nature portfolio

Corresponding author(s): Weiwei Peng

Last updated by author(s): May 20, 2025

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 (*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	E-Prime(version3.0) for collecting behavioral data; Continuous EEG data were recorded using a 32-channel Ag-AgCl electrode cap following the International 10-20 system (NeuSen Wireless EEG/ERP, NSW332, Neuracle Technologies, Changzhou, China).
Data analysis	MATLAB(R2016b); EEGLAB(2021.0);IBM SPSS(version 19);MEMORE macro in SPSS(V2.1). Custom MALTAB code used for preprocessing and analysis is available in the Open Science Foundation repository (https://osf.io/7gqwh/).

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 can be found on the Open Science Foundation repository (https://osf.io/7gqwh/) . Moreover, source data for the graphs in the main text are also provided in an excel file as Supplementary Data 1.

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	Each participant provided a self-reported sex. Eighty healthy adults (39 males, 41 females) were recruited.
Reporting on race, ethnicity, or other socially relevant groupings	All participants were Asian Chinese descent.
Population characteristics	Eighty healthy adults (39 males: mean age ± SEM = 21.62 ± 0.41 years; 41 females: mean age ± SEM = 20.54 ± 0.30 years) were recruited and randomly assigned to the M1 or DLPFC group (n = 40 each). All participants were screened to exclude individuals who had received any form of neuromodulation treatment within 30 days prior to the experiment. They were all of Asian Chinese descent, right-handed, and had normal or corrected vision. None had cardiovascular, neurological, or psychiatric disorders, pain, or current medication use.
Recruitment	Participants were recruited through campus advertisements at a local university.
Ethics oversight	Informed consent was obtained from all participants per the Declaration of Helsinki, with protocol approval from the Ethics Committee of the Medical School of Shenzhen University.

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	We investigated the protective effects of preemptive M1 and DLPFC tDCS on persistent pain in a double-blind, sham-controlled design.
Research sample	Eighty healthy adults (39 males: mean age ± SEM = 21.62 ± 0.41 years; 41 females: mean age ± SEM = 20.54 ± 0.30 years) were recruited from a local university and randomly assigned to the M1 or DLPFC group (n = 40 each). Data from 7 participants were excluded due to incomplete records or excessive EEG artifacts, leaving 36 in the M1 group and 37 in the DLPFC group.
Sampling strategy	As calculated by G*Power, the priori sample size for a medium effect size in comparing the analgesic effects of two groups using repeated-measures ANOVA, was 76 participants (effect size = 0.25, significance level = 0.05, power level = 0.99). Considering the possibility of data loss, eighty healthy adults were recruited and randomly assigned to the M1 or DLPFC group (n = 40 each).
Data collection	Participants' behavioral data were collected by E-Prime based on a computer and their EEG data were recorded using a 32-channel Ag-AgCl electrode cap following the International 10-20 system (NeuSen Wireless EEG/ERP, NSW332, Neuracle Technologies, Changzhou, China). None was present besides the participant and the researcher. The researcher and the participant were blind to tDCS type (real or sham).
Timing	Eighty healthy adults (39 males: mean age ± SEM = 21.62 ± 0.41 years; 41 females: mean age ± SEM = 20.54 ± 0.30 years; M1 group n = 40, DLPFC group n = 40) were recruited from June 2022 to November 2022. In addition, to respond to the reviewers' suggestions, eighteen participants in the control group (who received sham tDCS stimulation twice; 7 males: mean age ± SEM = 20.57 ± 0.81 years; 11 females: mean age ± SEM = 22.091 ± 0.97 years) were recruited from February 2025 to April 2025.
Data exclusions	Before the experiment, exclusion criteria were set. Data from 7 participants were excluded: Two participants failed to participate in the second session due to physical discomfort; Two participants had malfunctioning devices and incomplete data collection; Three participants had valid EEG segments below the mean minus three times the standard deviation.
Non-participation	Two participants failed to participate in the second session due to physical discomfort.
Randomization	Prior to the formal experiment, participants completed a series of standardized psychometric assessments, including the Fear of Pain Questionnaire-III (FPQ-III), the Pain Catastrophizing Scale (PCS), the Pain Sensitivity Questionnaire (PSQ), the Pain Resistance Scale (PRS), the Pain Vigilance and Awareness Questionnaire (PVAQ), and the Pain Anxiety Symptoms Scale (PASS). Using variance minimization algorithms (https://osf.io/6jfvk/) , we implemented covariate-adaptive randomization stratified by psychometric profiles and demographic variables (gender and age), achieving balanced group allocation (M1 vs. dlPFC) with equivalent baseline characteristics. Therefore, eighty participants were randomly assigned to either the M1 or DLPFC group, and whether they received

real or sham tDCS stimulation during the first session was also determined randomly.

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 to this study.
Novel plant genotypes	Not applicable to this study.
Authentication	Not applicable to this study.