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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 *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	Study 1 : COmputerized Real Time EXpremiments (CORTEX) software developed originally by Thomas White in the lab of Robert Desimone (formerly at the NIH Bethesda, MD, USA, now at MIT) was used for behavioral task and behavioral data collection. AlphaLabPro (AlphaOmega®) was the electrophysiological recording system used for extracellular neuronal activity data acquisition (single unit activity and Local Field Potential). The electrophysiological signal from each electrode was amplified (x 15000) and filtered (High-pass 250 Hz; Low-pass 6 KHz). Study 2: The experiment was programmed in PsychoPy \citep{Peirce2019psychopy2}. EEG was recorded concurrently using a TMSi SAGA system and a 64-electrode TMSi infinity gel headcap (TMSi, Enschede, The Netherlands), with ground on the left wrist and an online average reference. Cz was positioned using skull measurements (inion–nasion and preauricular midpoints). Impedances were kept below 10kΩ, and shielded TMSi cables minimized movement artifacts. Signals were sampled at 2048Hz. Custom software sent triggers marking stimulus onset and ball–paddle events to the EEG system.
Data analysis	Study 1: Analyses of behavioural and preprocessing of electrophysiological data were partly performed using custom codes in Matlab R2011b (MathWorks®), available to editors and reviewers. MClust, an open-source Matlab-based spike sorting toolbox, was used for the manual separation of putative cells from multi-site neurophysiological recordings (A David Redish http://redishlab.neuroscience.umn.edu/MClust/MClust.html). After the preprocessig analyses, electrophysiological data were exported to NeuroExplorer® which is a data analysis program to examine in our case sequencies of timestamps (spike trains, behavioral events) and short signal fragments (spike waveforms). Neurons were then classified based on their response to the various task events and their activity was normalized for statistical analyses with Matlab custom codes. Correlations between behavioral and normalized neuronal activities and hierarchical unsupervised clustering analysis were computed with IBM Spss Statistics®. Study 2: All EEG preprocessing and analysis were performed in Python using MNE-Python® and Numpy® packages. Bad channels were detected and interpolated using RANSAC from the AutoReject® package on epochs from -500 to 1000 ms (baseline: -500 to -200 ms). Data were re-referenced to the average and filtered (1–45 Hz, FIR). Blink and saccade components were removed via ICA (FastICA), using a template-matching procedure based on components identified in a

reference subject. Source modeling was performed using the Freesurfer fsaverage template (source: fsaverage-ico-5-src; BEM: fsaverage-5120-5120-5120-bem-sol, mindist=5 mm). Noise covariance was estimated from -500 to 1000 ms (baseline: -500 to -200 ms, tmax=-0.2). The forward model and noise covariance were used to compute the inverse operator (MNE, loose=0.2). Alpha-band (8–12 Hz) activity was extracted using multi-taper filtering and epoched (0–500 ms post-ball movement; baseline: -200 to 0 ms). Source estimates were mapped to the Schaefer 2018 atlas (400 parcels). Functional connectivity matrices were subsequently computed via the corrcoef function from the Numpy® package.

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

Empirical data for both studies are available on https://doi.org/10.5281/zenodo.16487740. The source code used for analysis and figure generation is available at https://github.com/ins-amu/SoFa-PI.

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	Study 2: Sex was verbally self-reported by participants during a brief on-site interview and recorded by a researcher on a standardized data sheet. Gender identity was not explicitly collected.
Reporting on race, ethnicity, or other socially relevant groupings	Study 2: Participants were not selected based on race, ethnicity, or other socially relevant classifications, and no prior assumptions or criteria related to these characteristics were used during recruitment.
Population characteristics	Study 2: Participants were non-clinical young adults (14 men; mean age=23.6 years, SD=2.1). Other than age and gender/sex, the Leibowitz Social Anxiety Scale (LSAS) was administered for the assessment of fear and avoidance associated with social phobia. Results showed no relation between LSAS scores and motor performance or social facilitation/inhibtion and LSAS scores were therefore not included in further analyses.
Recruitment	Study 2: Participants were recruited by the researchers from the he Department of Human Movement Sciences of the University of Groningen and a student rowing association in Groningen due to their easy accesibility. Biases that may be present are: 1) Education level: students were all students at the University of Groningen. 2) Age: Young (Ages 20-30) 3) Socially active: In this case, being part of a student rowing association typically meant that most participants were actively -to some extent- involved in committees and engaged in social activities commonly associated with membership in such an association.
Ethics oversight	Study 2: The study procedures were approved by the Central Ethics Board of the University Medical Centre of Groningen (UMCG) and according to the Declaration of Helsinki (World Medical Association).

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	Study 1: A quantitative experimental study include two non-human primates. Behavioral and neuronal data were collected on the dealy basis (one session per day) Study 2: A quantitative study that includes 28 participants. Participants took part in a single recording session lasting approximately 15 minutes. Behavioral data consisted of a motor task practice block and two randomly counterbalanced blocks, performed either in presence or absence of a conspecific.

Research sample

Study 1 : Behavioral data for both monkeys were collected over a total of 258 sessions (Monkey A, n= 181; Monkey M, n=77), and analyzed using the session as unit of analysis. Activity from 592 single neurons was recorded and more than half of them were selected because of their ativity related to processing of outcome signals (negative and positive feedback of the task).
To date, no non-invasive imaging technology offers sufficient spatial and temporal resolution to allow electrophysiological studies in non-human primates to be replaced. Electrophysiological studies in the awake and behavioural environment employ a limited number of animals, both because they require highly challenging techniques and procedures and because of their significant impact on animal welfare. The basic paradigm for studying brain activity at the single cell level in behavioural animals involves repeated penetration of electrodes in 2 or even 3 animals.

Study 2: The sample comprised 28 individuals (14 women and 14 men; mean age=23.6 years, SD=2.1), primarily university students from the University of Groningen. This convienence sample was selected to facilitate rapid recruitment due to its accessibility. One participant was excluded from data analysis due to a recording error (n_male_included = 13).

Sampling strategy

Study 1 : No sample size calculation was performed due to a lack of data and recommandation in the literature in in-vivo electrophysiological studies area (and because of this was the first research on the effect of social presence at the neural level). Instead, the sample size was considered sufficient when at least 80 positive and negative feedback-related neurons were recorded over time during complete behavioural sessions, with a good signal-to-noise ratio and without signal loss or degradation.

Study 2: participants were recruited based on convenience. Students recruited from the Department of Human Movement Sciences of the University of Groningen and a student rowing association in Groningen due to their easy accesibility. The sample size was determined based on prior studies using the same lateral manual interception task setup, showing significant between group differences with a similar number of trials per condition.

Data collection

Study 1 :
- Behavioral procedures : The monkeys were trained to associate abstract images with targets on a touchscreen either under social presence or in isolation. Under social presence, the two monkeys were sited in primate chairs facing each other, with their head immobilized, and alternated the roles of actor and spectator. Only the actor had access to the touchscreen, and thus performed the task and received rewards on correct trials. The spectator was not rewarded, had no incentive to produce any particular behavior, was never tested (as actor) during the same day, and when tested, a new set of stimuli was used (therefore preventing any observational learning to occur). When a monkey was tested in isolation, the other remained in the housing room located at a distance such that the actor was truly alone in the testing box, deprived from any communicative means with the conspecific through visual, auditory or olfactory channels. During task performance, the actor started trials by touching a white rectangle, which triggered the presentation of a cue at the center of the screen. The monkey was required to indicate among the four white squares (targets), the one associated with this cue. After a variable delay (500–700 ms), the cue went off (go signal) and the monkey had to move the hand and touch the chosen target. If correct, a green circle (positive feedback) informed the monkey that the choice was correct, and a reward (fruit juice) was delivered after 1 s. If the choice was incorrect, a red circle signaled the error (negative feedback), and no reward was delivered. Throughout the session anyone was present beside monkeys : the experimenters were absent from the monkey's recording room, but conducted the experiment in an adjacent one and monitored the progress using a camera.
- Neuronal recordings : Extracellular neuronal activity was recorded using a multichannel system (Alphalab). Single tungsten electrodes (FHC Instrument, 0.8–1.2 MX impedance) were inserted in the brain, and were moved down to the target cortical areas identified on the basis of MRI scans. Up to four electrodes were used simultaneously, two in the PFdl and two in ACC, whose location within each area varied from session to session in order to cover the area as much as possible. The signals recorded by each electrode were high- (6 kHz) and low-pass (250Hz) filtered, and amplified using Alphalab software. The neuronal signals were synchronized with task events (visual stimuli onset and offset, behavioral events, reward delivery timestamp) derived from the Cortex software, and stored as analog signals for off-line analyses. The electrode insertion depth was maintained throughout the recording session. The experimenters monitored the quality of the signal from each electrode so as to be able to exclude from the analyses electrodes for which the signal has been degraded or lost (too much pressure on the neurons, which could burst, or too much vibration due to the movements of the actor monkey). As the analyses were off-line, the experimenters were blind to the types of activity recorded and their possible modulation. As this was the very first single unit electrophysiological study of the effect of the presence of conspecifics, the experimenters had no particular expectations of the results. The only main hypothesis was that the activity of the neurons could be modulated by the experimental context.

Study 2:
- Behavioral procedures: Participants were asked to perform a manual lateral interception task either under social presence or in isolation. In the presence condition, the 'observer' sat in the participant's peripheral vision, sometimes monitoring the hands of the 'actor' but not the screen, so as to minimize evaluation-induced anxiety during the presence condition. Participants were unaware of the observer's true purpose and were informed that they were present to monitor the equipment. This was possible, because during the application of the EEG cap, the experimenter began introducing a cover story, mentioning potential slider defects and the possibility of someone entering the room to 'read the slider resistance'. Before the actual experiment commenced, the experimenter informed the participant that she would leave the room 'to look for technical support to test the equipment'. Participants were told that the experiment would run entirely without interference from the experimenter, meaning they could continue uninterrupted. Between the 10-trial practice block and the first experimental block, a 30-second break was programmed to allow a time to enter the room (in the case where the first block was the 'presence' condition). Similarly, an automatic 2-minute break was inserted between the two experimental blocks, during which the spectator could either enter or leave the room. The presence and absence conditions of the experimental blocks were counterbalanced, meaning that the spectator sometimes entered during the first block and sometimes during the second block. All female participants encountered the same female spectator, while all male participants encountered the same male spectator. Participants were instructed beforehand not to interact with the spectator, as this could introduce noise into the EEG signal. The experimenter was not present during the entire experiment. Participants were made aware of the true reason of the spectator and hypothesis of the experiment after the experiment was finished and they had filled out a questionnaire (Liebowitz Social Anxiety Scale; to correct for possible confounding effects of social anxiety on social presence) with pen and paper.
Recordings: The participants were stationed at a table positioned 2 meters away from a large 55-inch Samsung LED television screen with a resolution of 1920 × 1080 pixels and a refresh rate of 120 Hz. They were provided with a handheld knob connected to an in-house developed slider, which allowed them to laterally control a virtual paddle displayed on the screen. The objective was to

intercept a virtual ball that descended vertically across the screen. The positions of the slider were continuously recorded using a National Instruments data acquisition card. Kinematic data pertaining to the movements of the virtual paddle and ball were collected, along with information regarding whether the ball was successfully intercepted or not. The experiment was built and controlled using the PsychoPy software platform. Concurrent with the behavioral task, electroencephalographic (EEG) signals were recorded using a TMSi SAGA data recorder and a 64-electrode TMSi infinity gel headcap (TMSi, Enschede, The Netherlands). The ground electrode was placed on the left wrist of the participant, and an online average reference was employed. To ensure consistent cortical recordings across participants, skull measurements were taken, and the Cz electrode was positioned at the intersection of the midline between the inion and nasion, and the midline between the tragus of each ear. Electrode impedances were maintained below 10 kΩ, and shielded cables (TMSi) were utilized to minimize artifacts arising from cable movements. The EEG signals were sampled at a frequency of 2048 Hz. Furthermore, an in-house developed software system was integrated to send triggers to the EEG docking station, marking the onset of stimuli and the precise moment when the ball crossed the invisible interception axis or made contact with the paddle. Participants were randomly assigned to one of two counterbalanced groups and engaged in a game where they had to intercept a virtual ball (ball radius = 16 px) descending on the screen using a virtual paddle (width = 48 px, height = 13 px). The mapping was such that 16 px corresponded to 1 cm on the screen. Participants first completed a 10-trial practice block to familiarize themselves with the task, followed by two 80-trial experimental blocks.

Timing

Study 1: From 24 July 2012 to 6 September 2013 and from 18 March 2014 to 25 April 2014 for monkeys A
From 6 July 2011 to 30 September 2011 for the monkey M

Study 2: Data collection started 23-03-2023 and ended 10-05-2023.

Data exclusions

Study 1: Excluded neurons corresponded to those that were not considered active in relation to a particular event (e.g. a feedback signal) if the PSTH Z-score (normalized activity) was not greater than 1.96 (Confidence Interval of 0.95) in at least three consecutive bins (bin was a 10 ms time window) around the event (e.g. -200 ms to 500 ms for feedback). In each session, electrodes marked with poor signal quality (assigned on-line during the recording) were excluded from the analysis. Similarly, neurons firing non-preferentially (during both experimental conditions) were excluded from the analysis.

Study 2: One participant was excluded from data analysis due to a recording error (no signal in the second block).

Non-participation

Not concerned

Randomization

Study 1: Not concerned

Study 2: Absence-presence (A/P) order of the experimental blocks were defined prior to the experiments. Participants were assigned to experimental conditions (AP/PA order) based on their order of inclusion.

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

Animals and other research organisms

Policy information about studies involving animals; ARRIVE guidelines recommended for reporting animal research, and Sex and Gender in Research

Laboratory animals

Study 1: Macaca mulatta, 5 years old.

Wild animals

Study 1: The study did not involve wild animals.

Reporting on sex

Study 1: Sex was not considered in this study. Both monkeys were male.

Field-collected samples

Study 1: Did not involve samples collected from the field.

Ethics oversight

Study 1: The European Directive (2010/63/UE) on the use of nonhuman primates in scientific research.

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

Plants

Seed stocks	*Report on the source of all seed stocks or other plant material used. If applicable, state the seed stock centre and catalogue number. If plant specimens were collected from the field, describe the collection location, date and sampling procedures.*
Novel plant genotypes	*Describe the methods by which all novel plant genotypes were produced. This includes those generated by transgenic approaches, gene editing, chemical/radiation-based mutagenesis and hybridization. For transgenic lines, describe the transformation method, the number of independent lines analyzed and the generation upon which experiments were performed. For gene-edited lines, describe the editor used, the endogenous sequence targeted for editing, the targeting guide RNA sequence (if applicable) and how the editor was applied.*
Authentication	*Describe any authentication procedures for each seed stock used or novel genotype generated. Describe any experiments used to assess the effect of a mutation and, where applicable, how potential secondary effects (e.g. second site T-DNA insertions, mosiacism, off-target gene editing) were examined.*