

Reporting Summary

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Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- ☐ ☒ The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement
- ☐ ☒ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
- ☐ ☒ The statistical test(s) used AND whether they are one- or two-sided
Only common tests should be described solely by name; describe more complex techniques in the Methods section.
- ☐ ☒ A description of all covariates tested
- ☐ ☒ A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
- ☐ ☒ A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
- ☐ ☒ For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
Give P values as exact values whenever suitable.
- ☒ ☐ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
- ☒ ☐ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
- ☐ ☒ Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection

The experimental paradigm was conducted using Matlab 2019b and the toolbox 'Psychtoolbox' (<http://psychtoolbox.org/>; accessed September 2019). EEG data were recorded using an EGo EEG system (ANT Neuro Enschede, Netherlands) with 65 Ag/AgCl electrodes arranged in a 10/10 system layout (including left and right mastoids; using CPz as the reference and AFz as the ground). iEEG data were recorded using XLEK Neuroworks software (Natus Medical, San Carlos, California, USA) and an XLEK EMU128FS amplifier. Eye-tracking data was acquired using a Tobii Pro Spectrum system (Tobii AB, Sweden). Head rotations were recorded using a Polhemus Liberty system (Polhemus, Colchester, USA).

Data analysis

The EEG/iEEG data was analysed using Matlab 2021b, using the toolboxes 'Fieldtrip' (<https://www.fieldtriptoolbox.org/>) and 'Circular Statistics' (<https://github.com/circstat/circstatmatlab>), and custom code. Custom code is available at <https://github.com/benjaminGriffiths/human-hd>. The MRI data was analysed using SPM12 (<https://github.com/spm/spm12>; accessed January 2022), WFU_PickAtlas (https://www.nitrc.org/projects/wfu_pickatlas/; accessed January 2022) and Lead-DBS (<https://www.lead-dbs.org/>; accessed January 2022).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

Data acquired from the healthy participants will be made available upon publication. Due to concerns about patient anonymity, data acquired from the patients can be provided upon reasonable request.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender

No sex- or gender-based analyses were conducted as we had no a priori reason to suspect sex-/gender-related differences in our experiment.

Reporting on race, ethnicity, or other socially relevant groupings

No race-, ethnicity- or other socially relevant-based analyses were conducted as we had no a priori reason to suspect race-/ethnicity/other socially relevant-related differences in our experiment.

Population characteristics

See "Behavioural and social sciences study design" section

Recruitment

The healthy participants were recruited using a university-based e-mail list of interested individuals and through Facebook adverts.

Ethics oversight

The study was approved by the local ethics committee at LMU.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences

☒ Behavioural & social sciences

☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description

The study had a quantitative within-participants experimental design. Participants were equipped with an EEG cap or had implanted intracranial EEG electrodes. Participants were tasked with rotating their heads towards target displays in a variety of experiment setups (e.g., the use of/lack of cues; the positioning of the participant). EEG, eyetracking and motion tracking data were recorded simultaneously throughout the experiment. Experiment 1 contained an additional memory and sleep component not analysed here (see Schreiner et al., 2023, bioRxiv). This occurred after the fourth task and before the fifth task.

Research sample

Participants were young adults (age 18 to 40) and approximately equal parts male and female (see methods section for full details).

Sampling strategy

The sampling procedure was self-selecting: participants were contacted with details about the study and asked to get back in touch if they were interested in taking part. For Experiment 1, the scalp EEG sample matched the sample size used by similar studies of healthy participants (e.g., Kim et al., 2019, Hippocampus, n=30; Nau et al., 2020, Nat. Comm., n=20); the iEEG sample matched the sample size used by studies involving intracranial recordings (e.g., Topalovic et al., 2023, Nat. Neuro., n=12; Stangl et al., 2020, Nature, n=5). For Experiment 2, a power analysis was conducted using the data from Experiment 1, where a sample of 24 healthy participants was deemed sufficient to find an effect when power was > 0.9.

Data collection

The paradigm was presented on a standard computer monitor. Electrophysiological data was collected using an ANT Neuro EEG system or (in the case of the patients) Spencer depth electrodes on a XLTEK Neuroworks system. Eye-tracking data was collected using a Tobii Pro Spectrum system. Head-tracking data was collected using a Polhemus Liberty system. No one was present besides the participants and the researcher. The researcher and participant were aware of the current task (e.g., "head rotation without sound"; "virtual reality") as they needed to understand the associated instructions. The researcher was aware of the hypotheses. Participants had a lay understanding of what the experiment was investigating, but did not know the specifics of the hypotheses.

Timing

Data collection began around June 2020 and concluded around December 2022

Data exclusions

Several participants were excluded from the analysis due to recording complications.

For scalp EEG recordings of Experiment 1, 6 participants were excluded due to complications with motion tracking recordings. An additional participant was excluded from the "rotation without visual input" component of the analyses for the same reason. One participant was excluded from the "cued eye movements" task due to EEG recording complications. Three participants were excluded from the "rotation without visual input" task as they dropped out during the sleep stage of the experiment.

For the iEEG recordings of Experiment 1, one participant was excluded from all analyses due to motion recording complications. Three participants were excluded from the "cued eye movements" task due to eyetracking complications. One participant was excluded from the "rotation without visual input" task as they dropped out during the sleep stage of the experiment.

In Experiment 2, four participants were excluded from all analyses due to motion recording complications.

Non-participation

No participants declined to participate. Four participants dropped out after the sleep stage of Experiment 1 (three from the scalp EEG sample; one from the iEEG sample).

Randomization

N/A - it was a within-participant design, so participants were not assigned to experimental groups

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging