
# Design constraints & optimisation in fMRI

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Edinburgh SPM course 2019

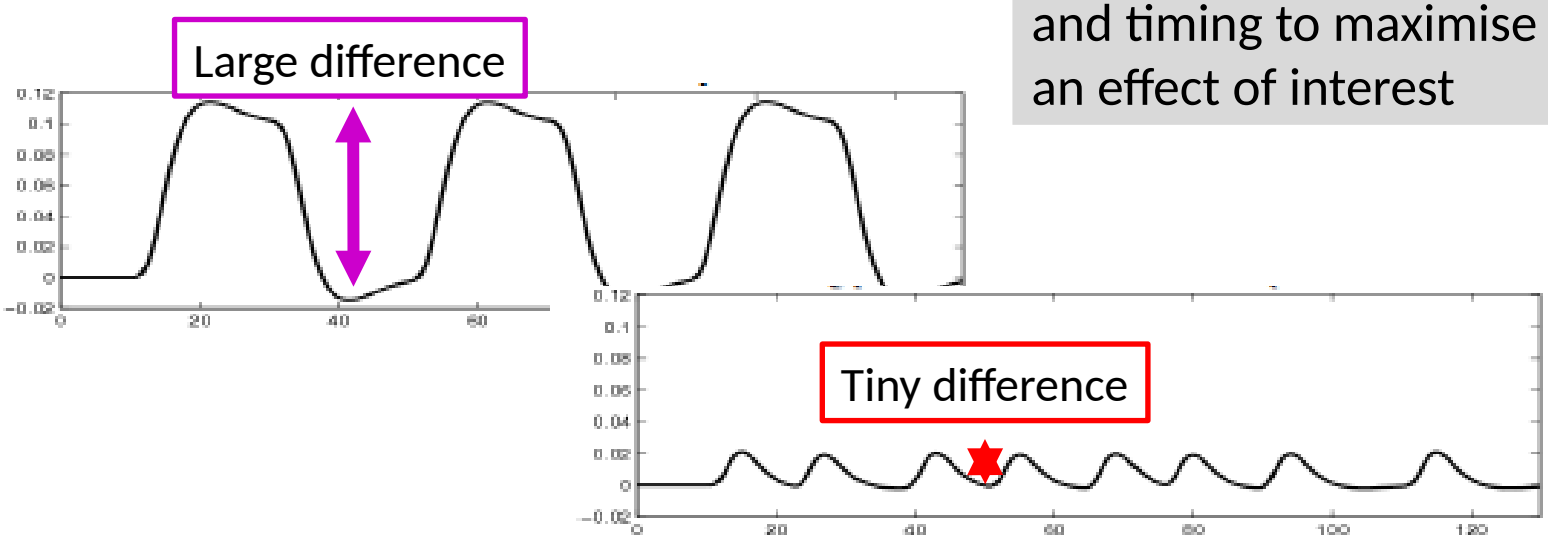

Thanks to Rik Henson, Cyril Pernet for slides

# Aim

- BOLD fMRI does not give an absolute measure of activity

✉ Always compare activity across conditions using contrasts

Design task, conditions and timing to maximise an effect of interest



# Overview

04 Design constraint & optimisation

- fMRI signal and noise
- Temporal design
- Regressor correlation
- A word on power

# fMRI signal and noise

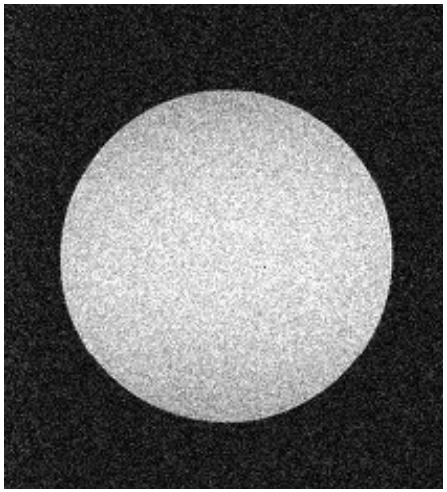
- fMRI signal is weak: functionally significant changes <5% signal intensity, so get all the signal you can

- Main sources of noise
  - Thermal (intrinsic) noise
  - System noise e.g. scanner drift,  RF coil issues
  - Image distortions e.g. susceptibility, Nyquist ghosting
  - Physiological noise, mainly cardiac & respiratory rhythms/ movement

# fMRI noise

- Thermal noise = due to electron motion, in scanner circuits and participant

  – This noise is unstructured (‘white’) and increases with higher resolution (smaller voxel size)



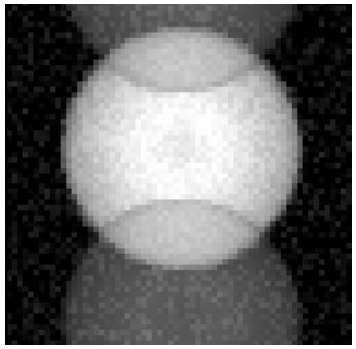
# fMRI noise

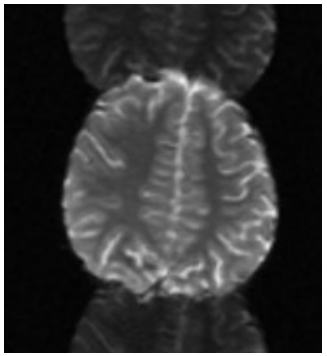
- Scanner drift = due to small changes in scanner magnetic field gradients over time

  - Slow changes in voxel intensities with time which are not of interest = 1 type of low frequency noise
  - Model separate ‘session constants’ per run

# fMRI noise

- Image distortions = nature of EPI plus specific sequence used and brain/skull properties*
  - **Nyquist ghost** 'wraparound'
  - Ask physicist – can adjust scanner shim etc





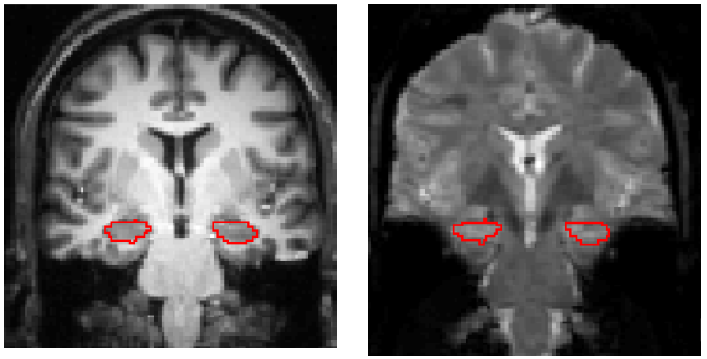
* There are lots of types of distortion related to equipment &/ or participant, this is a huge simplification

# fMRI noise

- Image distortions = nature of EPI plus specific sequence used and brain/skull properties

  - **Susceptibility artefact** – magnetic susceptibility of scanned tissue, like air/brain interfaces
  - Particularly orbitofrontal and anterior temporal
  - Ask physicist about different slice angles or different sequences e.g. multi-echo

Structural (LEFT) and functional (RIGHT)

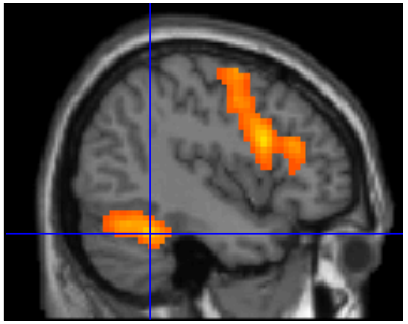


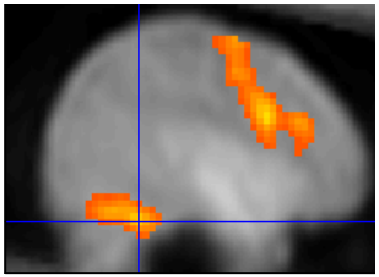
# fMRI noise

- Image distortions = nature of EPI plus specific sequence used and brain/skull properties

  - **Stretching** of images

    in slice ( *z*-) direction



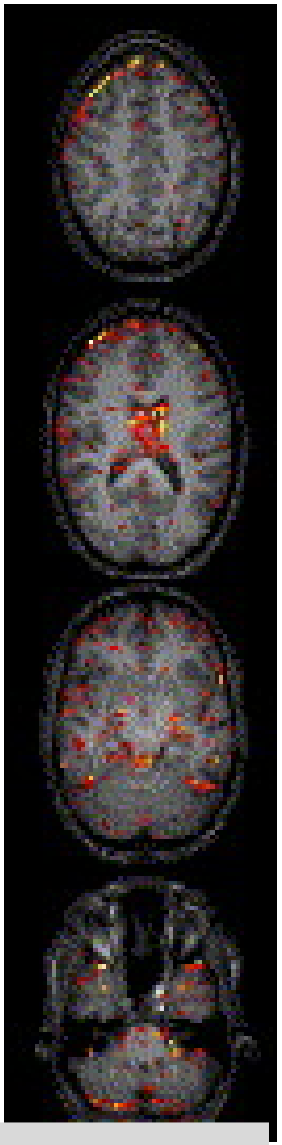


  - **Inhomogeneity** of field – physicist will minimise with shimming but can correct with fieldmap
  - Also interacts with motion, correct w/ fieldmap
  - And: artefacts due to **metal objects**

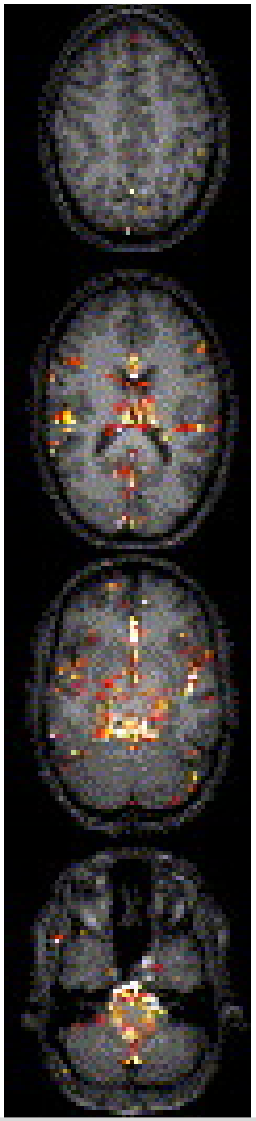
# fMRI noise

- Physiological noise = pulsations due to heart rhythm and breathing

- High frequency artefacts e.g. heartbeat every ~750 ms, sampled by slower scan e.g. TR 2 sec, 'aliasing' gives another type of **low frequency noise**



Respiratory

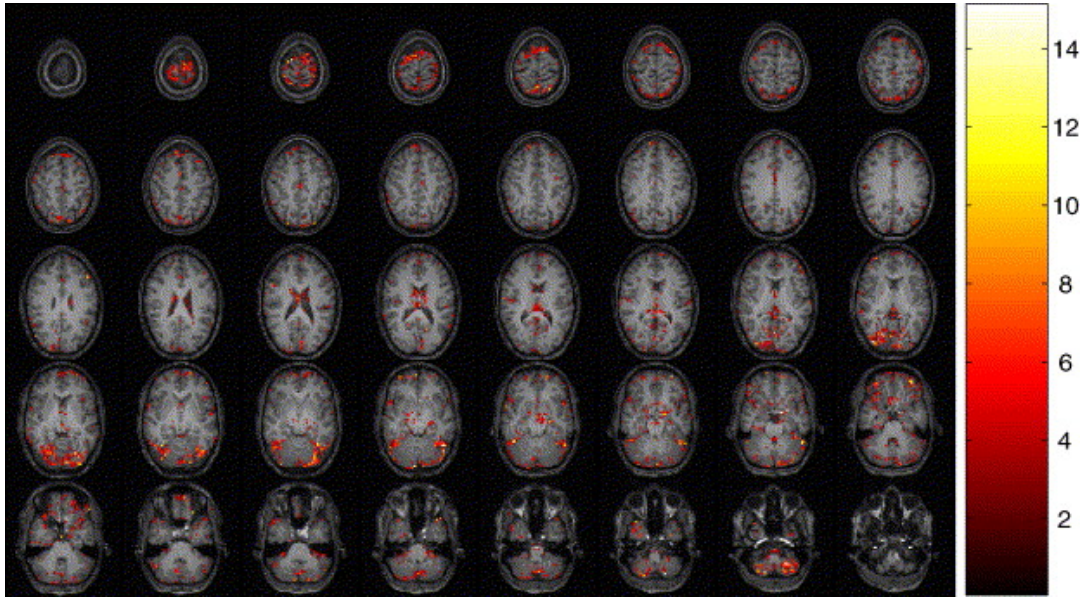


Cardiac

Lund et al. (2006)

# fMRI noise

- Physiological noise = head motion
- Very important – of order of half a voxel can cause serious issues due to partial volume effects, may need to exclude participant
- Correct in preprocessing and modelling steps




Lund et al. (2006)
See Friston et al. (1995)

# Interim summary: fMRI signal & noise

- fMRI is very noisy
- Multiple sources due to equipment, participant, sequences and their interactions
- Most noise is low frequency – this also affects the timing of your task, and modelling
- MUCH better to reduce than to adjust, esp. motion

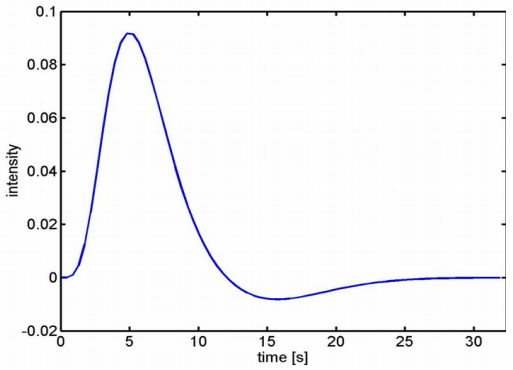
# Task timing

# Task design, signal and noise

- Must filter out large low frequency effects > ~0.01 Hz (1 cycle per 100 sec)
- To avoid removing effects of interest at the same time, need fairly high experimental design frequency

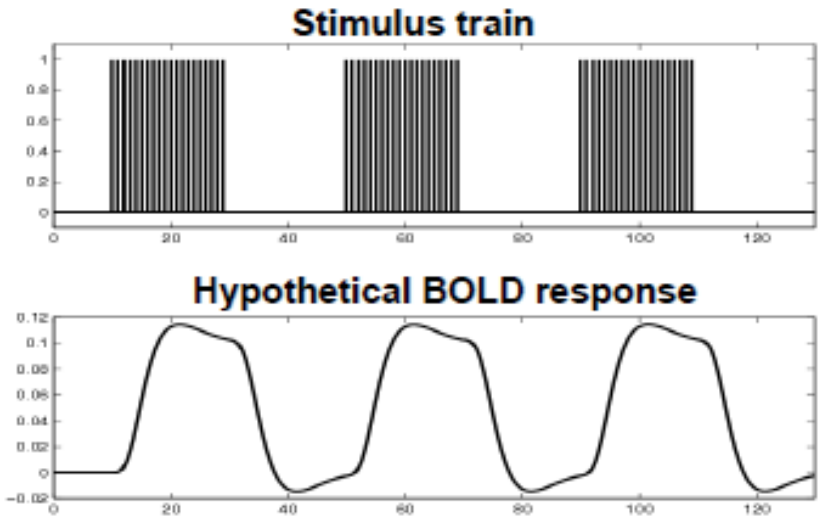
BUT

- 'Sluggish' BOLD response with slow response to neural changes effectively filters out high frequencies
- So also avoid very rapid expt. changes



# Task timing

## Block Design

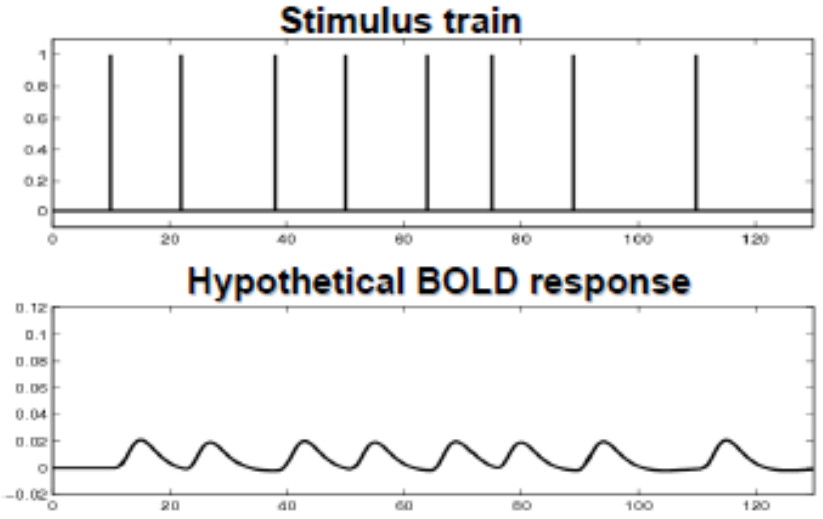



Analysis of whole block

Large effects (=efficient)

Block model assumes summation of BOLD responses to successive stimuli

## Event-Related Design




Analysis of single items

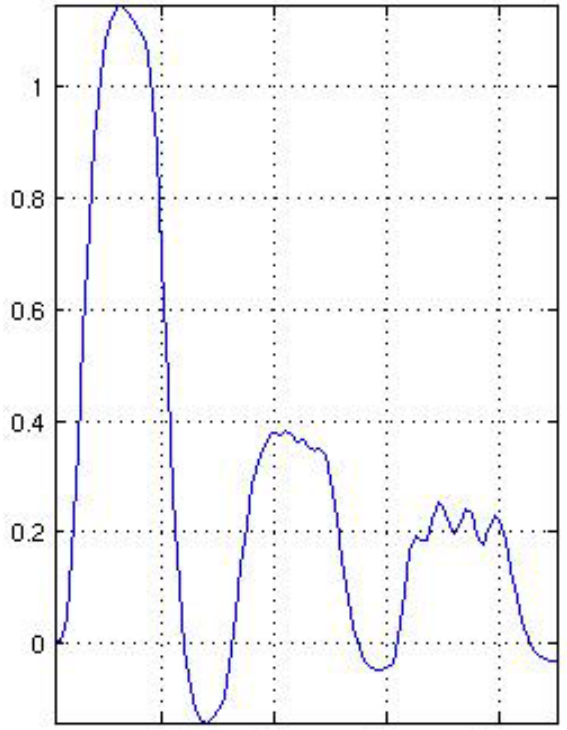
Smaller effects

Ability to distinguish BOLD responses to intermixed stimuli

[here: slow event-related]

# Alternating block design

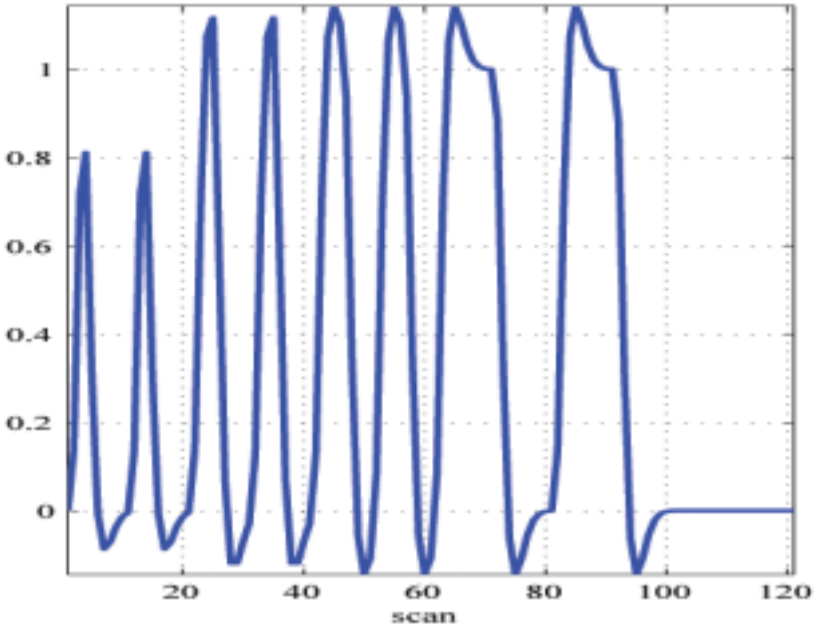
- Block and rest (or control) alternating
- If shorter SOA greater summation of responses, increasing signal strength
- BUT at too short SOA may get psychological issues and/or refractoriness of BOLD response

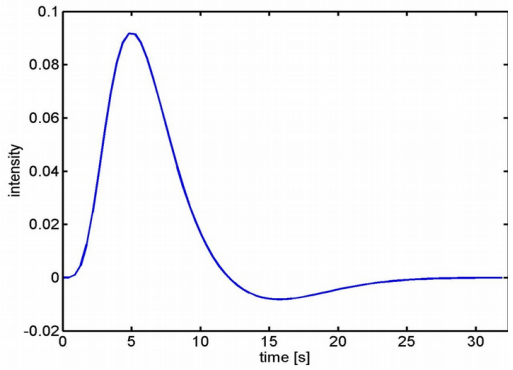



1 / 3.3 / 5 s SOA

# Alternating block design

- Block and rest (or control) alternating
- If longer cycle > 10-15 seconds, get return to baseline between blocks so signal strength is higher
- Due to sluggish haemodynamic response



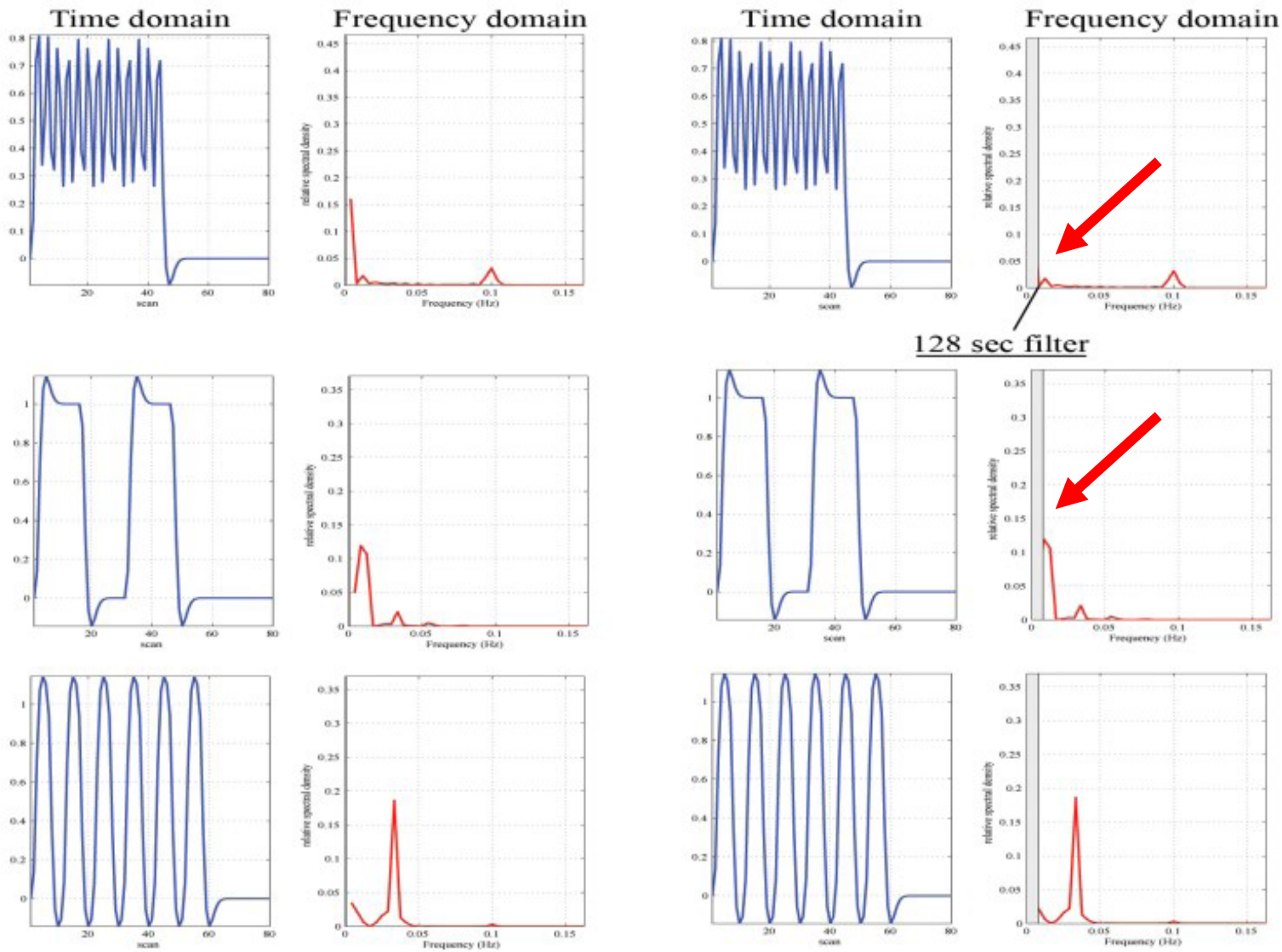

5 / 10 / 15 / 30 s blocks

# Alternating block design

5 sec blocks

45 sec blocks

15 sec blocks



# Interim summary: block design

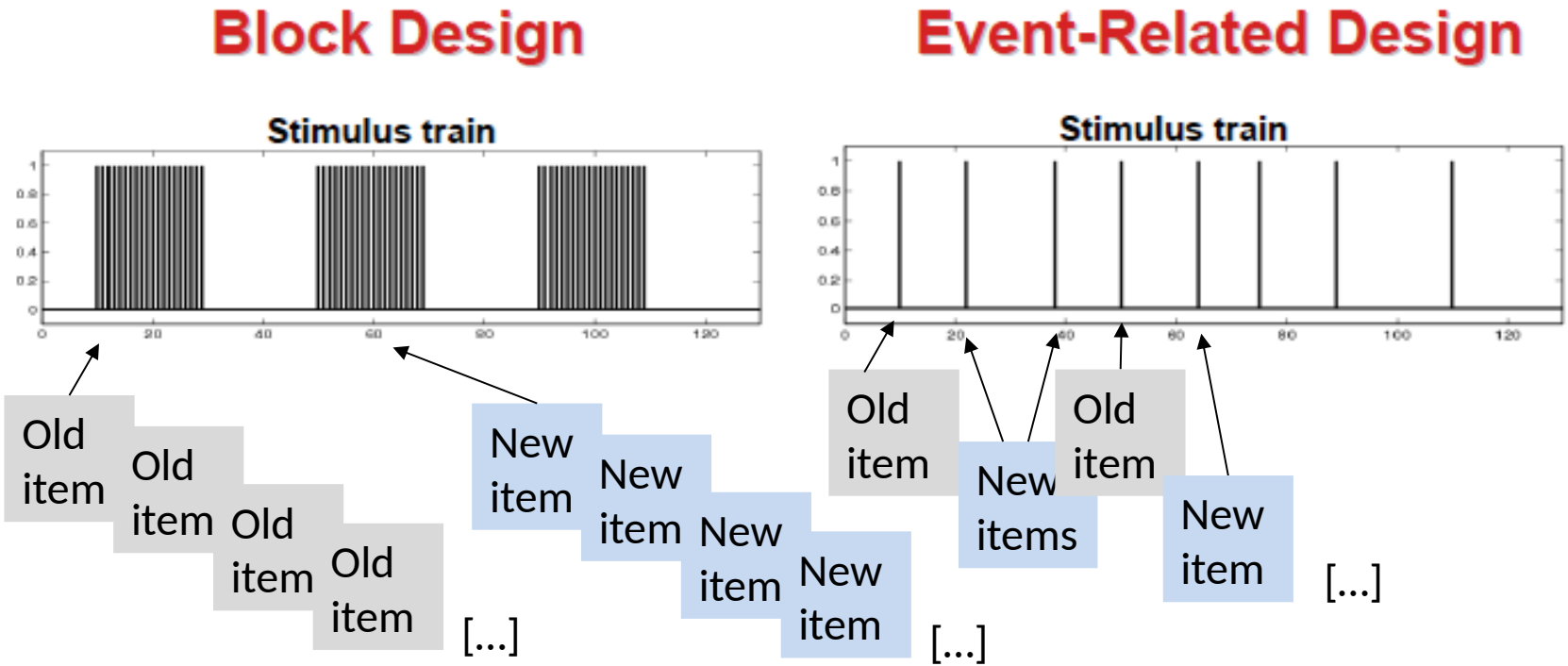
- Short SOA and long blocks good
- BUT avoid block frequency overlapping with low frequency noise
- Trade-off

✉ Optimum block duration ~16 s gives cycle length ~= duration of haemodynamic response function

# Why go event-related?

## Advantages of event-related design

- Intermixing of conditions avoids unwanted psychological effects e.g. habituation, expectancy, loss of concentration



# Why go event-related?

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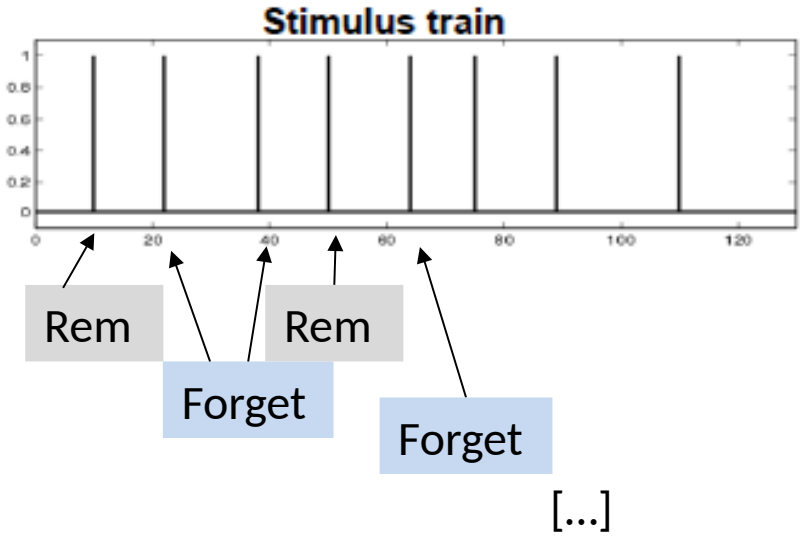
- Post-hoc classification of trials, e.g. Subsequent memory effect



# Why go event-related?

Advantages of event-related design

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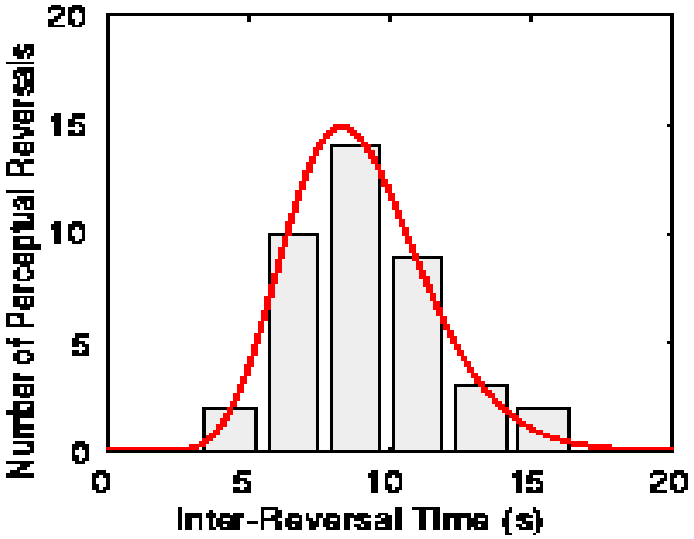
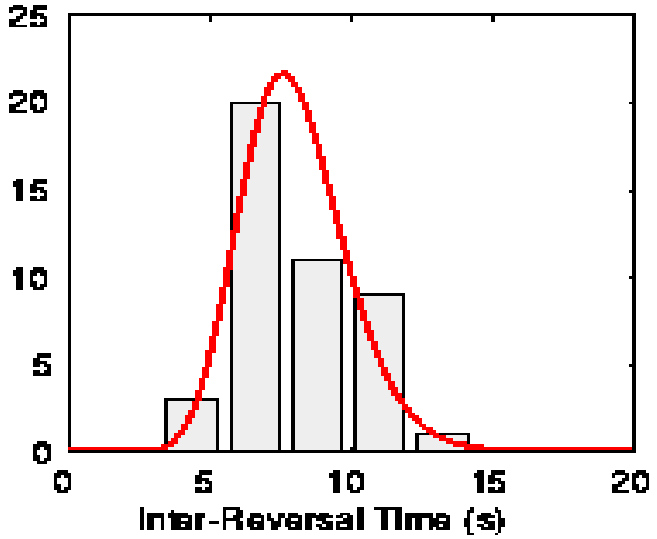
- Post-hoc classification of trials, e.g. Subsequent memory effect
- Some events can only be indicated by subject at particular time e.g. Spontaneous perceptual changes


Number of Perceptual Reversals
0
5
10
15
20
Inter-Reversal Time (s)


0
5
10
15
20
25
Inter-Reversal Time (s)

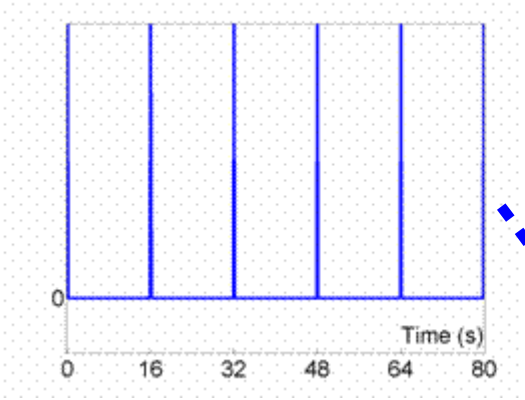
# Paradigm timing

## Advantages of event-related design

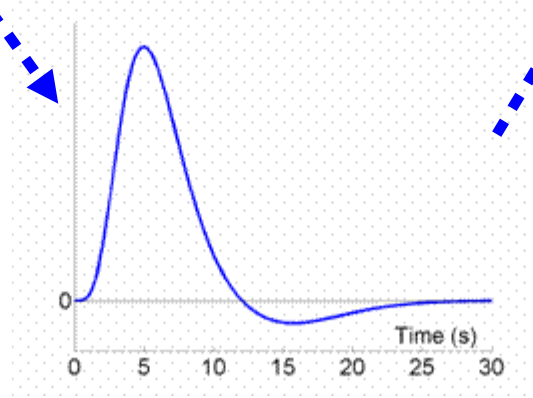
- Intermixing of conditions avoids unwanted psychological effects e.g. habituation, expectancy, loss of concentration
- Post-hoc classification of trials, e.g. Subsequent memory effect
- Some events can only be indicated by subject at particular time e.g. Spontaneous perceptual changes
- Some events cannot be blocked, e.g. oddball

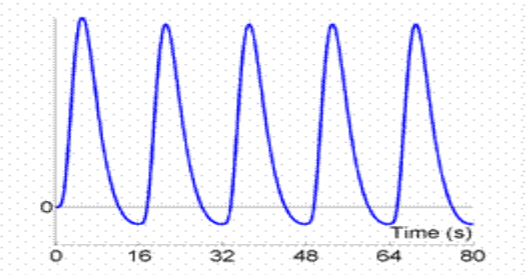
# Interim summary: event vs. block

- Detection power less for event-related designs – signal depends on how many events averaged
- Estimation power better for event-related, as can determine the shape of the haemodynamic response (though this means assumptions about its shape)
- Event-related much more flexible for cognitive studies
- But if you can go blocked, do!




Individual stimuli 32s apart



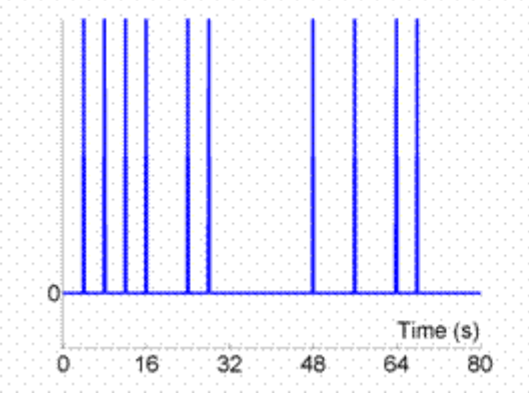

Individual BOLD responses: back to baseline

NOTE: a slow event-related design avoids any overlap of event responses

Very slow!

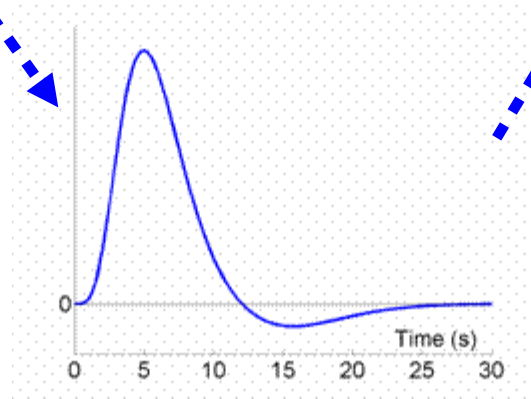
Used sometimes where separation of responses is really critical

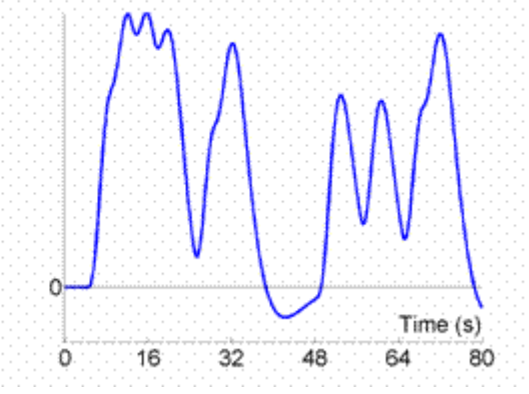
But less detection power as fewer trials




Stimuli random 50% chance every 4s

= equivalent to having 50% trials of interest, 50% ‘null’ events




Mixture of ‘on’ vs. ‘off’ measurement & separation of event-types

This rapid event-related design takes HRF into account in the **model**

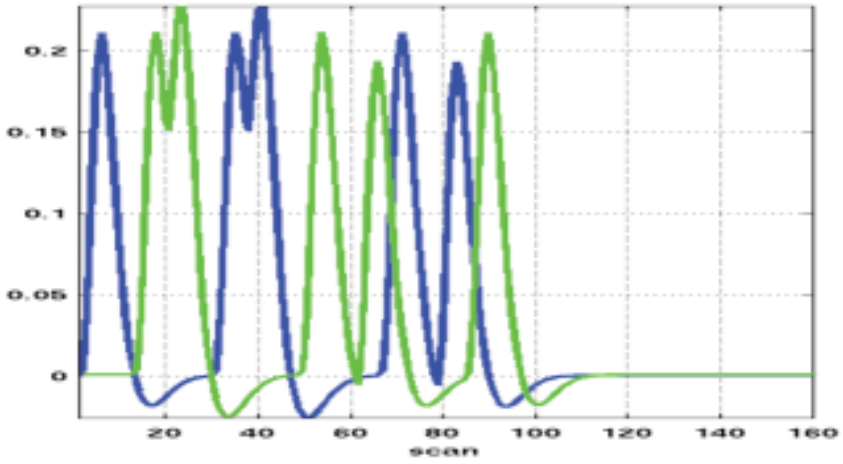
and allows overlap of event responses within & between conditions

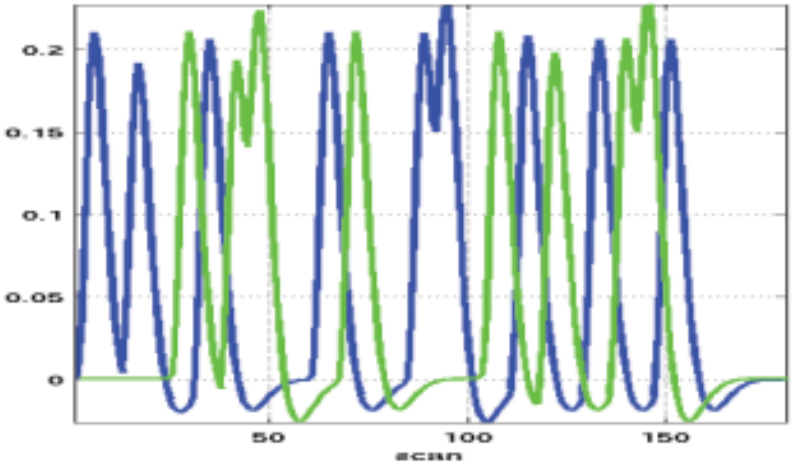
**MUCH** improves temporal resolution

This = a simple randomised design

# Rapid event-related designs

- Random – on each trial, condition A or B determined randomly
- 1st approximation: good to randomise order, or SOA, of trials close together in time
- Semirandom – another systematic variation of probability of A or B over time
- Can be the most efficient



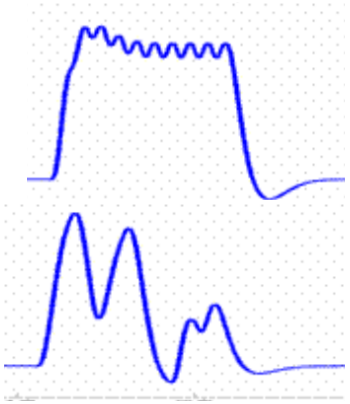




http://imaging.mrc-cbu.cam.ac.uk/imaging/DesignEfficiency

# Rapid event-related designs

## What is jitter?

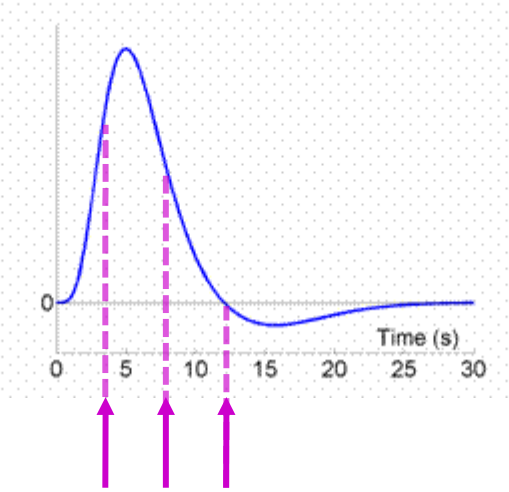
- Randomly or systematically varying the intervals between trials
- Can be done by varying SOA/ ISI or adding 'null events'



Top = no jitter
Bottom = jitter

## Why jitter?

- To achieve both 'clumping' and separation of trial types/ conditions and improve efficiency
- To ensure that entire haemodynamic response is sampled over trials




If long TR

http://imaging.mrc-cbu.cam.ac.uk/imaging/DesignEfficiency

# Statistical efficiency

- To maximise our statistic, minimise the variance of the contrast involved

- Efficiency defined this way depends on the fitted model
  and the contrast
  and the design matrix

- Efficiency is relative, compare different models with same contrast & no. of scans

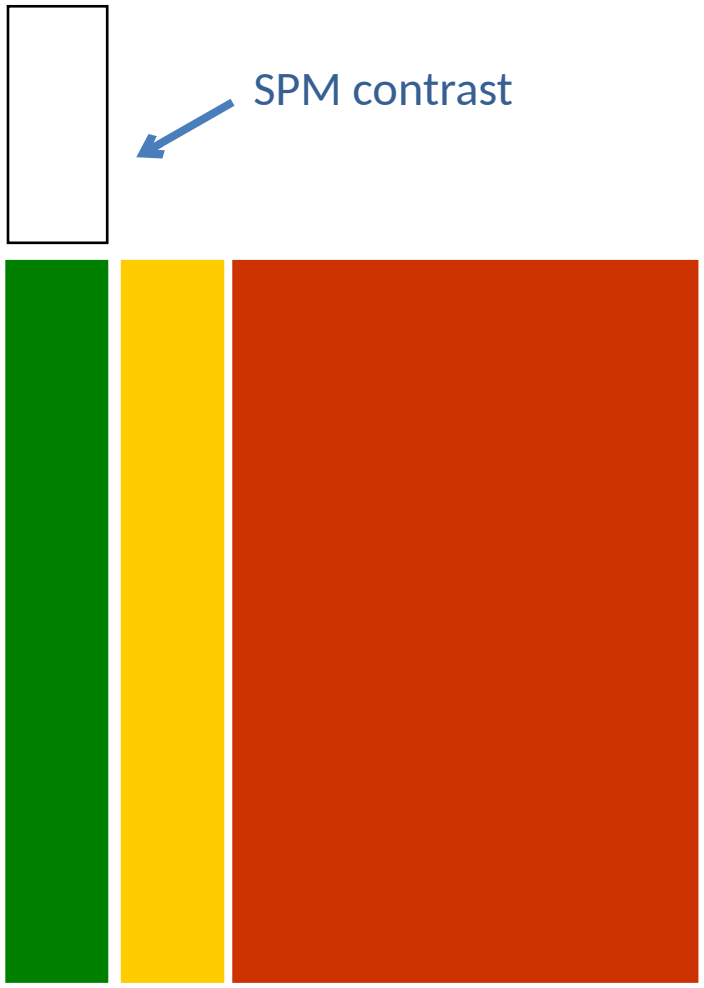
$T = c'*b / sqrt(var( c'*b ))$

$var( c'*b ) = s^2 c'*inv(X'X)*c$

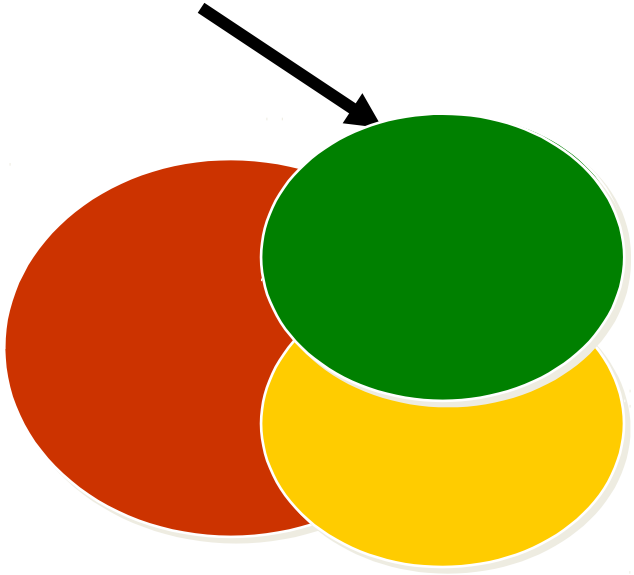
c = contrast
b = the parameter estimates contrasted
$s^2$ = noise
X = design matrix

Optimise trial timing using e.g. OptSeq, or manually calculate efficiency

# Correlated regressors




*Testing for the green:*

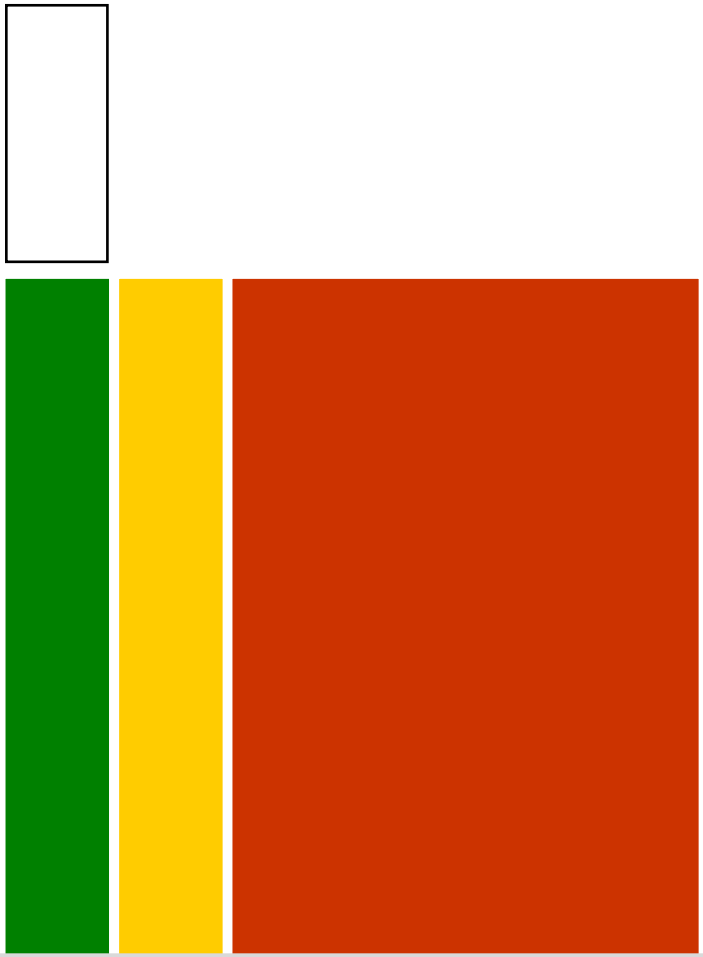


*Correlated regressors, for example:*

*green: subject age or WM delay activity*

*yellow: subject score or WM encoding*

# Correlated regressors



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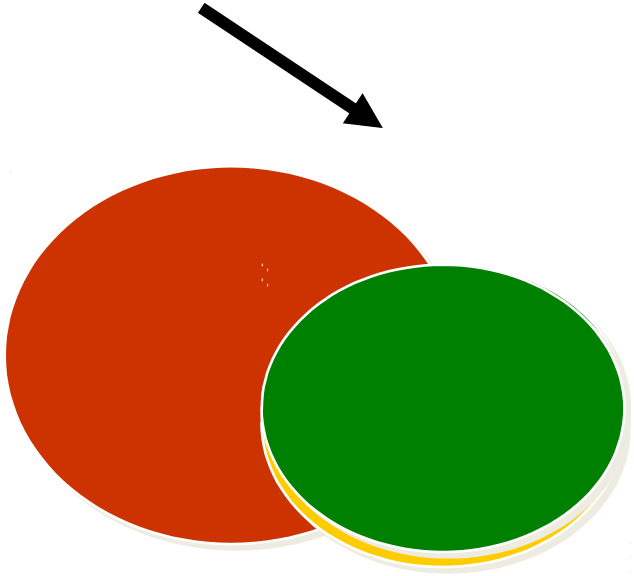


*Highly correlated.*
*Entirely correlated non estimable*

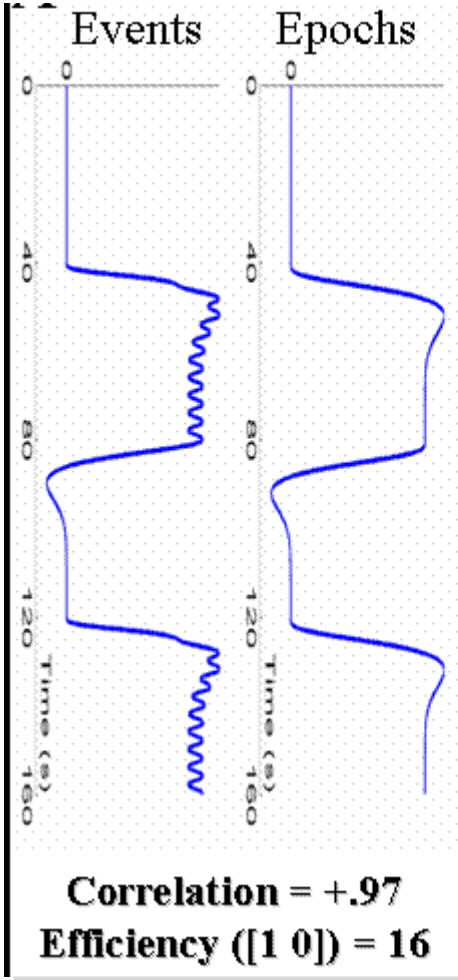
Can test for ‘effect of either or both’ but cannot separate after the fact

# Correlated regressors

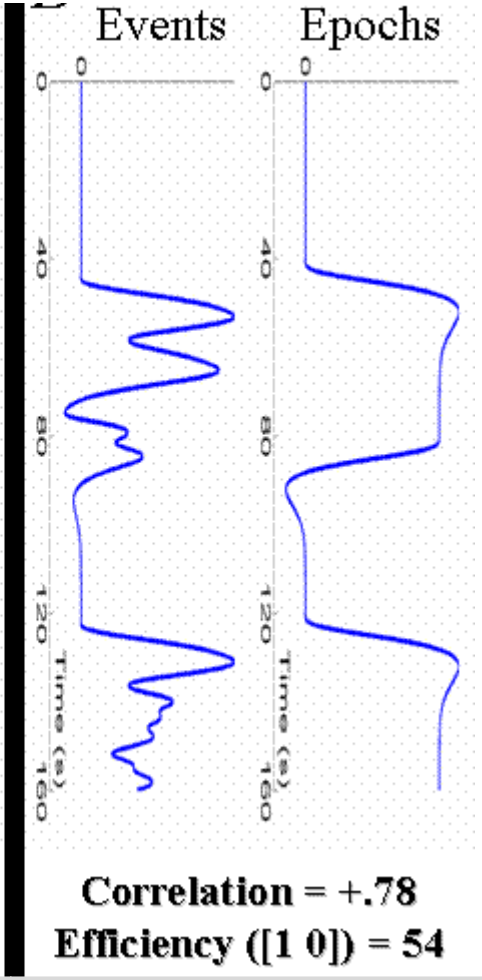
- If contrast involves correlated (collinear) regressors, it will be less efficient.
- E.g, mixed blocked/ event-related design for state and item-related activity (Chawla et al., 1999)

Efficiency again*

- e = 1 / trace (C $(X^TX)^{-1}$ CT)
- Efficiency is inversely proportional to design covariance




Fixed SOA = 4 s




Pseudorandom distribution of SOAs min = 2 s

* ignoring noise and using matrix form

# Interim summary

- Block design most efficient for detection of a response, highest statistical efficiency
- Low frequency experimental changes must be avoided, e.g. optimal block on/off 'fits' BOLD response ~32 s
- Event-related best for estimation of the course of the BOLD response, and for flexibility
- Random* intermixing of conditions and/or** jitter the SOA
- Statistical efficiency improved by low correlation of regressors

* pseudorandom might be better, see Liu et al., 2001

** for some recipes see http://imaging.mrc-cbu.cam.ac.uk/imaging/DesignEfficiency

# Other important stuff

- How long should I scan each participants for?

✉ As many trials as possible

✉ As long as you and the participant can afford

- How many scanner runs (sessions) do I need?

✉ For univariate studies, 1 is best*

✉ More increases variance, reduces efficiency

✉ Keep contrasts within-session

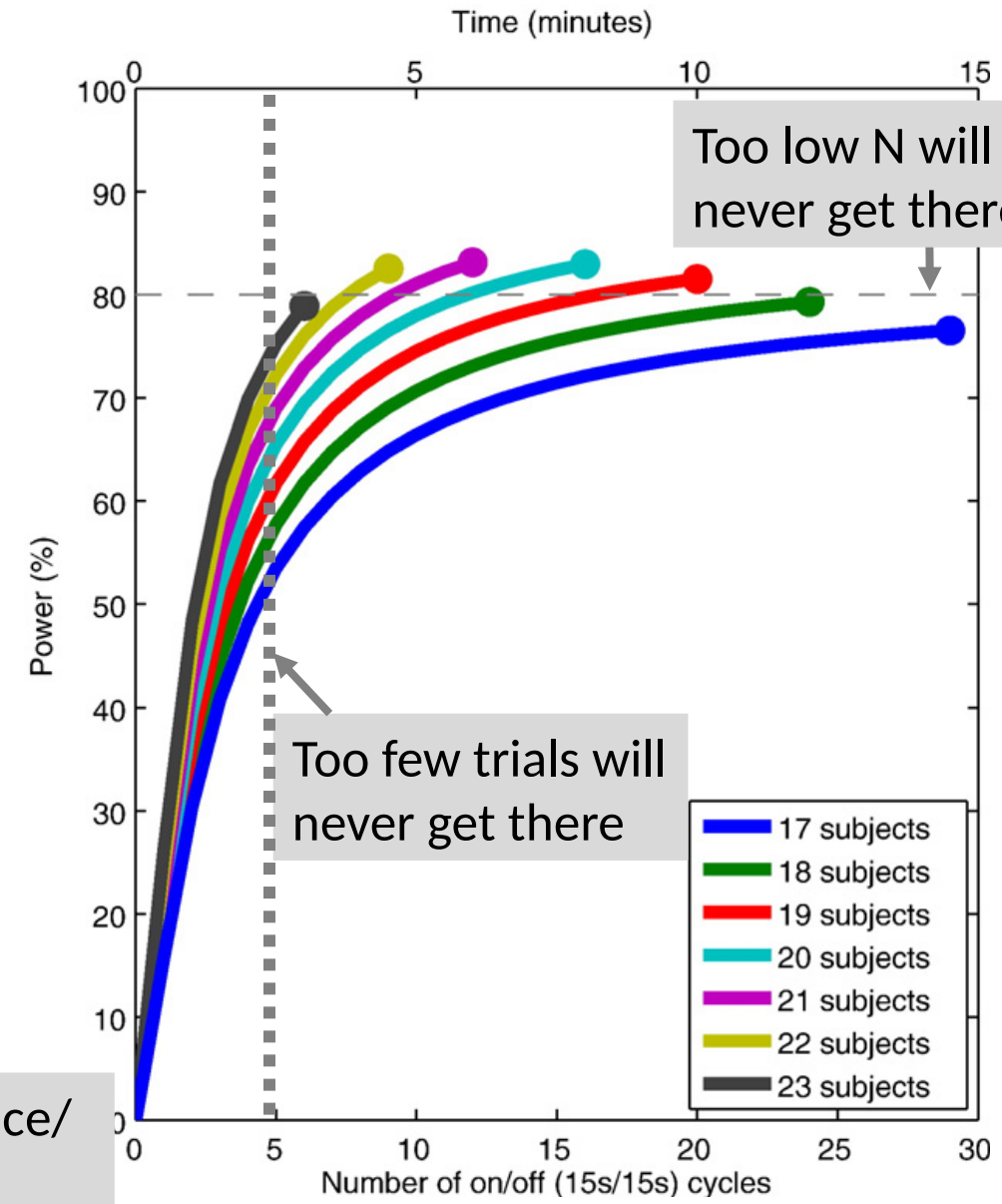
- How many participants do I need?

* The opposite applies for multivariate studies – Advanced Course!

# A note about power

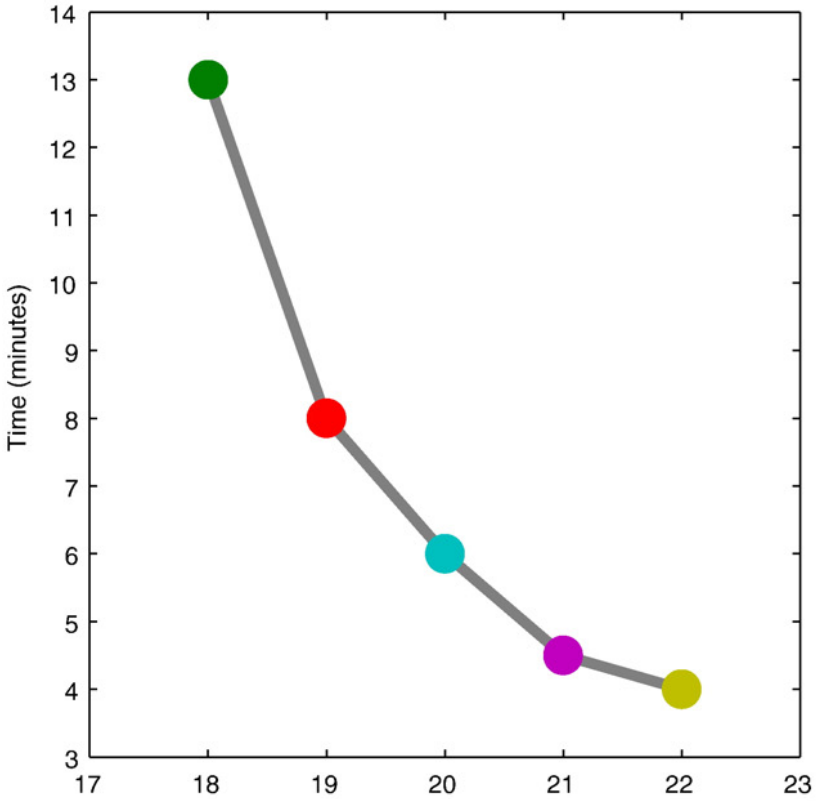
- Statistical power in a multilevel model depends on no. of observations, and variance, at both levels of the model

- Insufficient no. of trials **and** insufficient N can mean your study is underpowered!

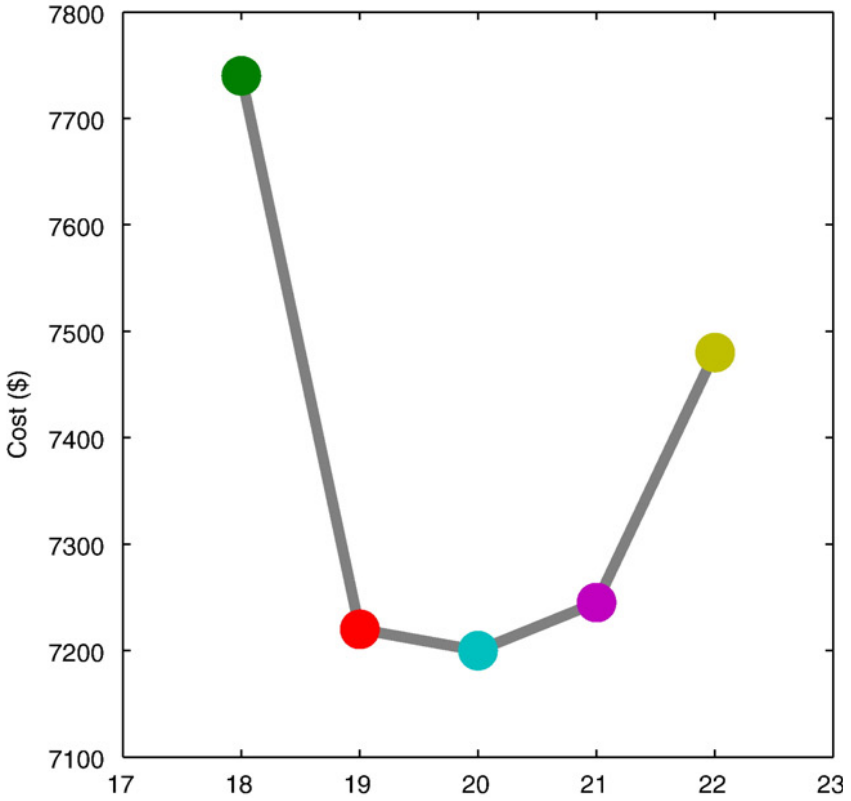



NB just one example, set mean/ variance/ constraints, will NOT generalise!

# A note about power




What N? No. of needed cycles per participant for .80 power
N = 22 looks best




What N? Cost of achieving .80 power by varying cycle length and N
N = 20 looks best

Mumford & Nichols, 2008

# A note about power

- Statistical power in a multilevel model depends on no. of observations, and variance, at both levels of the model
- **Either** insufficient no. of trials **or** insufficient N can mean your study is underpowered!
- As power depends on statistical efficiency, need to know design X to fully specify – can do using pilot data, see fmripower.org *
- Alternatively from old data can estimate effect size at group level and determine N using non-specialist software – but don't ignore it!

neuropowertools.org also from Nichols & others; see andysbrainblog.blogspot.com and https://www.biorxiv.org/content/10.1101/049429v1

# Summary

**Main message: different designs for different questions**

Don't forget

- Scan for as long as possible (lots of trials, participants)
- your task-related changes of interest need to take place slowly but not too slowly

Want to know more?

- Temporal design efficiency and design optimisation
- http://imaging.mrc-cbu.cam.ac.uk/imaging/DesignEfficiency

# Thank you!