nature portfolio

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# 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<br>*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<br>*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

| | |
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| Data collection | We used the NeuroPort Central Suite software package (version 7.0.4; Blackrock Microsystems) to control the Neuroport system to collect data from the implanted ECoG device. The resulting signals across electrodes were further processed on the real-time computer, using a custom Python software package (rtNSR) that is capable of processing and analysing the ECoG signals, executing the real-time tasks, performing real-time decoding, and storing the data and task metadata. Custom code can be found at https://github.com/asilvaalex4/bilingual_speech_bci |
| Data analysis | We used common scientific computing packages in Python including NumPy, scikit-learn, pandas, seaborn and matplotlib during modelling and data analysis. The code required to replicate the main findings of the study is available from https://github.com/asilvaalex4/bilingual_speech_bci |

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 needed to recreate the main figures are provided as source data, and are also available at https://github.com/asilvaalex4/bilingual_speech_bci. The raw patient data are accessible to researchers from other institutions, but public sharing is restricted, as per our clinical trial protocol. Full access to the data will be granted on reasonable request to Edward Chang at edward.chang@ucsf.edu, and a response can be expected in under three weeks. Shared data must be kept confidential and not provided to others unless approval is obtained. Shared data will not contain any information that may identify the participant, to protect their anonymity.

## 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.

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| Reporting on sex and gender | The participant is male (he/him pronouns). |
| Reporting on race, ethnicity, or other socially relevant groupings | We did not examine the effect of these variables, because of our sample size of 1. |
| Population characteristics | The participant, a brainstem-stroke survivor, was 36 years of age at the start of the study. |
| Recruitment | Participants were recruited according to the approved clinical-trial protocol (ClinicalTrials.gov; NCT03698149). We include the following more detailed statement below (from our previous publication with the participant; Metzger et al. 2022, Nature Communications).<br><br>"Participants with motor impairments secondary to neurological disorders were recruited from clinics specializing in the treatment of stroke, ALS, and general neurological disorders, at UCSF and the San Francisco VA Medical Center.<br><br>Prior to enrollment into the study, an informal phone interview to schedule an office-based evaluation takes place, followed by three outpatient screening visits. During the first outpatient visit, we describe the trial in detail and answer all questions. Should the participant choose to continue, we schedule another visit to conduct a physical exam and to perform screening to determine eligibility. An MRI and CT of the brain is obtained for future surgical planning and to determine further eligibility. Additionally, an ECG and chest X-ray are also obtained. We schedule a third follow-up visit to review this data and answer remaining questions prior to enrollment in the trial.<br><br>To meet the eligibility criteria for enrollment in our trial, participants must fit specific clinical characteristics (see attached clinical protocol for full eligibility criteria). Therefore, we do not expect any noteworthy self-selection bias in this study or other studies that are part of this clinical trial, as participants who volunteer to participate will not differ from non-volunteers in any relevant clinical characteristics." |
| Ethics oversight | The study protocol was approved by the FDA, UCSF IRB, and the NIH. |

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

# Life sciences study design

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

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| Sample size | The sample sizes for the tests were primarily determined by the number of recording sessions possible with the current participant and the overall available data. We primarily estimated the number of task trials that would be required to reasonably estimate the measurements of interest along with performing statistical analyses. |
| Data exclusions | During the phrase-decoding task, the participant was instructed to continue attempting each word in the phrase regardless of decoding accuracy. However, on a small subset of trials, the participant self-reported making an error or not being able to continue the attempt (n=7 |

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| | out of 168 total trials). Similar to our prior work with this participant (Metzger et al. 2022), we excluded these trials from subsequent analysis to focus on the performance of our system rather than the performance of the participant. |
| Replication | We collected real-time decoding results over many blocks as well as performing cross-fold-validated decoding offline. These steps ensure that our results can be replicated over multiple sessions, days, and portions of data with the participant. However, true replication would require deploying a similar bilingual decoding system in another participant, which we aim to do in future. |
| Randomization | This was a single-participant study. |
| Blinding | Blinding was not applicable given the goal of designing a proof-of-concept bilingual decoding system for the participant |

# 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 |

## Clinical data

Policy information about clinical studies

All manuscripts should comply with the ICMJE guidelines for publication of clinical research and a completed CONSORT checklist must be included with all submissions.

| | |
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| Clinical trial registration | ClinicalTrials.gov; NCT03698149 |
| Study protocol | A description of the study can be found at https://clinicaltrials.gov/ct2/show/NCT03698149. The full clinical-trial protocol can be found as a supplementary file associated with our previous publication with the same participant (https://www.nejm.org/doi/suppl/10.1056/NEJMoa2027540/suppl_file/nejmoa2027540_protocol.pdf). |
| Data collection | Data collection occurred in a small office nearby the participant's residence. The clinical trial began in November 2018. The participant was recruited and enrolled in the study shortly afterwards, and was implanted with the study device in February 2019 at the UCSF Medical Center. Data for this specific study were collected during the year 2022 and in early 2023. |
| Outcomes | The outcomes are the same as our prior work with the participant (Metzger et al, 2022).<br><br>"This clinical trial is a phase 1 single-center early feasibility study to evaluate the potential of ECOG-based neural interfaces for controlling advanced neuroprotheses that restore motor and communicative functions. Due to the exploratory nature of this trial and the limited number of trial participants, we did not pre-define specific secondary outcomes. Our primary endpoint, which was pre-defined, is to assess the efficacy of the trial and is stated in the protocol as "Feasibility of control of a wearable exoskeleton device and communication interface." As such, a variety of analysis methods will be applied with trial participants throughout the trial with the aim to fully assess the efficacy of an ECOG-based neural Interface for motor and communication restoration. The data herein presented is not aimed at informing concrete conclusions regarding the primary outcomes of the trial." |