

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 PsychoPy 1.90.3.

Data analysis SPM 12, FSL 6.0.5, Python 3.8.13, R 4.1.3, Julia 1.7.2, Matlab R2019b, PhysIO Toolbox R2019a-v7.1.0, MACS v1.3, brms 2.16.2, PyStan 3.6.0, loo 2.5.1, fMRIPrep 1.2.5, custom code on https://github.com/carolfs/fmri_magic_carpet

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 behavioural and eye-tracking data can be found on https://github.com/carolfs/fmri_magic_carpet and the fMRI images can be found on <https://openneuro.org/datasets/ds004455>

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)

Behavioural & social sciences study design

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

Study description	Healthy young participants performed a behavioural task in the fMRI scanner with simultaneous eye tracking. Data are quantitative and experimental.
Research sample	Participants between 18-30 years old were recruited from the University of Zurich's Registration Center for Study Participants. We did not collect information on gender. This sample is representative of healthy young university students, in line with our previous study (Feher da Silva and Hare, 2020) and others employing the two-stage task and healthy human participants, including Daw et al. (2011), which we aimed to replicate.
Sampling strategy	The sample size was determined by a power analysis ($R = 0.4$, $\beta = 0.8$, two-tailed P -value = 0.05, N required = 48) based on our previous behavioural findings (Feher da Silva and Hare, 2020). The sampling procedure was convenience sampling.
Data collection	Behavioural data were collected on computers. fMRI data were acquired from a 3T Philips Achieva scanner with an eight-channel sensitivity-encoding head coil (Philips Medical Systems). Eye tracking was performed with an EyeLink 1000 eye tracker (SR Research). Researchers were not blind to the experimental condition or hypothesis and were present with the participant during task performance. Participants were on their own when reading the instructions, practicing the task, and filling in the questionnaire.
Timing	Start: 16 Oct 2018. Stop: 13 Dec 2018.
Data exclusions	We excluded 4 participants assigned to the story condition and 2 participants assigned to the abstract condition. One participant was excluded because the task presentation program crashed during the experiment and some behavioural results were lost, two participants received the wrong instructions (i.e., those meant for participants in the other condition), one participant fell asleep in the fMRI scanner during the task, one participant could not complete the required pregnancy test before entering the fMRI scanner, and one participant's fMRI images were grossly distorted as determined by visual inspection. Questionnaires were completed by 93 of the final 94 participants. For pupil diameter data, we decided a priori to exclude the data for a session if the data spanned less than 80% of the session's time; included data belonged to 36 participants in the abstract condition and 37 participants in the story condition.
Non-participation	No participants dropped out of the experiment.
Randomization	Participants were randomly allocated to a condition (abstract or story instructions).

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
☐	☒ Human research participants
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☐	☒ MRI-based neuroimaging

Human research participants

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

Population characteristics

Recruitment

Participants were recruited from the University of Zurich's Registration Center for Study Participants. See our supplemental material (pages Q1-Q2) for a list of inclusion and exclusion criteria. Participants were randomly allocated to a condition (abstract or story), hence there were no biases that could have affected comparisons between conditions.

Ethics oversight

Zurich Cantonal Ethics Commission (ethics protocol KEK-ZH-Nr. 2010-0327/3 #31 approved on 9 March 2016)

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

Magnetic resonance imaging

Experimental design

Design type

Two-stage task, performed by participants randomly assigned to abstract or story instruction conditions.

Design specifications

150 trials performed in 3 run of 50 trials. Each run lasted 842.5 s. Intervals between trials varied between 1.95 s and 7.04 s.

Behavioral performance measures

Recorded variables were first-stage and second-stage choices and reaction times. The minimum number of completed trials (excluding slow responses) was 140.

Acquisition

Imaging type(s)

functional, structural

Field strength

3T

Sequence & imaging parameters

Gradient echo T2*-weighted echo-planar images with BOLD contrast, 42 slices acquired in ascending order with 3 mm thickness, 3 x 3 mm² voxel resolution, 0.6 mm gap between slices, repetition time of 2.5 s, echo time of 30 ms, flip angle of 90°. T1-weighted structural images were also acquired.

Area of acquisition

Whole brain.

Diffusion MRI

☐ Used

☒ Not used

Preprocessing

Preprocessing software

fMRIPrep 1.2.5 and Gaussian kernel smoothing with full-width at half-maximum (FWHM) of 6 mm.

Normalization

Spatial normalization was performed through nonlinear registration with antsRegistration, using brain-extracted versions of both T1w volume and template.

Normalization template

ICBM 152 Nonlinear Asymmetrical template version 2009c

Noise and artifact removal

To correct physiological artefacts created by heart rate and breathing, the default pipeline of the PhysIO toolbox was employed to obtain 18 regressors for each run. Additionally, to correct artefacts caused by head motion, we added 6 regressors for rotation and translation, a regressor for the framewise displacement, and additional noise regressors calculated using anatomical CompCor.

Volume censoring

We excluded volumes marked as "non-steady-state" by fmriprep as well as volumes marked as "motion outliers" (having framewise displacement greater than 0.5 mm or standardised DVARS greater than 1.5 mm). Functional runs where over 30% of TRs were affected were entirely excluded. In total, six runs were excluded, two from the same participant and four from another four participants.

Statistical modeling & inference

Model type and settings

First level: mass univariate. Second level: fixed effects.

Effect(s) tested

Combined-RPE model: model-free reward prediction error, model-based reward prediction error. Separated-RPE model: model-free reward prediction error, model-based reward prediction error, feedback reward prediction error. Categorical model: main effects of transition (common, rare) and outcome (reward, no reward). Condition comparison model: main effect of condition (abstract, story).

Specify type of analysis: ☐ Whole brain ☐ ROI-based ☒ Both

Anatomical location(s) Anatomical locations were determined using the Harvard-Oxford atlas.

Statistic type for inference
(See [Eklund et al. 2016](#))

Threshold-free cluster enhancement (TFCE) with height = 2, extent = 0.5 and connectivity = 6.

Correction

FWE

Models & analysis

n/a	Involvement in the study
☒	☐ Functional and/or effective connectivity
☒	☐ Graph analysis
☒	☐ Multivariate modeling or predictive analysis