

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

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 (<i>n</i>) 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
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ 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. <i>F</i> , <i>t</i> , <i>r</i>) with confidence intervals, effect sizes, degrees of freedom and <i>P</i> value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☒ | ☐ 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 <i>d</i> , Pearson's <i>r</i>), 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	For online estimation of the cortical currents in insular cortex from MEG data, we used Variational Bayesian Multimodal EncephaloGraphy (VBMEG)(ATR Neural Information Analysis Laboratories, Kyoto, Japan) in MATLAB (version R2013). A polygon model of the cortical surface was constructed based on structural MRI data using FreeSurfer software (Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Charlestown, MA, USA). We used G*Power 3.1 to calculate the required sample size. we use spm8 for MRI segmentation
Data analysis	Resting-state MEG data processing was performed using Brainstorm, which is an open-source application available under the GNU general public license (http://neuroimage.usc.edu/brainstorm), and MATLAB version R2017b. Statistical analysis was performed via Python 3.8.5 with the scipy package v.1.5.2

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](#)

The data for this research can be accessed upon request from the corresponding author (T.Y.). The data are not openly accessible due to privacy and/or consent concerns regarding the research participants.

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	We collected information solely on the biological sex of the subjects and did not gather data regarding their cultural gender. Efforts were made to ensure a balanced representation of sex among the participants. Because we did not assume sex differences in the experimental results, we did not conduct analyses based on sex.
Reporting on race, ethnicity, or other socially relevant groupings	We did not assume racial differences in the experimental results, and subjects were not screened for race during recruitment. No analyses based on race were conducted.
Population characteristics	A total of 20 healthy volunteers, including 11 males and 9 females, were initially recruited for the study. One female subject withdrew partway through the study, resulting in 19 subjects (11 males and 8 females) completing the trial. The mean age of the subjects was 28.8 years, with an age range of 22-58 years.
Recruitment	We recruited subjects through online solicitation.
Ethics oversight	The study adhered to the Declaration of Helsinki, was performed per protocols approved by the Ethics Committee of Osaka University Clinical Trial Center (No. 18472-2) and was registered in the UMIN Clinical Trials Registry (UMIN000037063). We obtained written informed consent from all subjects after informing them of the purpose and possible consequences of this study. All ethical regulations relevant to human research participants were followed.

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](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	We used G*Power 3.1 to calculate the required sample size for a t test, setting the effect size as 0.7 (large effect), the power at 0.8 and the significance level at 0.05, and the results indicated that 19 participants would be necessary for the study, we initially set the sample size to 20 participants.
Data exclusions	Besides one subject who dropped out midway, we did not exclude any data.
Replication	We have made every effort to ensure the reproducibility of our experimental findings by employing a double-blind randomized controlled design, using standardized procedures and validated tools, applying rigorous statistical methods, and carefully documenting and normalizing data collection processes.
Randomization	Before starting the study, we prepared a randomization list using block randomization with block sizes of 2 and 4.
Blinding	The randomization list was kept confidential by the experiment operator. This list equally divided the twenty subjects we intended to recruit into two groups. The blocked randomization list was incorporated into the experiment initiation program, which was subsequently encrypted. During the setup, the operator input the subject's ID to launch the neurofeedback program. Through this process, the subjects and the experiment operator were blinded to the training allocation.

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

Plants

Seed stocks

Not applicable.

Novel plant genotypes

Not applicable.

Authentication

Not applicable.