Event-related fMRI

With thanks to:

Rik Henson - Karl Friston, Oliver Josephs

Overview

1. Advantages of efMRI
2. BOLD impulse response
3. General Linear Model
4. Temporal Basis Functions
5. Timing Issues
6. Design Optimisation
7. Nonlinear Models
8. Example Applications

Advantages of Event-related fMRI

1. Randomised trial order
   c.f. confounds of blocked designs (Johnson et al 1997)

2. Post hoc / subjective classification of trials
   e.g, according to subsequent memory (Wagner et al 1998)

3. Some events can only be indicated by subject (in time)
   e.g, spontaneous perceptual changes (Kleinschmidt et al 1998)

4. Some trials cannot be blocked
   e.g, "oddball" designs (Clark et al., 2000)

5. More accurate models even for blocked designs?
   e.g, "state-item" interactions (Chawla et al, 1999)

(Disadvantages of Randomised Designs)

1. Less efficient for detecting effects than are blocked designs
   (see later…)

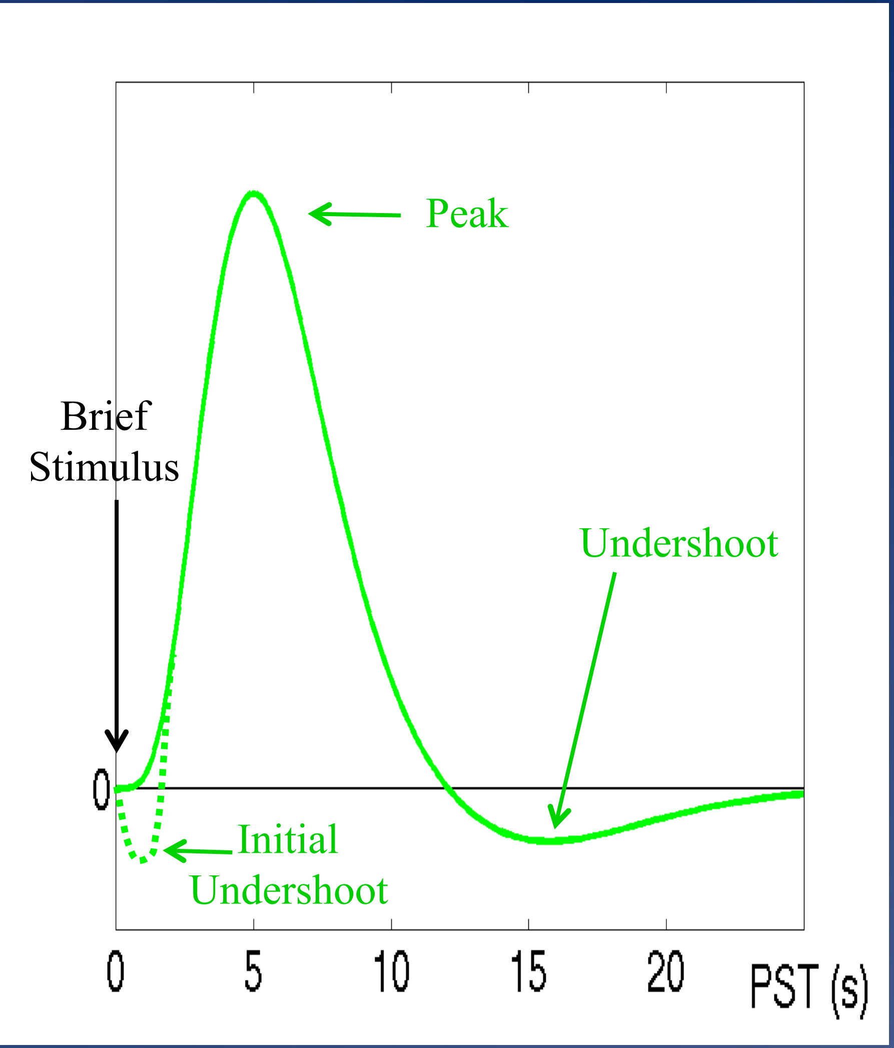
2. Some psychological processes may be better blocked
   (eg task-switching, attentional instructions)

Overview

1. Advantages of efMRI
2. BOLD impulse response
3. General Linear Model
4. Temporal Basis Functions
5. Timing Issues
6. Design Optimisation
7. Nonlinear Models
8. Example Applications

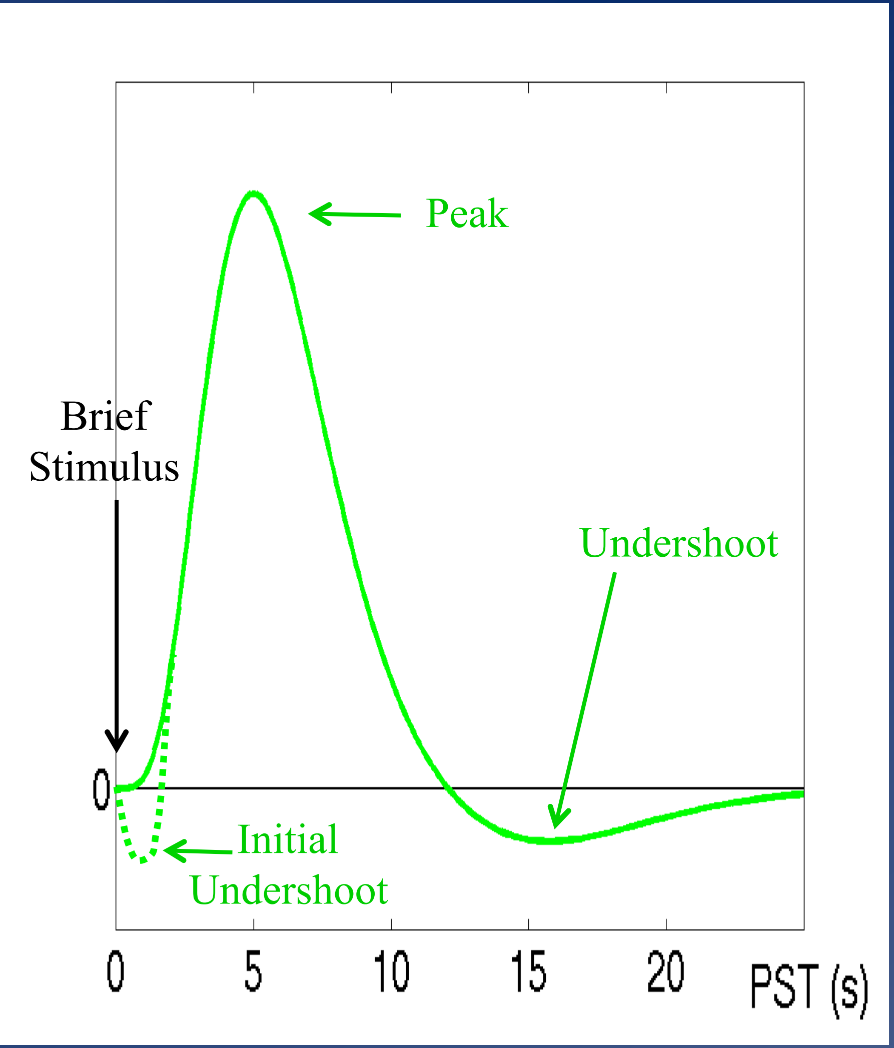
BOLD Impulse Response

- Function of blood oxygenation, flow, volume (Buxton et al, 1998)
- Peak (max. oxygenation) 4-6s poststimulus; baseline after 20-30s
- Initial undershoot can be observed (Malonek & Grinvald, 1996)
- Similar across V1, A1, S1…
- … but differences across:
  other regions (Schacter et al 1997)
  individuals (Aguirre et al, 1998)



BOLD Impulse Response

- Early event-related fMRI studies used a long Stimulus Onset Asynchrony (SOA) to allow BOLD response to return to baseline
- However, if the BOLD response is explicitly modelled, overlap between successive responses at short SOAs can be accommodated…
- … particularly if responses are assumed to superpose linearly
- Short SOAs are more sensitive…



Overview

1. Advantages of efMRI
2. BOLD impulse response
3. General Linear Model
4. Temporal Basis Functions
5. Timing Issues
6. Design Optimisation
7. Nonlinear Models
8. Example Applications

General Linear (Convolution) Model

GLM for a single voxel:

$$y(t) = u(t) \otimes h(\tau) + \varepsilon(t)$$

$u(t)$ = neural causes (stimulus train)

$$u(t) = \sum \delta\,(t - nT)$$

$h(\tau)$ = hemodynamic (BOLD) response

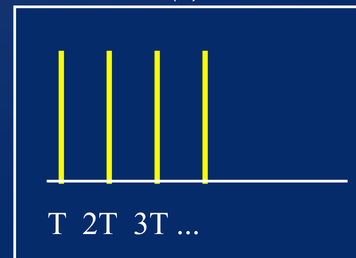
$$h(\tau) = \sum \beta_i\, f_i\,(\tau)$$

$f_i(\tau)$ = temporal basis functions

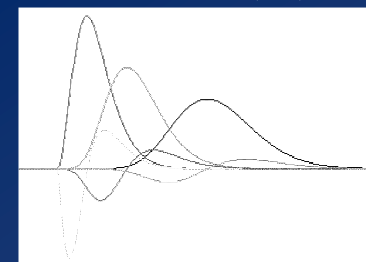
$$y(t) = \sum \sum \beta_i\, f_i\,(t - nT) + \varepsilon(t)$$

$$\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}$$

$u(t)$



$h(\tau)= \sum \beta_i\, f_i\,(\tau)$



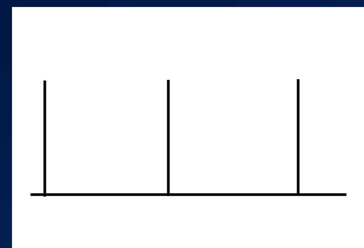
convolution

sampled each scan

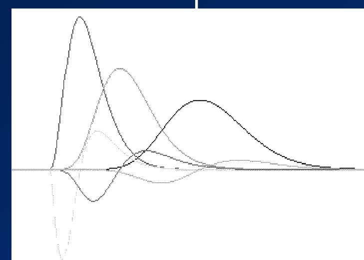
Design Matrix

General Linear Model (in SPM)

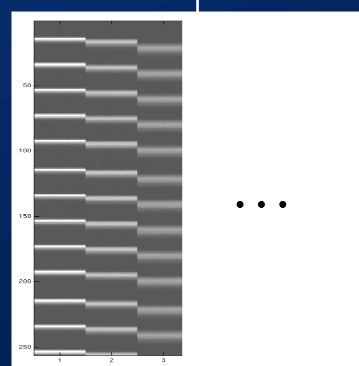
Auditory words
every 20s

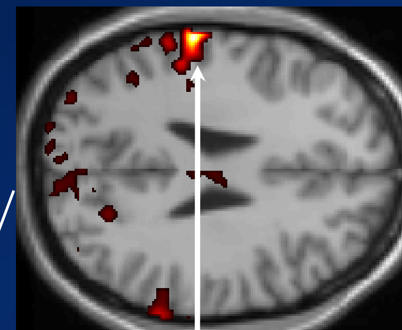


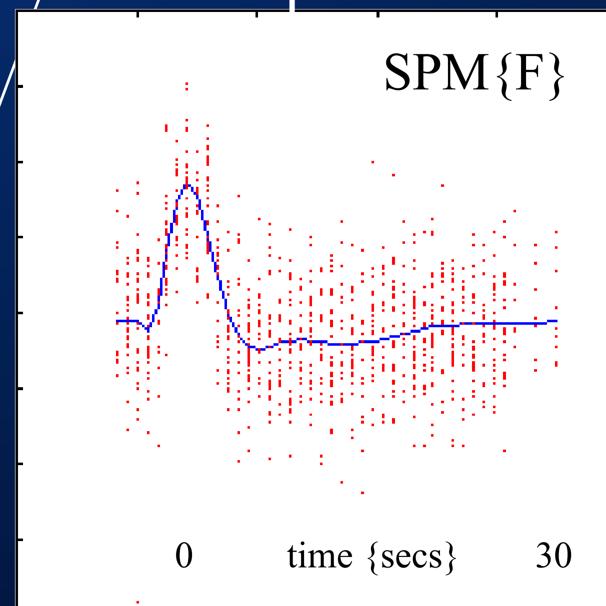
Gamma functions $f_i(\tau)$ of
peristimulus time τ
(Orthogonalised)



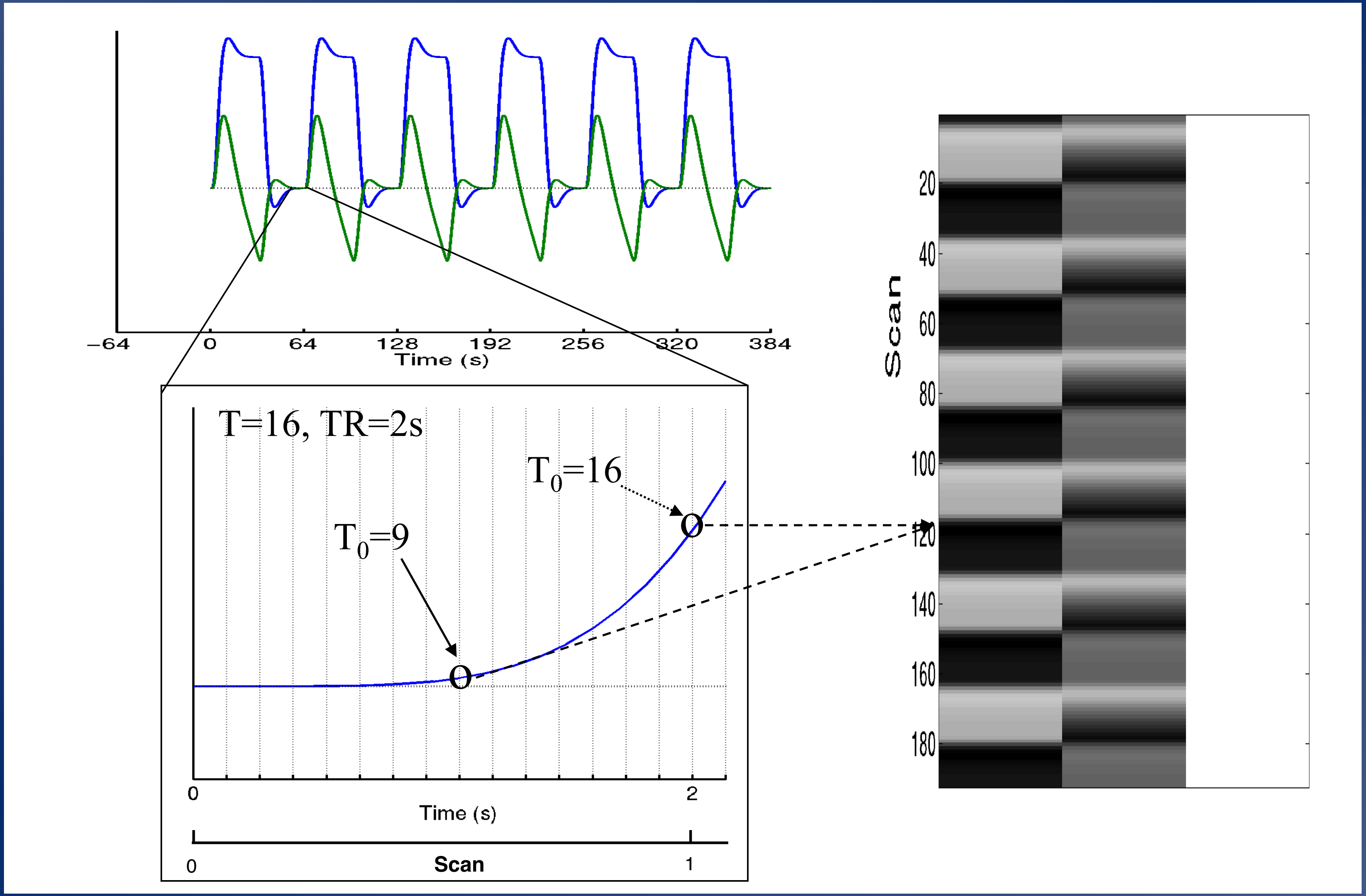
Sampled every TR = 1.7s
Design matrix, **X**
$[x(t) \otimes f_1(\tau) \mid x(t) \otimes f_2(\tau) \mid \ldots]$







A word about down-sampling

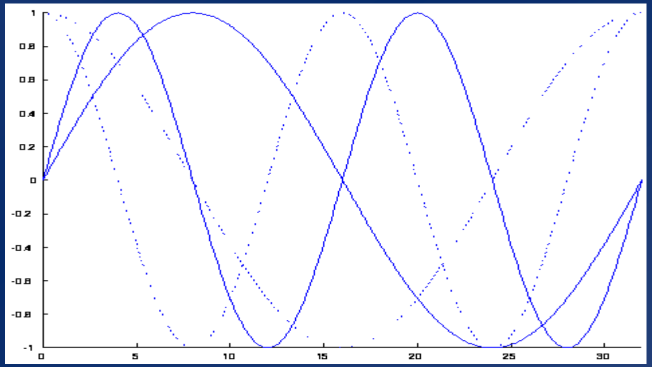


Overview

1. Advantages of efMRI
2. BOLD impulse response
3. General Linear Model
4. Temporal Basis Functions
5. Timing Issues
6. Design Optimisation
7. Nonlinear Models
8. Example Applications

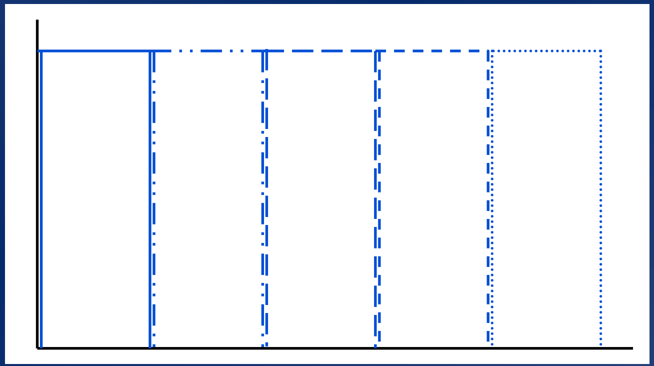
Temporal Basis Functions

- Fourier Set
  - Windowed sines & cosines
  - Any shape (up to frequency limit)
  - Inference via F-test



Temporal Basis Functions

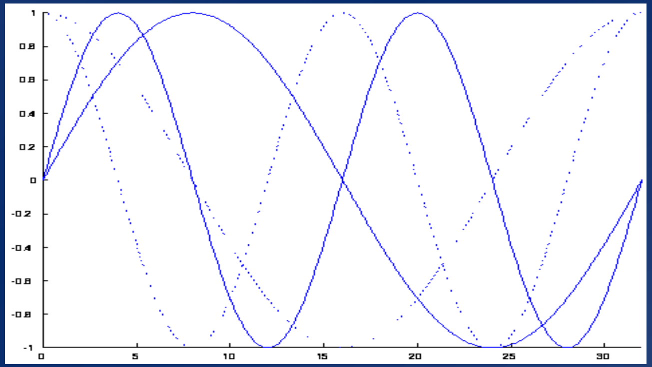
- Finite Impulse Response
  - Mini “timebins” (selective averaging)
  - Any shape (up to bin-width)
  - Inference via F-test

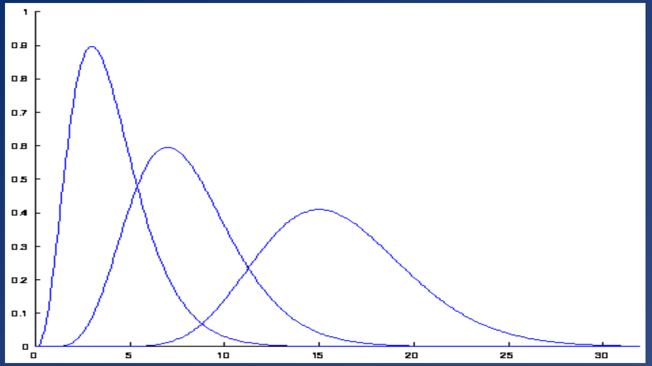


Temporal Basis Functions

- Fourier Set
  - Windowed sines & cosines
  - Any shape (up to frequency limit)
  - Inference via F-test

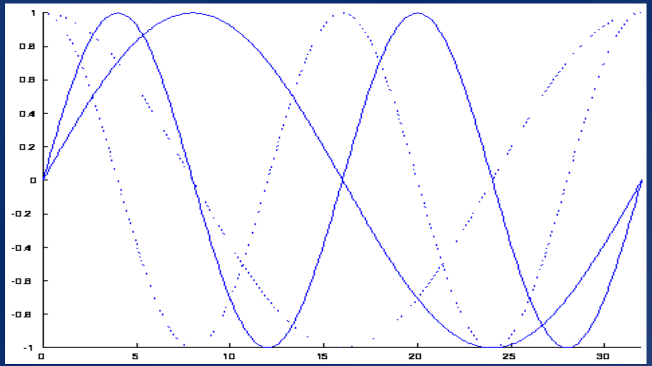
- Gamma Functions
  - Bounded, asymmetrical (like BOLD)
  - Set of different lags
  - Inference via F-test

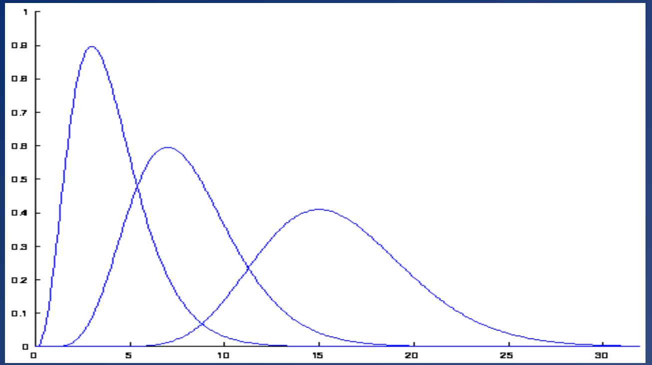


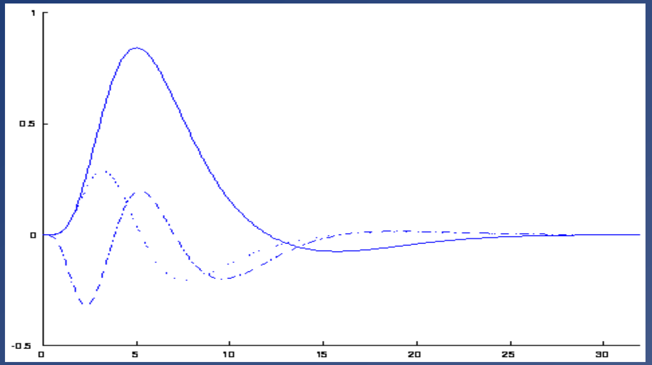


Temporal Basis Functions

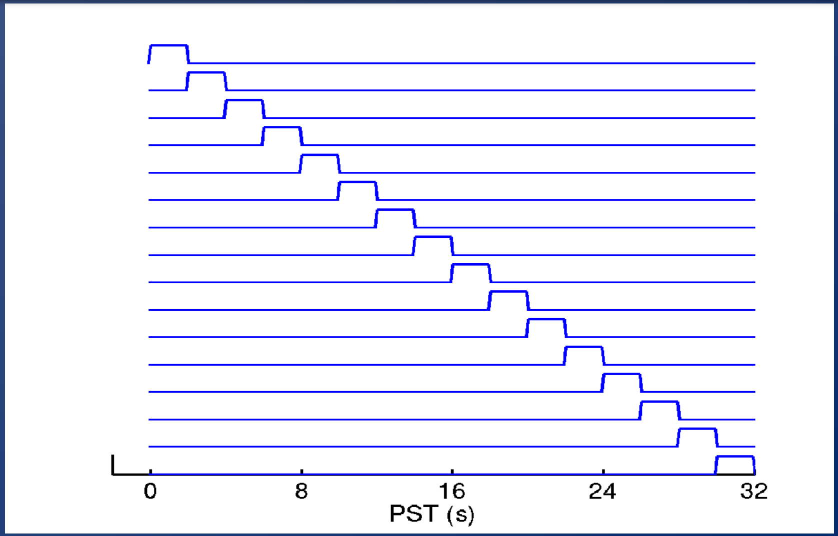
- Fourier Set
  - Windowed sines & cosines
  - Any shape (up to frequency limit)
  - Inference via F-test
- Gamma Functions
  - Bounded, asymmetrical (like BOLD)
  - Set of different lags
  - Inference via F-test
- "Informed" Basis Set
  - Best guess of canonical BOLD response
  - Variability captured by Taylor expansion
  - "Magnitude" inferences via t-test…?

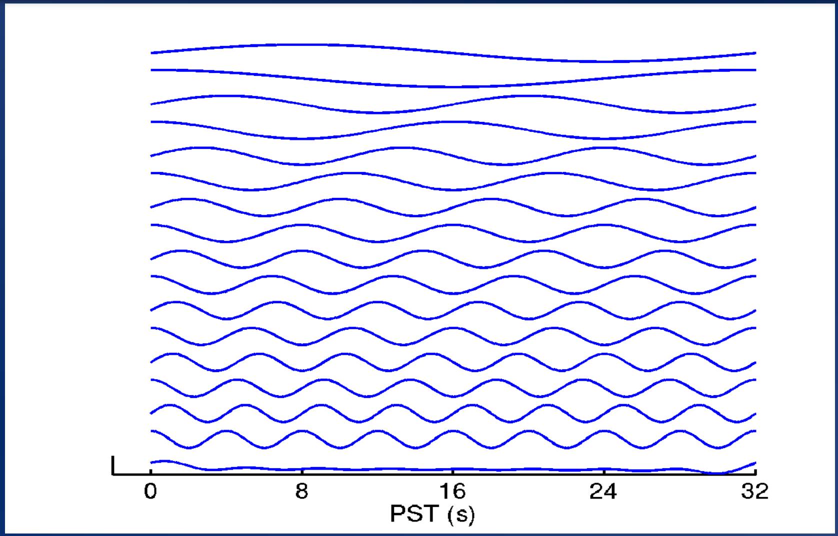


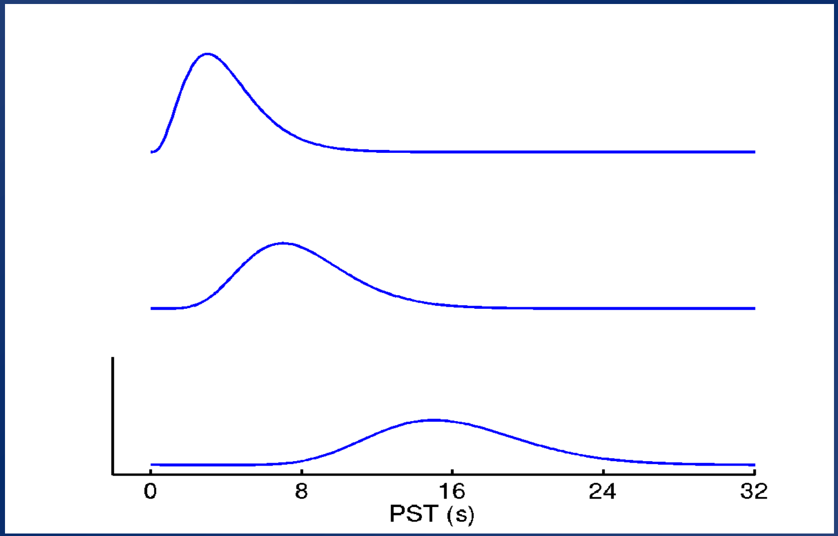


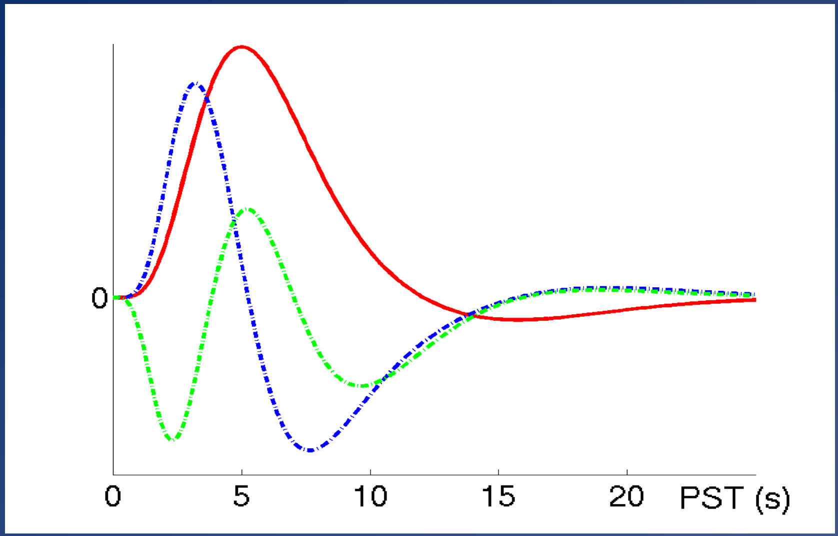


Temporal Basis Functions

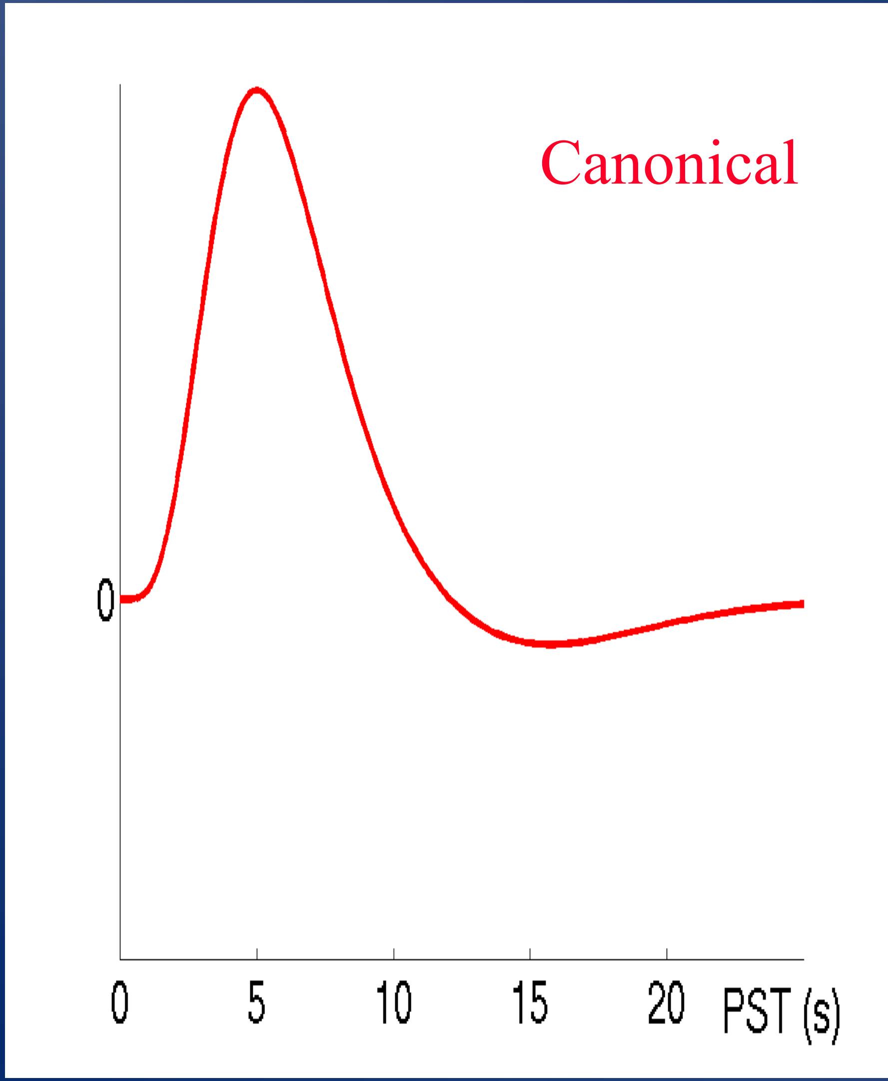








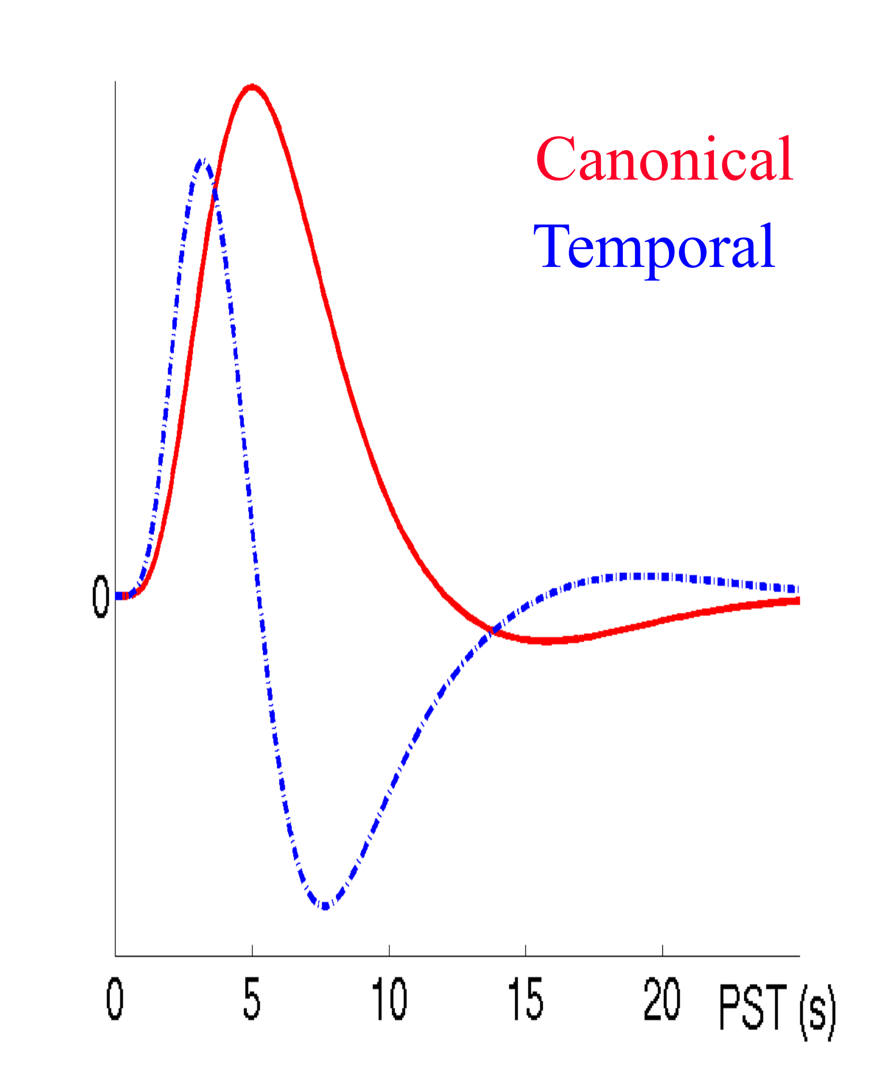
Temporal Basis Functions



"Informed" Basis Set
(Friston et al. 1998)

- Canonical HRF (2 gamma functions)

Temporal Basis Functions



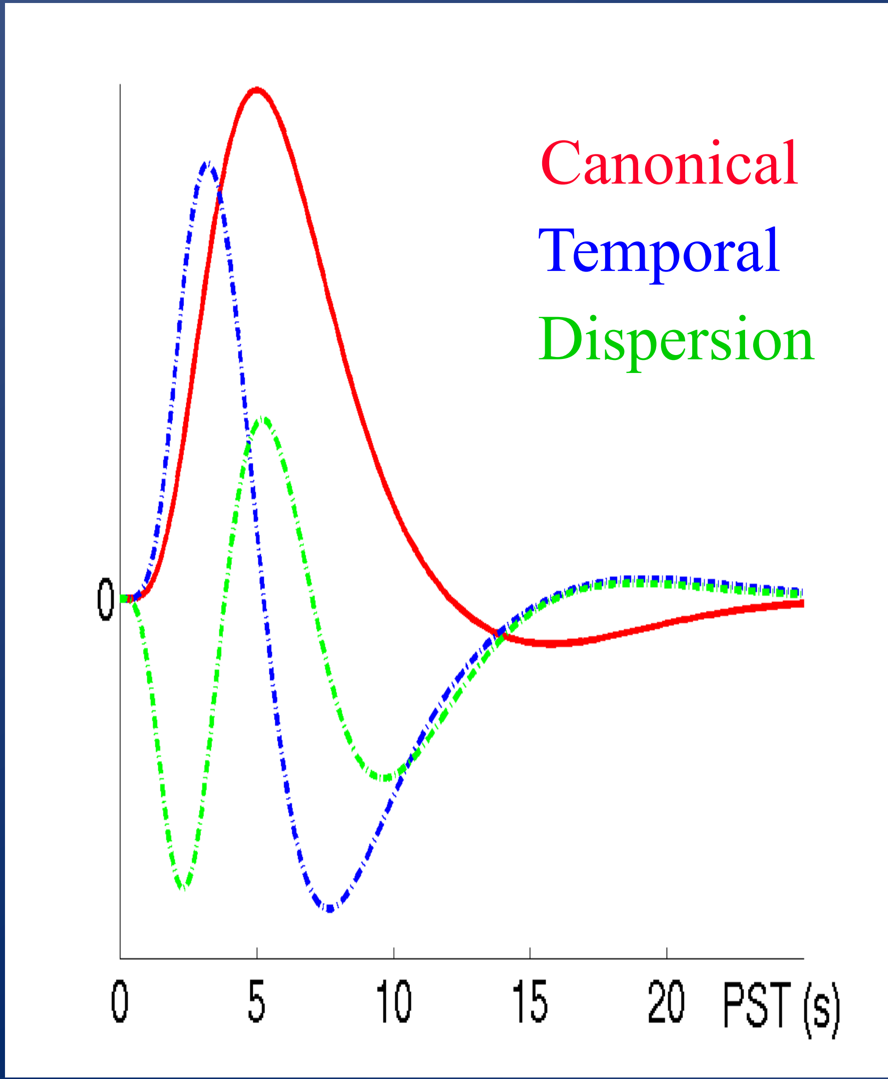
"Informed" Basis Set
(Friston et al. 1998)

- Canonical HRF (2 gamma functions)

  plus Multivariate Taylor expansion in:

  time (*Temporal Derivative*)

Temporal Basis Functions



"Informed" Basis Set
(Friston et al. 1998)

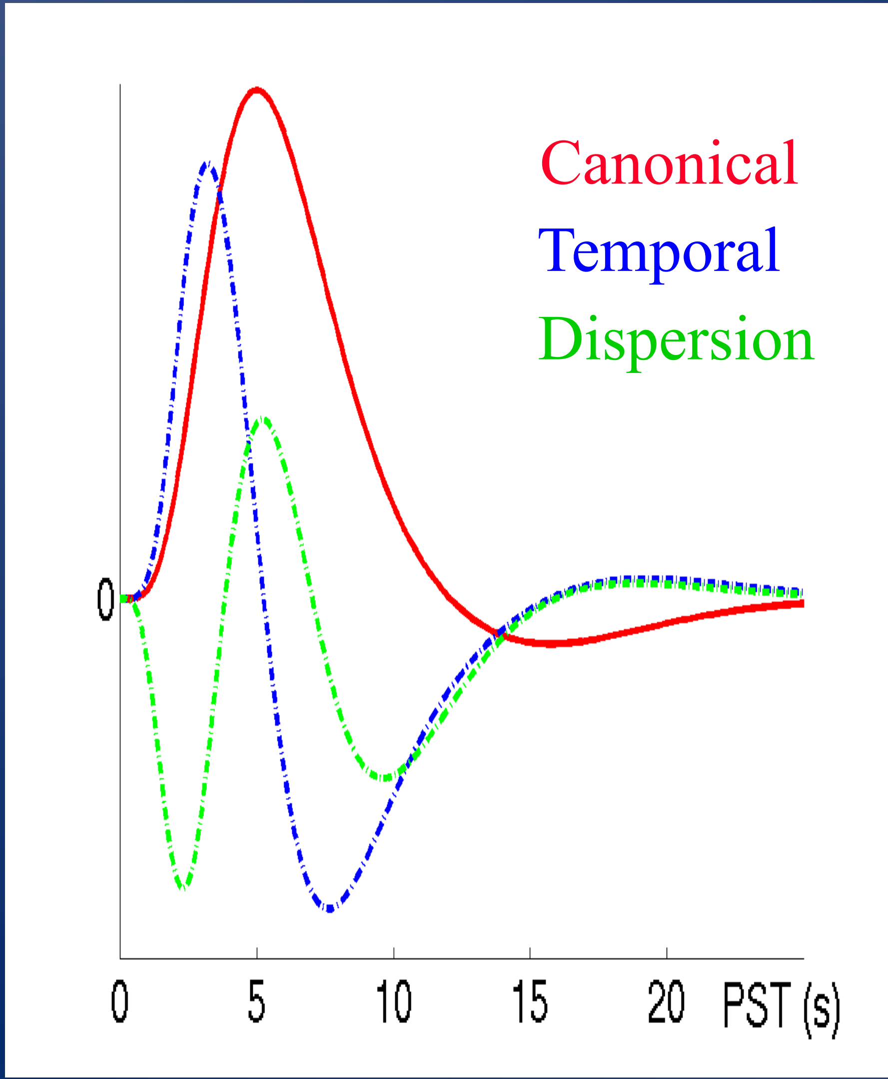
- Canonical HRF (2 gamma functions)

plus Multivariate Taylor expansion in:

time (*Temporal Derivative*)

width (*Dispersion Derivative*)

Temporal Basis Functions



"Informed" Basis Set
(Friston et al. 1998)

- Canonical HRF (2 gamma functions)

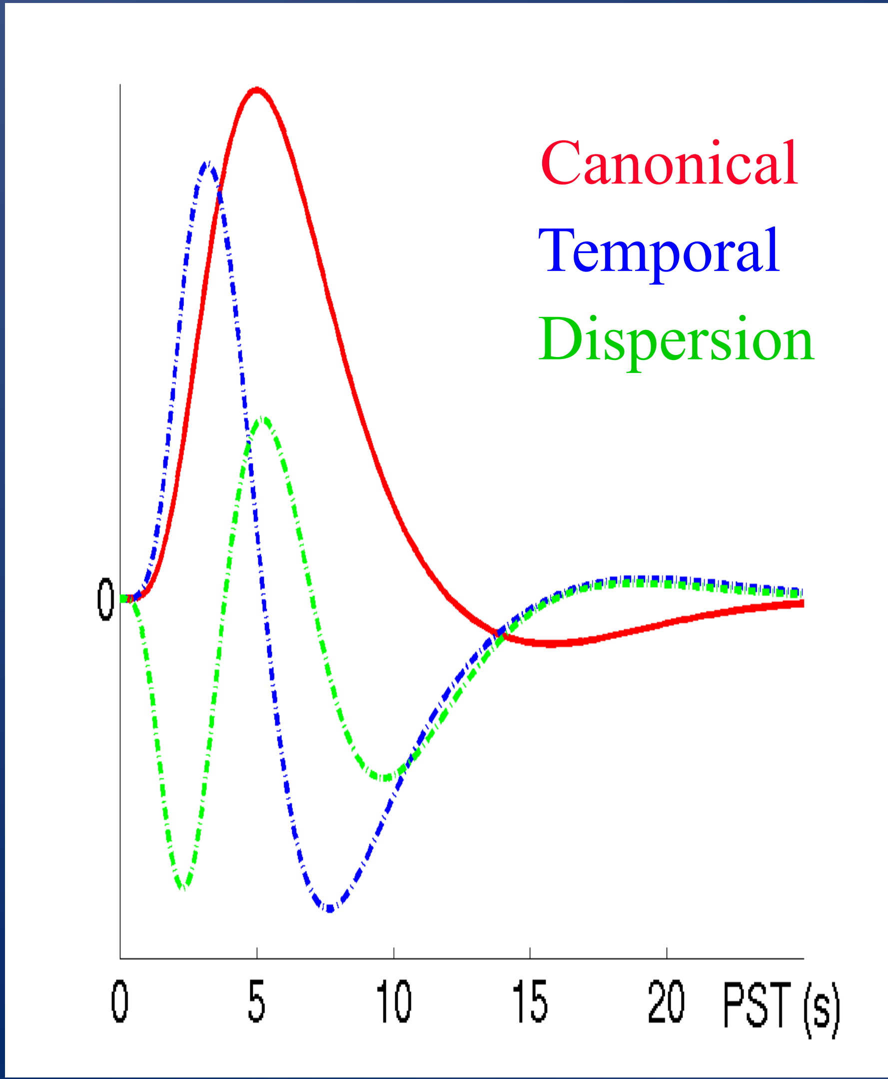
  plus Multivariate Taylor expansion in:

  time (*Temporal Derivative*)

  width (*Dispersion Derivative*)

- F-tests allow for any "canonical-like" responses

Temporal Basis Functions



"Informed" Basis Set
(Friston et al. 1998)

- Canonical HRF (2 gamma functions)

  plus Multivariate Taylor expansion in:

  time (*Temporal Derivative*)

  width (*Dispersion Derivative*)

- F-tests allow for any "canonical-like" responses
- T-tests on canonical HRF alone (at 1st level) can be improved by derivatives reducing residual error, and can be interpreted as "amplitude" differences, **assuming** canonical HRF is good fit…

(Other Approaches)

- **Long Stimulus Onset Asychrony (SOA)**

  Can ignore overlap between responses (Cohen et al 1997)

  ... but long SOAs are less sensitive

- **Fully counterbalanced designs**

  Assume response overlap cancels (Saykin et al 1999)

  Include fixation trials to "selectively average" response even at short SOA (Dale & Buckner, 1997)

  ... but unbalanced when events defined by subject

- **Define HRF from pilot scan on each subject**

  May capture intersubject variability (Zarahn et al, 1997)

  ... but not interregional variability

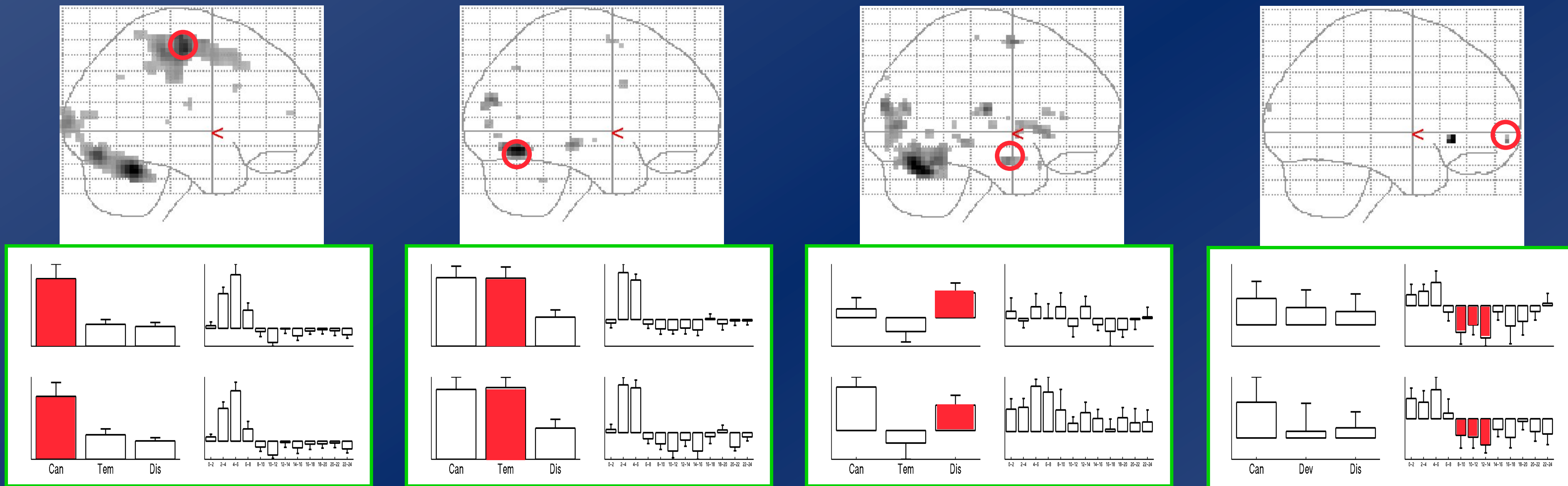
- **Numerical fitting of highly parametrised response functions**

  Separate estimate of magnitude, latency, duration (Kruggel et al 1999)

  ... but computationally expensive for every voxel

Temporal Basis Sets: Which One?

In this example (rapid motor response to faces, *Henson et al, 2001*)…



Canonical + Temporal + Dispersion + FIR

…canonical + temporal + dispersion derivatives appear sufficient

…may not be for more complex trials (eg stimulus-delay-response)

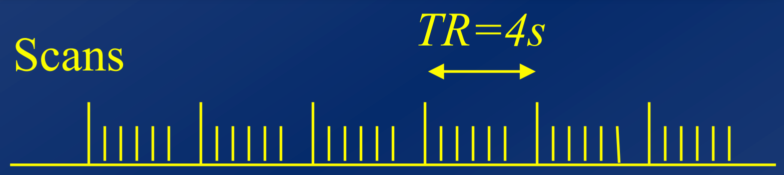
…but then such trials better modelled with separate neural components (ie activity no longer delta function) + constrained HRF (Zarahn, 1999)

Overview

1. Advantages of efMRI
2. BOLD impulse response
3. General Linear Model
4. Temporal Basis Functions
5. Timing Issues
6. Design Optimisation
7. Nonlinear Models
8. Example Applications

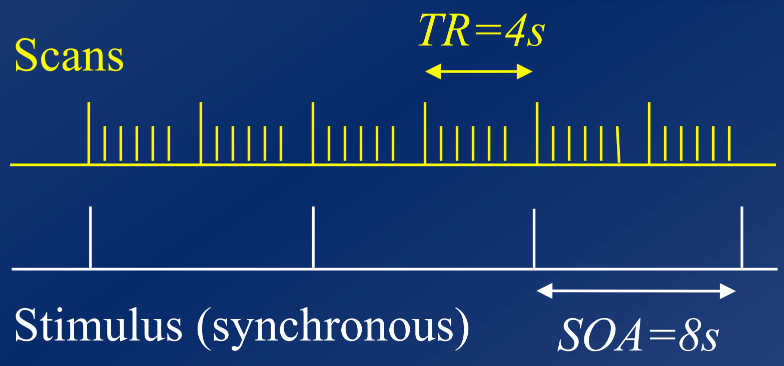
Timing Issues : Practical

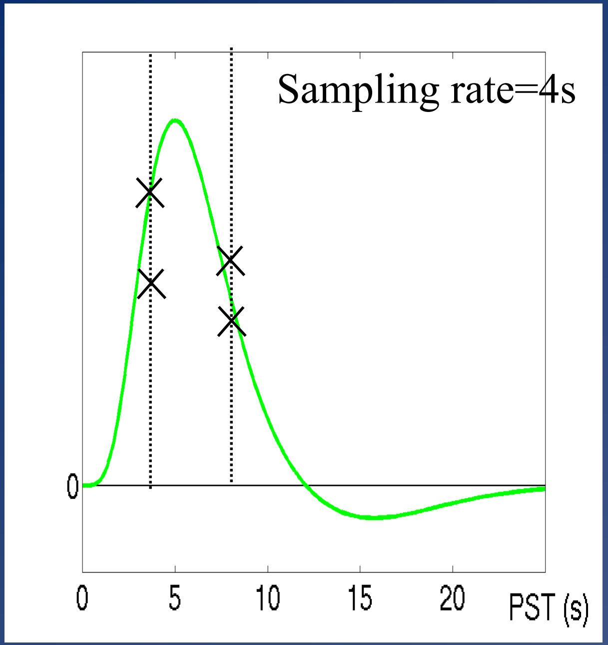
- Typical TR for 48 slice EPI at 3mm spacing is ~ 4s



Timing Issues : Practical

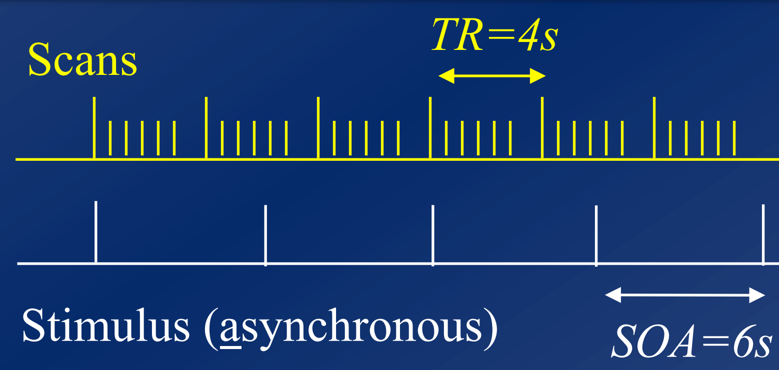
- Typical TR for 48 slice EPI at 3mm spacing is ~ 4s
- Sampling at [0,4,8,12…] post-stimulus may miss peak signal

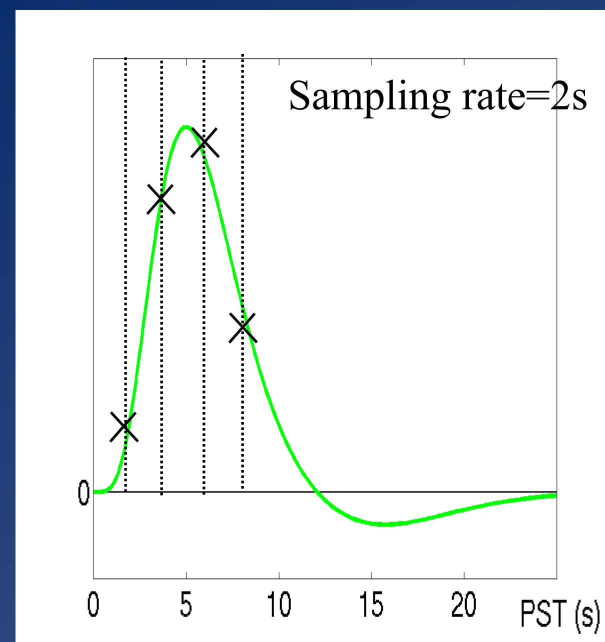




Timing Issues : Practical

- Typical TR for 48 slice EPI at 3mm spacing is ~ 4s
- Sampling at [0,4,8,12…] post-stimulus may miss peak signal
- Higher effective sampling by: 1. Asynchrony
  eg SOA=1.5TR





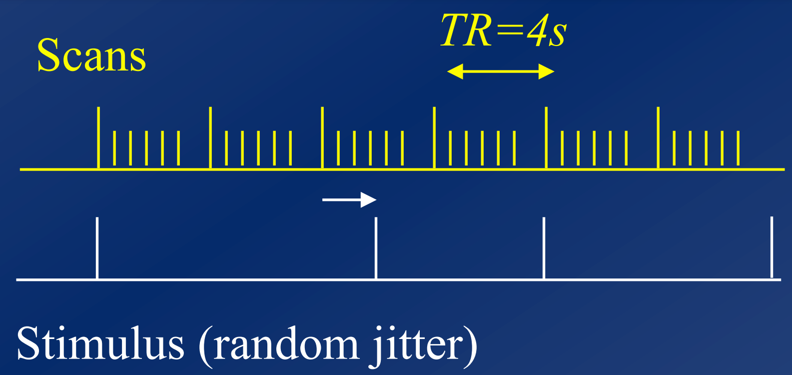
Timing Issues : Practical

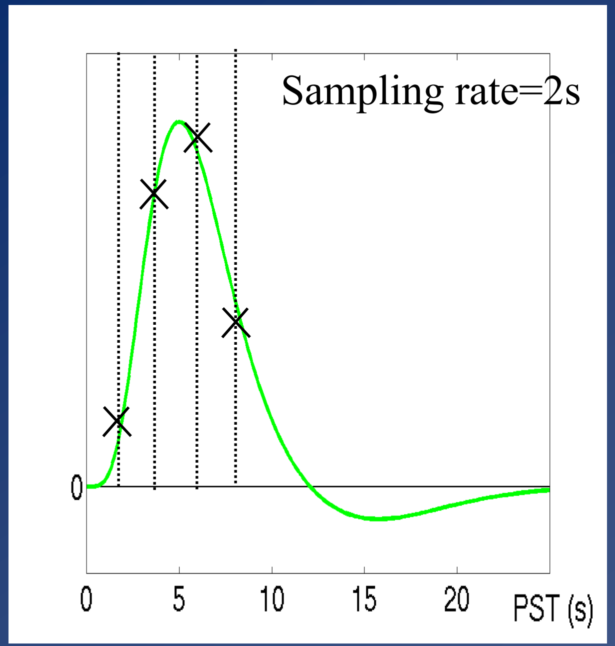
- Typical TR for 48 slice EPI at 3mm spacing is ~ 4s
- Sampling at [0,4,8,12…] post-stimulus may miss peak signal
- Higher effective sampling by: 1. Asynchrony

  eg SOA=1.5TR

  2. Random Jitter

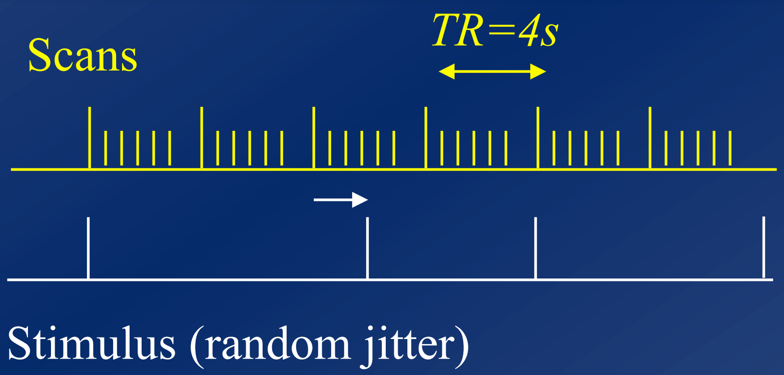
  eg SOA=(2±0.5)TR

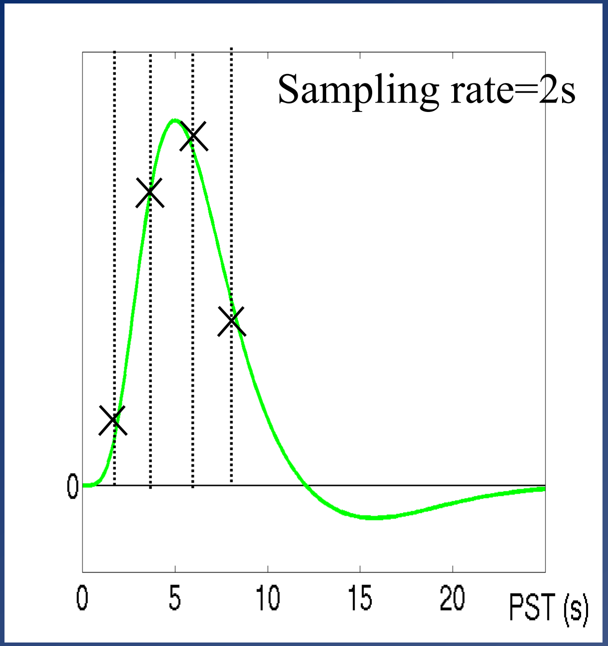




Timing Issues : Practical

- Typical TR for 48 slice EPI at 3mm spacing is ~ 4s
- Sampling at [0,4,8,12…] post-stimulus may miss peak signal
- Higher effective sampling by: 1. Asynchrony
  eg SOA=1.5TR
  2. Random Jitter
  eg *SOA=(2±0.5)TR*
- Better response characterisation (Miezin et al, 2000)





Timing Issues : Practical

- …but "Slice-timing Problem"

(Henson et al, 1999)

Slices acquired at different times,
yet model is the same for all slices

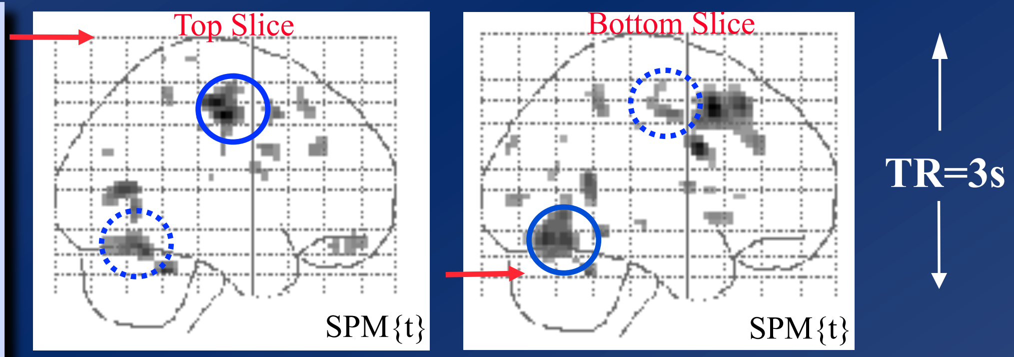
Timing Issues : Practical

- …but "Slice-timing Problem"

(Henson et al, 1999)

Slices acquired at different times, yet model is the same for all slices

=> different results (using canonical HRF) for different reference slices



Timing Issues : Practical

- …but "Slice-timing Problem"

  (Henson et al, 1999)

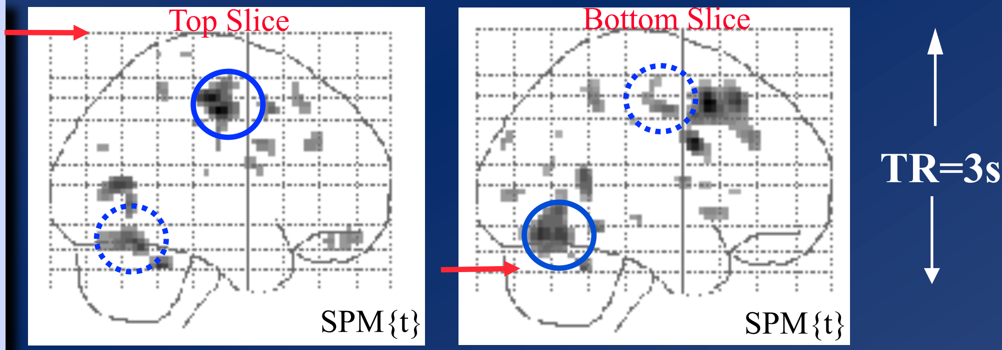
  Slices acquired at different times, yet model is the same for all slices

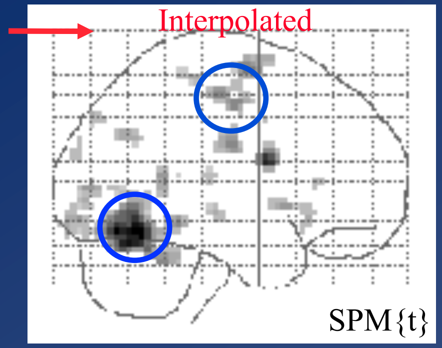
  => *different results (using canonical HRF) for different reference slices*

- Solutions:

1. Temporal interpolation of data

   … but less good for longer TRs





Timing Issues : Practical

- …but "Slice-timing Problem"

  (Henson et al, 1999)

  Slices acquired at different times, yet model is the same for all slices

  => *different results (using canonical HRF) for different reference slices*

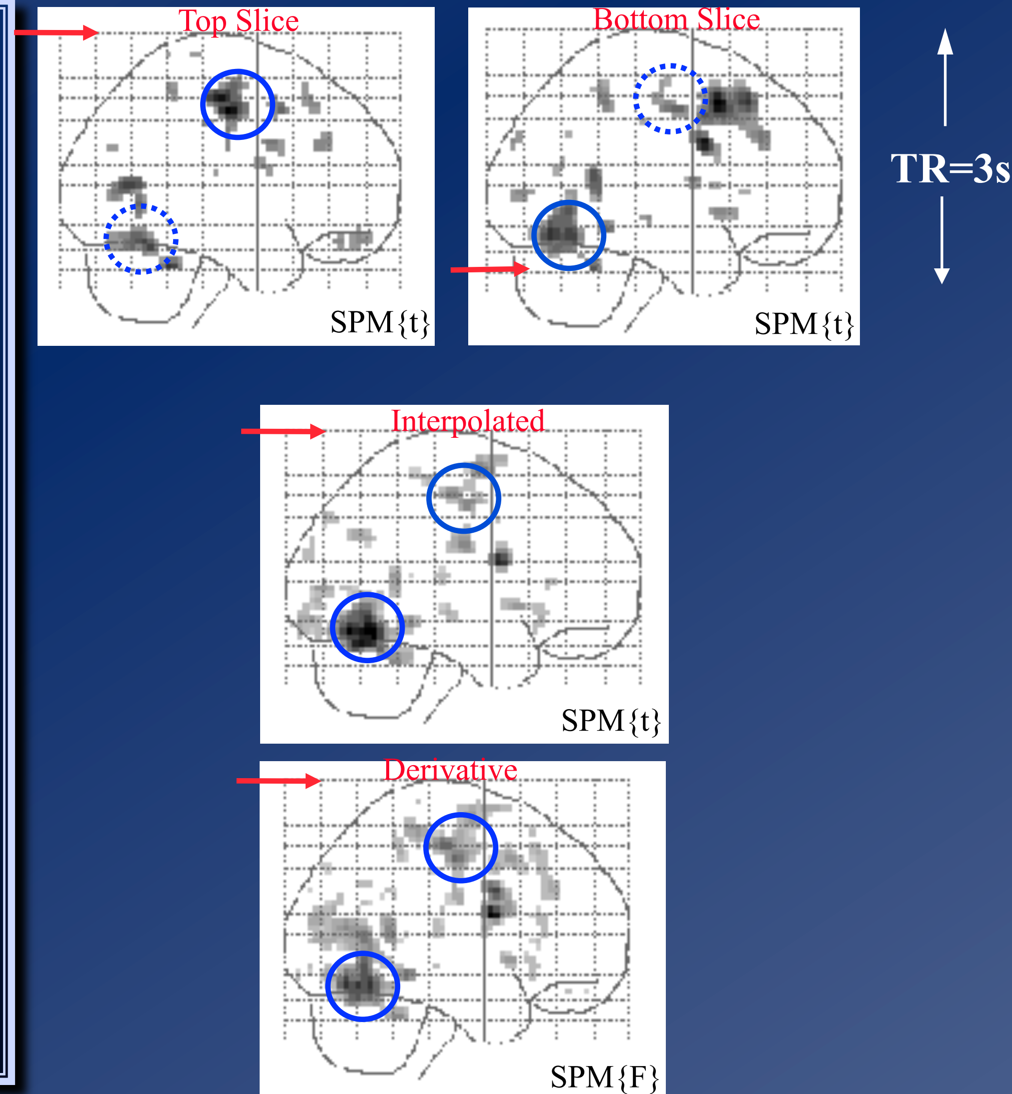
- Solutions:

1. Temporal interpolation of data

   … but less good for longer TRs

2. More general basis set (e.g., with temporal derivatives)

   … but inferences via F-test

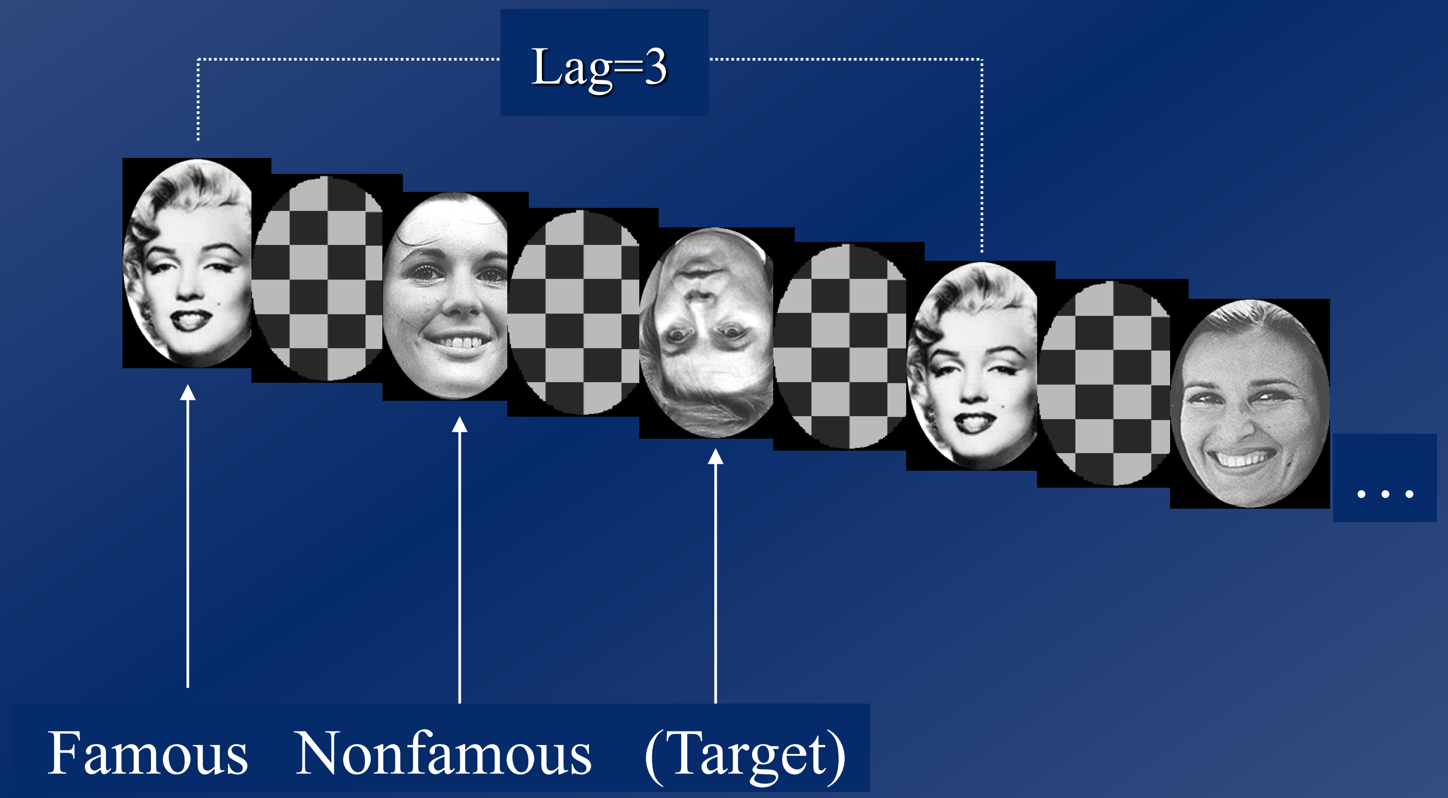


Overview

1. Advantages of efMRI
2. BOLD impulse response
3. General Linear Model
4. Temporal Basis Functions
5. Timing Issues
6. Design Optimisation
7. Nonlinear Models
8. Example Applications

Example 1: Intermixed Trials (Henson et al 2000)

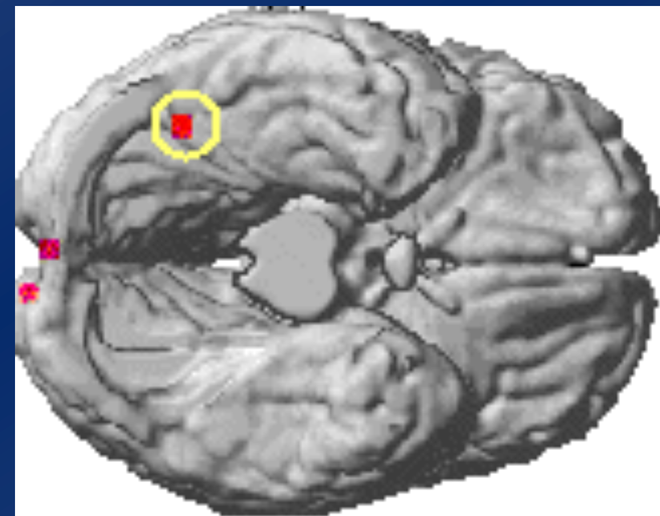
- Short SOA, fully randomised, with 1/3 null events
- Faces presented for 0.5s against chequerboard baseline, SOA= (2 ± 0.5)s, TR=1.4s
- Factorial event-types:
  1. Famous/Nonfamous (F/N)
  2. 1st/2nd Presentation (1/2)

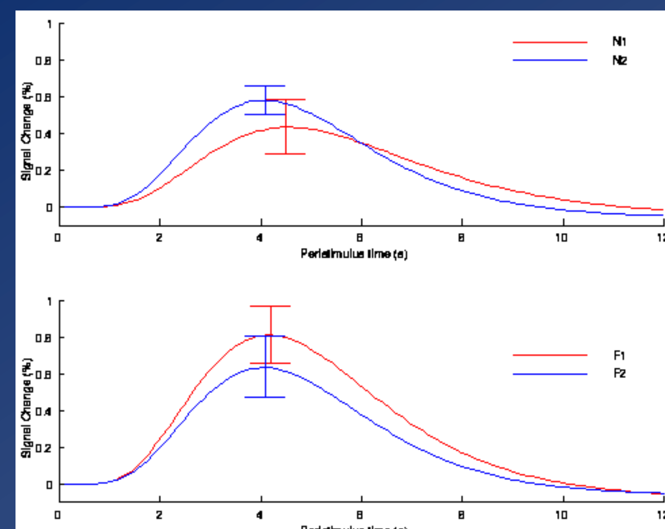


Lag=3
...
Famous
Nonfamous
(Target)

Example 1: Intermixed Trials (Henson et al 2000)

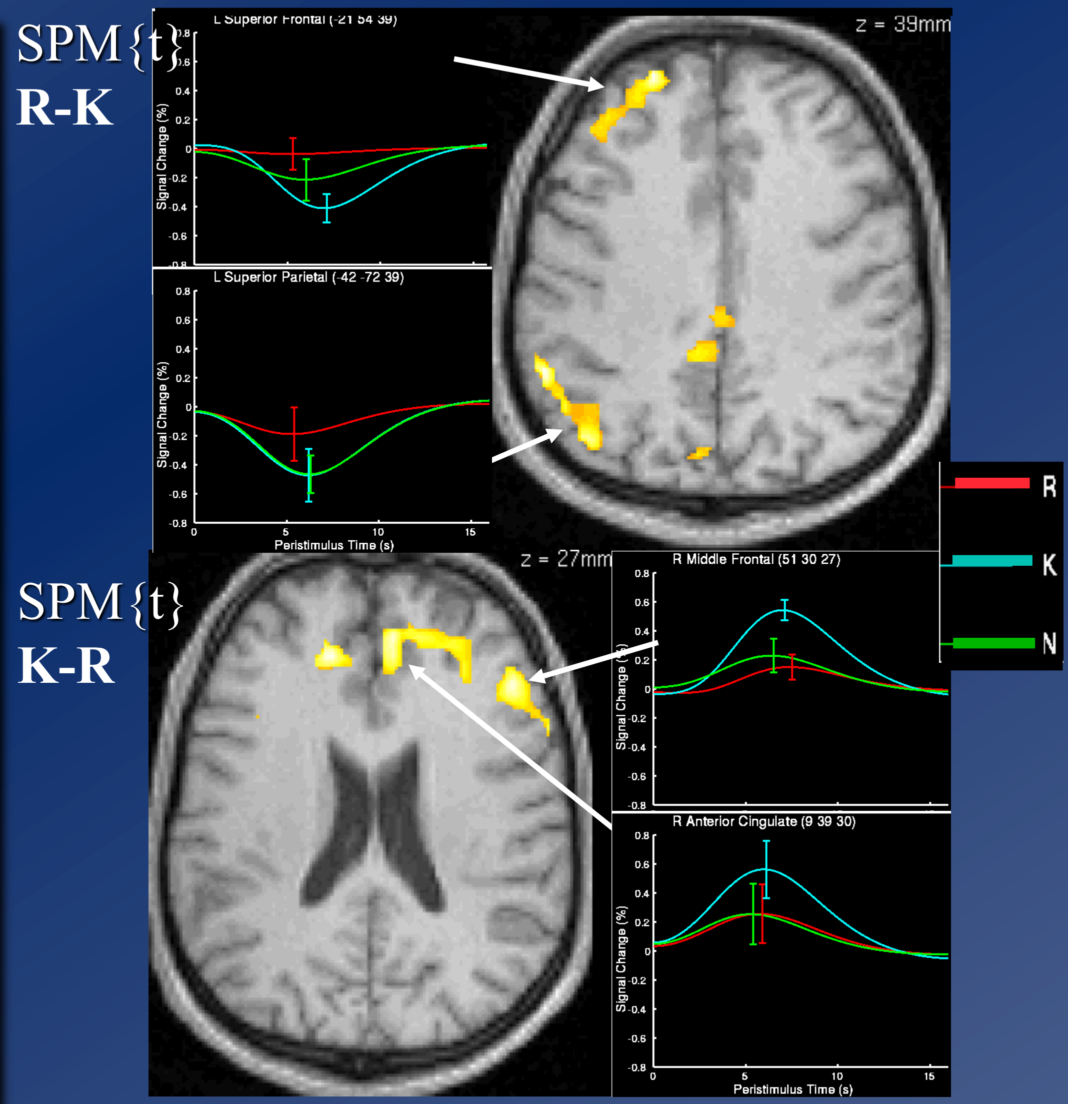
- Short SOA, fully randomised, with 1/3 null events
- Faces presented for 0.5s against chequerboard baseline, SOA=(2 ± 0.5)s, TR=1.4s
- Factorial event-types:
  1. Famous/Nonfamous (F/N)
  2. 1st/2nd Presentation (1/2)
- Interaction (F1-F2)-(N1-N2) masked by main effect (F+N)
- Right fusiform interaction of repetition priming and familiarity





Example 2: Post hoc classification (Henson et al 1999)

- Subjects indicate whether studied (Old) words:
  - i) evoke recollection of prior occurrence (R)
  - ii) feeling of familiarity without recollection (K)
  - iii) no memory (N)
- Random Effects analysis on canonical parameter estimate for event-types
- Fixed SOA of 8s => sensitive to differential but not main effect (de/activations arbitrary)



THE END