Multisensory stimulus presentation and movement tracking during neuroimaging

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Introduction

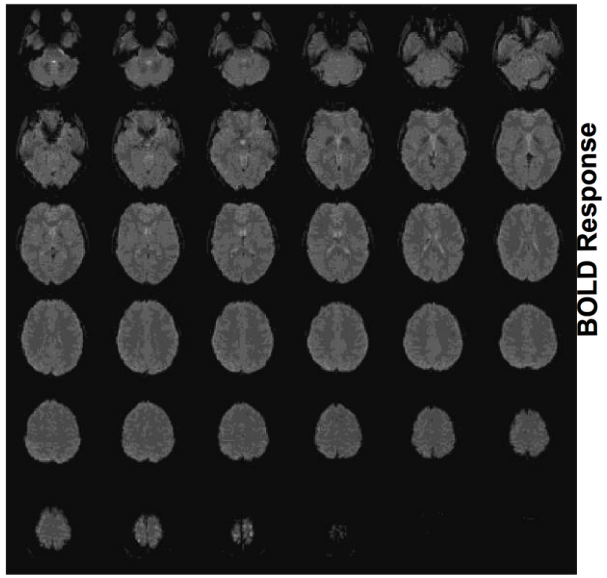
MRI scanner design

- MRI scanners are **primarily designed for medical** diagnostic use
- Patient/participant is lying down, head in the middle of the scanner
- Head coil around the head
- Safety squeeze ball in hand

fMRI experiment scans

- Structural (anatomical) scan (~8 mins)
- **Functional scans** (fMRI) (~50 mins)
- Fieldmap (correct for magnetic inhomogenities (~2 mins)

One functional volume in slices (approx. 2 seconds for one whole-brain volume)



BOLD response

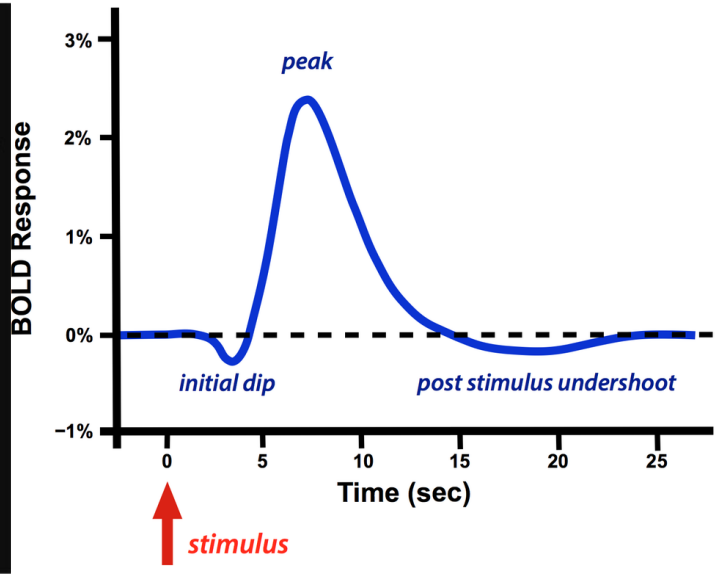
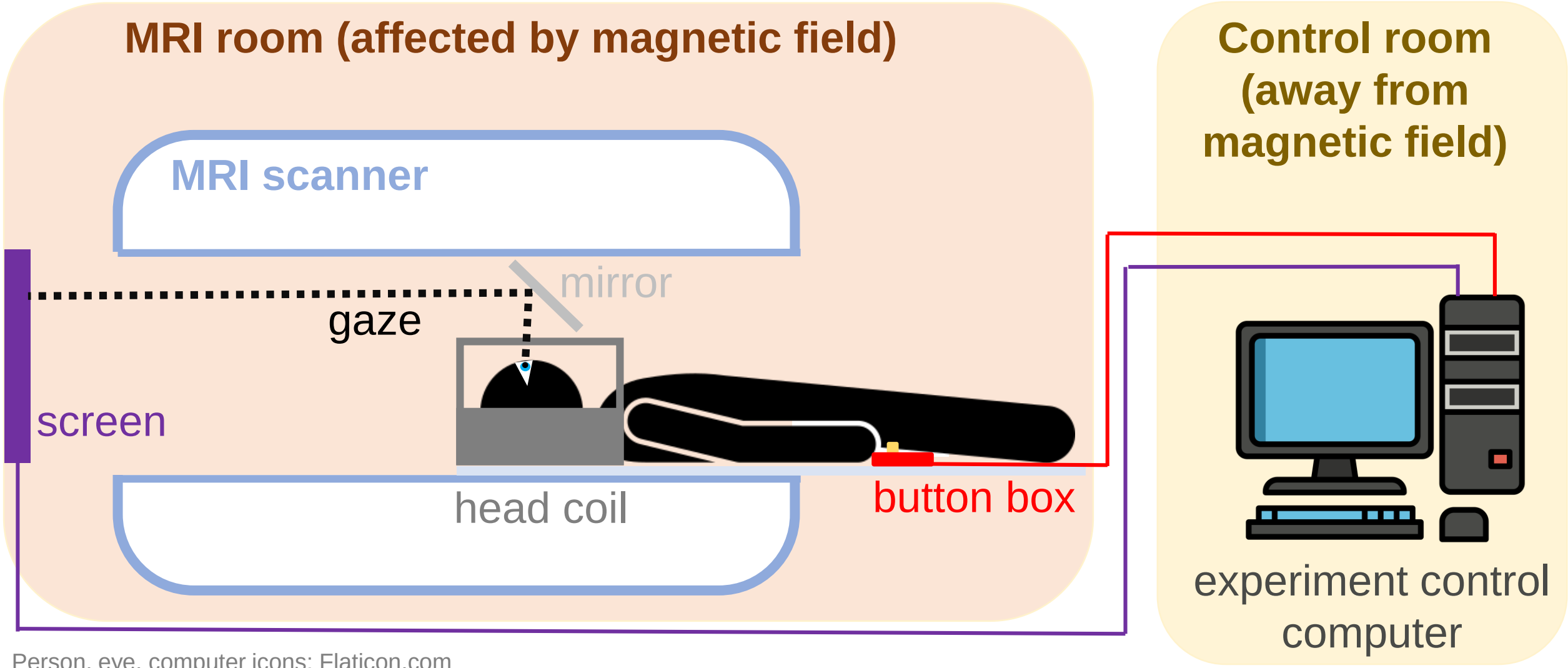


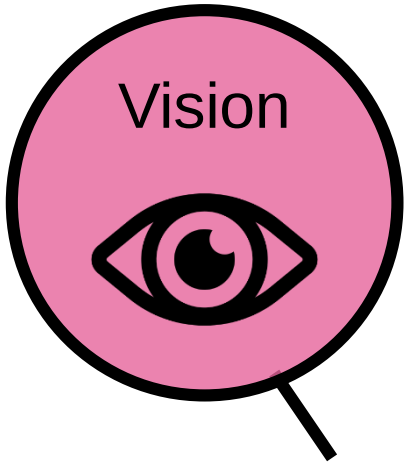
Image credit: Andy's Brain Book

Typical fMRI experiment setup

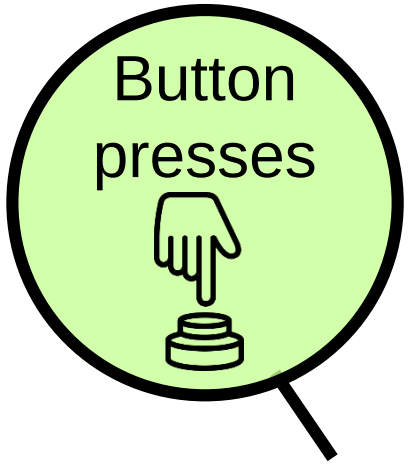


Person, eye, computer icons: Flaticon.com

Typical fMRI setup



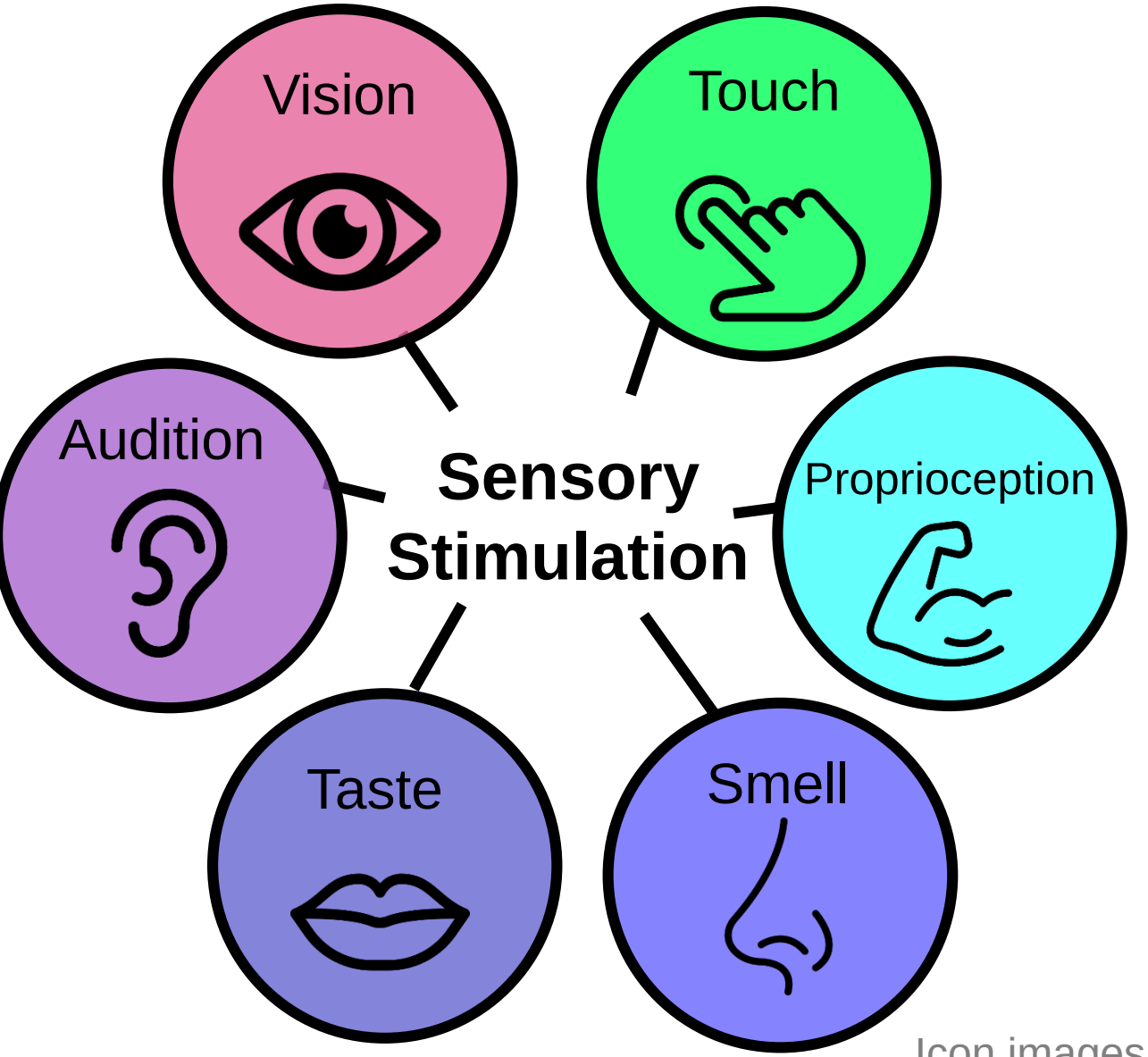
Sensory Stimulation



Response Recording

Icon images: Flaticon.com

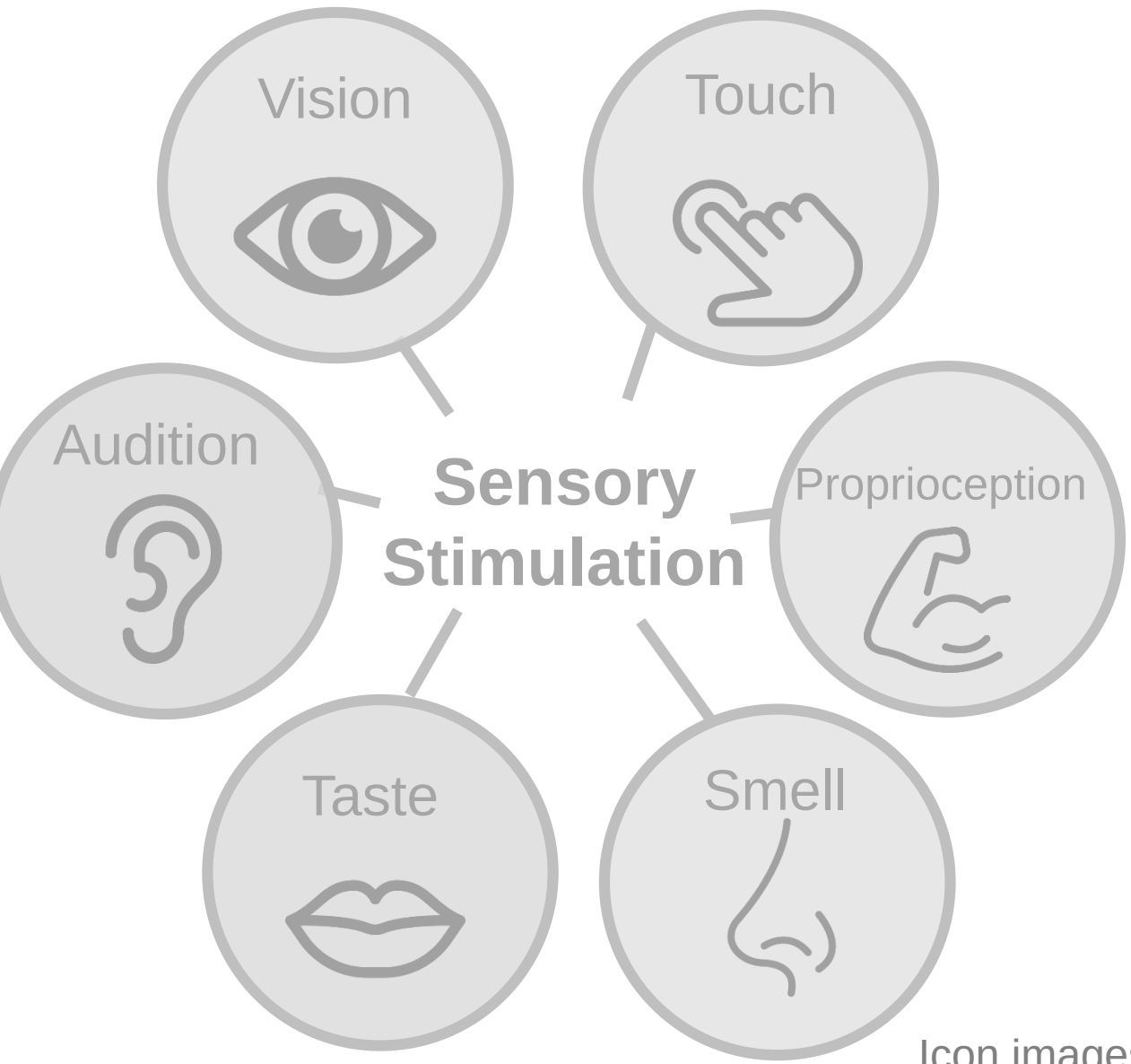
Sensory Stimulation Techniques

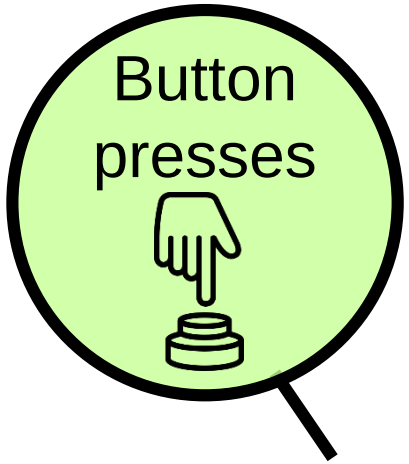


Response Recording

Icon images: Flaticon.com

Typical fMRI setup

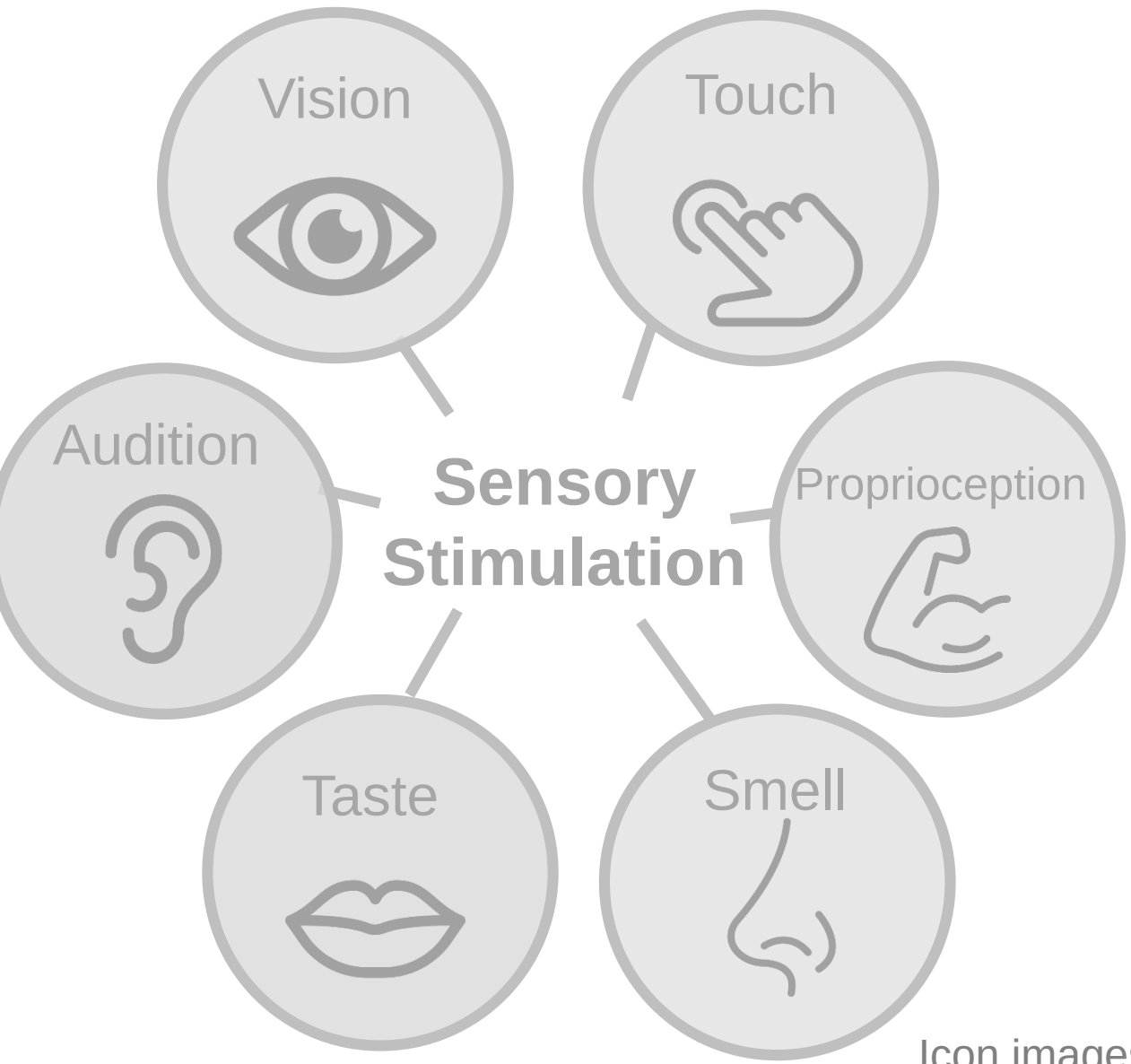


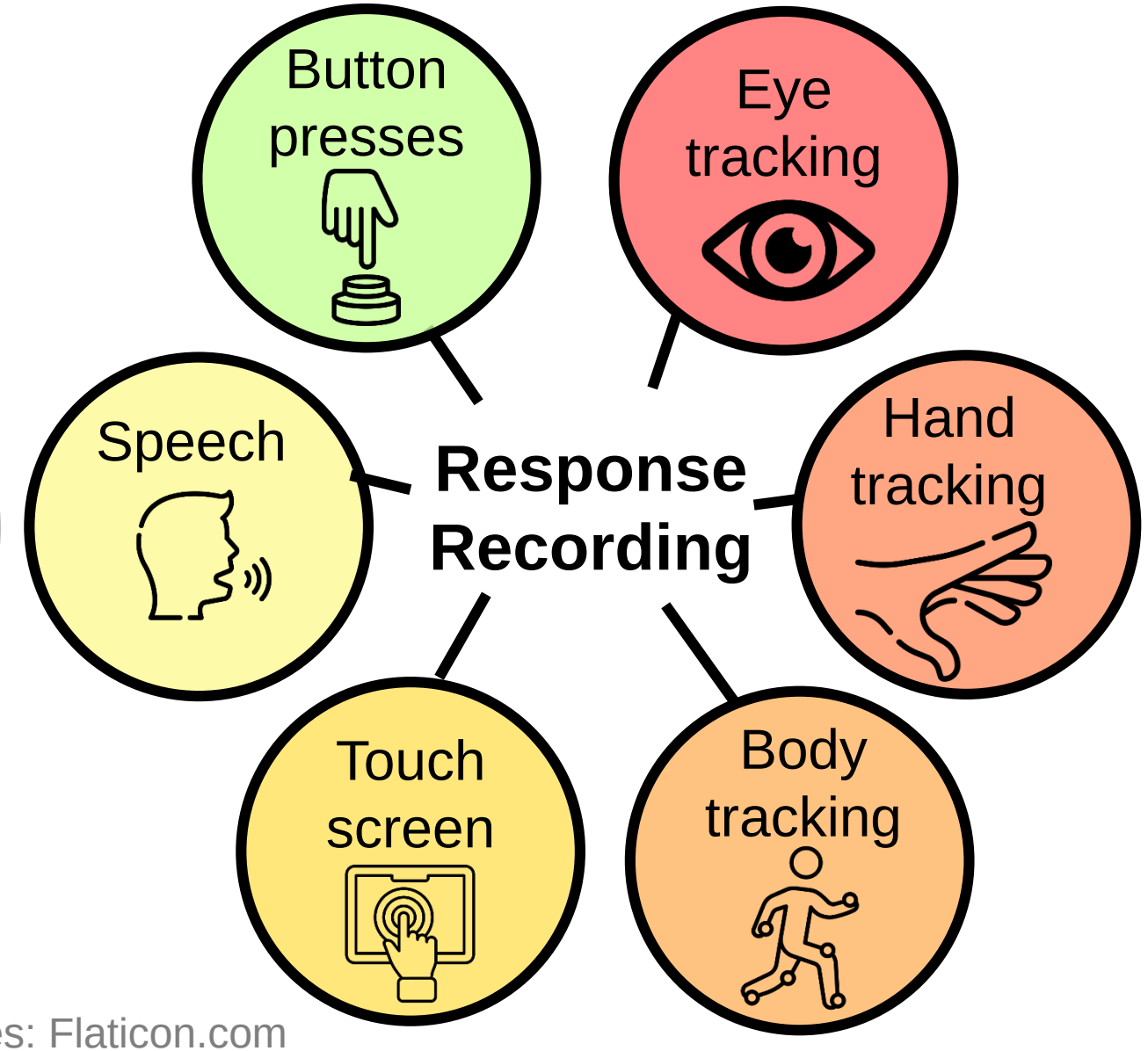


Response Recording

Icon images: Flaticon.com

Response Recording Techniques

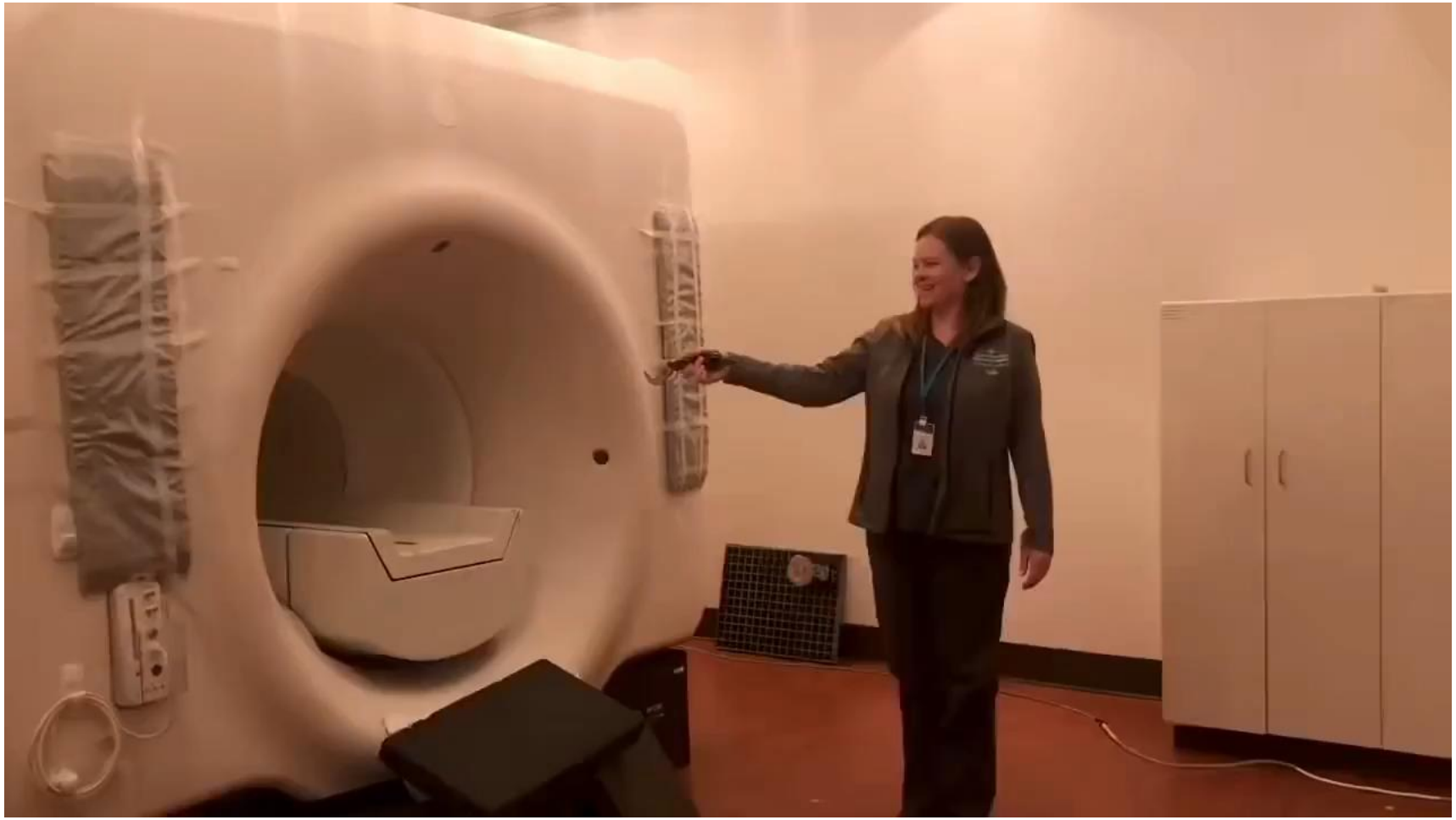




Icon images: Flaticon.com

Why are there limitations to the equipment we can use?

The MRI magnetic field



The MRI magnetic field

Key safety constraints:

- No metallic implants
- No metallic objects on body (e.g. jewellery)

Why?

- Can become projectiles
- Can move (e.g. implants in body)
- Can heat-up during scanning causing burns

MEG

MEG scanners use ultra-sensitive sensors inside a magnetically shielded room.

Outside equipment can generate magnetic noise that can:

- Overwhelm the brain signal.
- Distort recordings.

Even tiny magnetic fields from ordinary electronics are **much stronger** than brain signals.

Two main equipment approaches:

Specialist MR-compatible equipment:

- Bought from specialised companies (e.g. VPixx, MRC-Systems, Cambridge Research Systems, Nordic Neuro Lab)

PROS

- Works out of the box (in theory)
- Increasing variety

CONS

- Very expensive £££
- Not every type of equipment has been developed

Custom-made by in-house technicians, designers, or you:

- Custom-built to fit specific experiment
- Non MR-compatible control equipment can be kept outside the scanner

PROS

- Good fit to experiment needs
- Often much cheaper

CONS

- Can require technical expertise
- Can be time consuming to develop 🕐🕐🕐

Today’s Lecture

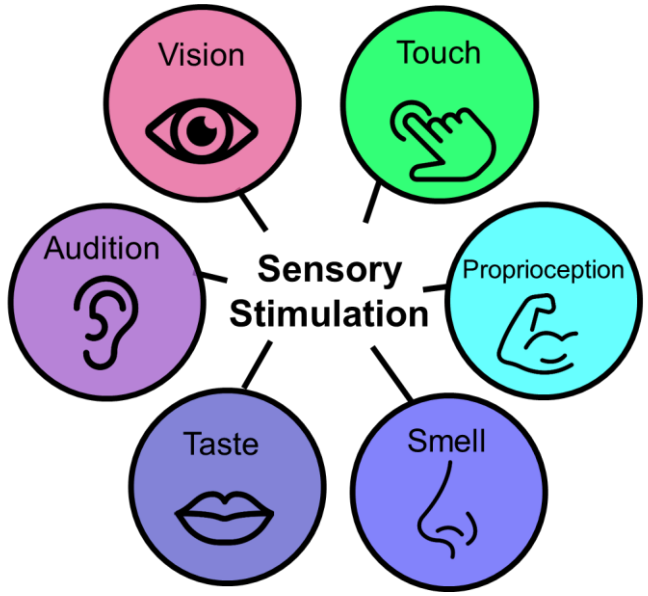
Part 1: Multisensory stimulation

Part 2: Movement recording

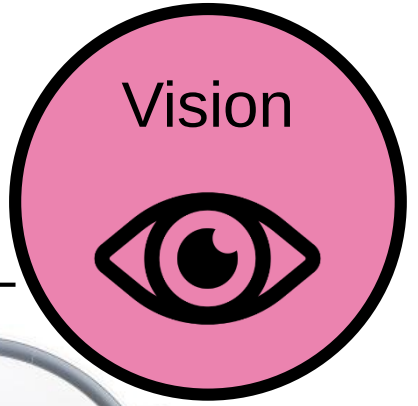
Part 3a: Experiment synchronisation (theory)

Part 3b: Experiment synchronisation (practical demonstration)

Part 1: Multisensory Stimulation



Vision: screens and projectors



What are they for?

- Common way to show visual stimuli. Participant **views the screen or projected image via a mirror** attached to the head coil.

MR-compatible screen:
Cambridge Research Systems

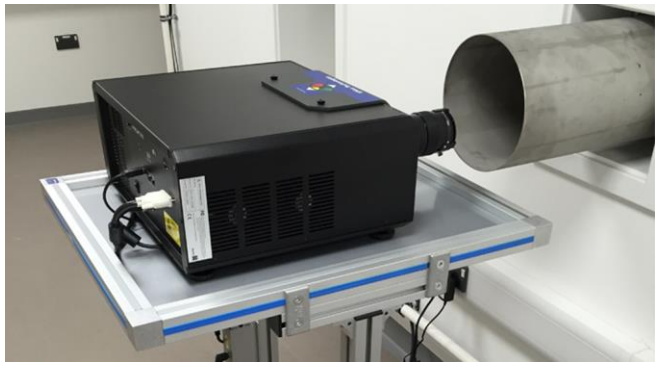
Approaches:

- **MR-compatible screen**.

👍 Display quality (e.g. colour) 👎 Expensive

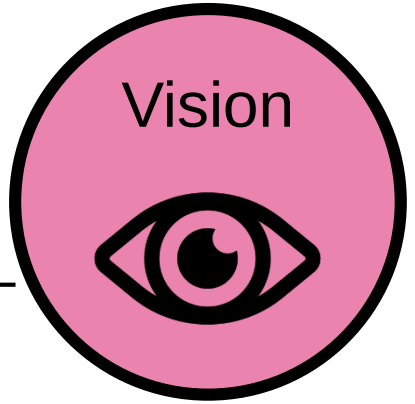
- **Projector.**

👍 Flexible choice of projector



Projector: VPixx

Vision: MR-compatible goggles



What are they for?

- Create an **immersive environment**, as participants only see via goggles.
- Similar to virtual reality, but head cannot be moved.

Goggles: Nordic Neuro Lab

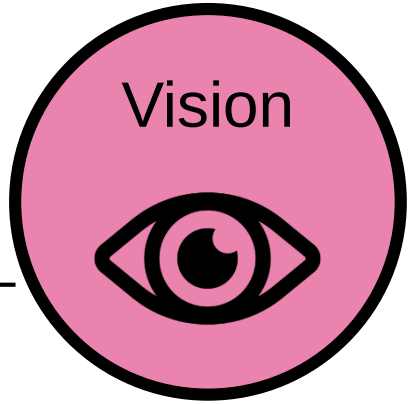
Approaches:

- Commercial **MR-compatible goggles**.
- Tilting of the head coil (may not be possible with current head coils).

Tilted head coil and goggles allows participant to an avatar as their body.

Preston & Ehrsson (2016)

Vision: LEDs

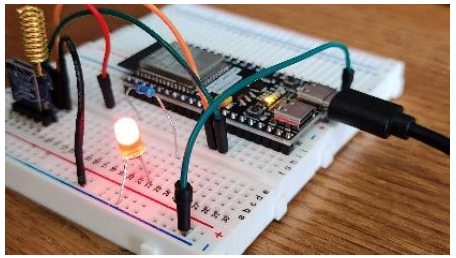


What are they for?

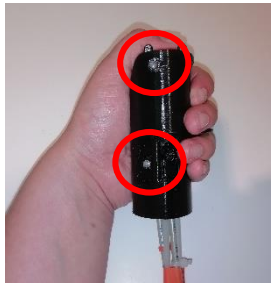
- **Flexible positioning** of simple visual stimuli.
- **Infrared** LED – **illumination that is invisible** to the participant (but not to a camera).

Approaches:

- **Normal LED** outside scanner room, **transmitted using long optic fibre**.
- MR-compatible LEDs.



Simple LED controlled by an Arduino. Transmitted via long optic fibre.

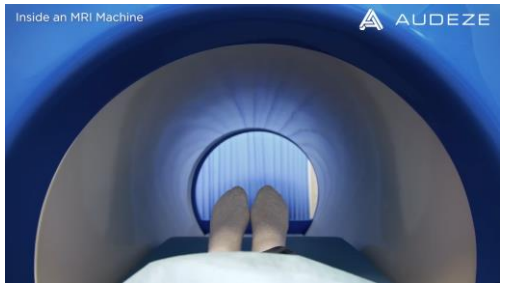


Optic fibres connect to two positions on a custom handheld device.

Audition: overview

Key Constraints

- Loud noises made by scanner.
- Hearing protection is required to protect the participants' hearing.



Solutions

- **MR-compatible headphones.**
- Over-ear headphones (with ear plugs).
- In-ear headphones (with padding over the ears).

Over-ear headphones

In-ear headphones

Images: Cambridge Research Systems

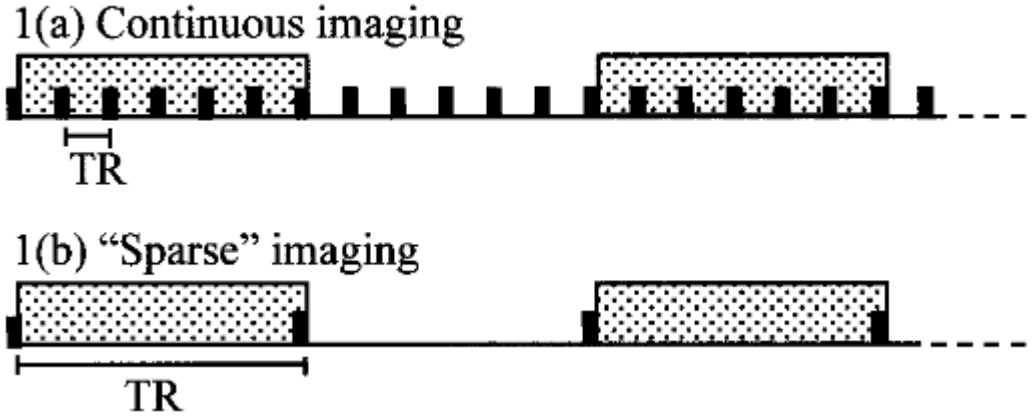
Audition: sparse imaging

Loud noises of MRI scanner:

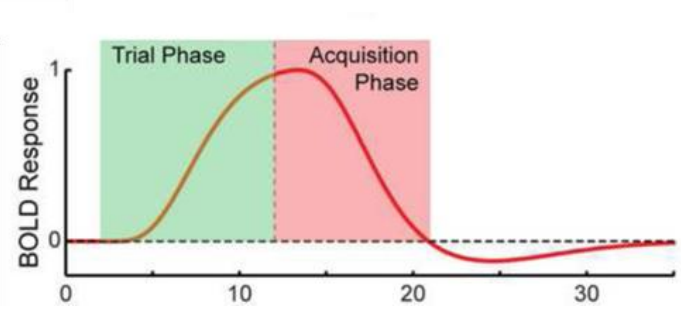
- Activate auditory cortex
- Mask experiment sounds

Sparse imaging:

- Scanner stops temporarily
- Stimuli presented in silent gap
- Scanner turns on and collects the BOLD responses (peak is delayed)



Bars indicate periods of auditory stimulation.
Hall et al., 1999



Touch: pneumatics

What is it for?

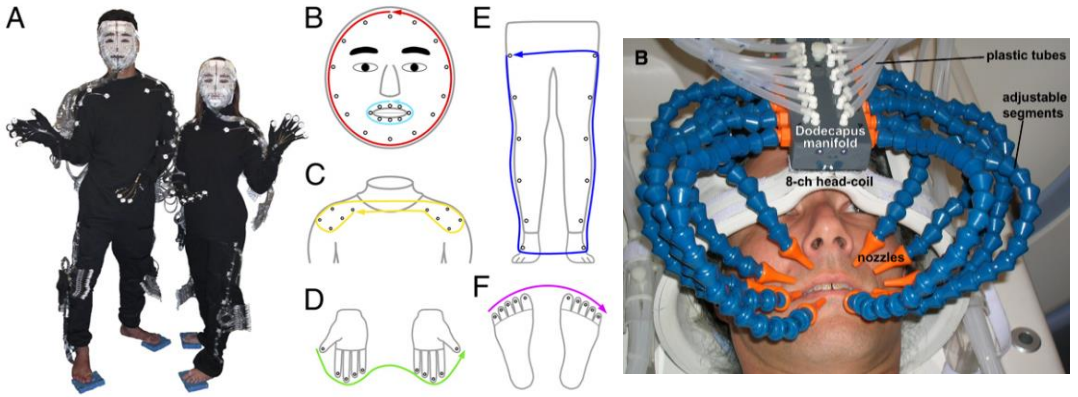
- Air is used to deliver touch stimulation at specific times to various skin locations.

How does it work?

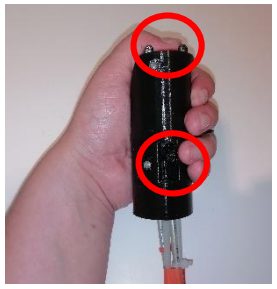
- **Pneumatics** - air compressor outside scanner, tubes deliver air puffs or drive object movement in scanner room.

Approaches:

- Air puffs can directly stimulate the skin.
- Air can drive object movement in scanner room (e.g. Dowdall et al., 2025)



Custom built suits and setups to deliver air puffs on specific face and body locations. Huang et al., (2007, 2012)



Air puffs stimulate thumb and ring finger on a custom 3D printed device.
Foster et al., (in prep.)

Touch: experimenter in the scanner

What is the approach?

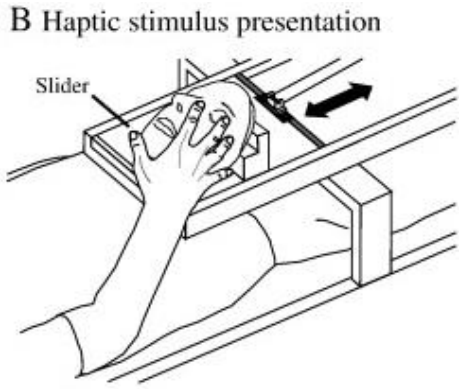
- Experimenter is in the MR-scanner room and places objects in reach of the participant at specified times.

Flexible and low cost

Experimenter fatigue and potential mistakes (e.g. wrong object).

Experimenter must wear ear protection.

Further examples: Kim et al. 2017; Shahzad et al., 2025



Objects from different categories given to participant via slider.

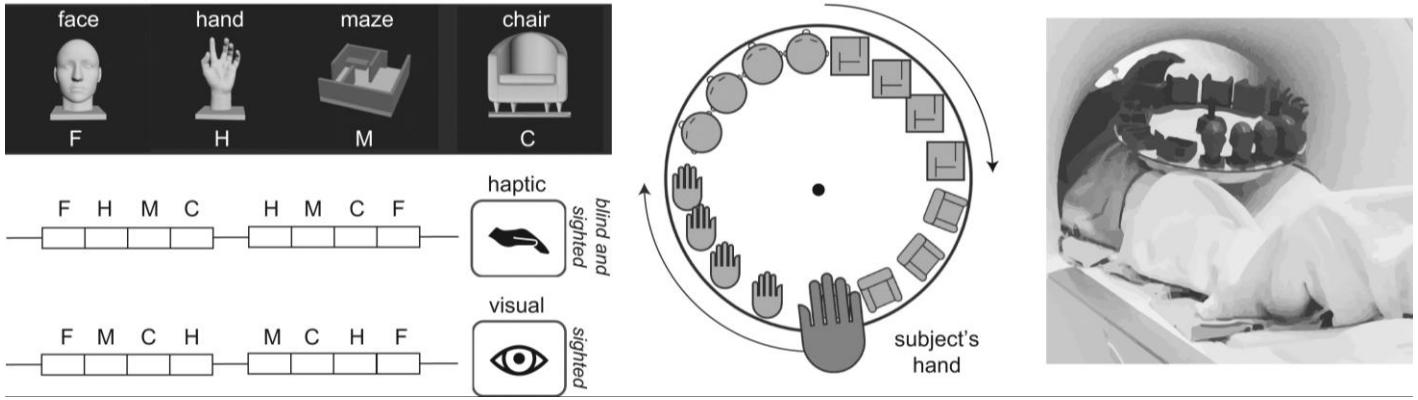
Kitada et al., (2010)

Experimenter touches participant to induce full body illusion (similar to rubber hand illusion)

Preston & Ehrsson (2016)

Touch: haptic exploration

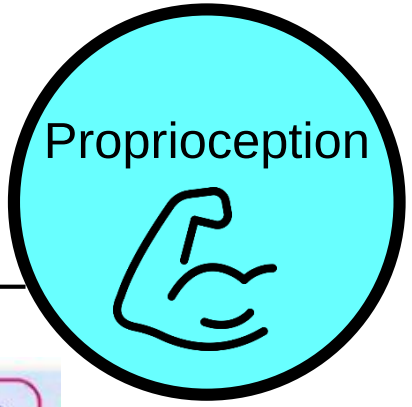
Haptic exploration using a wheel



Participants haptically explore the shape of the current object on the wheel, moving onto the next object for the next trial.

Murty et al., (2020)

Proprioception

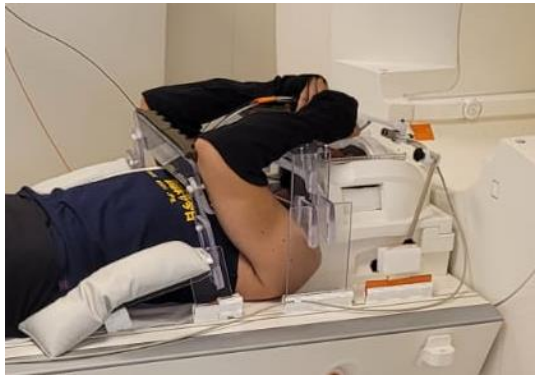


- Proprioception is the sense of body posture and movement using receptors in muscles, joints, and tendons.

Mittendorff et al., 2021

Key Constraints

- Crossing of limbs can induce conductive loops leading to burns.
- Participant movements can cause scan artefacts.



Custom-designed plexiglass arm support

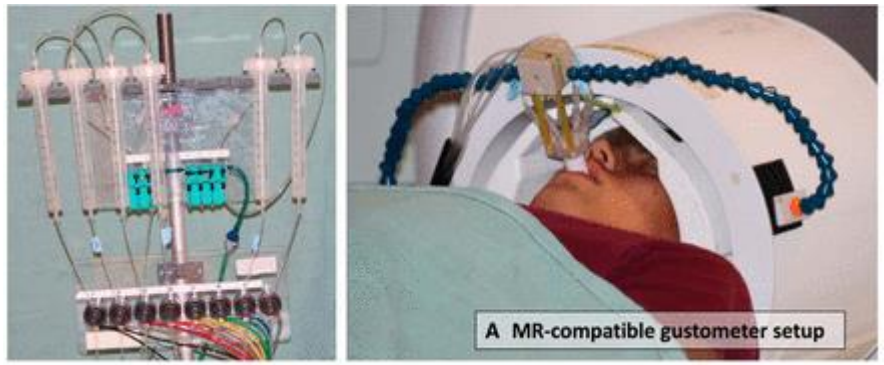
Solutions

- Custom-built limb supports made with MR-safe material (e.g. plexiglass). Can attach to the MRI scanner rails.
- Pads and clothing (e.g. cotton) between touching limbs.

Taste

Approaches:

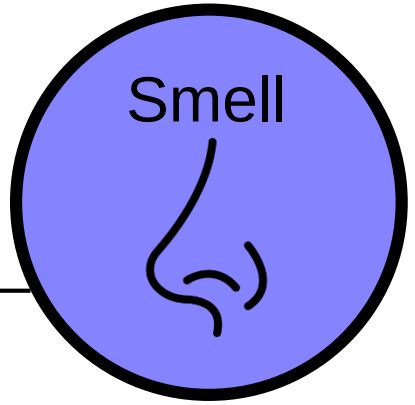
- Custom-built **pneumatically-driven** MRI-compatible **gustometer** systems.
- Deliver specific amounts of **liquid tastant** into the mouth of participant, controlled from outside the scanner room.
- Washout is a fluid similar to saliva.
- Both custom lab-built setups and commercial options possible.



MRI-compatible custom-made gustometer setup.

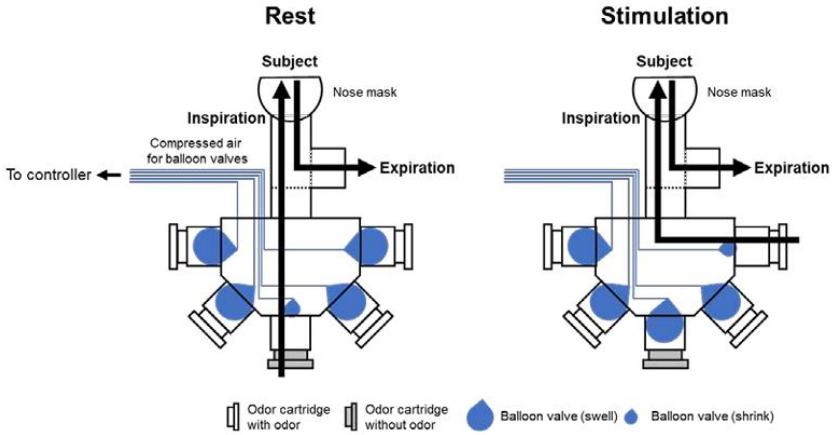
Avery et al., 2020

Smell

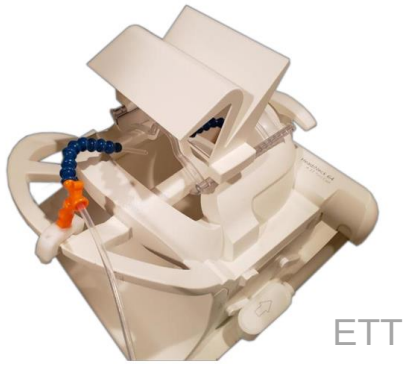


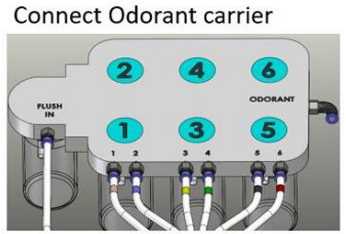
Approaches:

- **Olfactometer** - instrument designed to precisely deliver, dilute, and measure odorant concentrations to study the sense of smell.
- Commercial options available, custom-built possible.
- Breathing induced by sniffing can affect MR-signal. Respiration can be measured in addition to task.



Donoshita et al., 2021





ETT Olfactometer for MRI

Physiological measurements

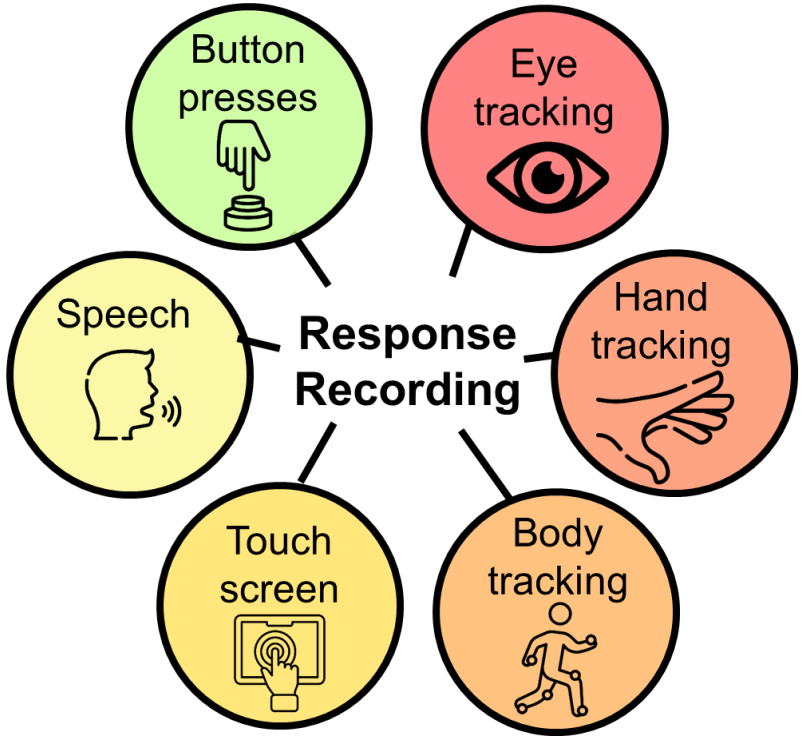
Physiological measurements can be recorded, including:

- **Heart rate** via ECG
- **Respiration** via respiratory cushion
- **Pulse monitoring** via pulse oximeter

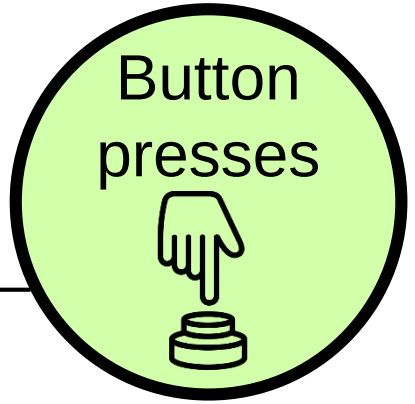
These are often available via the MRI scanner manufacturer (e.g. Siemens)

These physiological signals can be used **as fMRI regressors to reduce affects of physiological noise** on signal.

Part 2: Movement Recording



Button presses



What is it for?

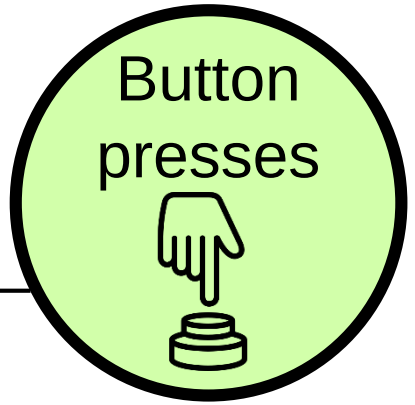
- Standard approach to **record simple responses** of participants during fMRI
- Even if you are not interested in analysing responses– task responses **ensures participants pay attention** throughout your experiment

Common approaches :

- Commercial companies sell **MR-compatible button boxes**
- Many different shapes/sizes, for all 5 fingers of both hands
- Also possible to develop custom buttons if necessary

Images: Vpixx, Cambridge Research Systems

Button presses



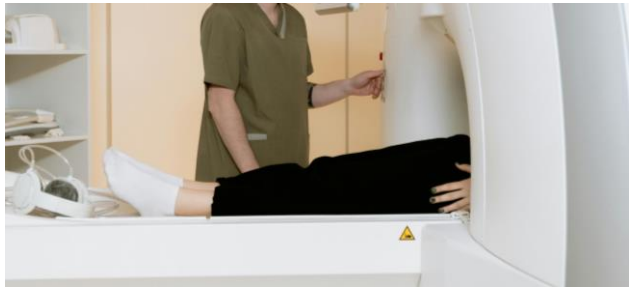
Be aware that:

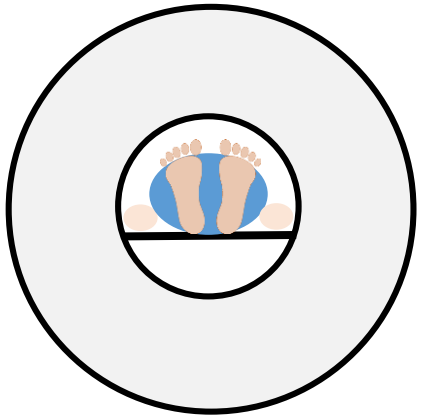
- Participants can’t easily see their hands
- Participants don’t have much space in the scanner

Common problems because of this:

- Participant presses the wrong button
- Participant leans on a button, making it constantly pressed

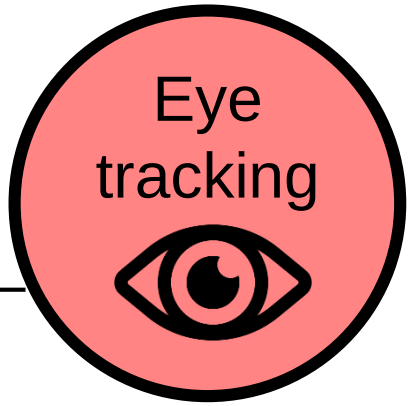
These problems can be **solved by experiment coding (see Section 3) and vigilance during experimental sessions**





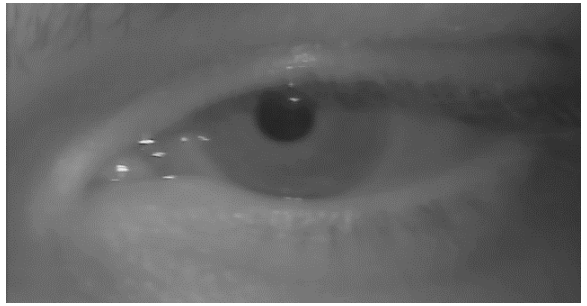
Participants arms are close to the bore walls of the scanner

Eye tracking: overview



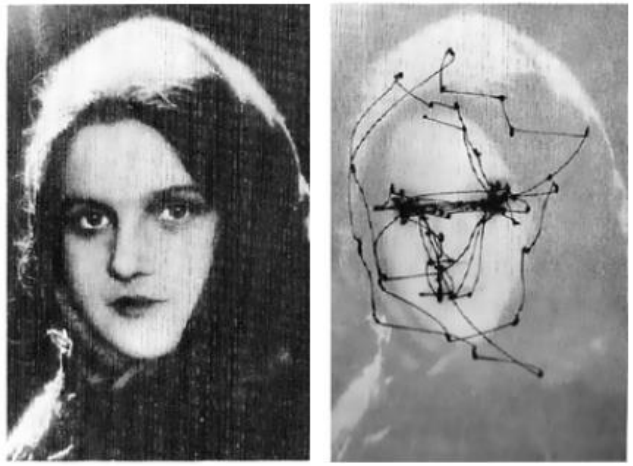
What is it for?

- Recording **eye movements**
- Determining **focus of attention**
- Ensuring maintenance of **fixation**
- Recording pupil size



Common approaches:

- MR-compatible video cameras in the scanner room
- Long-range video camera positioned outside the scanner room.

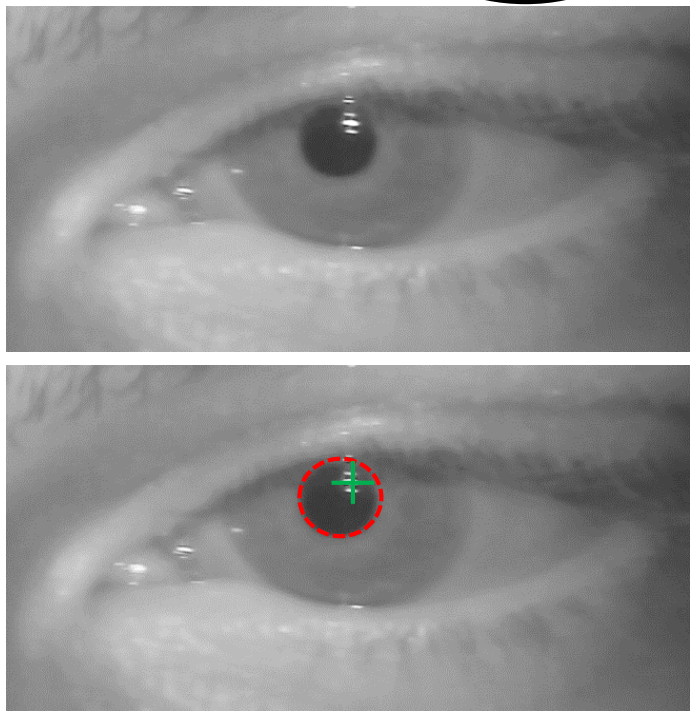


Eye tracking: method

Eye tracking method steps:

- **Record video** of one or both eyes ensuring a clear view of the **pupil** and (ideally also) **corneal reflection** from infrared LED
- **Calibration** – show fixation points sequentially at the corners of the stimulus screen
- **Validation** – test the learned calibration with new fixation points. Repeat the calibration if the validation does not show good enough accuracy.

Tip: getting a good eye image is key to good eye tracking – you may need to reposition the camera in case of problems.



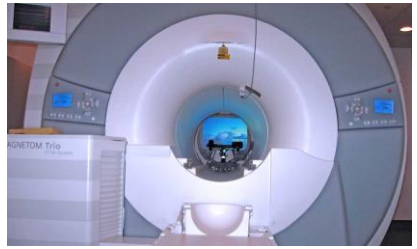
Red circle: detected pupil (focus of attention)

Green cross: corneal reflection (stable comparison point)

Eye tracking: fMRI approaches

MR-compatible in-bore eye tracker (e.g. Eyelink 1000)

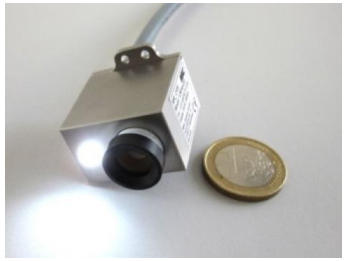
- high sampling rate, excellent data quality
- expensive



Eye tracker in MRI scanner bore: Eyelink 1000 - SR Research

Small MR-compatible camera (e.g. MRC Systems).

- flexible positioning for good view of eye
- lower sampling rate



Small MR-compatible camera: MRC Systems

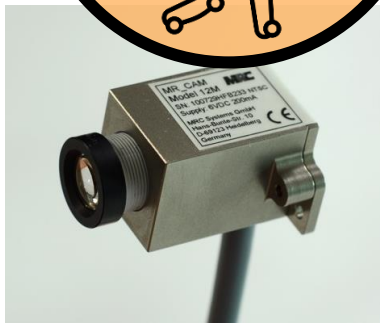
Long-range camera positioned outside the scanner room.

- camera does not need to be MR-compatible
- poor data quality

Hand & body: overview

Key Constraints

- Movements can cause **scanning artefacts**.
- Limit to possible movements due to participant position.



Small MR-compatible camera: MRC Systems

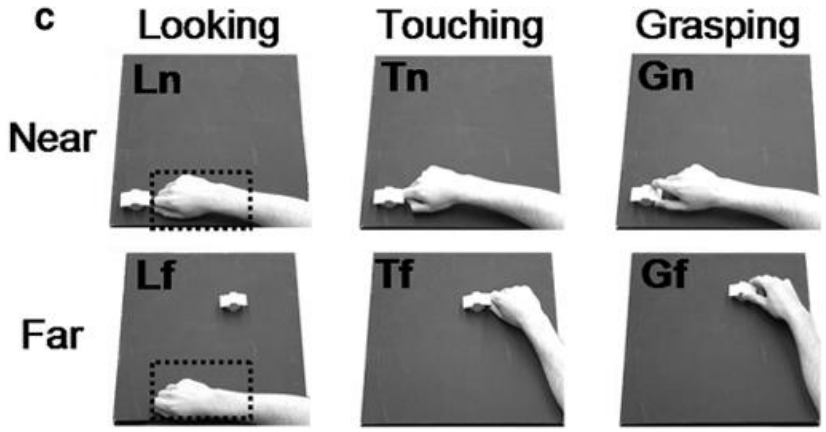
Solutions

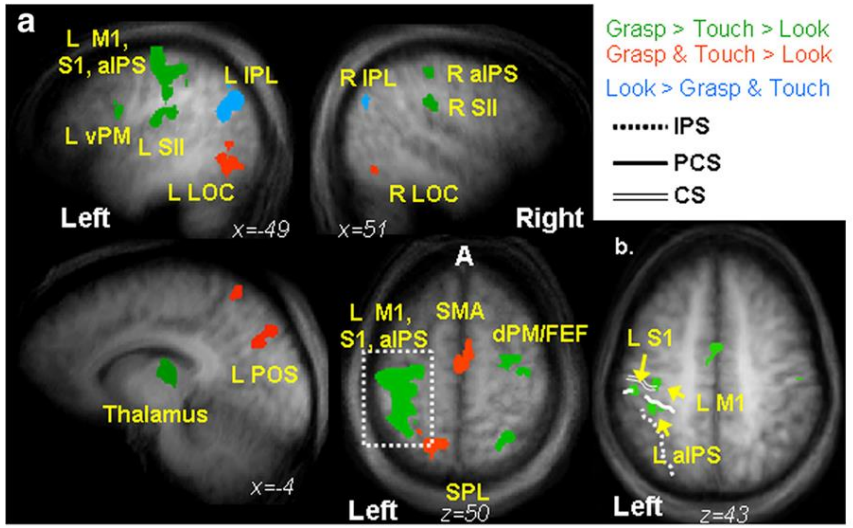
- Design experiment for **minimal movements.**
- Use **small MR-compatible cameras** to record movements (e.g. face movements).
- Use **long-range cameras** placed away from the magnetic field or outside the scanner room.
- LEDs to enhance a body landmark (e.g. fingertip).

Long-range camera

Hand: grasping movements

- Participants **grasped objects** of different shape
- **Lego** used to vary **object shape**
- LEDs used for fixation, and to illuminate only at the start of trial
- Infrared (IR) sensitive **camera used to record videos** of grasping movements. An **IR LED on the camera illuminates the scene for the camera, out of participant visible light spectrum**

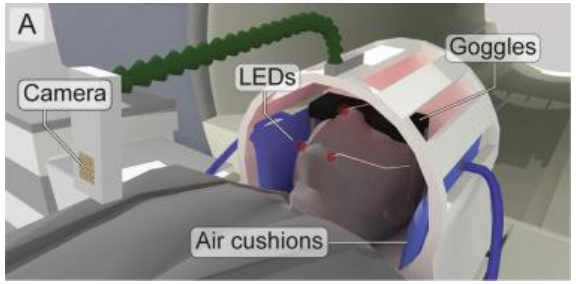


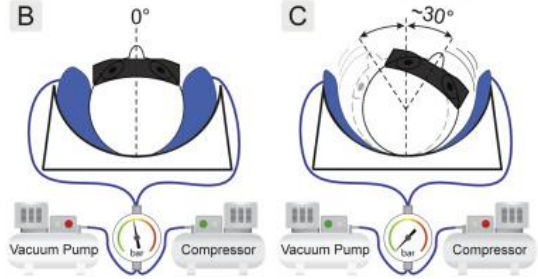


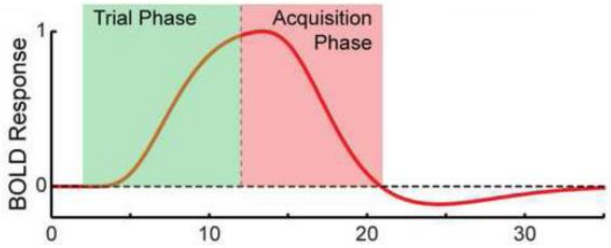
Cavina-Pratesi et al., (2010)

Body: visual-vestibular integration

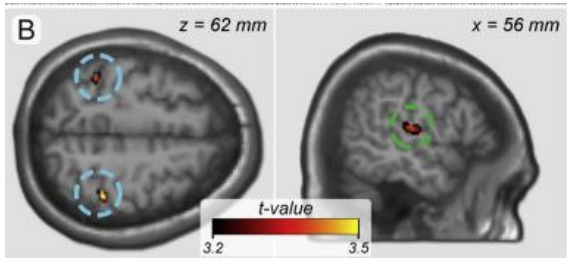
- Participants **moved their head** from side-to-side while experiencing **congruent or incongruent visual flow** via goggles
- **Head returns to midline position (tracked by LEDs**). Fixation colour indicates correct position to participants.
- Due to **slow BOLD response**, analysis could be done on **peak BOLD phase when the head was stable.**





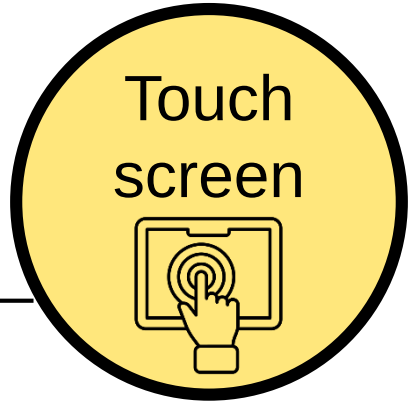


Congruent vs Incongruent Motion



Schindler & Bartels (2018)

Touchscreen

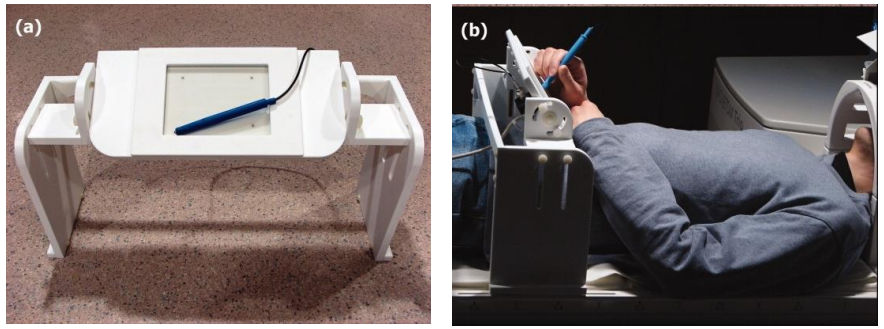


What is it for?

- Recording **continuous movements** from fingers/stylus
- Recording **writing movements**

Approaches:

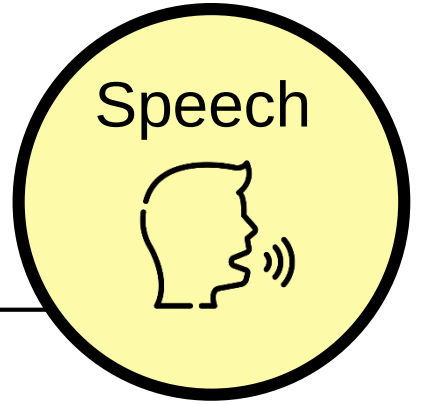
- **Custom adaptation of touch glass** (not developed for MR). Touch glass surface is non ferromagnetic, and can be attached to shielded and filtered cabling



Tablet for writing and drawing during fMRI. Tam et al., 2011

Another example of the touch glass approach:
Gertz et al., 2017

Speech



What is it for:

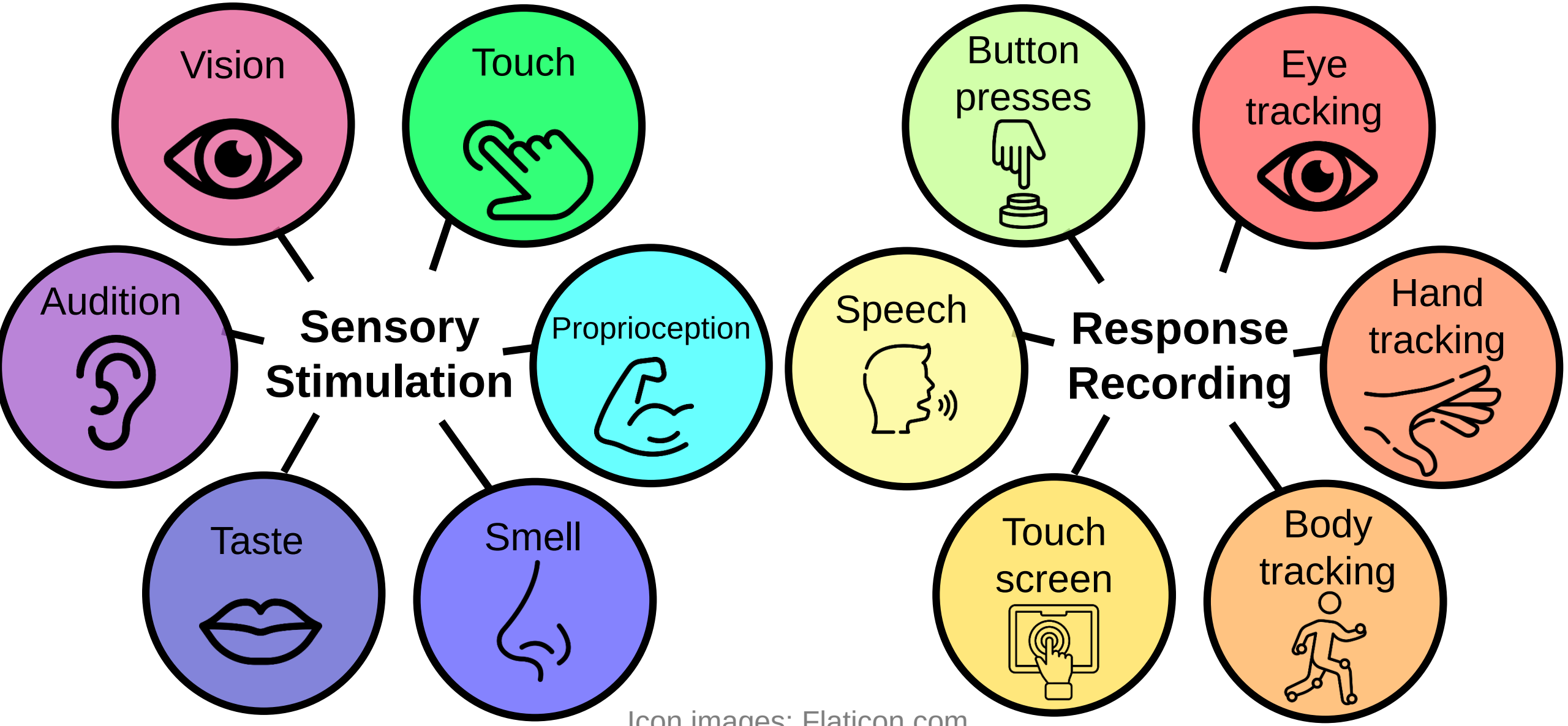
- Recording participant speech

Approaches:

- Commercial MR-compatible microphones
- **Noise-cancelling** (speech without scanner noise interference)
- **Sparse imaging** (see Audition) can also improve speech recording

FOMRI-III microphone

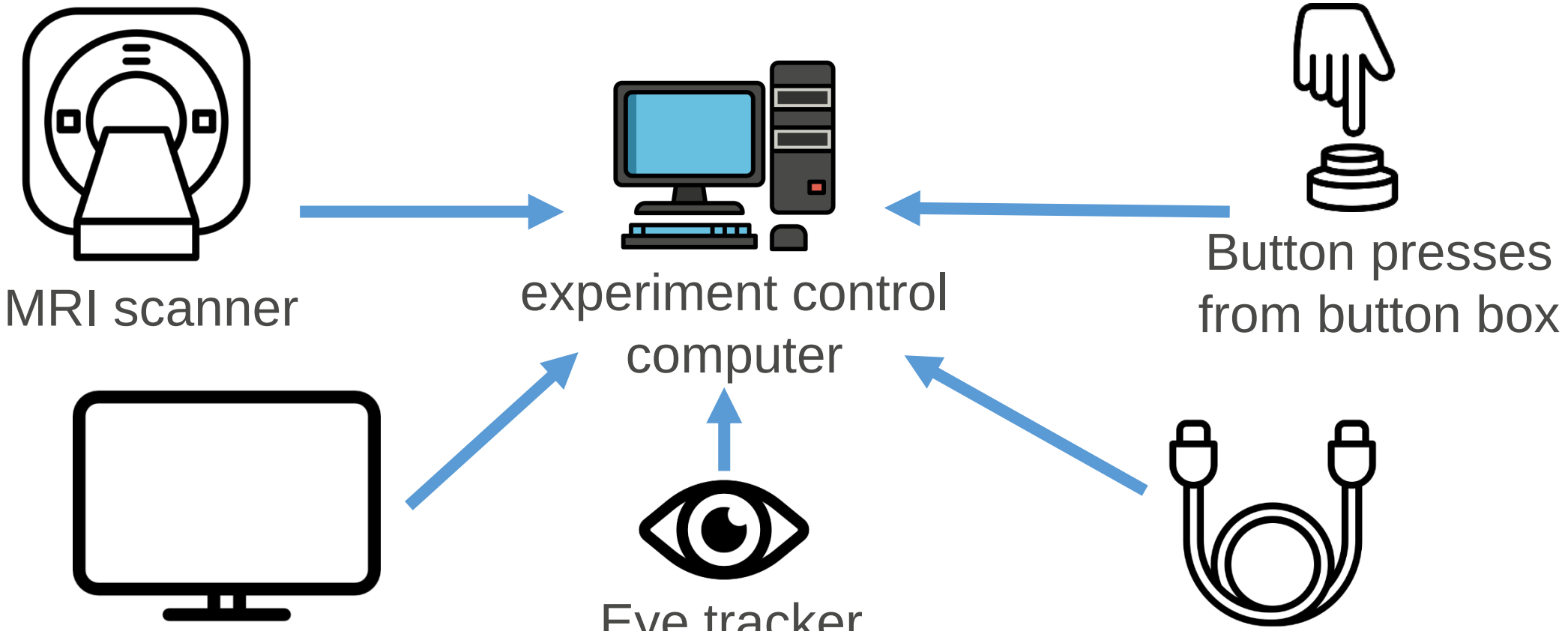
Stimulation and Responses



Icon images: Flaticon.com

Part 3a: Experiment Synchronisation

Multimodal experiment example

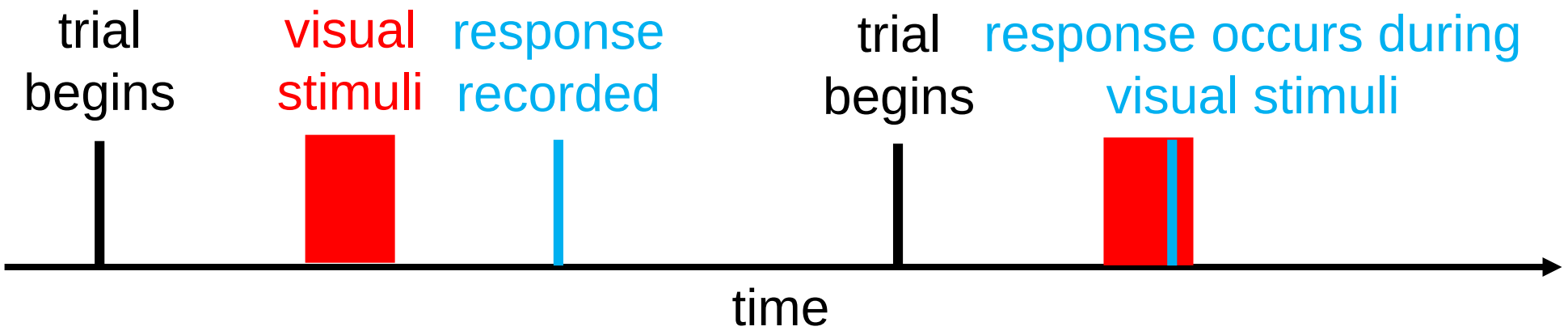


Icon images: Flaticon.com

Multimodal experiments

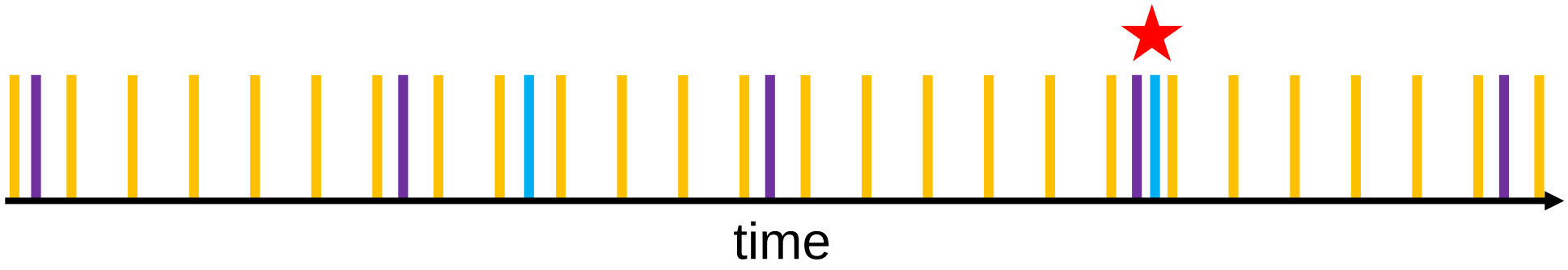
- **Multiple pieces of hardware and software.**
- Experiment code needs to ensure each piece of hardware/software **is triggered at the correct time**.
- Experiment code needs to ensure **accurate timing**.
- Experiment code needs to ensure that **all scanner triggers and participant responses are recorded**.

Example problems



- **Code needs to be able to record responses** (e.g. button presses) that **occur during the visual stimuli**, at the correct time (i.e. not recorded as happening after the visual stimuli).

Example problems



★ Indicates a **scanner trigger and response button press occurring within a response checking window**

- Code **needs to be able to record both** at the correct times (otherwise some triggers/responses could be missed)

General tips

- Use a **toolbox designed for neuroscience/psychology experiments**. They provide the accuracy and flexibility of low-level programming languages (e.g. C), while allowing you to program in a high-level programming language (e.g. Matlab, Python). Psychtoolbox has the most reliable timing and widest variety of features making it very suitable for multimodal imaging studies.
- Research and **read the guidelines** of the hardware and software you use and the experiment control toolbox.

General tips

- **If timing is of key importance to your study** (e.g. synchronous visual/audio stimuli) think about **measuring timing using external devices**, for example:
  - Photometer – measure monitor output.
  - Microphone – measure auditory output.
  - Button press using a motor – measure button press responses with a known response time.
- **Test your experiment** as much as possible to find potential interaction problems.
- **Check your experiment data** for potential problems - participants will do things you never expected!

While loops

While loops continually iterate a loop. They allow you to:

- Continually check if button responses or triggers (e.g. scanner) are received.
- Communicate quickly with devices if a state changes (e.g. at 2 s into the trial, trigger an LED to light up).

Matlab/Octave Example

```
while condition
    % code to repeat
end
```

Python Example

```
while (condition) {
    // code to repeat
}
```

Timing functions

- Timing functions allow you to query the current time and **compare between timestamps** (e.g. current time – trial start).
- **Psychtoolbox GetSecs function**: returns the time in seconds (with high precision), using the **highest precision realtime clock** on each operating system.
- **Comparing timestamps** within a trial means that any random delays do not affect every trial.

```
trialStart = GetSecs;

while 1

    if GetSecs > 2 + trialStart
        break
    end


end
```

Simple example code that ends the loop 2 seconds after the trial start.

Scanner triggers and button presses

- **For many scanners, scanner triggers** (indicating start of a brain volume recording) **and button box key presses** are both **received as key presses** by the experiment computer.
- Scanner triggers and button boxes may or may not been seen as separate devices (depending on operating system, experiment control software, etc.).
- **Psychtoolbox KbQueue Function** outputs **detailed key press information for all keys** (not just the most recently pressed key).
- This **solves many potential interactions problems**, e.g. – wrong button pressed, multiple buttons pressed, scanner trigger and button press occur close in time.

Communication with hardware/software

Input/output hardware

- Connection usually requires identifier of the port the device is connected to (e.g. on Windows Com1; on Linux /dev/ttyACM0)
- Psychtoolbox IOPort allows fast reading/writing of data via a serial port connection

```
% Open connection to device on port /dev/ttyACM0
handle = IOPort('OpenSerialPort', '/dev/ttyACM0');

% Write data to device
IOPort('Write', gogglehandle, 't');

% Read data from device
[data] = IOPort('Read', handle);

% Close connection
IOPort('Close', handle);
```

Other software

- Specific hardware may come with it's own software (e.g. eye tracker control software). You then need to send triggers to/from this software.
- Example, zeromq for tcp connection

```
% connect to eye tracker software via zeroMQ
requester = zmq_request('add_requester', 'tcp://127.0.0.1:50020');
% send message
zmq_request('send_request', requester, 't');
% receive message
reply = zmq_request('receive_reply', requester, 3000);
```

Part 3b: Experiment Synchronisation Demo

Thanks for listening, feedback welcomed!

https://forms.office.com/e/ADJeg2xPf6