Functional Magnetic Resonance Imaging

GitHub https://github.com/dcdace/fMRI_training

Dace [datza] Apšvalka

February 2026

Outline

- Introduction
- **Experimental design**
- Data management
- Pre-processing
- Statistical analysis
- Practical demo

Experimental design

fMRI experiment terminology

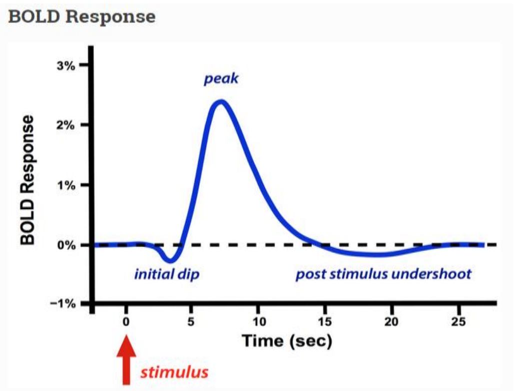
- **Session:** The time from when the participant enters the scanner until they leave. This usually includes multiple scanning **runs** with different pulse sequences (e.g., anatomical, functional). A participant can be invited for a follow-up session on a different day. That would then be *Session 2*.
- **Run:** A period of continuous data acquisition using a single pulse sequence. Functional acquisitions are often split into multiple runs (5–10 minutes) with brief breaks in between.
- **Volume:** A single 3D brain image captured at one time point during fMRI scanning, consisting of multiple slices. Typically, there is one anatomical volume and more than 100 functional volumes per run.
- **Condition:** A specific experimental manipulation or **stimulus** type used to group **trials**. For example, 'look at faces' (*Condition 1*) or 'look at houses' (*Condition 2*).
- **Block:** A continuous period when the participant is presented with a particular **condition**. Blocks are typically used in block-design experiments.
- **Trial:** A single instance when a particular **condition** is presented, or a specific behaviour is observed. For example, the first occurrence of the 'faces' **condition** is *Trial 1*, and the second occurrence is *Trial 2*.
- **Epoch:** A continuous period in the experiment. In event-related designs, an epoch often describes the time window around a specific **event** (e.g., -2 to +12 seconds relative to stimulus onset).
- **Event:** A time point marking when something occurs during the experiment. An event can represent a **stimulus** onset, a participant response, or another critical moment (e.g., a feedback screen). A **trial** can consist of multiple **events**. For example, a working memory **trial** may consist of a stimulus (**event**), a retention interval (**epoch**), and a response (**event**).
- **Stimulus:** Any external input or cue presented to the participant, such as an image, sound, or word. A stimulus is what you present, while an **event** is when it happens (or when a participant reacts).
- **SOA (Stimulus Onset Asynchrony):** The time between the onset of one **stimulus** and the onset of the next **stimulus**, regardless of their durations.
- **ITI (Inter-Trial Interval):** The time between the end of one **trial** and the start of the next.
- **ISI (Inter-Stimulus Interval):** The time between the end of one **stimulus** and the start of the next within the same **trial**.

Experimental constraints

- **Physical constraints**
  - Strong magnetic field
  - Small space
  - Loud
  - Horizontal position

Some equipment won’t work
Limited range of motion
Limited peripheral vision
Difficulty hearing
Uncomfortable

- **Physiological constraints**
  - BOLD is slow
  - BOLD is a relative measure – the absolute values are meaningless
  - The data are continuous time-series, not discrete events



- **Psychological constraints**
  - Stimulus predictability
  - Time on task
  - Participant strategies
  - Temporal precision of the cognitive process
  - Unintended cognitive activity

Good practices in fMRI experimental design (Huettel, Song & McCarthy, 2009)

- Evoke cognitive processes of interest
  - What will subjects do
- Collect as much data as possible from each subject
  - How many trials do I need
- Collect data from as many subjects as possible
  - What statistical power can I achieve
- Choose your stimulus conditions and the timings of their presentations to evoke maximal changes in the cognitive processes of interest
  - How to increase the efficiency of the experiment
- Organise the timings of experimental stimuli so that successively elicited processes of interest are minimally correlated with each other, over time
  - Variable intervals between successive events
- Where possible, obtain measures of your subject's behaviour that can be related to the fMRI activation
  - task performance, memory effects, personality traits

Design efficiency in fMRI (Rik Henson, 2026)

https://github.com/RikHenson/fMRIefficiency

Study this carefully, when designing your fMRI experiment!

How to design efficient fMRI experiments

Rik Henson (https://www.mrc-cbu.cam.ac.uk/people/rik.henson), 2025

This notebook addresses the question of how to design fMRI experiments that are sensitive to (efficient for) a specific hypothesis (i.e, statistical planned comparison or "contrast") using the General Linear Model (GLM). The properties of the BOLD signal measured by fMRI - particularly its "sluggish" nature - can make the design of efficient experiments difficult to intuit.

There are three sections. The first focuses on optimal designs for detecting the mean activation across a number of trials in a single voxel (or ROI). This section follows a similar format to https://imaging.mrc-cbu.cam.ac.uk/imaging/DesignEfficiency, trying to explain key concepts from a signal-processing perspective, mathematical perspective and statistical perspective (see also [Henson, 2015]). It is hoped that at least one of these different perspectives will aid your intuitions.

The second section focuses on estimating activation for each trial separately (assuming some variability in that activation), as leveraged for example for estimating functional connectivity between two ROIs using "beta-series regression". The final section focuses on estimating patterns of activation across voxels for each trial, as used in multi-voxel pattern analysis (MVPA). Finally, there are some answers to some common questions that I have been asked over the years. But first we start with some terminology and general advice.

Table of Contents

Design efficiency in fMRI (Rik Henson, 2026)

- **Scan as long as possible**
  - Subjects can function satisfactorily and comfortably for between 40-60 min within the MRI environment.
  - For group results, scanning more subjects with fewer volumes might give more power than scanning fewer subjects with more volumes per subject.

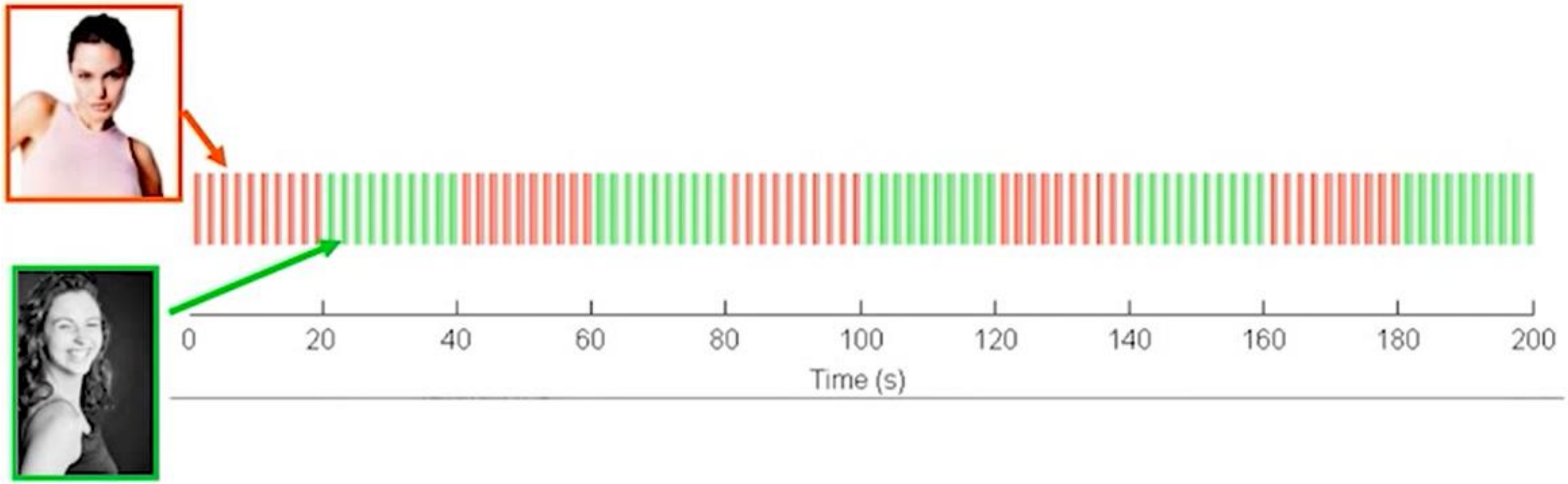
- **Keep the subject as busy as possible**
  - The time during which the subject is not engaged in the task of interest should be minimised.
    - Inter-trial interval (ITI) should be kept as short as possible.
    - The only situation where you might want longer ITIs (or blocks of rest) is if you want to measure "baseline". However, “baseline” is rarely meaningful.

- **Do not contrast trials that are far apart in time**
  - fMRI data is typically filtered to remove changes slower than 0.01 Hz—equivalent to cycles longer than 100 seconds, assuming these are background noise.
  - Avoid designing your experiment with trials you want to compare more than 100 seconds apart, as these low-frequency signals could be filtered out.
    - In blocked designs, do not use blocks that are too long. The optimal block length in an on-off design, regardless of any high-pass filtering, is ~16s.
    - Avoid using many conditions of which the important contrasts only involve a subset.

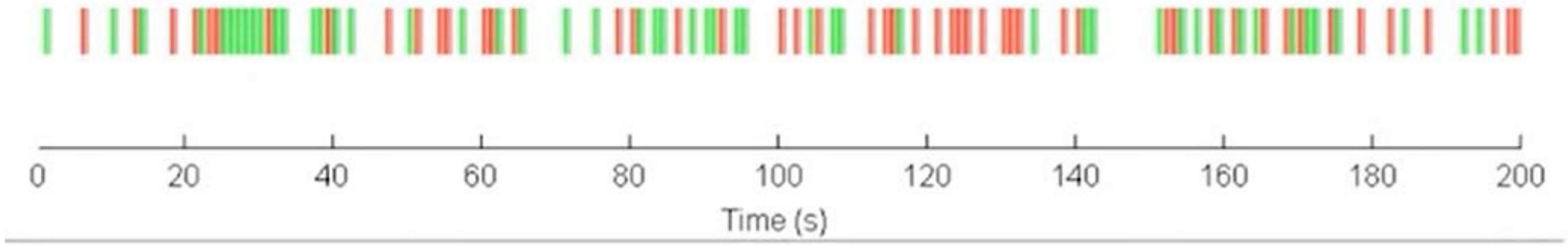
- **Randomise the order of trials close together in time**
  - Either vary the order of different trial types (conditions) or vary the inter-trial-interval.

Types of designs

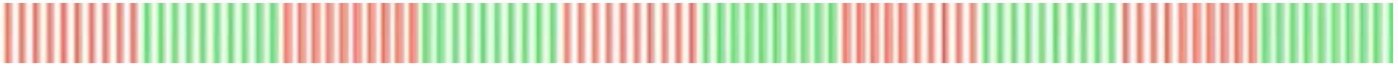
- **Block design**: similar events are grouped



- **Event-related design**: events are mixed



Block designs



- Advantages
  - Maximal efficiency
    - A 2-condition ~16-second block design is optimal for power
  - Reduced task-switching costs
  - Forgiving with respect to the exact form of the HRF

- Problems
  - Stimulus predictability (e.g., in Go/No-go task – don't press a button when X occurs: **N B M V**; **X X X X**)
  - Chance to apply strategy (e.g., in the Stroop task: **blue red green**; **blue red green**)
  - Cannot detect rapid/transient events

- Note
  - Too short blocks don't let HRF return to the baseline – the signal will be reduced
  - Too long blocks are confounded by low-frequency noise (MRI scanner drift)
  - Not recommended to have more than 4 conditions

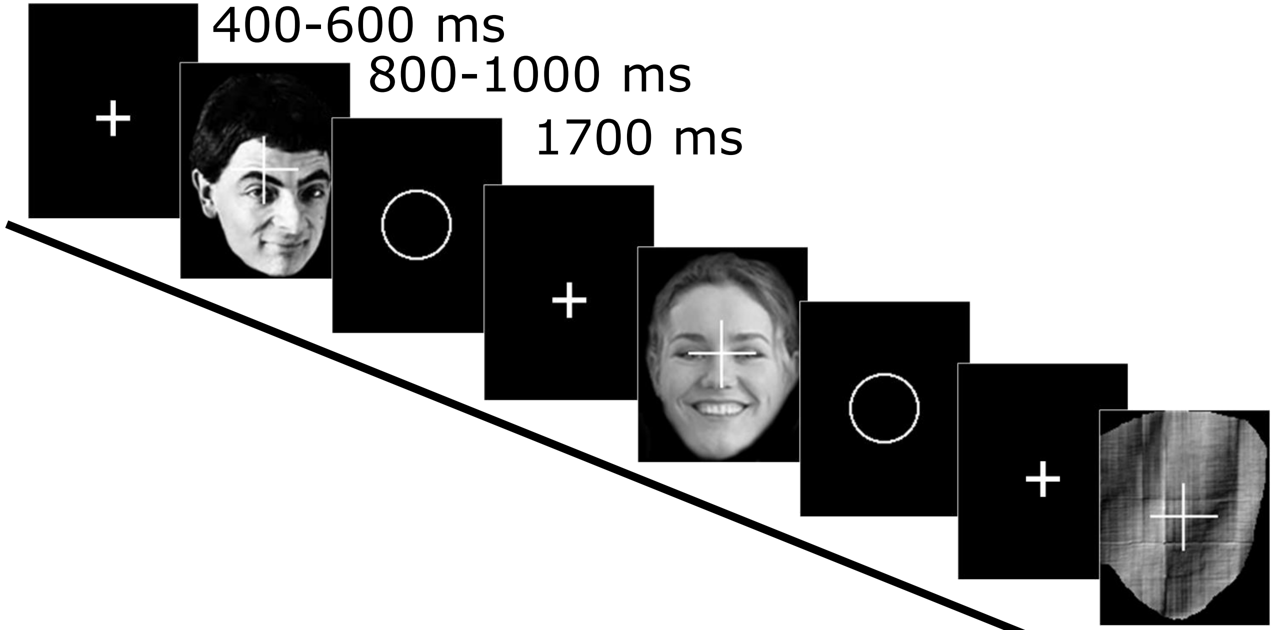
Event-related designs

- Advantages
  - Avoid predictability and strategy
  - Can detect transient effects
  - More flexible - can accommodate more complex experimental designs and a wider variety of stimuli or tasks

- Problems
  - Lower detection power - requires more trials to achieve the same level of statistical power as block designs
  - Enhanced task-switching costs
  - Strong effect on presentation rate – requires design optimization (e.g. Optseq2 tool)
  - Sensitive to the exact form of the HRF

- Note
  - Each event is separated in time from the previous event with an inter-stimulus-interval (ISI)
  - Short 2-6 second jittered ISIs improve efficiency

Example Experiment: Face Recognition



N = 16 subjects

Stimuli: 3 types of greyscale face images:

- ~150 x Familiar
- ~150 x Unfamiliar
- ~150 x Scrambled

Task: Judge face symmetry

20s Rest after ever 50s

7 min long runs

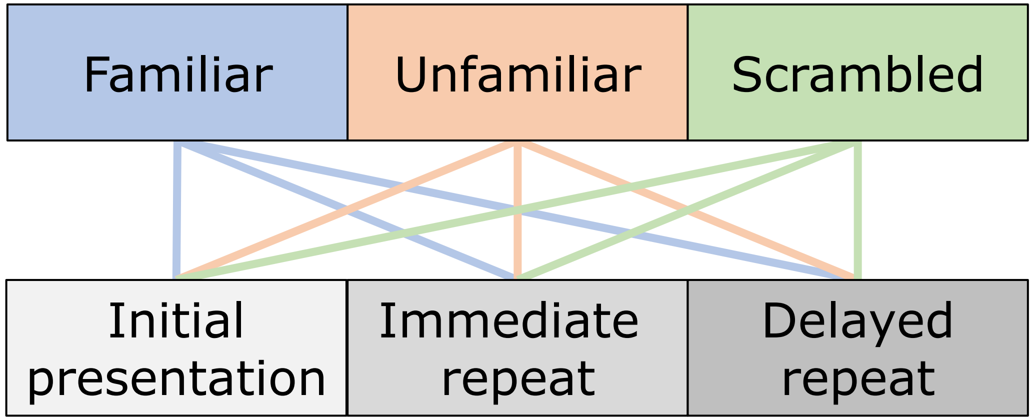
9 runs

Each image was presented twice, with the second presentation occurring either immediately after (**Immediate Repeats**), or after 5–15 intervening stimuli (**Delayed Repeats**), with 50% of each type of repeat.

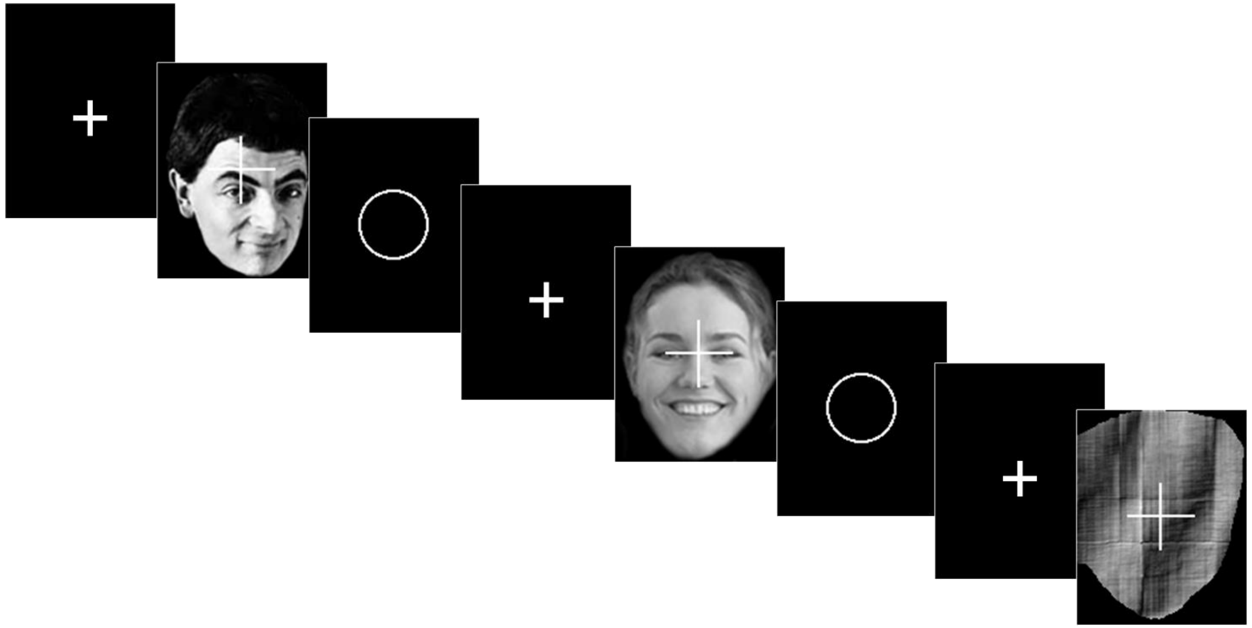
Example Experiment: Face Recognition

- Nine Conditions (3 x 3)

Face



Presentation



Possible questions to investigate

- Brain areas for Faces
- Brain areas for Face Familiarity
- Response to Initial vs Repeated presentations
- Response to the Repetition of Familiar vs Repetition of Unfamiliar
- ...

Example Dataset

https://openneuro.org/datasets/ds000117/

www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES

» Electroencephalography -EEG

» Brain imaging

» Functional magnetic resonance imaging

» Cognitive neuroscience

Received: 07 April 2014

Accepted: 05 January 2015

Published: 20 January 2015

A multi-subject, multi-modal human neuroimaging dataset

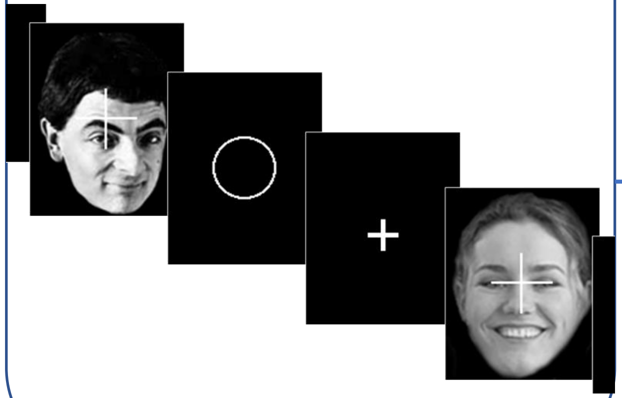
Daniel G. Wakeman[1,2] & Richard N. Henson[2]

We describe data acquired with multiple functional and structural neuroimaging modalities on the same nineteen healthy volunteers. The functional data include Electroencephalography (EEG), Magnetoencephalography (MEG) and functional Magnetic Resonance Imaging (fMRI) data, recorded while the volunteers performed multiple runs of hundreds of trials of a simple perceptual task on pictures of familiar, unfamiliar and scrambled faces during two visits to the laboratory. The structural data include T1-weighted MPRAGE, Multi-Echo FLASH and Diffusion-weighted MR sequences. Though only from a small sample of volunteers, these data can be used to develop methods for integrating multiple modalities from multiple runs on multiple participants, with the aim of increasing the spatial and temporal resolution above that of any one modality alone. They can also be used to integrate measures of functional and structural connectivity, and as a benchmark dataset to compare results across the many neuroimaging analysis packages. The data are freely available from https://openfmri.org/.

Wakeman & Henson (2015), *Scientific Data*, http://www.nature.com/articles/sdata20151

Famous vs **Unfamiliar** faces are processed differently in the brain

Design an experiment

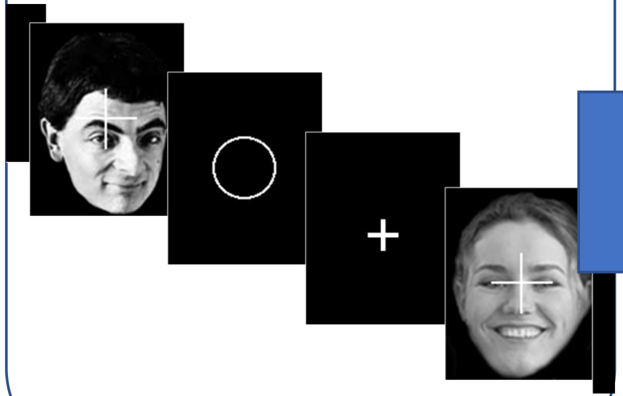


Collect the MRI data

What do we do now?

Famous vs **Unfamiliar** faces are processed differently in the brain

Design an experiment



Data

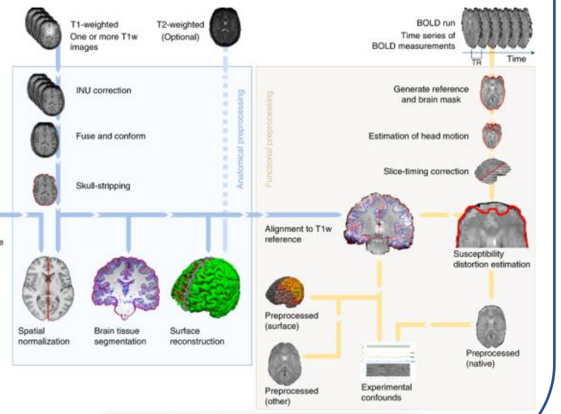
Stimuli
Timing

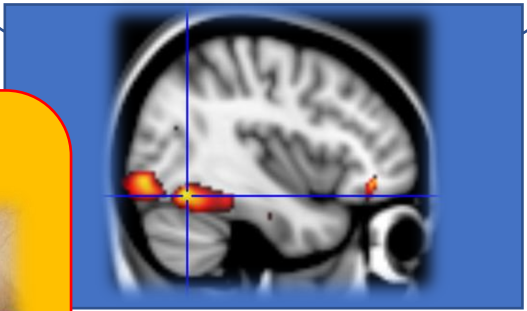
Collect the MRI data

Data

Anatomical image
Functional images
Event details

Pre-process & Analyse





The final push

Famous vs **Unfamiliar** faces are processed differently in the brain

Design an experiment

Data

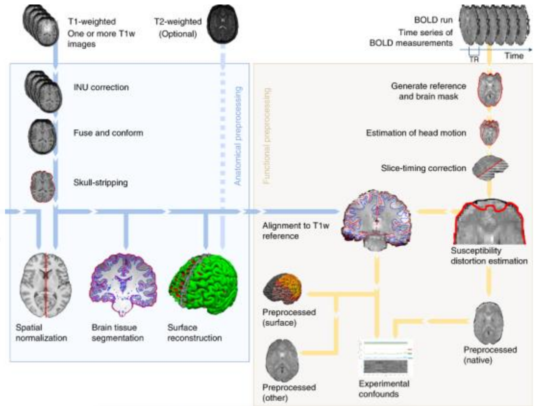
Stimuli
Timing

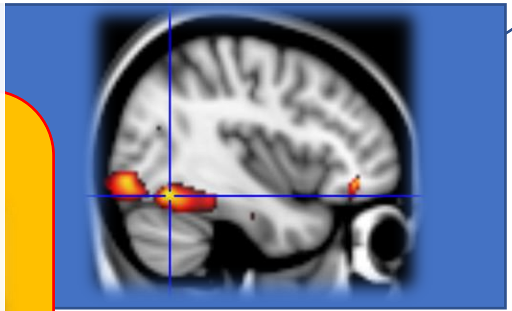
Collect the MRI data

Data

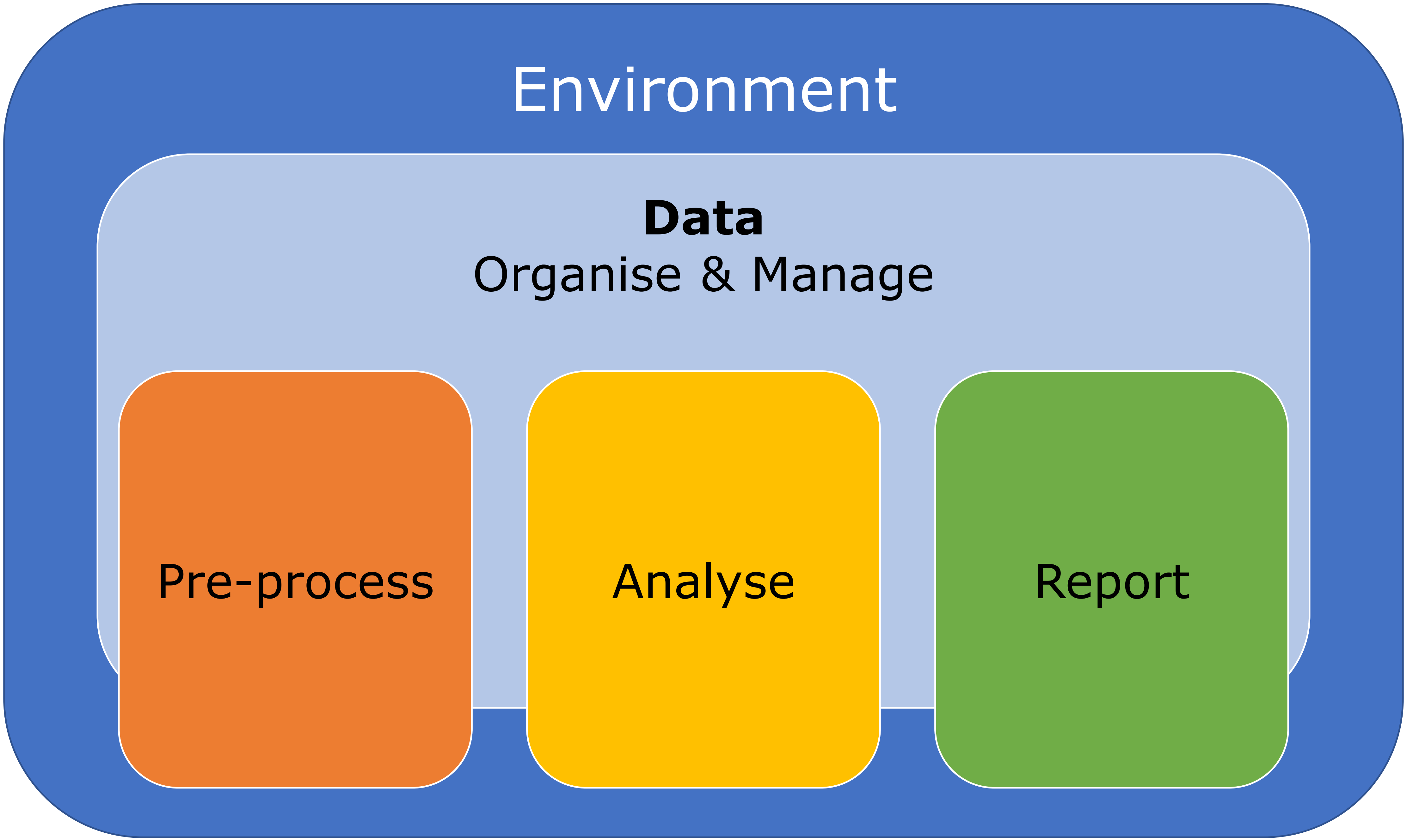
Anatomical image
Functional images
Event details

Pre-process & Analyse





The final push


Environment
Data
Organise & Manage
Pre-process
Analyse
Report

Outline

- Introduction
- Experimental design
- **Data management**
- Pre-processing
- Statistical analysis
- Practical demo