MazeBuilder:

A virtual reality tool for use in spatial navigation research

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May 23rd, 2025

An essential **skill** for **autonomy** and **survival** in animal species and humans[1,2]

One of the brain's **most important functions**; brains are only needed by creatures that move around[3]

A complex ability that draws on multiple basic **cognitive processes**[4,5,6,7,8]

Cognitively demanding

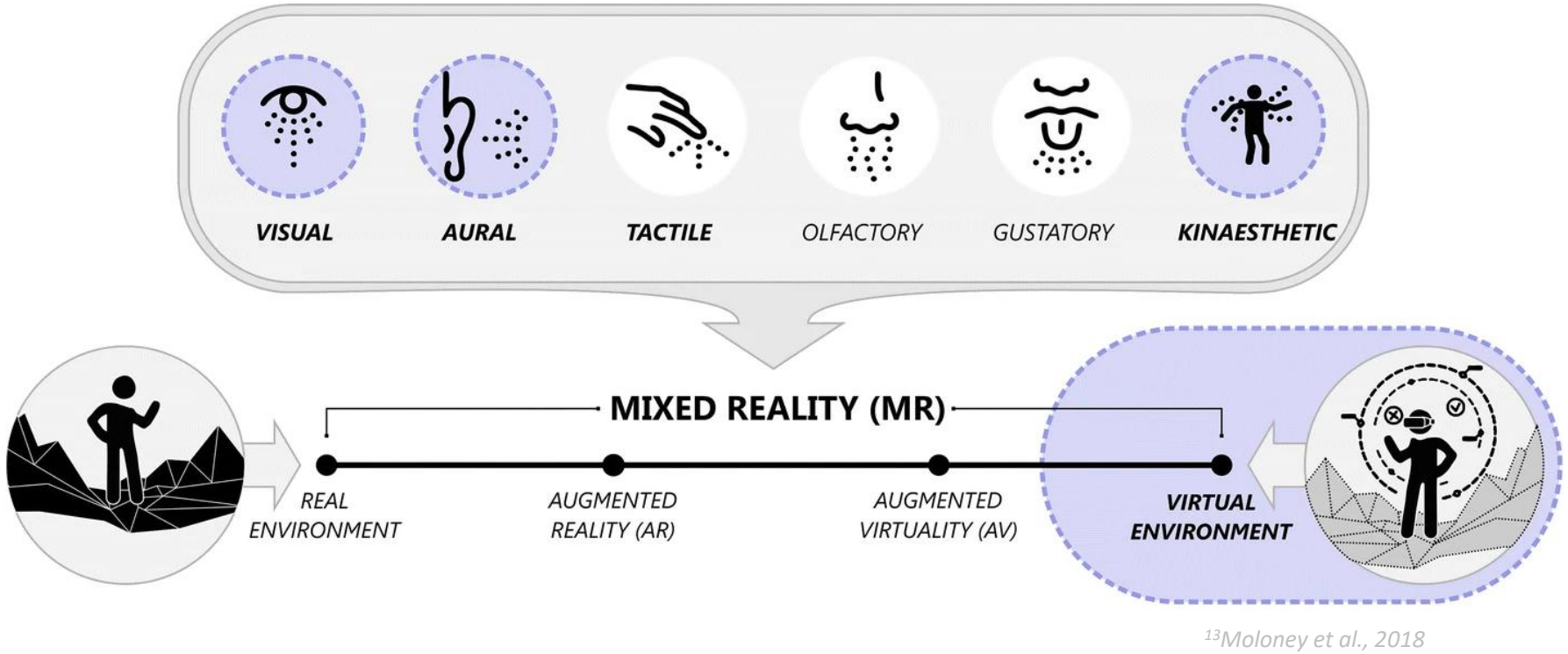
Photo by Eddy Er, 2013

One way to study SN is using **virtual reality**

The use of virtual reality (VR) in neuroscience research has grown steadily alongside wider availability of affordable head-mounted displays[10]

VR provides the ability to study spatial navigation in a **safe** and **ecologically-valid environment**

Benefits of VR include **heightened realism** and an **increased immersive experience** while allowing for **experimental control**[11]



[13]Moloney et al., 2018

SN performance in VR and in real life are **highly correlated**[11,12]

Can be paired with neuroimaging

The use of **non-invasive neuroimaging** such as EEG during spatial navigation in VR allows us to evaluate **neural correlates** in humans during the performance of realistic navigation tasks

Problem: There are accessibility barriers related to **programming knowledge** and **access to resources** that hinder widespread VR use and the development of more applications in research

Problem: Cybersickness

Exposure to VR technology; similar to motion sickness[14-16]

General discomfort, eye strain, stomach awareness, nausea, pallor, sweating, fatigue, drowsiness, disorientation, etc.[17-20]

61–80% experience increased discomfort after short VR exposure[21] Dropout rates of 20% or more are common[22,23]

CAN LAST UP TO 24 HOURS[19]

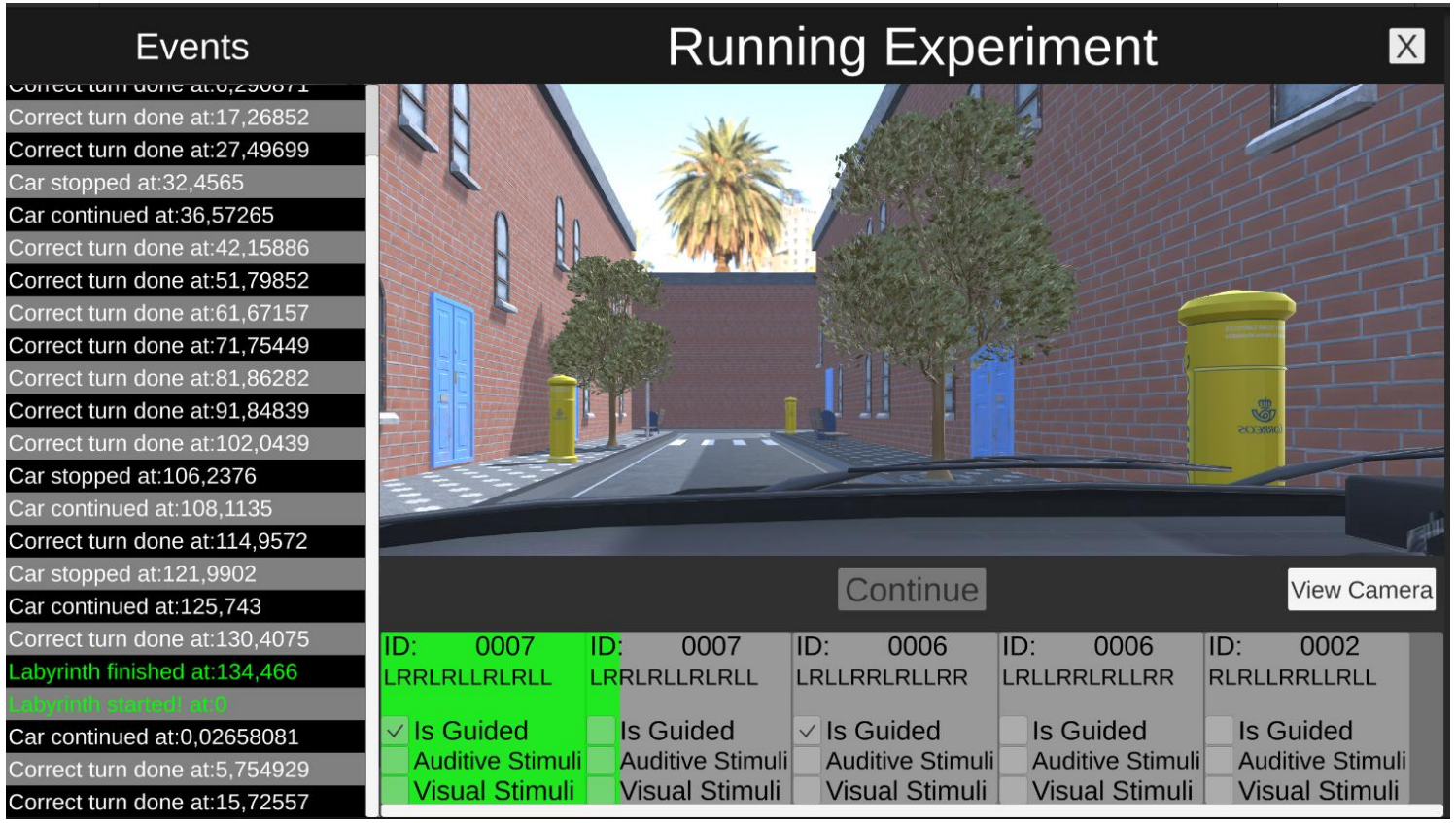
Consequences: negative user experience, reduced performance and use, shortened duration of VR exposure, diminished overall enjoyment, lower likelihood of repeat use[17-25]

OBJECTIVE:

Reduce barriers to the use of virtual reality in neuroscience research, through the design and dissemination of open-access software with a cybersickness pre-screening

MazeBuilder

Introducing MazeBuilder: a **stand-alone open-access** tool, which allows researchers to easily create **virtual environments** and use them in SN **research**



The environment reproduces the streets of a **customizable city-like environment**, that the participant navigates while **driving a car**

No previous VR or game engine knowledge necessary. The tool can be downloaded as an:

Executable program

Unity program

Can be rendered using **standard, commercially available VR gear** or a **computer monitor/keyboard**

Minimal requirements for Unity include:
any CPU supporting SSE2, RAM memory 4 to 8 GB
and a Graphics Card that is DirectX10 compatible

Different ways to move around

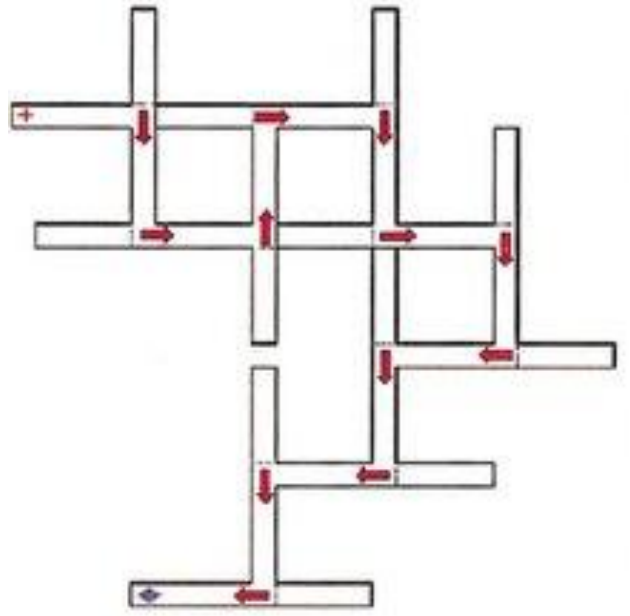
Importantly, software **can be used even without VR**

MazeBuilder

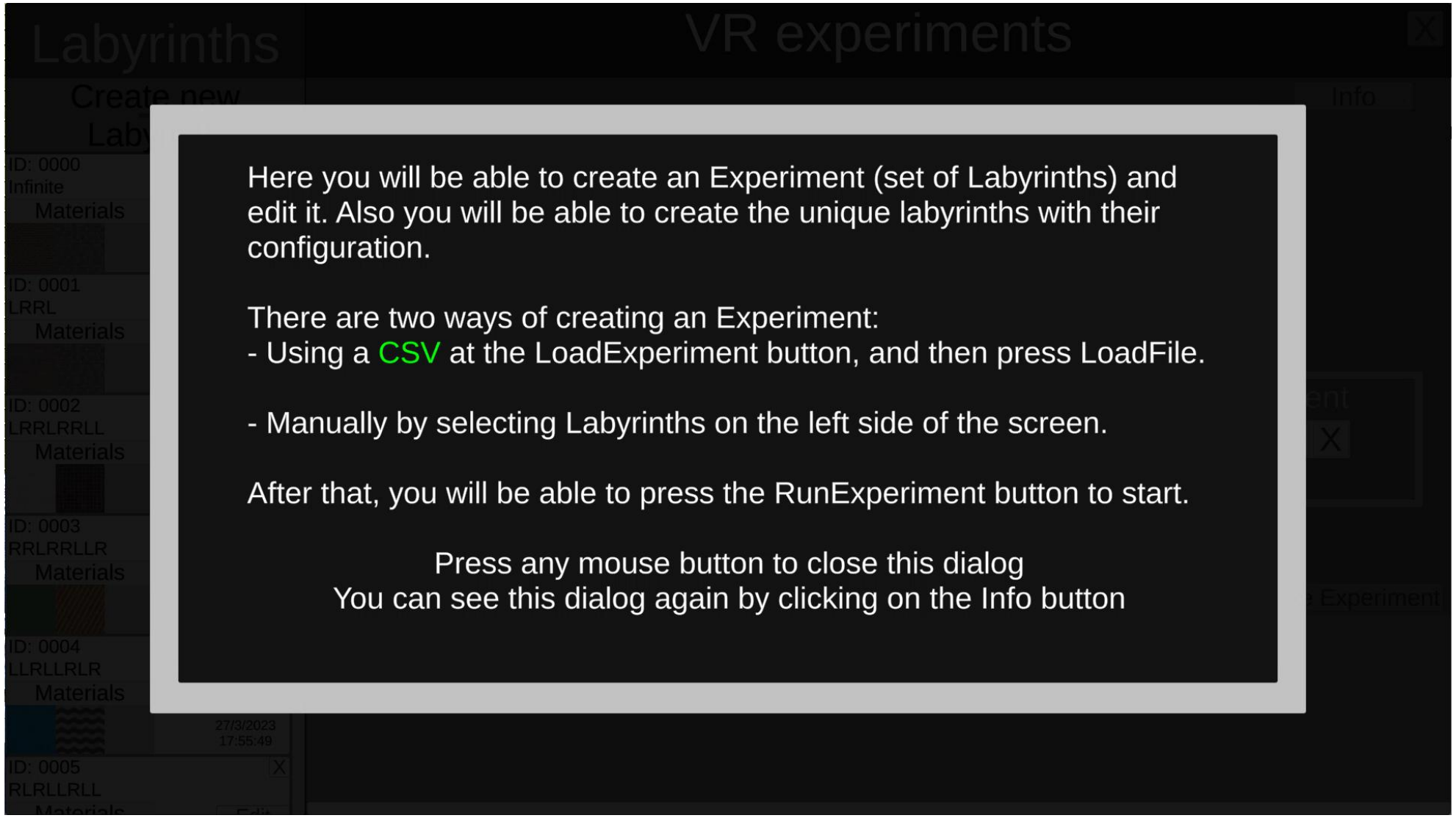
In MazeBuilder, the researcher can easily **create**, **store**, and **present** T-junction mazes with pre-designed trajectories

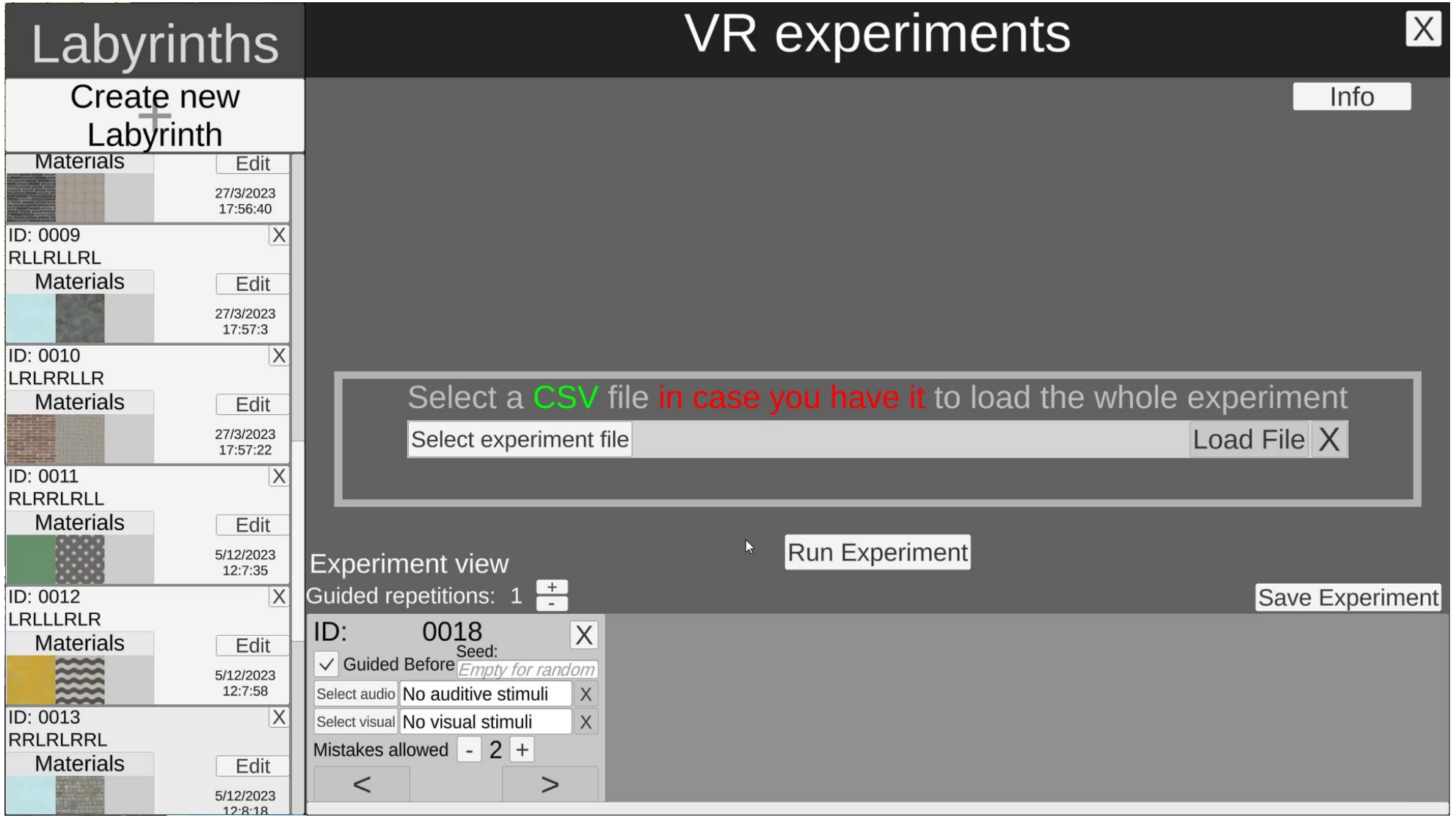
Capabilities:

- Edit maze characteristics
- Create experiments made up of numerous mazes
- Edit experiment properties (maze order, number of errors, guided/non-guided, etc.)
- Load and save experiments
- Record behavioural data
- Synchronization to EEG
- Eye-tracking capabilities
- Additional audio and visual stimulation



Interface: Maze Design and Execution




Labyrinths
VR experiments
Create new Labyrinth
Info
Materials
Edit
27/3/2023 17:56:40
ID: 0009
RLLRLLRL
27/3/2023 17:57:3
ID: 0010
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ID: 0011
RLRRLRLL
5/12/2023 12:7:35
ID: 0012
LRLLLRLR
5/12/2023 12:7:58
ID: 0013
RRLRLRRL
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Select a CSV file in case you have it to load the whole experiment
Select experiment file
Load File
Run Experiment
Experiment view
Guided repetitions: 1
Save Experiment
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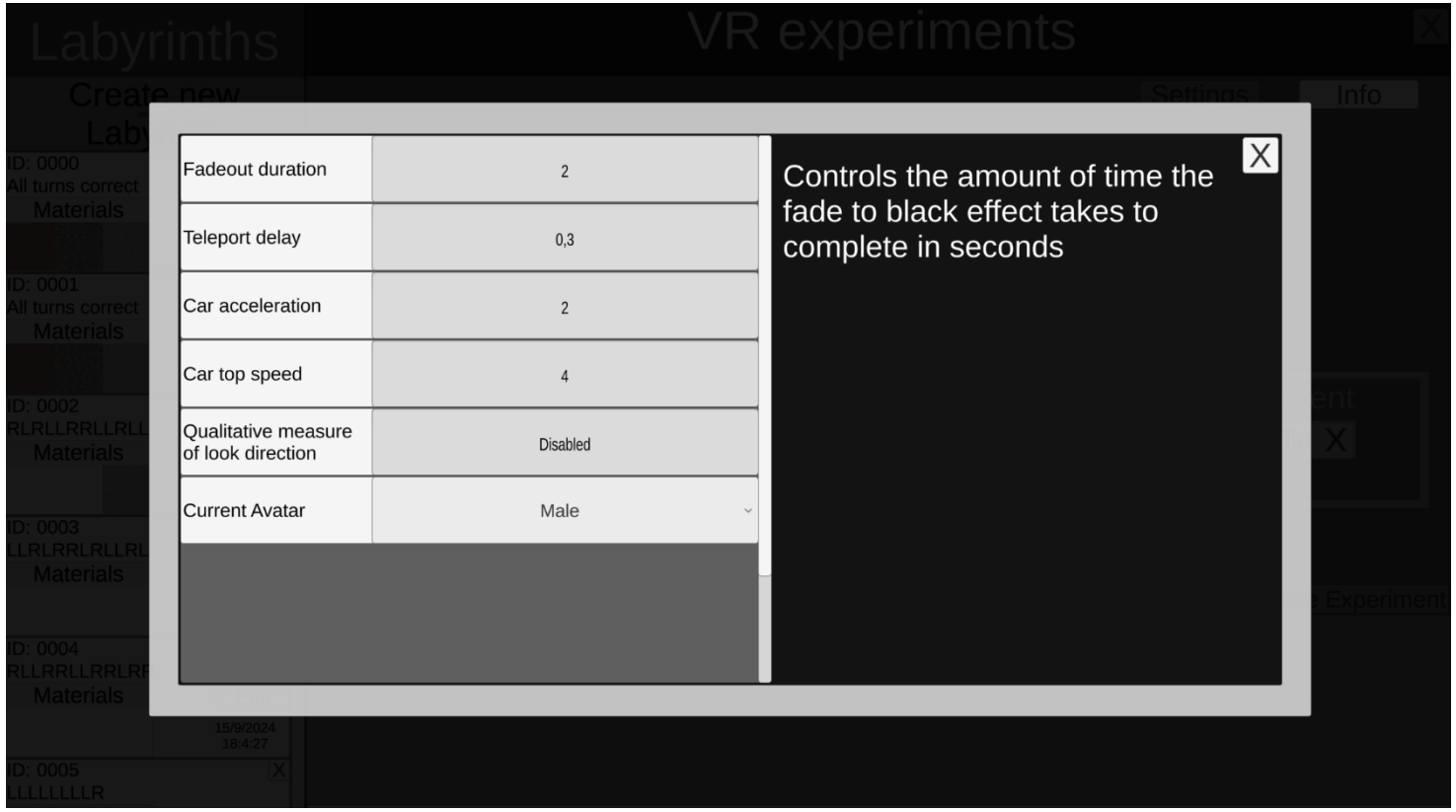
Guided Before
Seed:
Empty for random
Select audio
No auditive stimuli
Select visual
No visual stimuli
Mistakes allowed - 2 +



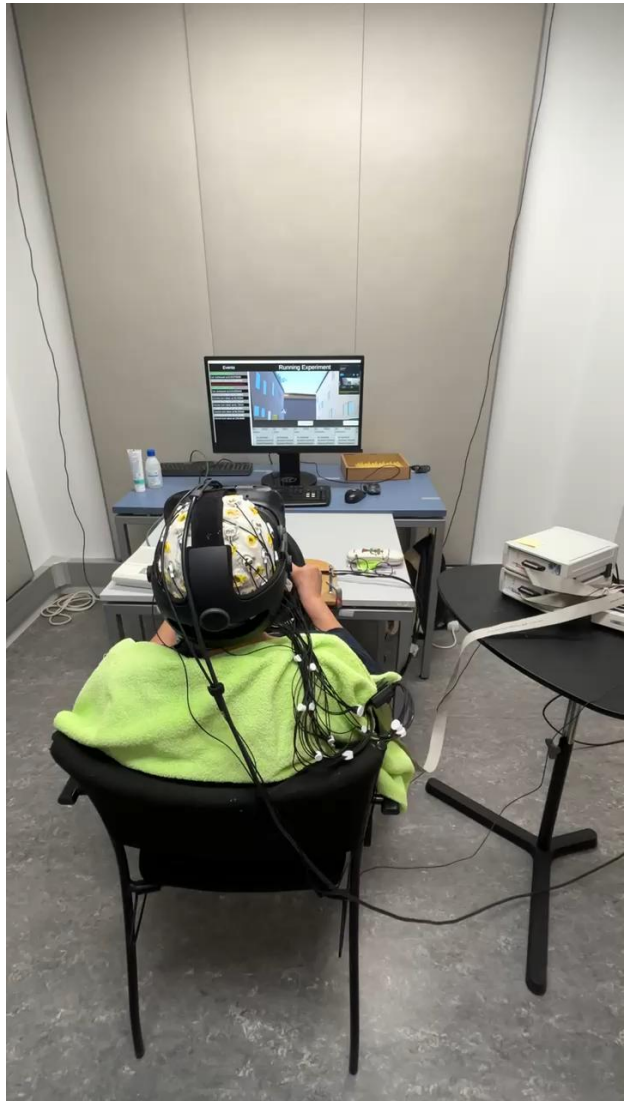
Fadeout

Teleport delay

Acceleration and top speed

Avatar

You can also add new settings to this screen

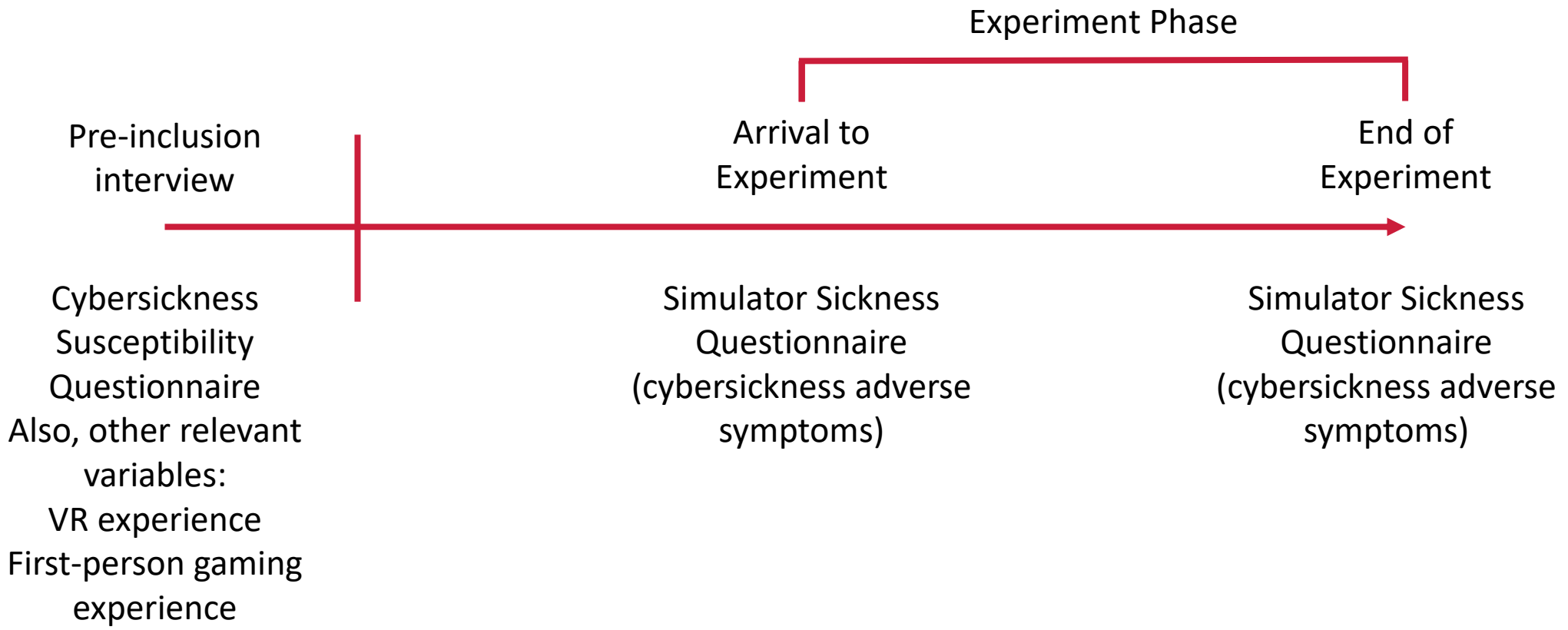


Behavioural data files
Eye tracker logs
EEG recording

Open-access
No programming knowledge required
Experimentally validated
Ability to integrate sensory stimulation
Ability to use alongside EEG and eye-tracking

MazeBuilder: Screening Workflow

MazeBuilder incorporates a screening workflow to reduce participant drop-out due to cybersickness

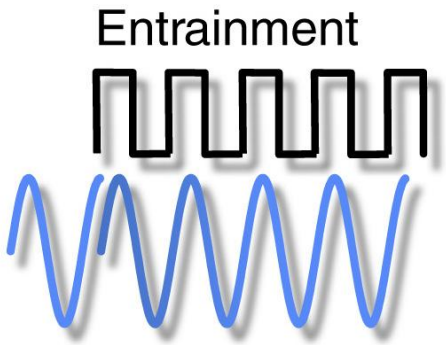


Proof of Concept Studies

Several different experiments done with MazeBuilder so far:

Topomark Young Adults

Entrainment



Topomark Older Adults

Proof of Concept: Topomark

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Volume 35, Issue 4
April 2025

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JOURNAL ARTICLE

Single-trial characterization of frontal theta and parietal alpha oscillatory episodes during spatial navigation in humans

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Mireia Torralba-Cuello ✉ , Angela Marti-Marca , Márta Szabina Pápai , Salvador Soto-Faraco

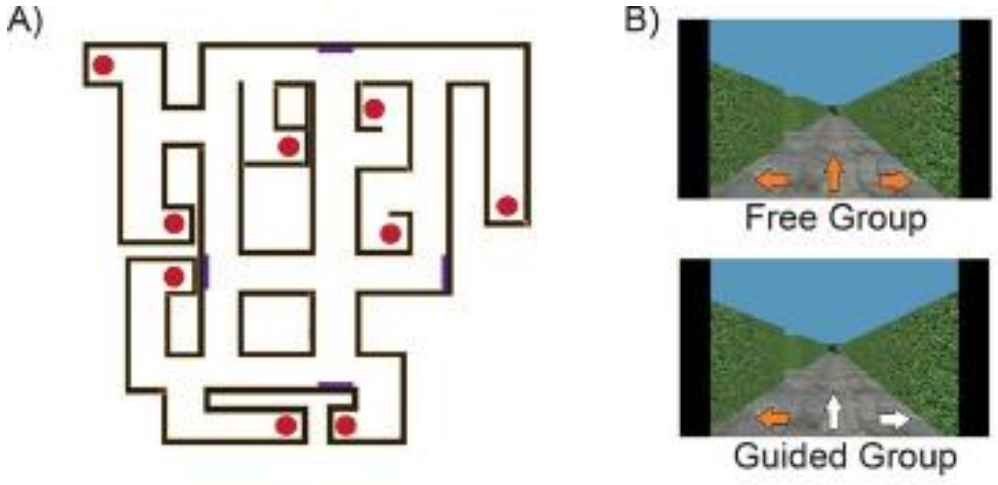
Cerebral Cortex, Volume 35, Issue 4, April 2025, bhaf083,
https://doi.org/10.1093/cercor/bhaf083
Published: 23 April 2025 **Article history** ▾

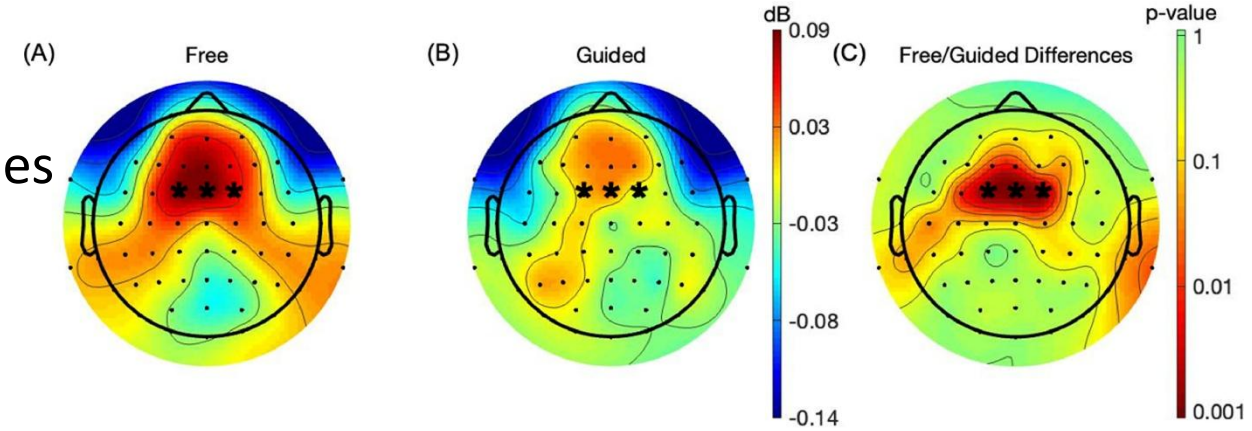
SCAN ME FOR ARTICLE

In both animal models and humans, **hippocampal theta** (3-8Hz) linked to spatial navigation

Amplitude of theta oscillations has been found to increase during:

- **movement** vs. standing still[24]
- **navigation** vs. non-navigation[25]
- **difficult** vs. easy tasks[26,27]
- **free-roaming** vs. guided[28]
- approaching a **target**[29]
- **collisions**[30]
- **path re-calculation**[31]
- **post navigational**[32,33] (some studies indicate **successful**[34,35]**, but**[27]) decision





Chrastil et al., 2022

Alpha oscillatory activity (8-14Hz) linked to spatial navigation

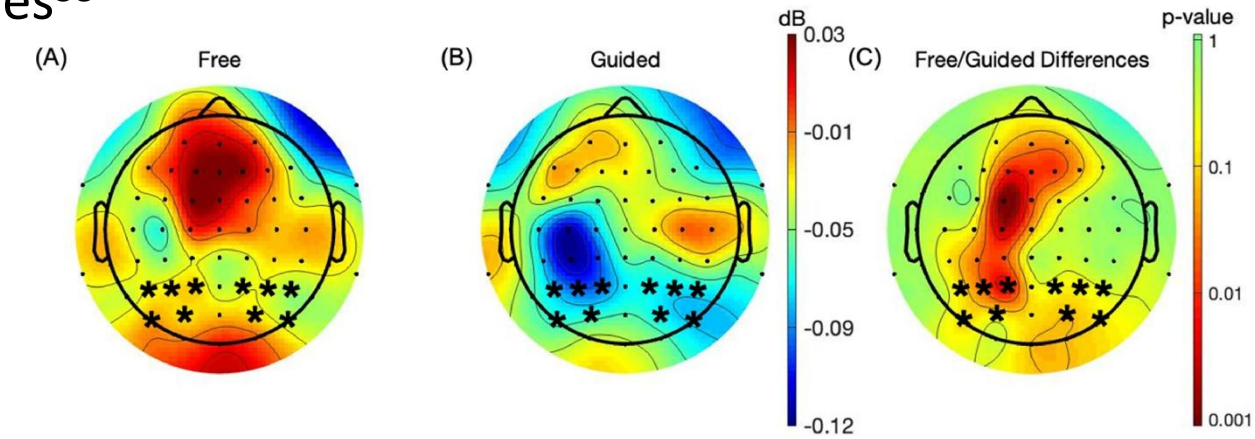
Amplitude of alpha oscillations decreases during:

- **information gathering**[36]
- **navigation** vs. non-navigation[37]
- **collisions**[38]

And increases during:

- **free roaming** vs. guided navigation[35]
- **walking away** from maze boundaries[38]

There is a link between theta and alpha oscillations and aspects of spatial navigation



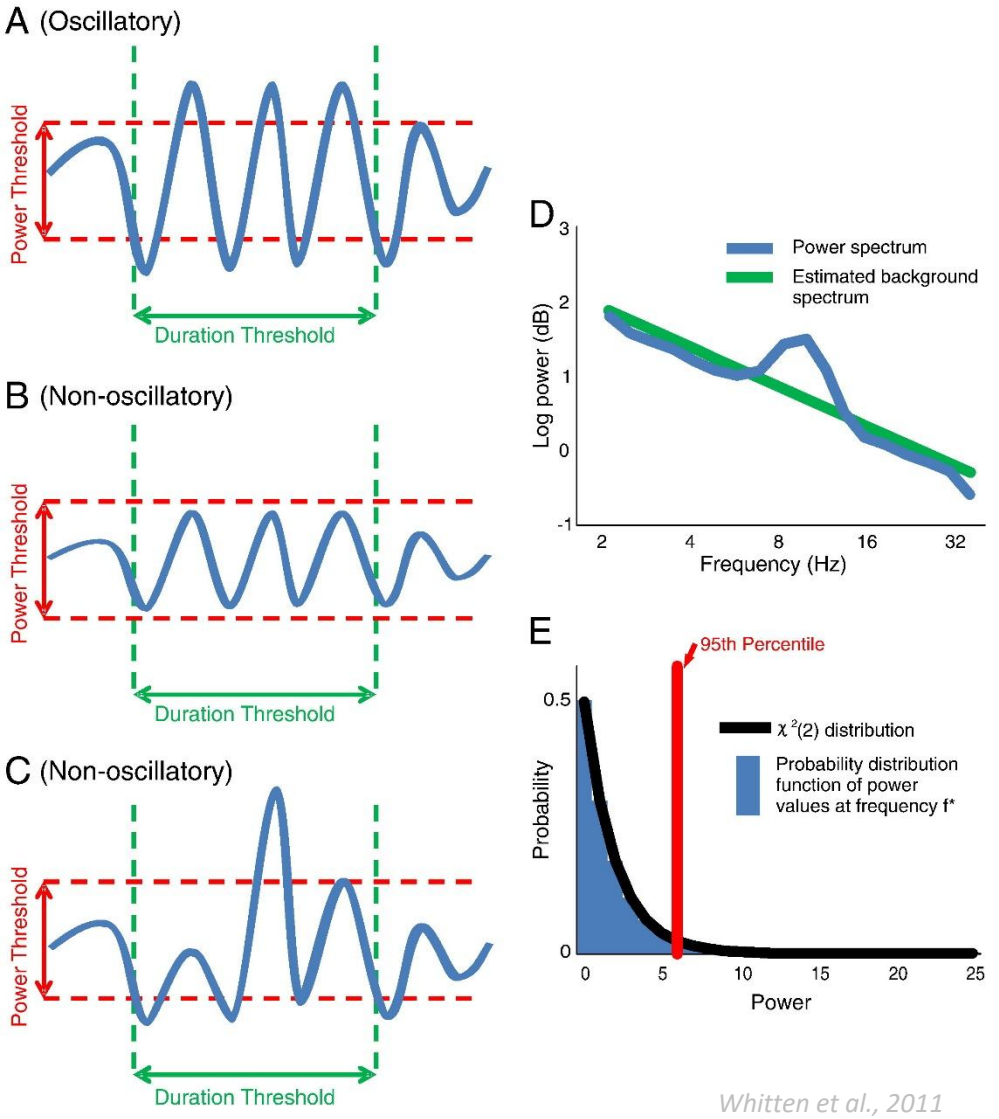
Chrastil et al., 2022

Proof of Concept: Topomark

Oscillatory activity is important to SN theories, but non-invasive research in humans is **limited**

Most studies have focused on **averaged** activity not on momentary variability; aperiodic activity

Important to study **transient** episodes of oscillatory activity separately from background, **aperiodic** neural activity



Whitten et al., 2011

Objective and Hypothesis

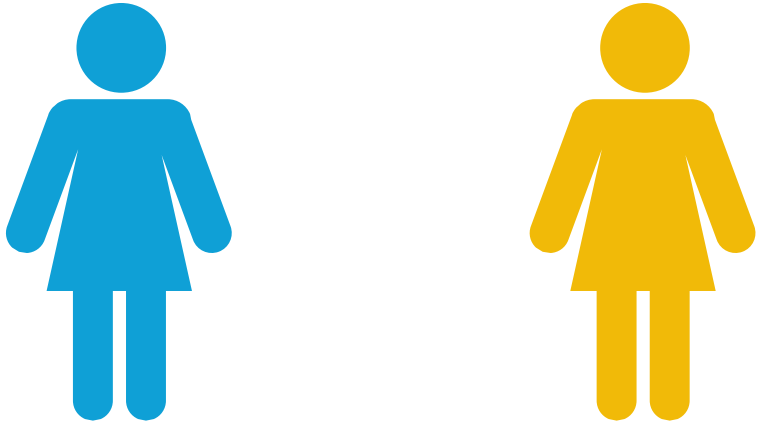
to study theta and alpha oscillatory episodes at single-trial level during learning and recall of paths in a VR environment, using EEG

RESEARCH QUESTION:

How do **oscillatory episodes**, specifically modulations in the abundance of theta and alpha oscillatory activity at a single-trial level relate to **navigational task demands**?

HYPOTHESIS: Theta and alpha activity encode relevant information related to spatial navigation and therefore we predict that oscillatory episodes at each of the frequency bands can be related to **different aspects** of the spatial navigation task

Participants



24 participants
11 males, 13 females
25.21±5.33 years old

Exclusion criteria:

- History of epilepsy, diagnosed neurological or psychiatric disorder, motion sickness susceptibility (screened prior to inclusion using the CSQ)

Method

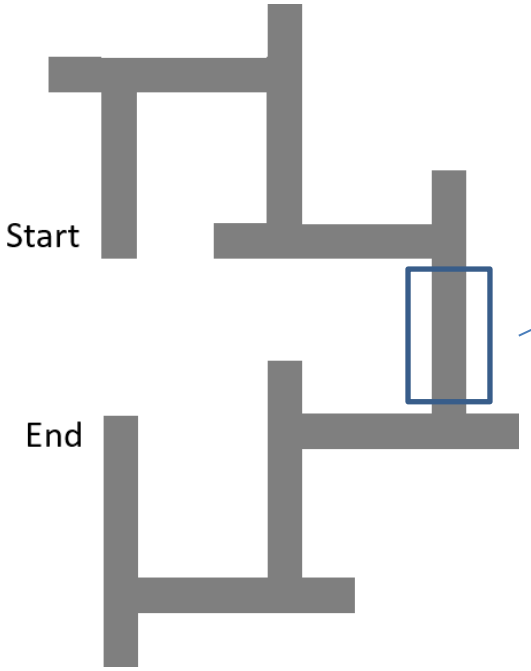
VR Environment

Habituation → Training → Stage 1 → Distractor task → Stage 2

T-junction environment
No dead ends
Until familiarization with commands

5 T-junction mazes (10 junctions each)
Each maze:
Guided (up to 3 runs)
Immediate recall (up to 3 runs)

5 T-junction mazes (10 junctions each)
Each maze:
Delayed recall (up to 5 runs)



3 X

Guided

Immediate Recall

5 X

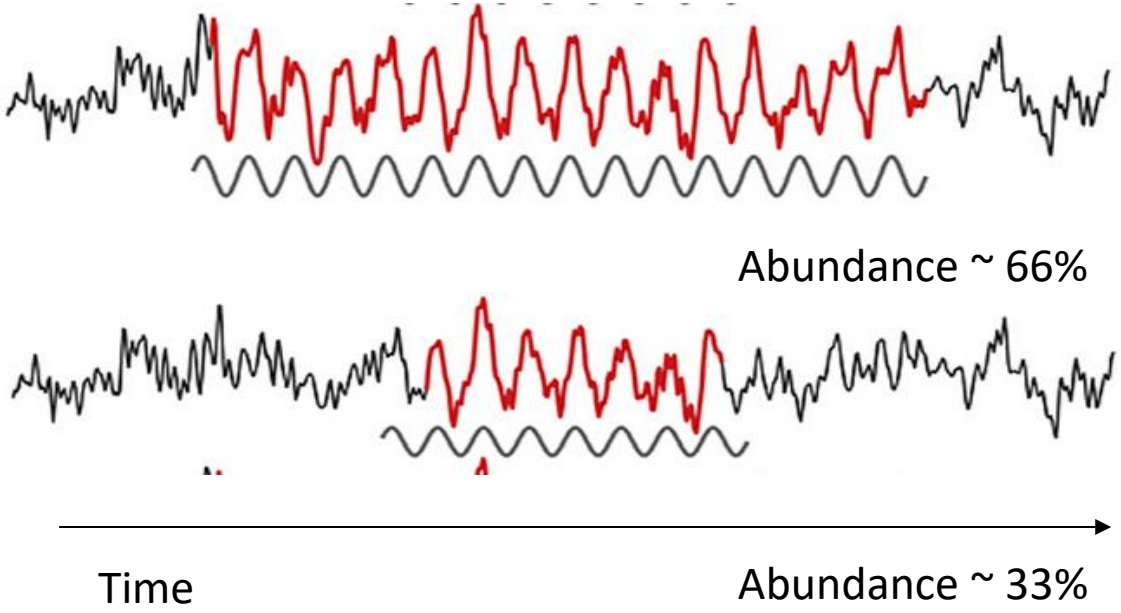
Delayed Recall

64 active electrodes, 500 Hz sampling rate, theta (3 to 8 Hz) and alpha (8.5 to 14 Hz)

fBOSC toolbox[40] used to identify **oscillatory episodes**

Abundance: the percentage of time in which an oscillatory episode is detected in a given segment of data

The electrodes with the highest theta and alpha abundance at the group level were then used for further trial analyses



$$Abundance \sim \text{Stage} + \text{Run} + \text{Junction} + \text{Time} + \text{Correct} + \text{Solved} + (1|\text{Participant})$$

Time-scale

Stage

Immediate recall

Delayed recall

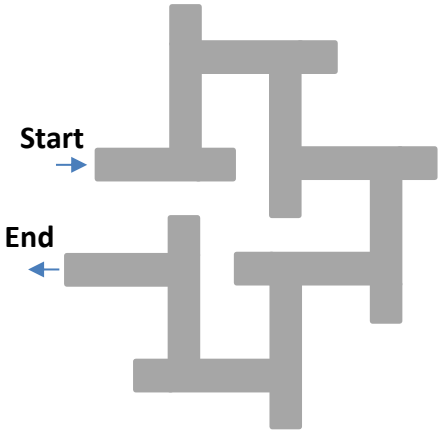
Run

1

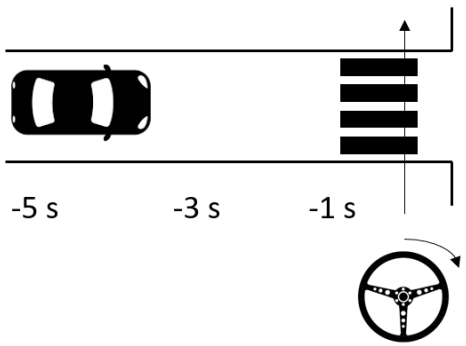
2

1

Junction



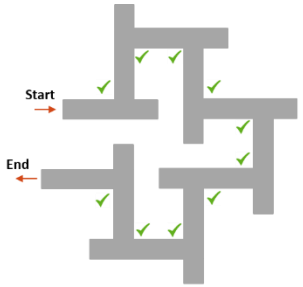
Time to decision

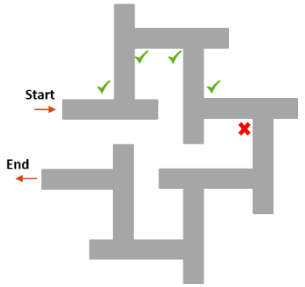


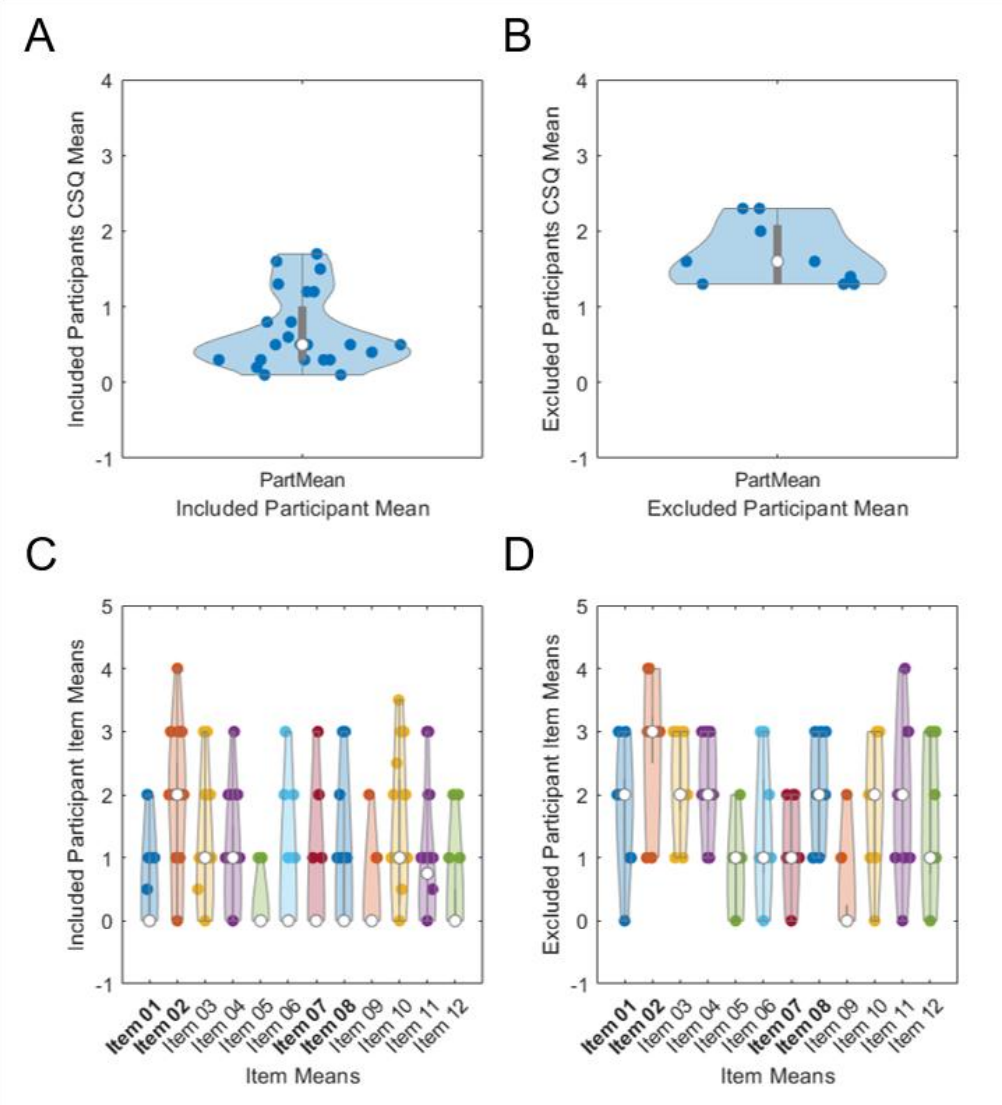
Accuracy

Correct

Solved







Cybersickness Susceptibility Questionnaire:

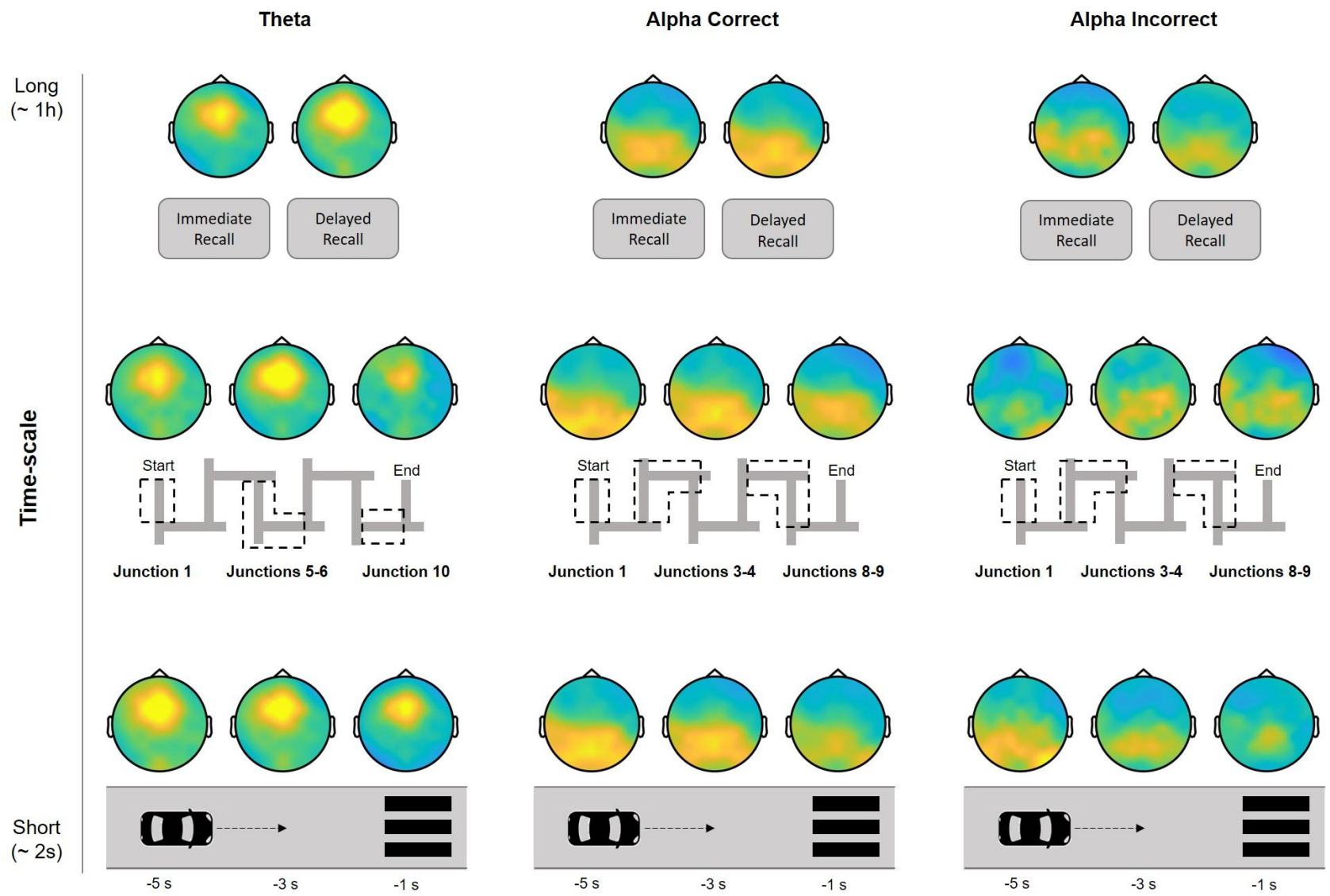
- **included**, mean score of **0.7±0.48** on the Motion Sickness portion ("rarely")
- **excluded** participants (n=9); mean score of **1.7±0.40** ("occasionally")

Particular interest to specific items: **cars** (items 1, 2) and **buses** (7-8); excluded had higher ratings

Simulator Sickness Questionnaire (presence of potentially adverse symptoms); mean total score 2.0±1.57 (max=60); none were excluded

0% attrition rate!!

Results


Theta
Alpha Correct
Alpha Incorrect
Long
(~ 1h)
Immediate Recall
Delayed Recall
Time-scale
Start
End
Junction 1
Junctions 5-6
Junction 10
Junctions 3-4
Junctions 8-9
Short
(~ 2s)
-5 s
-3 s
-1 s

Discussion

- An increased abundance of theta episodes during Delayed as compared to Immediate recall; **more abundant on difficult tasks** perhaps showing effortful retrieval of previously encoded paths.
- This could also explain why theta abundance is higher in the middle portions of the maze as there is no primacy or recency effect here.
- We see increased abundance at the early moments of a junction, which might suggest that subjects **accessed encoded path information early** and once a decision is made, encoded information is no longer accessed.
- **Theta might be related to the difficulty of the task and access to encoded information**

Discussion

- Alpha abundance on the other hand was related with successful navigational decisions, with increased abundance being seeing on trials preceding a correct decision; perhaps active inhibition of task-irrelevant representations
- May also represent switches between internal and external attention; this would also explain why alpha abundance is higher on delayed recall stage (suppress distracting info to focus on accessing internal representations)
- **Alpha might be related to switching and focusing attention**

Future Steps

The next version of MazeBuilder will incorporate a free roaming mode, in a grid-like environment, with customizable landmarks

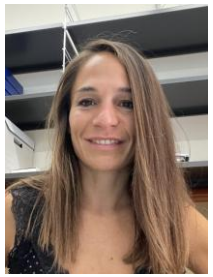
Currently running experiments on older adults

All of the information will be open source and available on Github

DEMO DURING POSTER SESSION! COME FIND US

Acknowledgments

Thanks for your attention!






References

[1]Iggena et al., 2023
[2]Parra-Barrero et al., 2023
[3]Llinás, 2001
[4]Albert et al. 1999
[5]Eichenbaum 2017
[6]Do et al. 2021
[7]Patai and Spiers 2021
[8]Parra-Barrero et al. 2023
[9]Lithfous et al., 2013
[10]Rouhani et al., 2024
[11]Diersch & Wolbers, 2019
[12]Cushman et al. 2008
[13]Moloney et al., 2018
[14]Cobb et al., 1999
[15]Kim et al., 2018
[16]Keshavarz et al., 2022
[17]Kennedy et al., 1993
[18]LaViola, 2000
[19]Stanney et al., 2003
[20]Cha et al., 2021
[21]Lassoe et al., 2023
[22]Reed et al., 2007
[23]Stanney et al., 1999
24Liang et al., 2018
25Araújo et al., 2002
26Kahana et al., 1999
27Caplan et al., 2001
28Chrastil et al., 2022
29Bauer et al., 2021
30Gehrke & Gramann, 2021
31Do et al., 2021
[32]Bischof & Boulanger, 2003
[33]White et al., 2012
[34]Bauer et al., 2021
[35]Chrastil et al., 2022
[36]Delaux et al., 2021
[37]Araújo et al., 2002
[38]Gehrke & Gramann, 2021
[39]Whitten et al., 2011
[40]Seymour et al., 2022