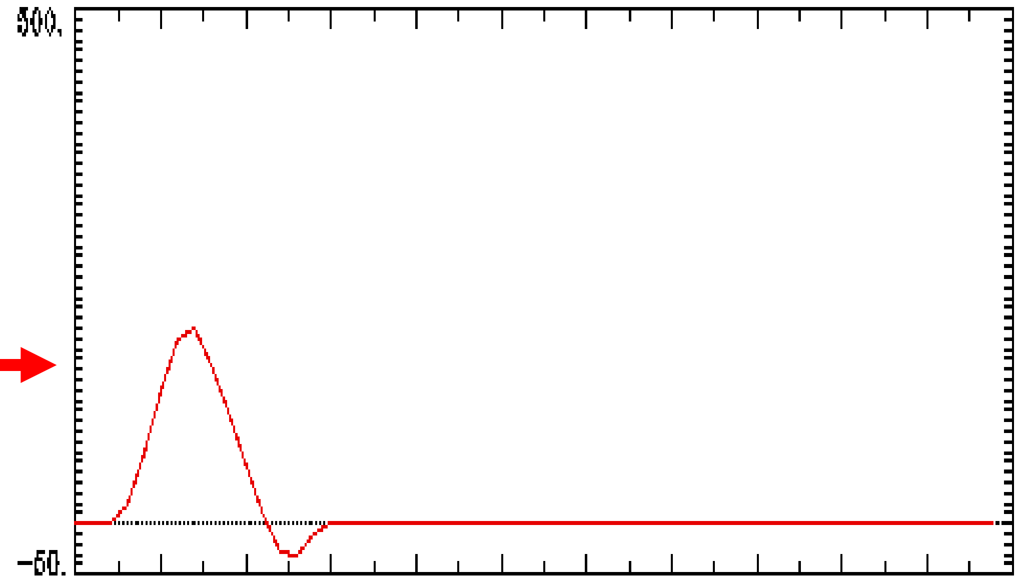
$g(t)$ → System → $z(t)$

$af(t) + bg(t)$ → System → $ay(t) + bz(t)$

$f(t)$ → System → $y(t)$

$f(t-t_0)$ → System → $y(t-t_0)$

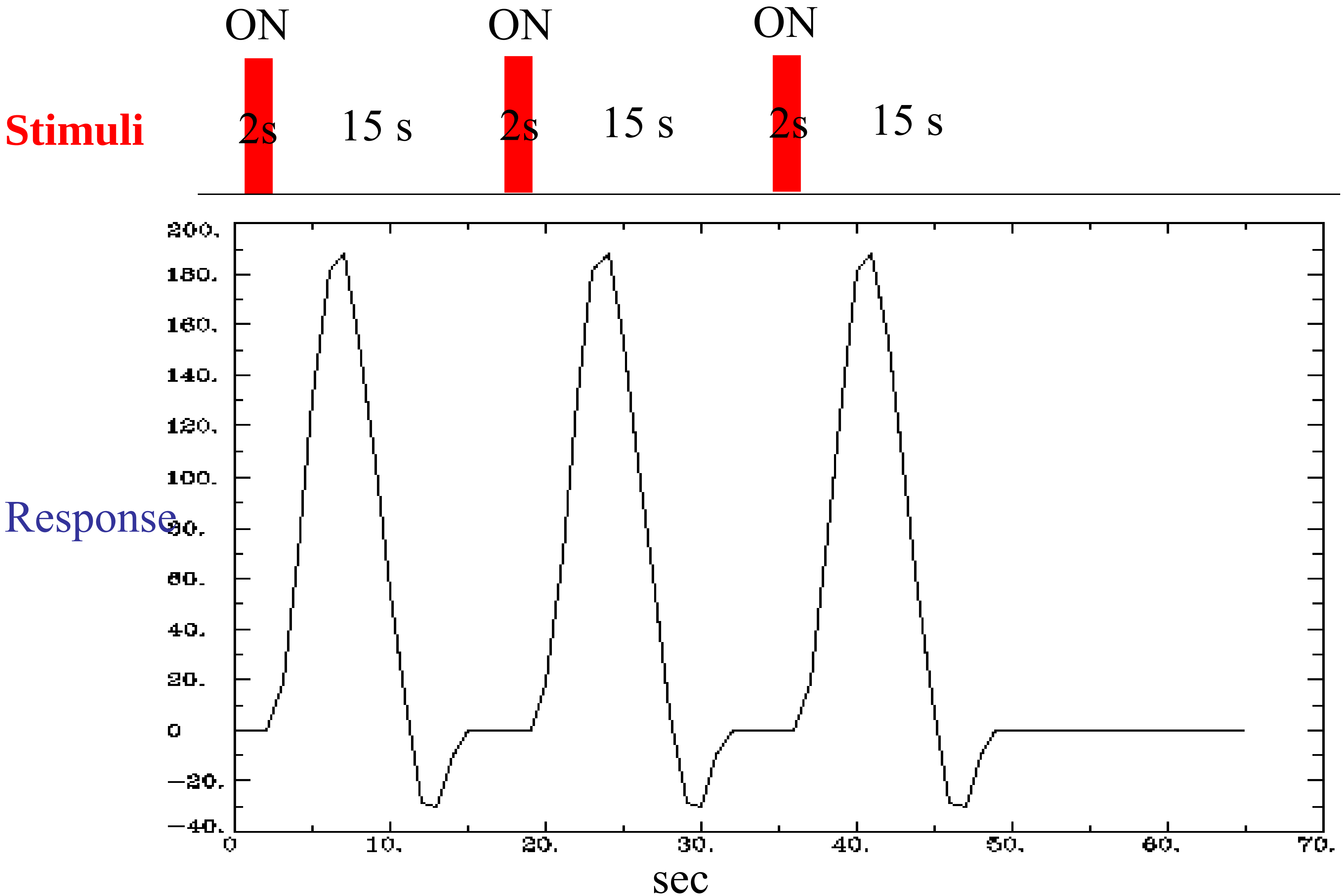
Present for 2 seconds

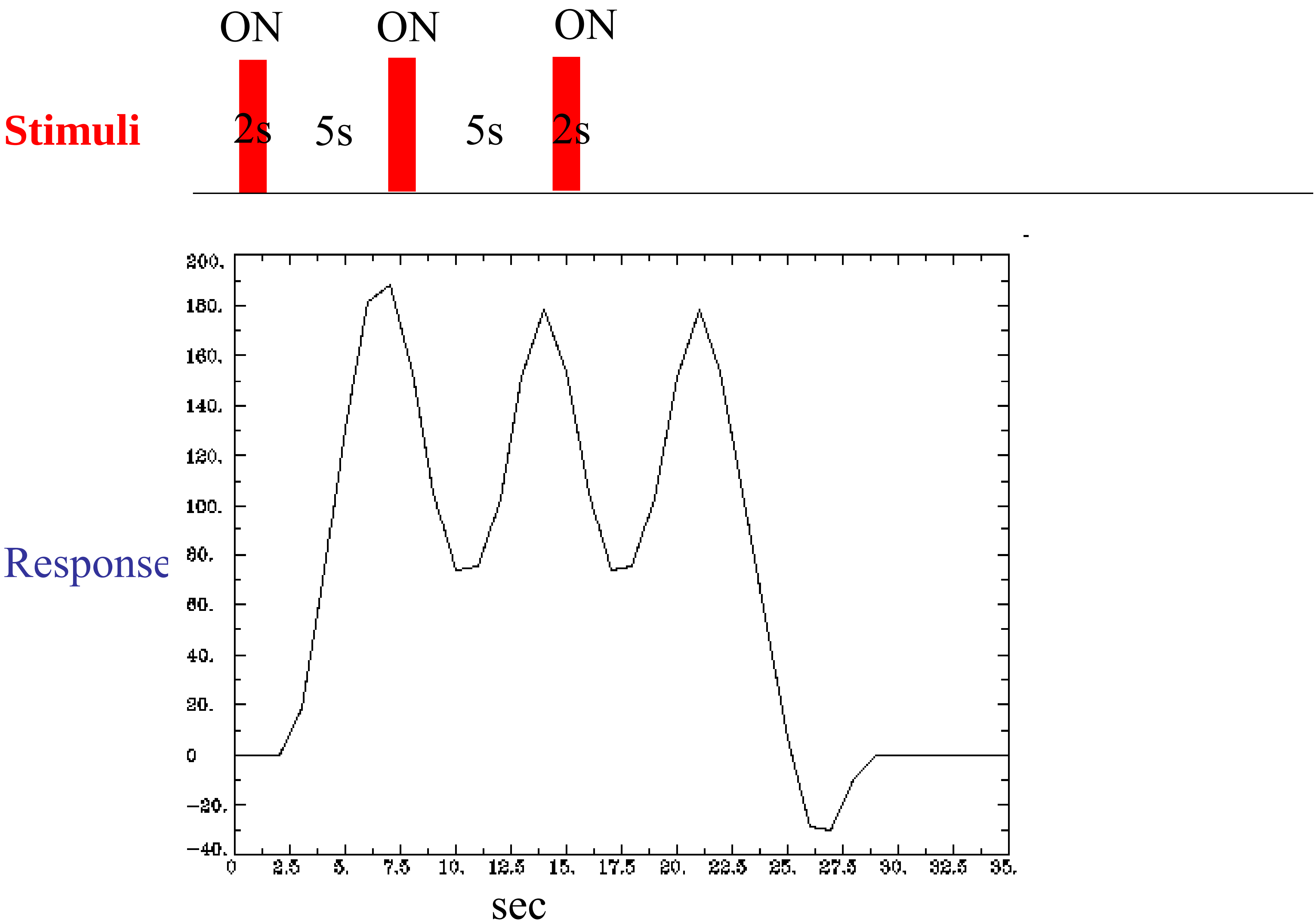


impulse → impulse response

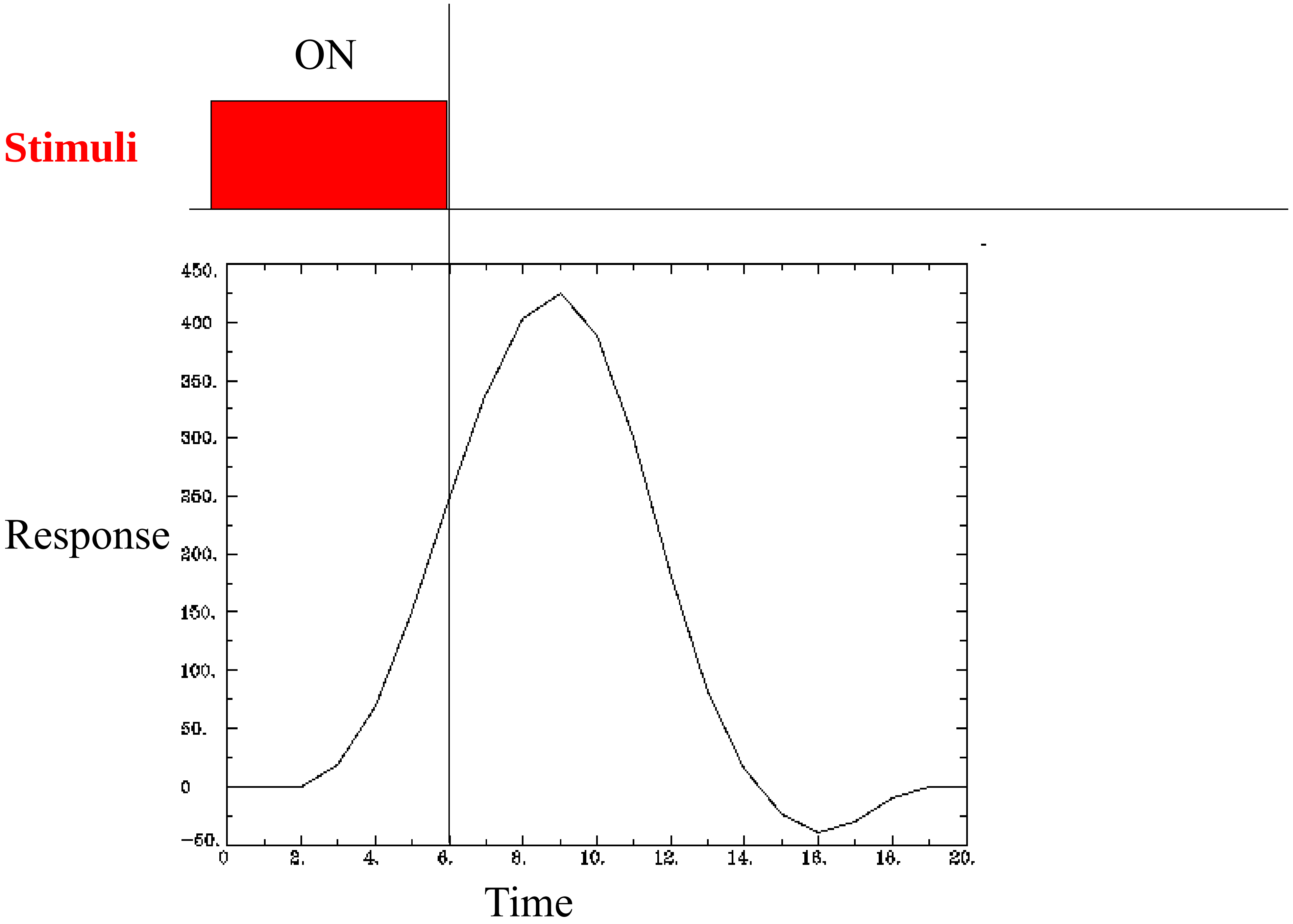
$\delta(t)$ → System → $h(t)$

Traditional (Slow) Event Related Design





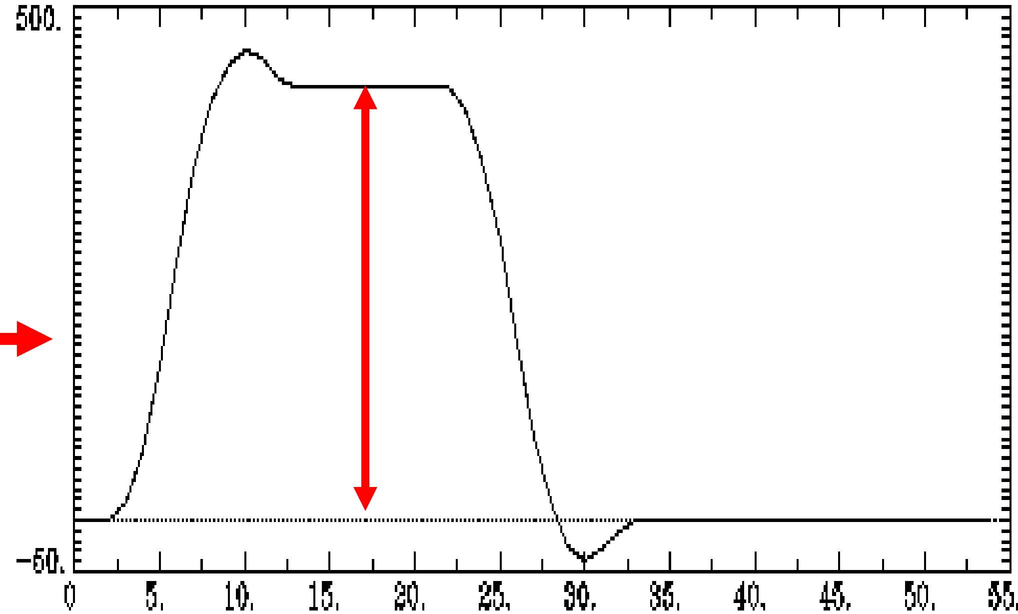
ON
ON
ON
Stimuli
2s
5s
5s
2s
Response
200.
180.
160.
140.
120.
100.
80.
60.
40.
20.
0
−20.
−40.
0
2.5
5.
7.5
10.
12.5
15.
17.5
20.
22.5
25.
27.5
30.
32.5
35.
sec

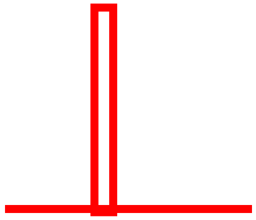


ON
Stimuli
Response
450.
400
350.
300.
250.
200.
150.
100.
50.
0
−50.
0
2.
4.
6.
8.
10.
12.
14.
16.
18.
20.
Time

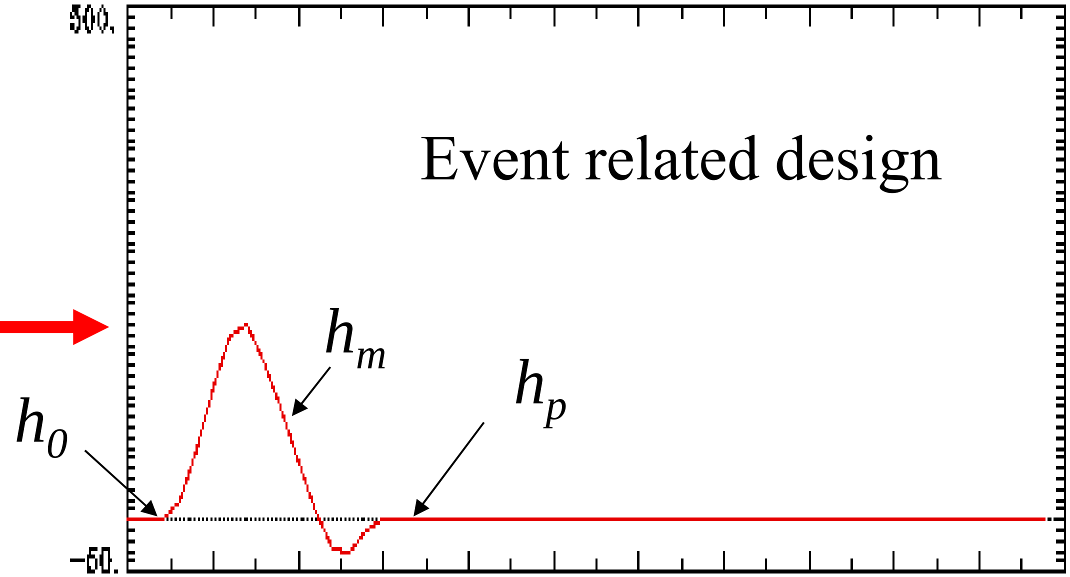
Block Design

Present 10 pictures
With 2 seconds each



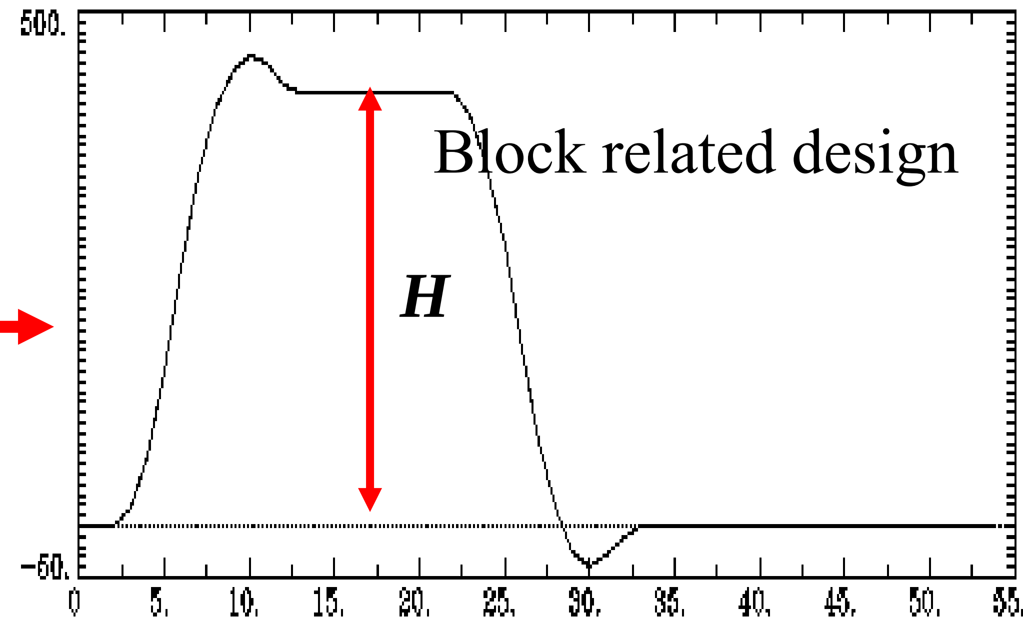


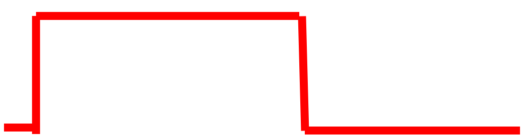
Present for 2 seconds



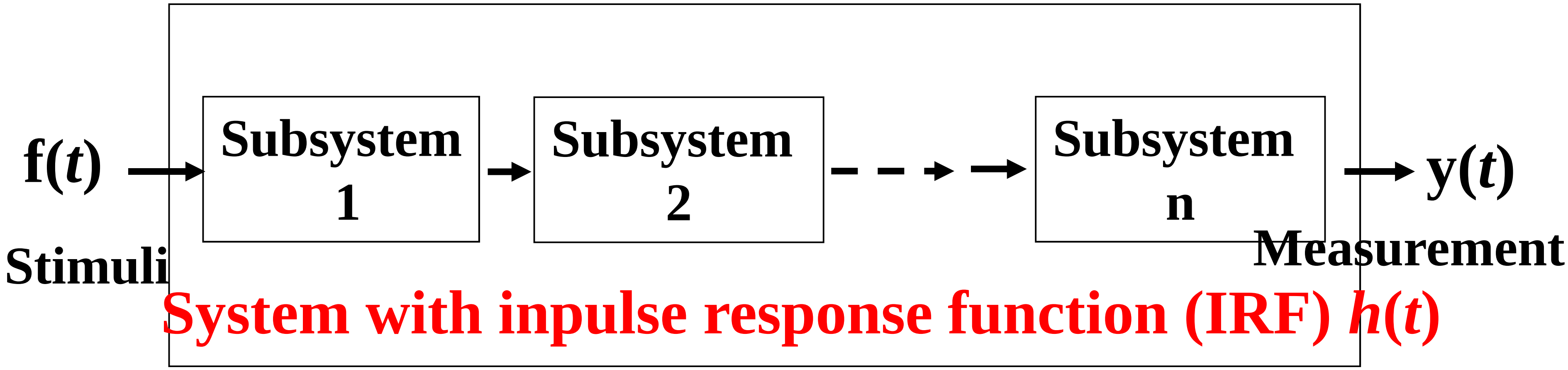
$$H \approx \sum_{m=0}^{p} h_m$$

Present 10 pictures
With 2 seconds each





Modeling of fMRI



$$y(t) = f(t) \otimes h(t)$$

$$= \int_0^t f(\tau) h(t-\tau) d\tau$$

deconvolution

***h*(*t*)**

Continuous: $$y(t) = f(t) \otimes h(t) = \int_0^t f(\tau)h(t-\tau)d\tau$$

Discrete times: $$y(n\Delta t) = \sum_{m=0}^{n} f(m\Delta t)h(n\Delta t - m\Delta t)\Delta t$$

In short hand,

$$y_n = \sum_{m=0}^{n} f_m h_{n-m}$$

$$= \sum_{m=0}^{n} f_{n-m} h_m$$

Assume $h_m = 0$ for n ≥ p, then

$$y_n = \sum_{m=0}^{p} f_{n-m} h_m$$

Lathi BP. *Linear Systems and Signals*. Berkeley-Cambridge Press. 1992.

Using the matrix notation,

$$Z = \begin{bmatrix} Z_p \\ Z_{p+1} \\ . \\ . \\ . \\ Z_{N-1} \end{bmatrix}, \qquad X = \begin{bmatrix} 1 & p & f_p & \dots & f_0 \\ 1 & p+1 & f_{p+1} & \dots & f_1 \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ 1 & N-1 & f_{N-1} & \dots & f_{N-p-1} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ h_0 \\ . \\ . \\ . \\ h_p \end{bmatrix} \qquad \varepsilon = \begin{bmatrix} \varepsilon_p \\ \varepsilon_{p+1} \\ . \\ . \\ . \\ \varepsilon_{N-1} \end{bmatrix}$$

$$Z_n = k\sum_{m=0}^{p} f_{n-m}h_m + \varepsilon_n$$

measurement — Z_n; y_n — $\sum_{m=0}^{p} f_{n-m}h_m$; Error — ε_n

Including constant baseline + linear trend, the MR signal measured

$$Z_n = y_n + \beta_0 + \beta_1 n + \varepsilon_n$$
$$= \beta_0 + \beta_1 n + h_0 f_n + h_1 f_{n-1} + \cdots + h_p f_{n-p} + \varepsilon_n$$

For $n = p, p+1, \ldots, N-1$

$$Z_n = \beta_0 + \beta_1 n + k y_n + \varepsilon_n$$

For $n = 0, 1, \ldots, N-1$

Using the matrix notation,

$$Z = \begin{bmatrix} Z_0 \\ Z_1 \\ . \\ . \\ . \\ Z_{N-1} \end{bmatrix}, \qquad X = \begin{bmatrix} 1 & 0 & y_0 \\ 1 & 1 & y_1 \\ . & . & . \\ . & . & . \\ . & . & . \\ 1 & N-1 & y_{N-p-1} \end{bmatrix},$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ k \end{bmatrix} \qquad \varepsilon = \begin{bmatrix} \varepsilon_0 \\ \varepsilon_1 \\ . \\ . \\ . \\ \varepsilon_{N-1} \end{bmatrix}$$

$$\mathbf{Z} = \mathbf{X}\,\boldsymbol{\beta} + \boldsymbol{\varepsilon}$$

The MR signal intensity at a voxel from a 7-min run

The design matrix (when the stimulus ON and OFF)

Baseline signal + linear trend + IRF

Error term

k

$\otimes$

$h(t)$

Model

$$\hat{\beta} = \begin{bmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \hat{k} \end{bmatrix} = (X^t X)^{-1} X^t Z$$

$$y(t) = f(t) \otimes h(t)$$

$$y'(t) = f(t) \otimes h'(t)$$ ← Model

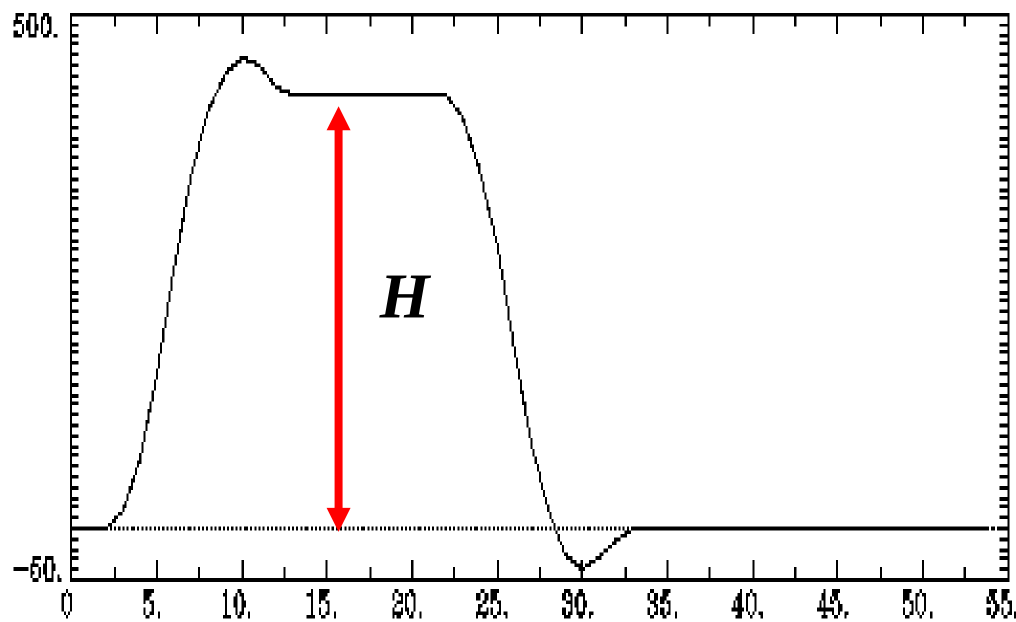
In AFNI, gamma functions:
(1) Default: Cox special
(2) Mark Cohen

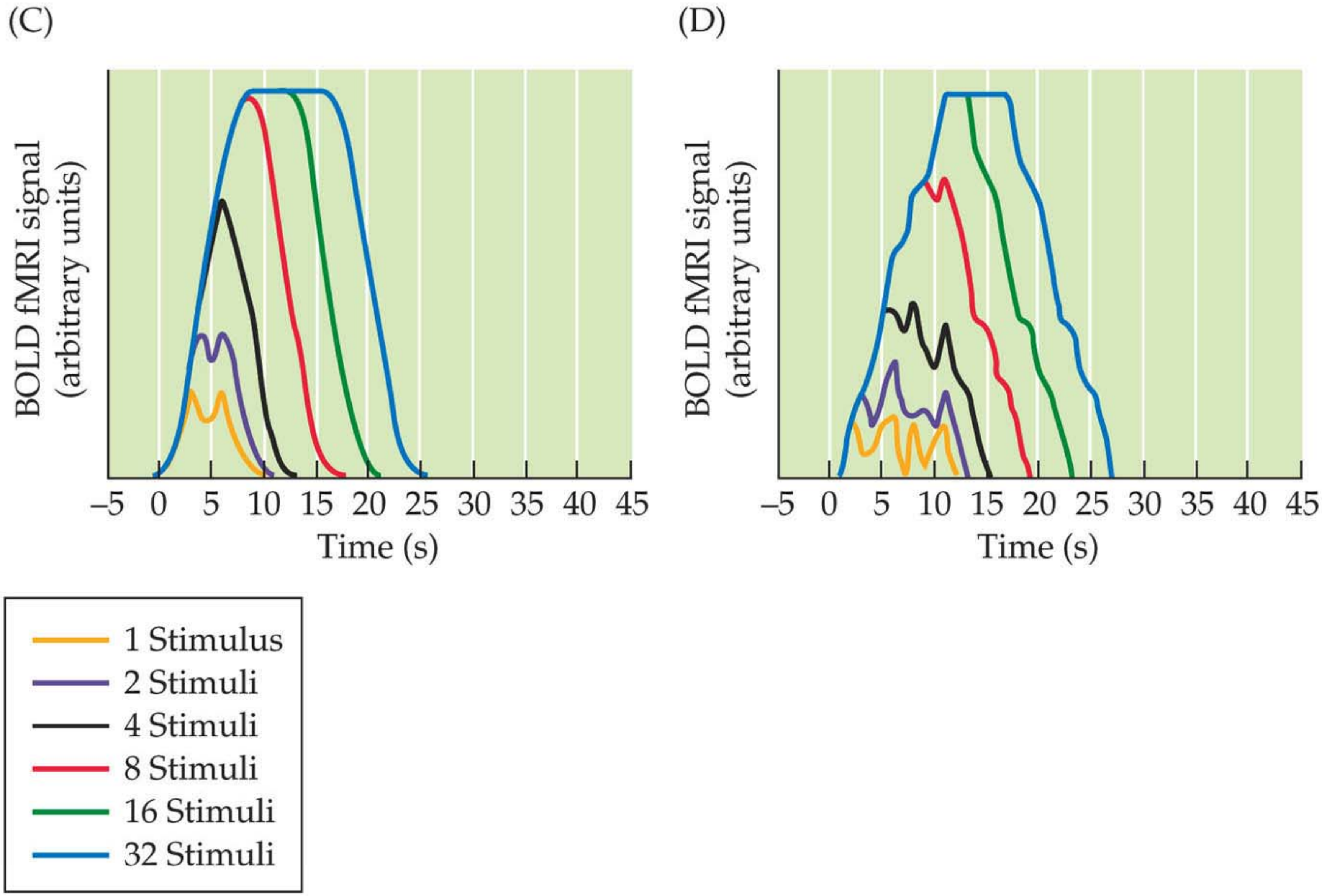
if $$h(t) = kh'(t)$$

then $$y(t) = ky'(t)$$

% signal change

$$= \frac{\hat{k}H}{\hat{\beta}_0}$$



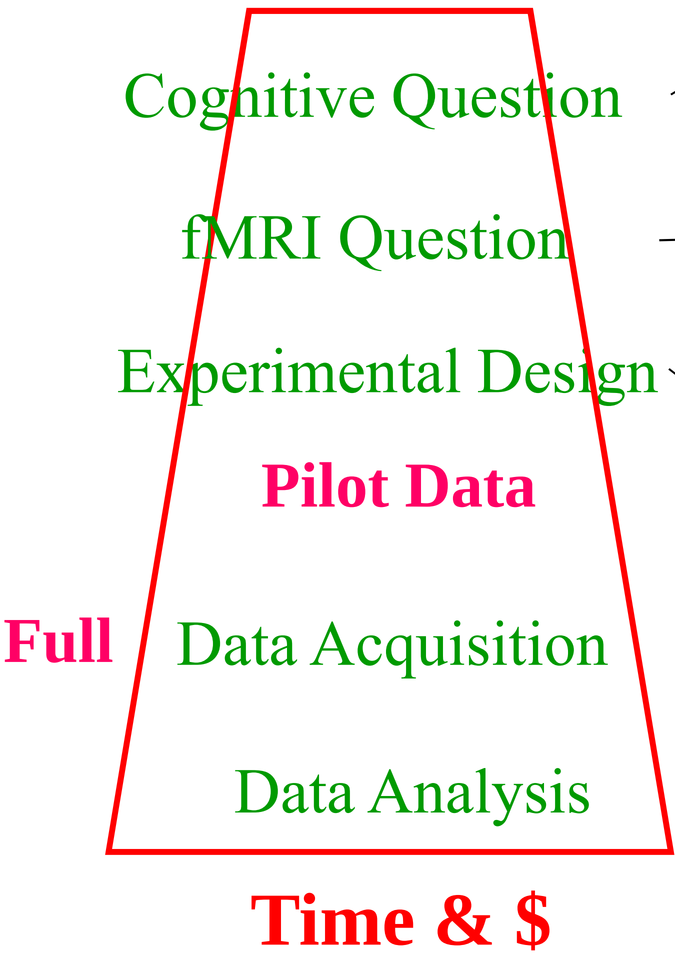


FUNCTIONAL MAGNETIC RESONANCE IMAGING, **Figure 11.11 (Part 2)**

Example

Henderson JM, Larson CL, Zhu DC. Cortical activation to indoor versus outdoor scenes: an fMRI study. Exp Brain Res. 2007;179:75-84.

Engineering Process



Indoor and Outdoor belongs to different scene sub-categories. Does the bran process them differently?

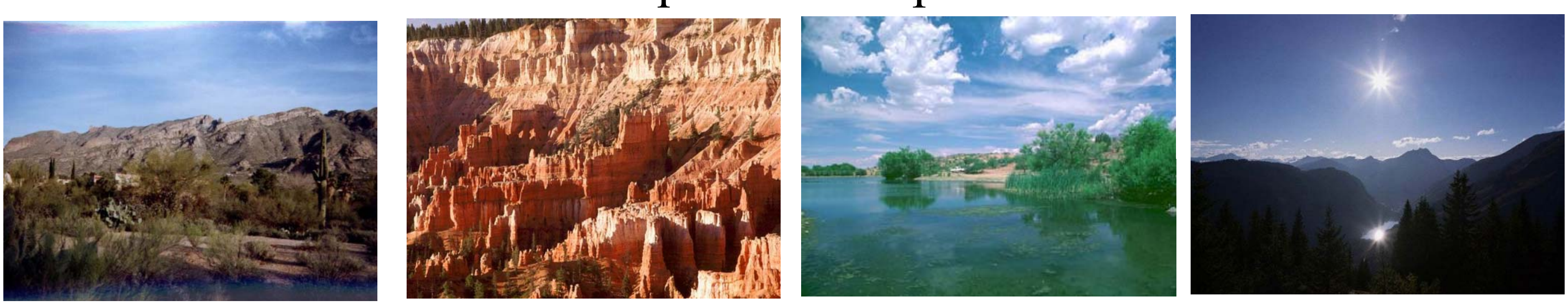
Do they have different BOLD activation at scene processing area PPA (parahippocampal place area)? How about retrosplenial cortex?

1. Block design for good detection.
2. Need Face as control to find PPA.
3. Need a lot of unique stimuli to find out if Indoor and Outdoor have different BOLD responses.

160 unique faces

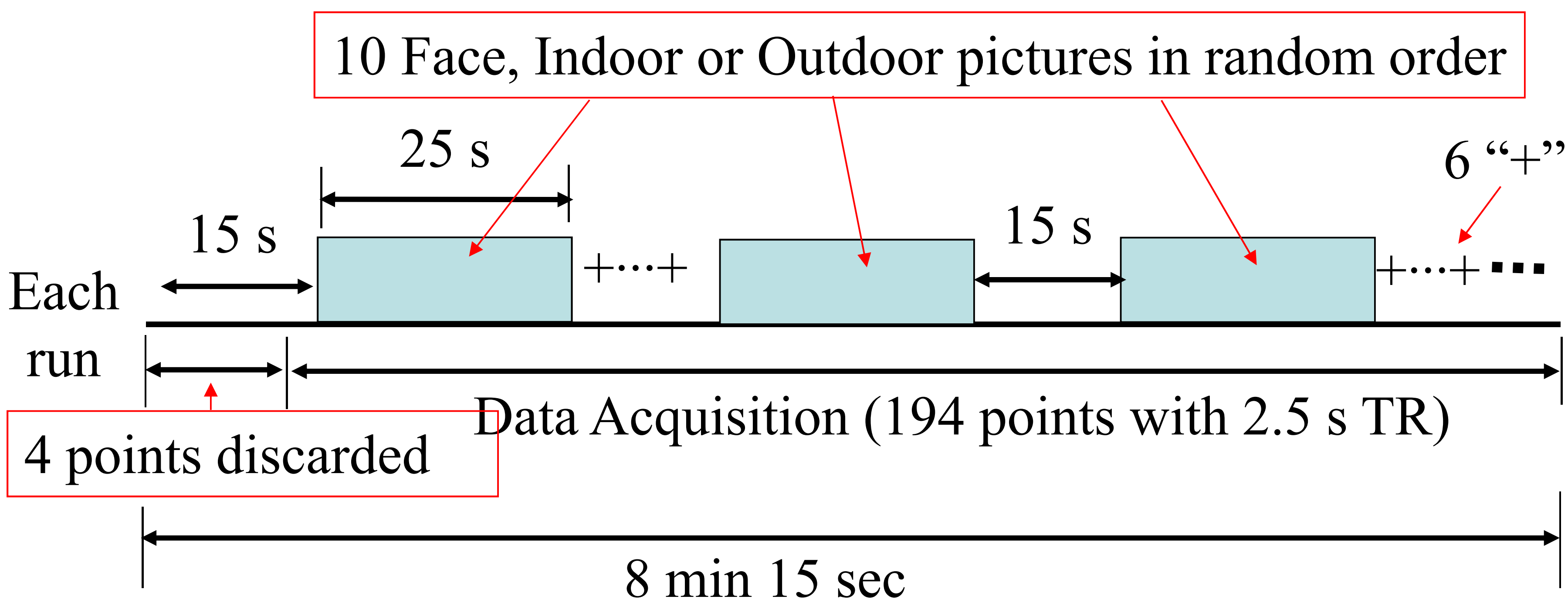
160 unique indoor pictures

160 unique outdoor pictures



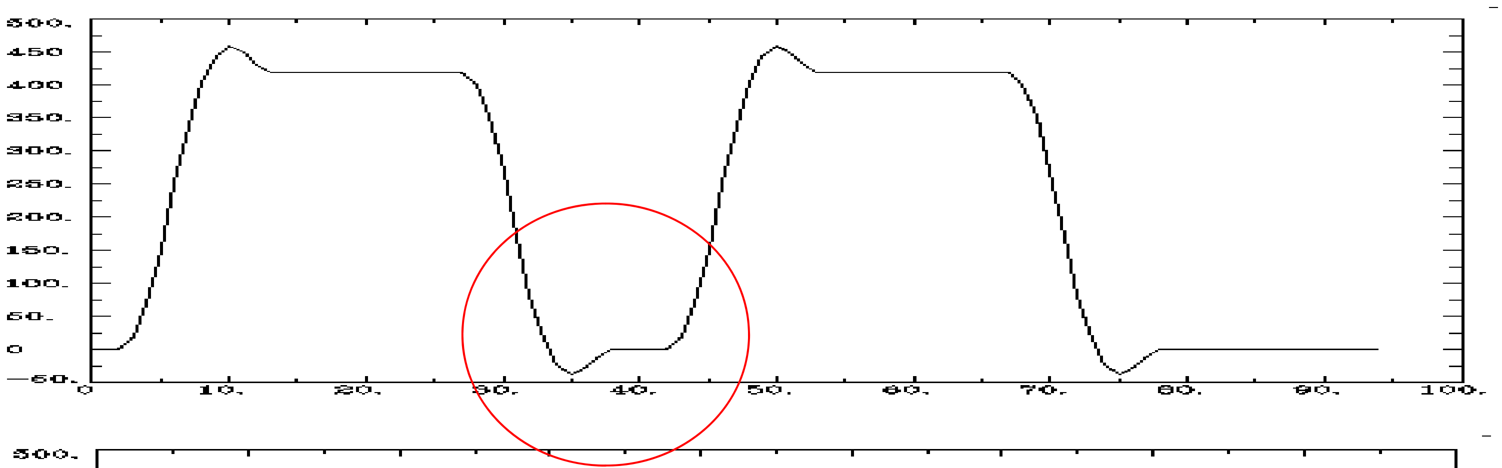
Detailed Design

160 neutral faces, 160 indoor pictures and 160 outdoor pictures.
No pictures will be repeated.
Block design.
4 runs.
Stimuli are randomized.
At each run, 6 "+" initial baseline + 12 blocks
At each block, 10 pictures + 6 "+".

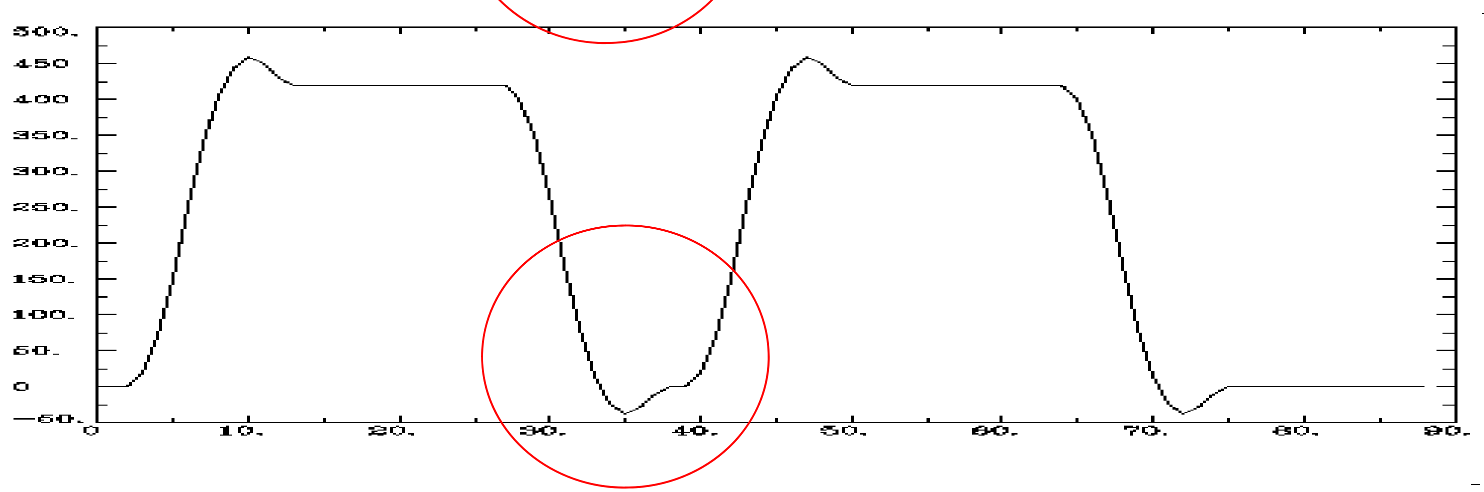


Why choose 15 sec of baseline?

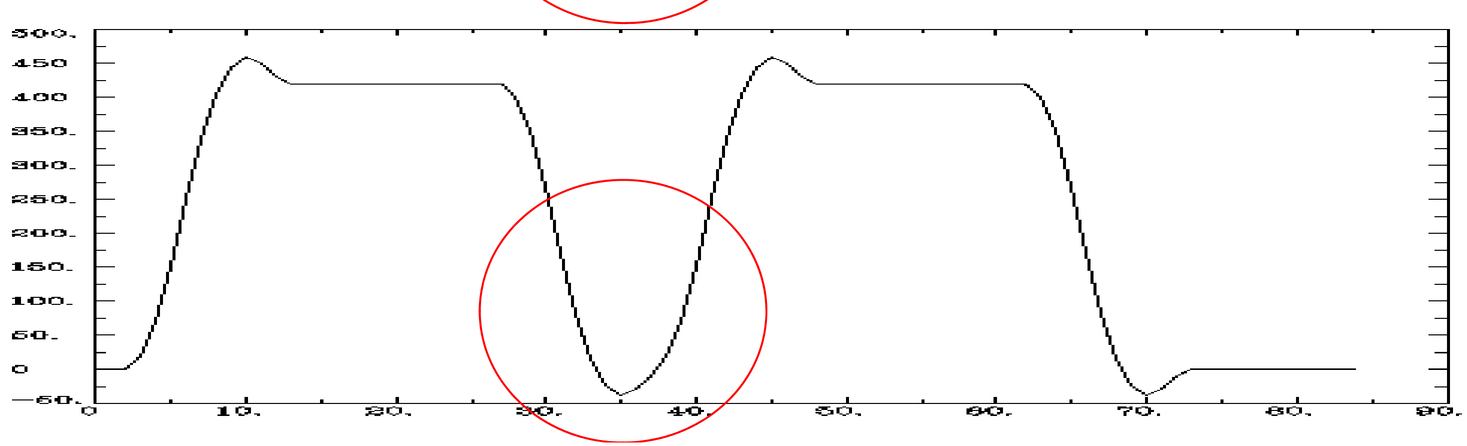
25 sec ON
15 sec OFF



25 sec ON
12 sec OFF

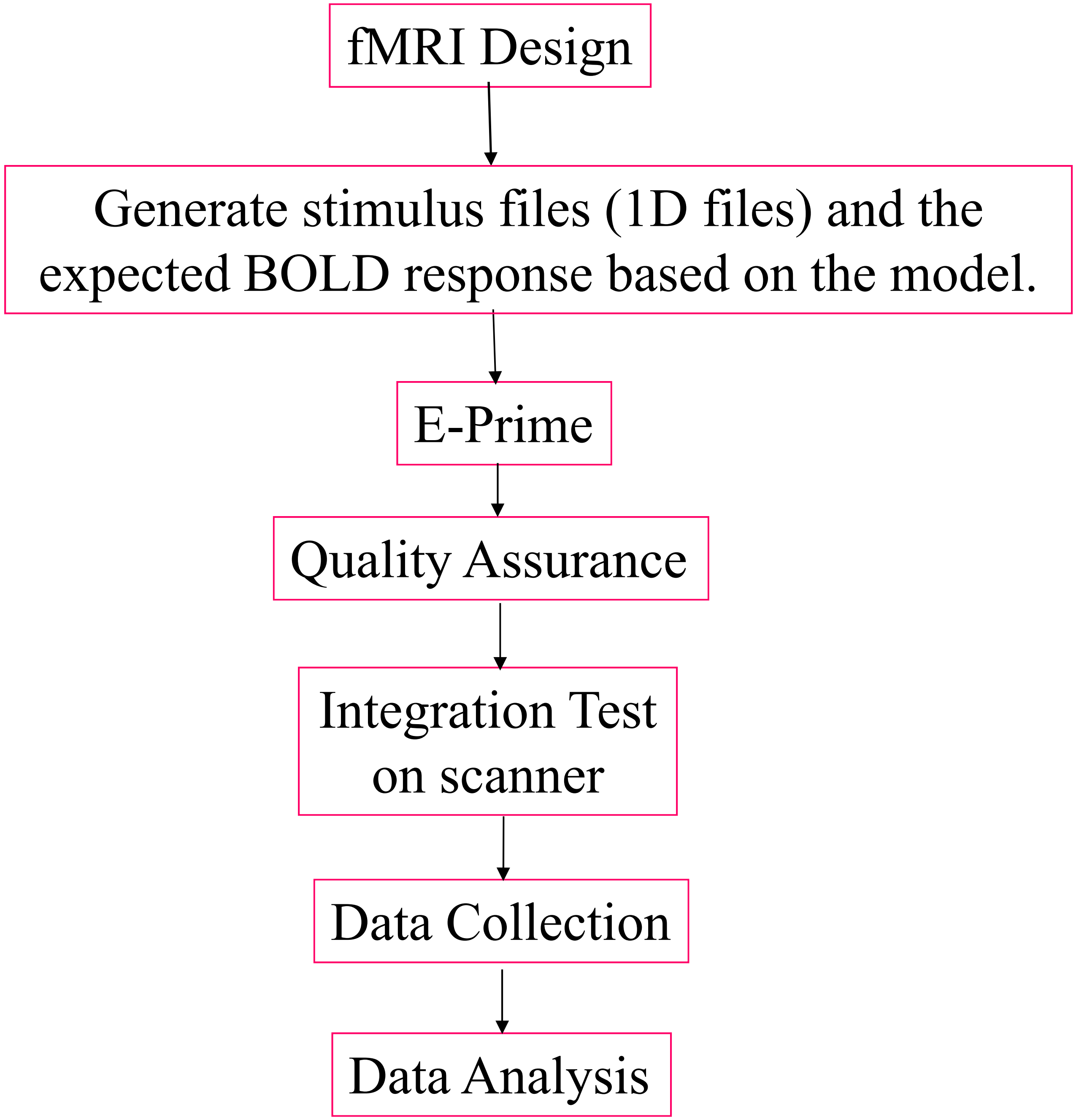


25 sec ON
10 sec OFF



Other considerations: Why choose 25 sec ON and 15 sec OFF?

1. Good duty cycle → shorten the scan time for same detection power.
2. Multiple of TR (2.5 sec).
3. We believe 25 sec is still good for maintaining the attention.


fMRI Design
Generate stimulus files (1D files) and the expected BOLD response based on the model.
E-Prime
Quality Assurance
Integration Test on scanner
Data Collection
Data Analysis

Generate stimulus files (1D files) and the expected BOLD response based on the model.

Reading Materials:
Chapter 8 and Chapter 10

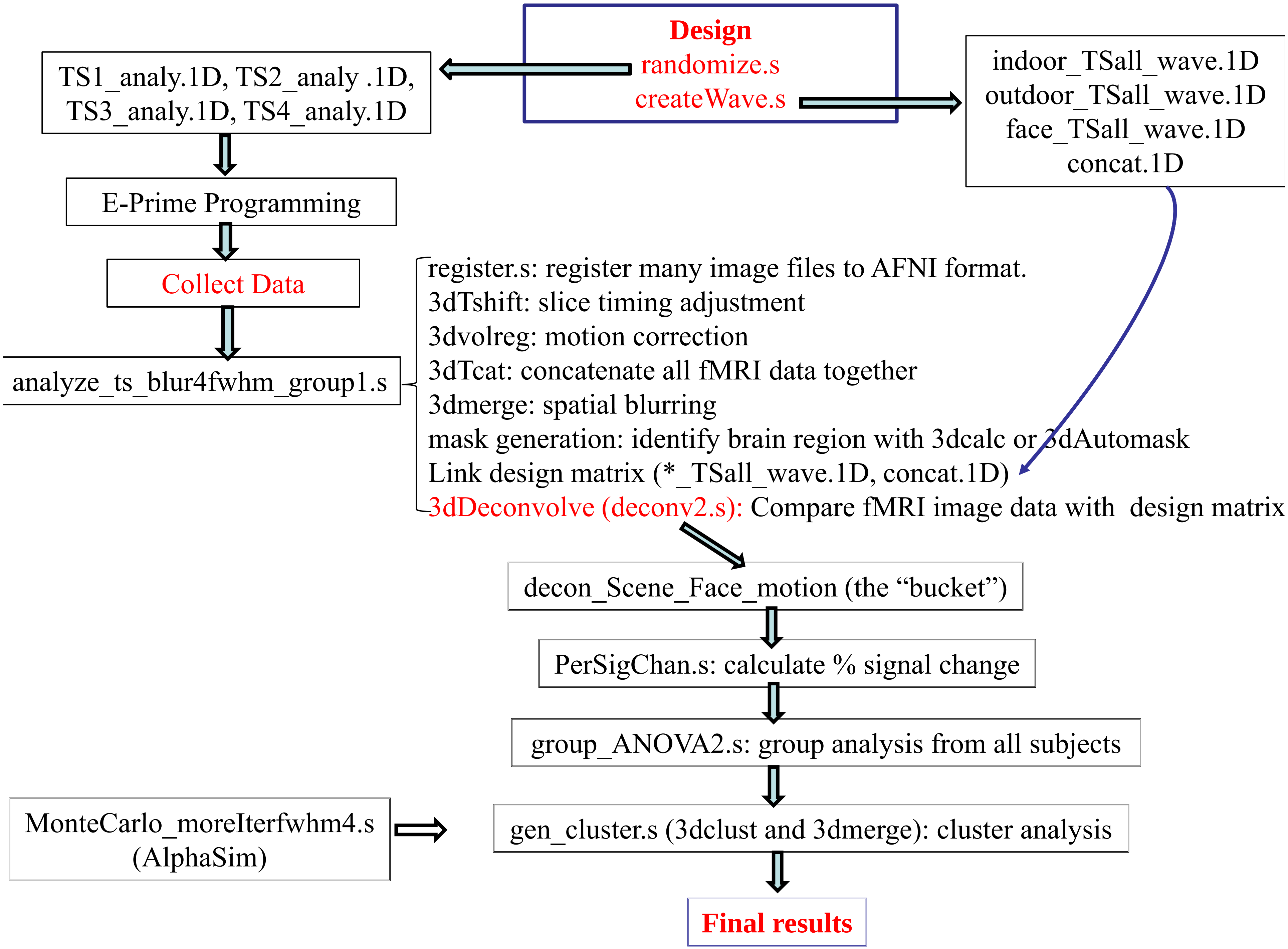
Data Analysis

1. Data Pre-processing:
   (1) Registration to AFNI
   (2) Slice timing adjustment
   (3) Motion correction
   (4) Spatial blurring
   (5) Mask generation

2. Data Processing:
   (1) Deconvolution analysis
   (2) Noise analysis (optional)
   (3) Overall significance level
   (4) Group analysis (ANOVA's)
   (5) ROI analysis

Block Design Hand-On

- Scripts to generate a block-design experiment
- Run the script to do the data analysis
- Explain the scripts.


Design
randomize.s
createWave.s
TS1_analy.1D, TS2_analy .1D,
TS3_analy.1D, TS4_analy.1D
indoor_TSall_wave.1D
outdoor_TSall_wave.1D
face_TSall_wave.1D
concat.1D
E-Prime Programming
Collect Data
analyze_ts_blur4fwhm_group1.s
register.s: register many image files to AFNI format.
3dTshift: slice timing adjustment
3dvolreg: motion correction
3dTcat: concatenate all fMRI data together
3dmerge: spatial blurring
mask generation: identify brain region with 3dcalc or 3dAutomask
Link design matrix (*_TSall_wave.1D, concat.1D)
3dDeconvolve (deconv2.s): Compare fMRI image data with design matrix
decon_Scene_Face_motion (the "bucket")
PerSigChan.s: calculate % signal change
group_ANOVA2.s: group analysis from all subjects
MonteCarlo_moreIterfwhm4.s
(AlphaSim)
gen_cluster.s (3dclust and 3dmerge): cluster analysis
Final results