

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

Data were collected with readily available software (Psychtoolbox, Brainard, 1997, RRIC SCR_002881; MATLAB 2018a, Mathworks, RRID SCR_001622).

Data analysis

Data were analyzed with readily available software (FieldTrip, Oostenveld et al., 2011, <http://www.fieldtriptoolbox.org/>; CircStat 2012, Berens, 2009, <https://philippberens.wordpress.com/code/circstats/>; CURRY 7.0, Compumedics Neuroscan, RRID: SCR_009546; Automated Anatomical Labeling, Tzourio-Mazoyer et al., 2002, <http://www.jichi.ac.jp/brainlab/tools.html>).

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/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research [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 list of figures that have associated raw data
- A description of any restrictions on data availability

The data that support the findings of this study are available from the corresponding author upon request.

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](https://www.nature.com/documents/nr-reporting-summary-flat.pdf)

Life sciences study design

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

Sample size	No statistical methods were used to pre-determine sample sizes but our sample sizes are similar to those reported in previous publications (Violante et al. 2017 <i>Elife</i> ; Helfrich et al. 2014 <i>Public Library of Sciences, Biology</i> ; Polania et al. 2012 <i>Current Biology</i>).
Data exclusions	Out of 91 subjects from Experiment 1, 5 were excluded due to excessive eye movements and 2 voluntarily withdrew before completing the study. Out of 31 subjects from Experiment 2, 3 voluntarily withdrew before completing the study. No subjects were excluded in Experiments 3 and 4. It is common in the field of human electrophysiology to have a small number of subjects removed due to excessive eye movements and it is common in multi-day human neuroscience studies that not all subjects will be retained.
Replication	The primary behavioral findings of Experiment 1 were replicated in a second cohort of subjects in Experiment 2.
Randomization	The order of stimulation was counterbalanced across subjects in Experiments 1 and 3, randomized across subjects in Experiment 2, and a pre-stimulation baseline control was implemented in Experiment 4 in addition to the sham control condition from Experiment 1. Randomization procedures were also used in stimulus presentations and experimental conditions. Duration of the intertrial interval was randomly jittered with a rectangular distribution. Target presence trials were randomly interleaved with target absent trials. Clockwise tilt trials were randomly interleaved with counterclockwise tilt trials. The memory and non-memory control blocks were administered in a block-wise fashion in alternating order.
Blinding	The experiments were double blind (both subject and experimenter blinding was instituted), sham-controlled, and within-subjects.

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
<input checked="" type="checkbox"/>	<input type="checkbox"/> Antibodies
<input checked="" type="checkbox"/>	<input type="checkbox"/> Eukaryotic cell lines
<input checked="" type="checkbox"/>	<input type="checkbox"/> Palaeontology
<input checked="" type="checkbox"/>	<input type="checkbox"/> Animals and other organisms
<input type="checkbox"/>	<input checked="" type="checkbox"/> Human research participants
<input checked="" type="checkbox"/>	<input type="checkbox"/> Clinical data

Methods

n/a	Involved in the study
<input checked="" type="checkbox"/>	<input type="checkbox"/> ChIP-seq
<input checked="" type="checkbox"/>	<input type="checkbox"/> Flow cytometry
<input checked="" type="checkbox"/>	<input type="checkbox"/> MRI-based neuroimaging

Human research participants

Policy information about [studies involving human research participants](#)

Population characteristics	Experiment 1 consisted of 42 younger adults aged 20-29 years, mean age 24.4 ± 2.8 SD, 20 female, all right-handed, mean years of education 15.7 ± 1.3 SD, and 42 older adults aged 60 to 76 years, mean age 68.8 ± 4.4 SD, 22 female, all right-handed, mean years of education 17.0 ± 2.3 SD. Experiment 2 consisted of 28 older adults aged 62-75 years, mean age 69.6 ± 3.7 SD, 14 female, all right-handed, mean years of education 16.4 ± 1.4 SD. Experiment 3 consisted of 18 younger adults aged 21-28 years, mean age 25.3 ± 2.3 SD, 9 female, all right-handed, mean years of education 16.1 ± 1.2 SD. Experiment 4 consisted of 14 of the poorest performing younger adults from Experiment 1 aged 21-29 years, mean age 26.8 ± 1.8 SD, 9 female, all right-handed, mean years of education 14.8 ± 1.1 SD.
Recruitment	Subjects were recruited from the greater Boston area via posting announcements on local and electronic bulletin boards and were selected based on the following eligibility requirements: no metal implants in head, no implanted electronic devices, no history of neurological problems or head injury, no skin sensitivity, no claustrophobia, not being pregnant, no current use of psychoactive medication, normal color vision, and normal or corrected-to-normal visual acuity. As with all research requiring volunteers, the possibility of introducing self-selection bias is unavoidable. As a result, it is possible that individuals inclined to sensation-seeking or thrill-seeking are more likely to pursue research studies requiring volunteers. However, in the present

study, these personality traits were not explicitly under investigation, and the effects of this bias are unlikely to harm results based on more enduring measurements of electrophysiology.

Ethics oversight

Boston University Institutional Review Board, Charles River Campus.

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