

Reporting Summary

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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	Participants completed questionnaires using REDCap electronic data capture tools. Food ratings including the fMRI task were made with PsychoPy3 (v2023.1.0). Body weight was measured with an electronic scale (Health O Meter ProPlus digital scale) and height was measured with a wall-mounted stadiometer. Waist and hip circumference were measured using Gulick tape measure following World Health Organization protocols (Waist Circumference and Waist-Hip Ratio, n.d.) for the calculation of waist-to-hip ratio. Dietary recalls were performed using the multi pass method and recorded into Nutrition Data System for Research (NDSR; version 2022; University of Minnesota, Minneapolis, MN). A small-volume whole room indirect calorimeter (WRIC) (MEI Research, Ltd) was used to measure participants' metabolic rate, respiratory exchange ratio, carbohydrate oxidation, and fat oxidation (Baugh et al., 2024). For blood sample analyses, glucose concentrations were measured in duplicate using a point of care system (Hemocue Glucose 201 System, HemoCue, CA, USA), insulin concentrations were quantified using an enzyme-linked immunosorbent assay (ELISA; ALPCO, NH, USA), and Hemoglobin A1c was determined with a point of care analyzer (Afinion HbA1c, Abbott Laboratories, IL, USA). Throughout the metabolic session participants were also fitted with accelerometers (ActiGraph wGT3X-BT) on their right wrist and left ankle to measure movement (LaMunion et al., 2017). All MRI data were acquired with a 3 Tesla Siemens MAGNETOM Prisma scanner using a 64-channel head coil. Data and code underlying this manuscript are available from the Virginia Tech Data Repository at https://doi.org/10.7294/32077803 .
Data analysis	All statistical analyses on metabolic and behavioral data were conducted with R version 4.4.1 (2024-06-14). fMRI data were preprocessed and analyzed with FSL version 6.0.7.17 (FMRIB Software Library) and SPM Version 25.01.02 (Statistical Parametric Mapping) implemented in MATLAB R2021b. Data and code underlying this manuscript are available from the Virginia Tech Data Repository at https://doi.org/10.7294/32077803 .

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 underlying this manuscript are available from the Virginia Tech Data Repository at <https://doi.org/10.7294/32077803>. Neuroimaging data have been deposited on OpenNeuro, accession number ds007693.

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

Sex was considered in the study design. Participants self-reported their sex in response to the question, "What sex were you assigned at birth?" Gender identity was also assessed using the question, "What best describes your gender identity?"; however, gender was not included in the present analyses. The final sample consisted of 18 males and 39 females, as reported in Table 1 and the Results section. Sex was included as a covariate in all fMRI models. Additionally, sex was entered as a covariate in the willingness-to-pay analyses, and the results were unchanged.

Reporting on race, ethnicity, or other socially relevant groupings

Participants self-reported their race in response to the question, "Please select the race(s) which best describe you." The following response options were provided: White; Black or African American; American Indian or Alaska Native; Asian Indian; Chinese; Filipino; Japanese; Korean; Vietnamese; Other Asian; Native Hawaiian or Other Pacific Islander; Guamanian or Chamorro; Samoan; Other; and Prefer not to disclose. Race is reported in Table 1 but was not included in subsequent analyses.

Population characteristics

See below.

Recruitment

Study participants were recruited from the University and surrounding community in Roanoke, Virginia through social media advertisements, campus advertisements, and flyers. Interested individuals filled out a general online screening form on Ripple Science software from June 2023 to December 2025 to provide self-report information for the determination of study eligibility.

Ethics oversight

All study protocols were given ethical approval by the Virginia Tech IRB (#21-1052).

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

The study used a randomized, within-participant crossover design in which quantitative data were collected.

Research sample

Study participants were recruited from the University and surrounding community in Roanoke, Virginia through social media advertisements, campus advertisements, and flyers. Interested individuals filled out a general online screening form on Ripple Science software from June 2023 to December 2025 to provide self-report information for the determination of study eligibility. To be eligible individuals had to be age 18 to 45 with a BMI between 18.5 and 25 (calculated from reported height and weight). Exclusion criteria included having dietary restrictions (food allergies, vegetarian, keto, etc.), medical conditions (including metabolic, neurologic, or psychiatric disorders) or medications used to treat these disorders, currently pregnant, current inhaled nicotine use, other recreational drugs other than periodic cannabis use, impaired taste or smell, contraindications for MRI, and vision not correctable to see MRI screen. Eligible individuals were invited for in person screening and consent.

Sampling strategy

Power analysis (Behavior). The overall sample size was estimated based on behavioral data from 11. Sample size was calculated in R 4.8 based on a repeated measures ANOVA model, and detecting differences in willingness to pay (bid amount in USD) among the degree of food processing condition groups 49. With a total sample size of 52 participants, pairwise comparisons among the two groups yielded 80% power to detect an effect size of Cohen's $f=0.40$ with a type I error rate of 5%. Based on this total sample size of 52, power was estimated for a generalized linear mixed-effects model, regressing the primary outcome (willingness to pay) on food

processing, sex, their two-way interaction, and controlling for potential confounders (hunger, energy expenditure, blood glucose, blood insulin). This was accomplished using 5,000 iterations of a Monte Carlo simulation, expected assumptions were based on the bidding data published in DiFeliceantonio et al. 11. In these simulations, the model parameters were estimated via restricted maximum likelihood, such that the specified model was compared to the null model using the likelihood ratio test, yielding 99% power to detect a statistically significant test at the 5% level of significance. In summary, a sample size of 52 participants provides sufficient power to detect a main effect difference in willingness to pay by food processing group. Power analysis (Associations between metabolism and fMRI). An ad hoc power analysis was conducted to ensure power was achieved for the subset of participants in the correlations between metabolic with brain responses. In the literature, the most relevant data are from Veldhuizen et al 2017, who reported a correlation of $r=.83$, which is much larger than the effect sizes used to power the study 15. We performed a power analysis based on a test of Pearson's correlation with that value. To achieve 95% power, 16 participants were needed at a significance level of .0001. Power analysis (Metabolism). A separate power analysis was conducted to evaluate the sample size needed to detect a difference in metabolic response to the meals consumed in the whole room indirect calorimeter. There was over 80% power to detect a difference, based on a paired t-test, in the AUC for energy expenditure, assuming a Cohen's d of .57 (medium size) and sample size of 27. Data collection and analysis were not performed blind to the conditions of the experiment

Data collection	All participant data were collected using a computer-based interface. No individuals were present during data collection other than the participant and the researcher, except for the MRI operator during the collection of neuroimaging data and the phlebotomist during intravenous blood draws. The researcher was involved in study design and therefore was not blinded to the study hypotheses. Additionally, blinding to experimental condition was not feasible, as the conditions consisted of distinct food items, but participants were not explicitly told what condition they were receiving.
Timing	Data collection started in end of June of 2023 and ended in December of 2025, and the metabolic sessions spanned end of June 2023 to March 2025.
Data exclusions	Of the 57 enrolled participants, 32 completed the metabolic sessions. All participants completed both the non-UPF and UPF conditions; however, one participant experienced a vasovagal response after the 60-min blood draw, resulting in early termination of that session. Due to IV patency issues, glucose samples could not be obtained for one condition in five participants. Insulin samples could not be obtained for one condition in three participants, and for both conditions in one participant. All 32 participants who completed the chamber sessions also underwent MRI scanning: two were excluded due to excessive head motion (>2 mm in ≥ 2 of the four runs), and one due to equipment failure.
Non-participation	A total of 61 participants completed in-lab eligibility screening. Four participants were excluded prior to enrollment (two were ineligible for the study payment system and two were not interested).
Randomization	The condition order for the metabolic sessions was randomized. The stimulus presentation order during the fMRI task was randomized using a genetic algorithm to optimize design efficiency (Wager & Nichols, 2003).

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.

Clinical trial registration	The study was registered at clinicaltrials.gov (NCT06017986).
Study protocol	The study protocol is available through the Virginia Tech Data Repository 10.7294/32077803.
Data collection	General study overview. Eligible individuals were invited for in person screening and consent. Data collection started in June of 2023 and ended in December of 2025, and the metabolic sessions spanned June 2023 to March 2025. Participants were compensated for their time. Metabolic session. Participants completed two separate metabolic sessions on different days in a randomized crossover design. To reduce participant burden, we did not require a specific session spacing. Seven participants had sessions within 3 days, 14

participants between 4 days and 2 weeks, 7 participants between 15 days and four weeks, and finally 4 participants had sessions with a greater than 4-week gap. For each session, participants were instructed to arrive after an overnight fast and to refrain from strenuous exercise on the preceding day. Sessions were scheduled to begin in the morning, after participants' habitual wake-up time. A small-volume whole room indirect calorimeter (WRIC) (MEI Research, Ltd) was used to measure participants' metabolic rate, respiratory exchange ratio, carbohydrate oxidation, and fat oxidation for 4 hours(Baugh et al., 2024). fMRI session. Participants were instructed to arrive neither hungry nor full, 3-hours fasted, and to refrain from strenuous exercise the day before. In relation to the metabolic sessions, 6 participants completed the fMRI session as the last session, 7 in-between metabolic sessions, and 16 as their before metabolic sessions. During this session, participants completed 4 runs of a Becker-deGroot-Marschak auction task to assess food value(Becker et al., 1964) while undergoing fMRI scanning(Newton-Fenner et al., 2023). Additional details can be found in supplemental materials.

Outcomes

This study is considered BESH (Basic Experimental Studies in Humans). Therefore, we used literature searches and expert consensus to design the experiments and identify outcomes.

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, mosaicism, off-target gene editing) were examined.

Magnetic resonance imaging

Experimental design

Design type

Task, event-related design

Design specifications

Each subject completed 4 auction task trails. Each trial lasted approximately 8.5 minutes and consisted of a jittered inter trial interval (mean 4-sec) followed by a food picture presentation period (5-sec), jittered fixation point (mean 4-sec), bid rating (5-sec maximum). Trial order, inter stimulus interval, and intertrial interval were chosen using a genetic algorithm approach to optimize fMRI design (Wager & Nichols, 2003). During each trail, participants bid their willingness to pay between 0 and 5 USD on 28 different foods presented in a randomized order.

Behavioral performance measures

Bid amount (\$0-\$5) was collected. If more than 25% of bids were either less than \$0.25 or missing across all runs, that participant was excluded.

Acquisition

Imaging type(s)

Echo Planar Images (EPI) and Magnetization-Prepared Rapid Gradient Echo (MPRAGE)

Field strength

3 Tesla

Sequence & imaging parameters

All MRI data were acquired with a 3 Tesla Siemens MAGNETOM Prisma scanner using a 64-channel head coil. Acquisition parameters for the functional echo-planar images (EPIs) were TE=34ms, echo spacing=0.66ms, TR=1.5s, flip angle=70, voxel size=2x2x2 mm, number of slices=72, and multiband acceleration factor=4. To allow distortion correction, sets of identical images were acquired with reverse (posterior-to-anterior and anterior-to-posterior) phase encoding polarity. A high quality T1 weighted anatomical image (TE=2.32ms, TR=2.3s, flip angle=8, slices=192, field of view=240mm, voxel size= 0.9x0.9x0.9 mm) was acquired for registration of functional images.

Area of acquisition

Whole brain coverage

Diffusion MRI

☐ Used ☒ Not used

Preprocessing

Preprocessing software

fMRI data were preprocessed with FSL version 6.0.7.17 (FMRIB Software Library) and SPM Version 25.01.02 (Statistical Parametric Mapping) implemented in MATLAB R2021b. Susceptibility-induced distortions were estimated using opposite phase encoded images and corrected with a Jacobian transformation using FSL (Smith et al., 2004) topup (Andersson et al., 2003). Preprocessing was then completed with SPM and includes realignment, coregistration of the functional images to each participant's T1-weighted anatomical image, and spatial smoothing with a 6mm full width half maximum gaussian kernel.

Normalization

During segmentation, nonlinear deformation fields were estimated to align each participant's anatomical T1-weighted image

Normalization	to standard space in SPM25. The resulting deformation fields were then applied to the EPI runs to warp the functional data into the standard space.
Normalization template	Group standard space, MNI-152
Noise and artifact removal	The following nuisance regressors were used for first level modeling: Friston's 24 head motion parameters (Friston et al., 1996) (6 SPM realignment parameters, 6 of their preceding values, and 12 corresponding squared terms), the mean signal extracted from the cerebrospinal fluid and white matter (along with their preceding values, and corresponding squared terms), DVARS (D referring to the temporal derivative, VARS referring to RMS variance over voxels)(Power et al., 2012; Smyser et al., 2011), and Framewise Displacement (FD) computed with fsl_motion_outliers, and a matrix of motion-outlier volumes (DVARS threshold at 75th percentile plus 1.5 times the interquartile range and/or greater than .5 mm of Framewise Displacement).
Volume censoring	Motion outlier volumes were identified as those exceeding a DVARS threshold defined as the 75th percentile plus 1.5 times the interquartile range and/or exhibiting Framewise Displacement greater than 0.5 mm. These volumes were deweighted, no volumes were removed.

Statistical modeling & inference

Model type and settings	Two first-level general linear models (GLMs) were specified. For both GLMs, the interval from the onset of the post-picture fixation period through bid submission (i.e., the participant-specific reaction time during each bidding period) was modeled as a regressor of no interest. Additional nuisance regressors as described above were entered. The first GLM was designed to capture food-cue reactivity by modeling the 5-s picture-viewing period with a boxcar regressor, with separate regressors for non-UPF and UPF trials (DiFeliceantonio et al., 2018; Tang et al., 2014). For the first GLM the non-UPF >UPF contrast was brought to the group level and used to test the association with the between-condition difference in peak metabolic response to the test meals (non-UPF – UPF) measured during the metabolic sessions using a one-sample t-test with age, sex, and metabolic difference. The second GLM was designed to capture value-related responses while accounting for measures that differed across conditions (frequency of consumption and perceived healthiness), such that effects attributed to food type were not confounded by these factors. Accordingly, the second was identical to the first but additionally included trial-wise willingness-to-pay, frequency of consumption, and perceived healthiness as parametric modulators of the 5-s picture-viewing regressor. Parametrically modulated UPF and non-UPF picture viewing was brought up to the second level in a full factorial model and the contrasts UPF>non-UPF and non-UPF>UPF were tested with sex and age as covariates.
Effect(s) tested	UPF>non-UPF, non-UPF>UPF. UPF>non-UPF metabolic response regressed against UPF>non-UPF picture viewing
Specify type of analysis:	☐ Whole brain ☐ ROI-based ☒ Both
Anatomical location(s)	Prior work has shown that peak metabolic responses are associated with striatal activation (de Araujo et al., 2013; Veldhuizen et al., 2017), and recent meta-analyses have also associated the striatum with differences in willingness to pay (Newton-Fenner et al., 2023; Y. Wang & Yao, 2024). Accordingly, we examined both GLMs using whole-brain corrected analyses and small-volume correction within an a priori striatal mask (caudate, putamen, and nucleus accumbens) derived from Harvard–Oxford atlas (Desikan et al., 2006).
Statistic type for inference	Voxel-wise, family wise error (FWE) corrected
(See Eklund et al. 2016)	
Correction	Corrections for multiple comparisons were applied using a voxel-wise FWE-corrected threshold of $p < 0.05$. For visualization of clusters containing the peak voxel, statistical maps are displayed at uncorrected $p < 0.001$, $k > 10$.

Models & analysis

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