

Supplemental Material

Research Articles | Behavioral/Cognitive

Behavioral relevance of early neural coding of low-level odor features in humans

<https://doi.org/10.1523/JNEUROSCI.0203-25.2025>

Received: 28 January 2025

Revised: 11 October 2025

Accepted: 16 October 2025

Copyright © 2025 the authors

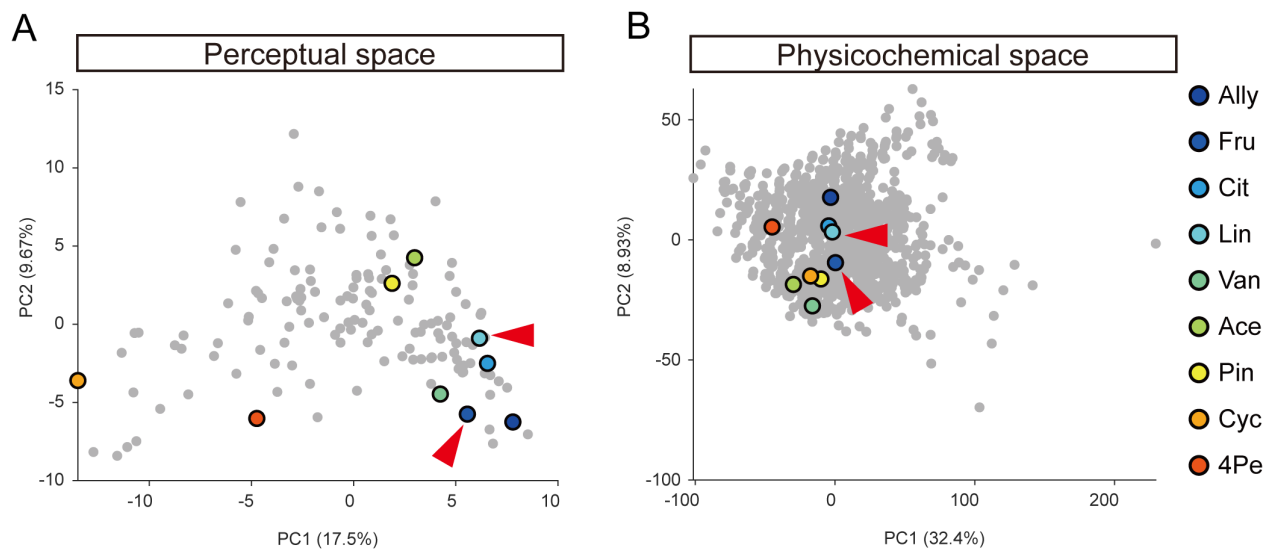


Figure S1. Odors selected to cover a wide distribution in perceptual and physicochemical spaces

Odors used in the current study (Exp.1 and 2) plotted in perceptual (A) and physicochemical (B) spaces. Principal component analysis (PCA) score plots are shown for the first two principal components (PCs), PC1 and PC2. The percentages of variance explained by each PC (%) are reported in parentheses. Each of the nine odors used in the current study was plotted with a unique color according to the color coding listed on the right. The gray dots represent other odors included in the PCA for each space (see below). Red arrowheads indicate the two odors used in both Exp. 1 and 2. The PCs shown in (A) were extracted based on the sensory rating data reported by Dravnieks, obtained from 138 mono-molecular odors using 146 verbal descriptors (Dravnieks, 1985). The PCs shown in (B) were extracted based on the physicochemical characteristics of 1,358 monomolecular odors (see Methods).

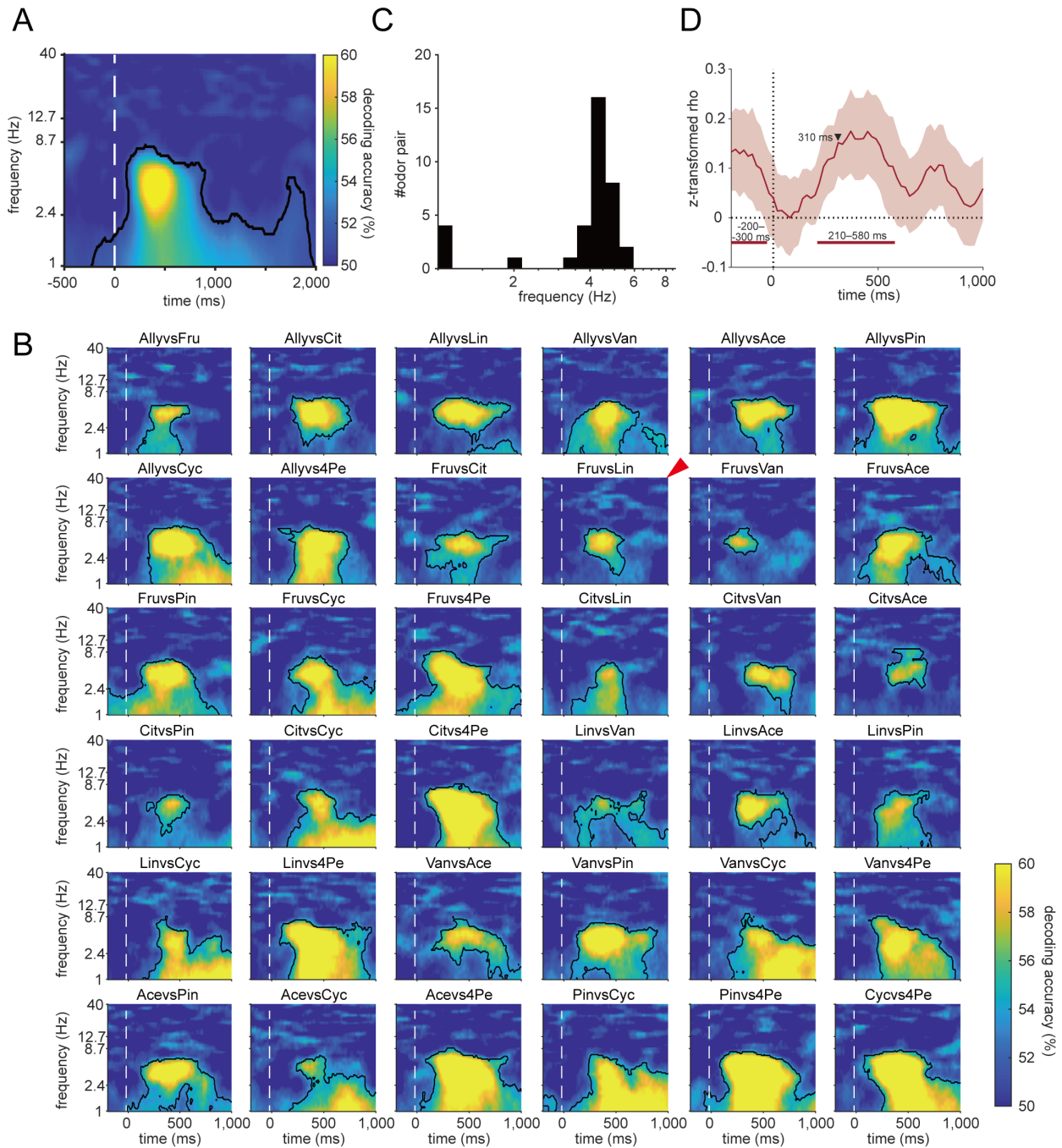


Figure S2. Peak decoding accuracy varied across odor pairs, occurring in the theta band, delta band, or both (Exp.1)

(A) To examine decoding dynamics before and after the time window of interest in the current study, grand mean decoding accuracies averaged across 36 odor pairs were plotted with an extended baseline period starting 500 ms before odor onset. The earliest significant decoding accuracy was observed at 220 ms before odor onset at 1.0 Hz. The black contour line indicates statistical significance (one-sided, one-sample Student's t-test, $p < 0.05$, cluster-based permutation correction). (B) Across-participant mean decoding accuracy for each odor pair obtained in Exp. 1. Black contour lines indicate statistical significance (one-sided, one-sample Student's t-test, $p < 0.05$, cluster-based permutation correction). The red arrowhead indicates the odor pair used in Exp. 2. (C) Histogram showing the number of odor pairs that exhibited the maximum decoding accuracy at the specified frequency band. No odor pairs that exhibited the maximum decoding accuracy at frequencies higher than 6 Hz were observed. (D) Correlation between neural RDMs in the theta band and delta band. Spearman's rank correlation coefficient was computed for each time point and participant, and then averaged after Fisher's z transformation. The bottom horizontal line indicates statistical significance (one-sided, one-sample Student's t-test, $p < 0.05$, cluster-based permutation correction). Shaded areas indicate 95% confidence intervals across participants. The Arrowhead and adjacent number indicate the time point of peak t-values.

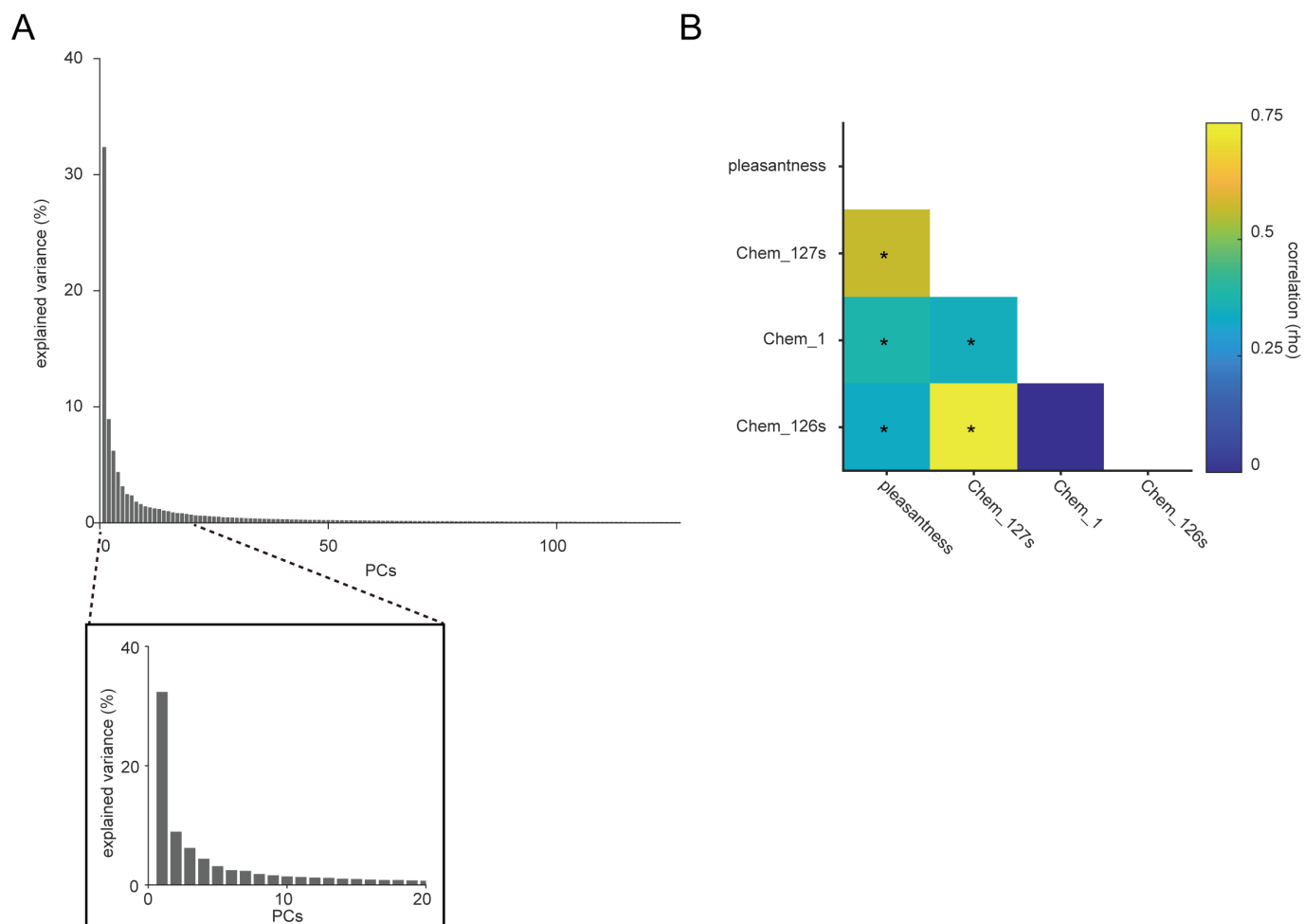


Figure S3. Dimensionality reduction of physicochemical features used in Exp. 1

(A) Percentage of variance explained by each of the first 127 PCs of odor physicochemical characteristics. The inset magnifies the explained variance of the first 20 PCs. (B) Correlation matrix for pleasantness and physicochemical RDMs. Chem_1 and Chem_127s refer to the physicochemical RDM constructed based on the first and the first 127 PCs, respectively. Chem_126s refers to the physicochemical RDM constructed based on the second to the 127th PCs. Spearman's rank correlation coefficient was computed for each participant and each pair of RDMs. After applying Fisher's z-transformation to the rho values, group-level inference testing for positive correlation was conducted using a one-sided one-sample Student's t-test (* $p < 0.05$, without any corrections for multiple testing).

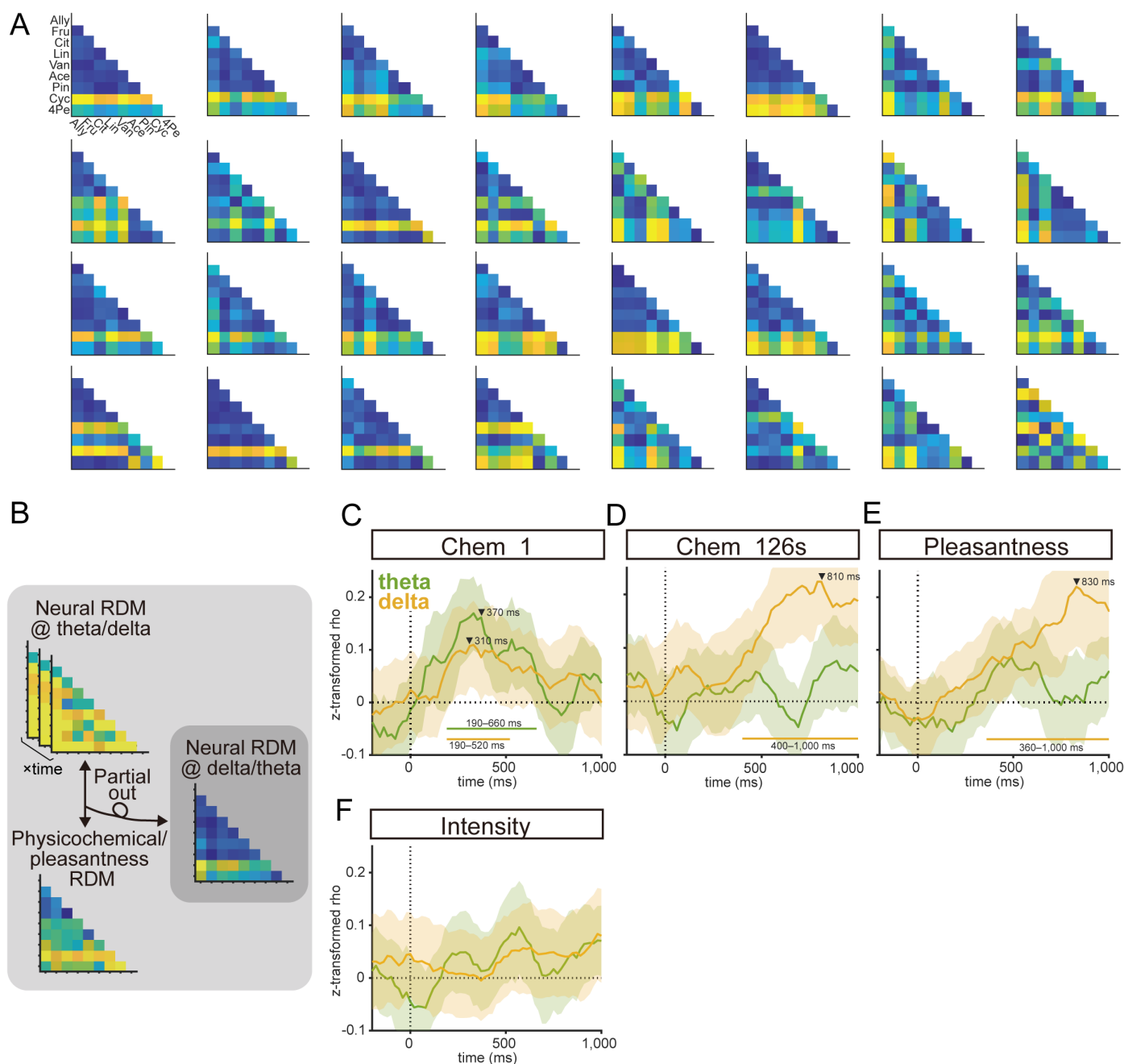


Figure S4. Individual RDMs and extended RSA

(A) Pleasantness RDMs of each of 32 participants, showing individual variability. (B) Analysis scheme of RSA, partialing out only the RDM of alternate frequency band, but not other odor properties. (C–F) Time course of z-transformed partial correlation coefficients between the delta (orange lines) or theta (green lines) bands and Chem_1 (C), Chem_126s (D), pleasantness (E), and intensity (F). RSA results without partialing out alternate characteristics showed a pattern similar to those with partialing out (Fig. 4B–D), except that delta activity exhibited an additional association with Chem_1 and an earlier association with pleasantness. Bottom horizontal lines indicate statistical significance (one-sided, one-sample Student's t-test, $p < 0.05$, cluster-based permutation correction). Shaded areas indicate 95% confidence intervals across participants. Arrowheads and adjacent numbers indicate the time points of peak t-values.

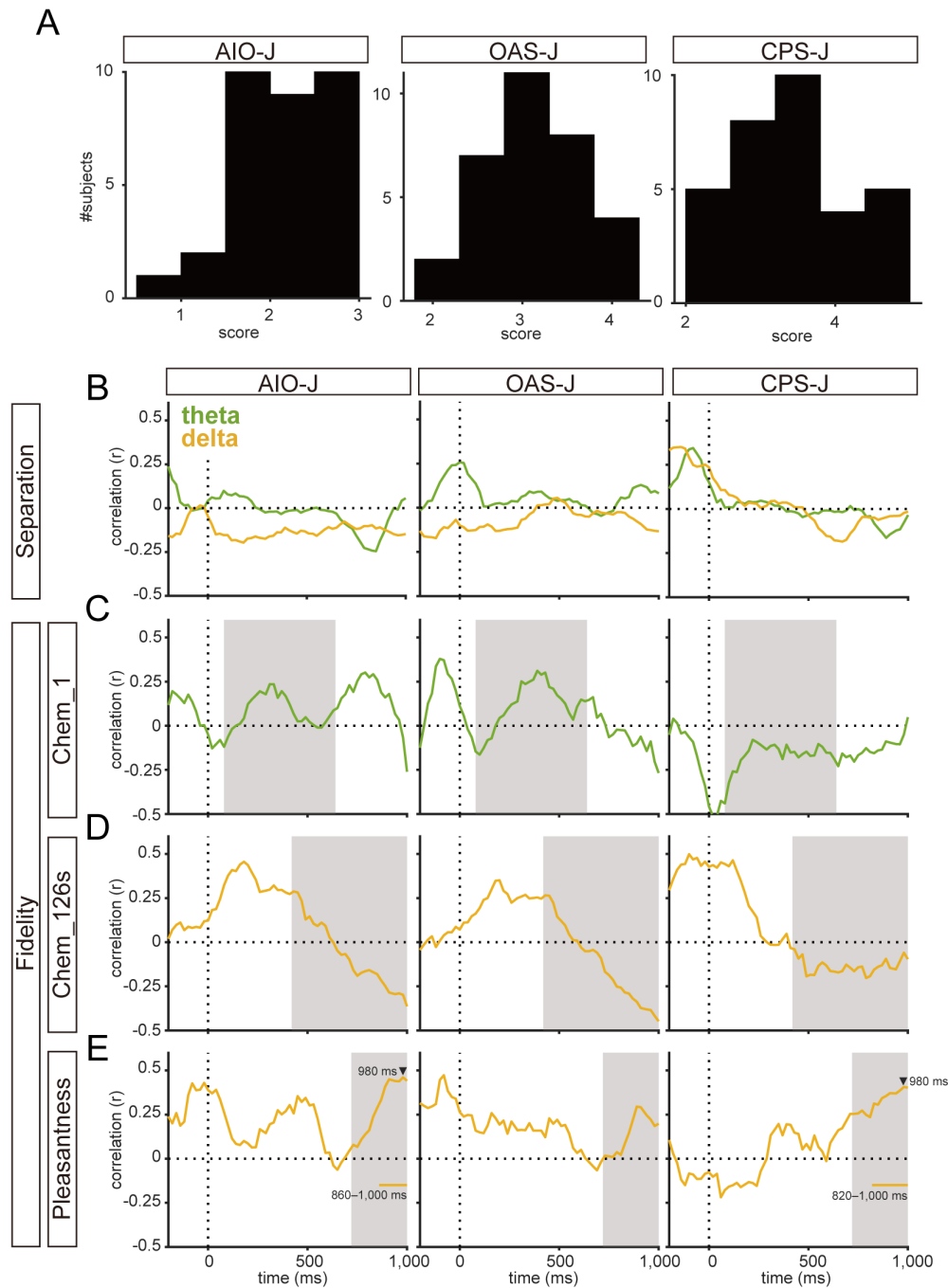


Figure S5. Distribution of olfaction-related scores and their association with odor separation and coding fidelity

(A) Histograms of scores from olfaction-related questionnaires. (B–E) Pearson’s correlation coefficients between questionnaire scores—AIO-J (left), OAS-J (middle), and CPS-J (right)—and neural odor separation (B), or coding fidelity to Chem_1 in theta (C), Chem_126s in delta (D), and pleasantness in delta (E). Neural odor separation was quantified using across-odor-pair-mean decoding accuracies, and coding fidelity was quantified using z-transformed RSA rho-values. In all panels, bottom horizontal lines indicate statistical significance (one-sided, $p < 0.05$, cluster-based permutation correction). Orange lines: delta band; green lines: theta band. Gray shaded areas in (C–E) indicate time windows with significant RSA partial correlations (Fig. 4B–D). Arrowheads and adjacent numbers indicate the time points of peak correlation. Significant correlations were found only between delta-band pleasantness coding fidelity and participants’ trait-level affective reactivity to odors, as measured by AIO-J and CPS-J.

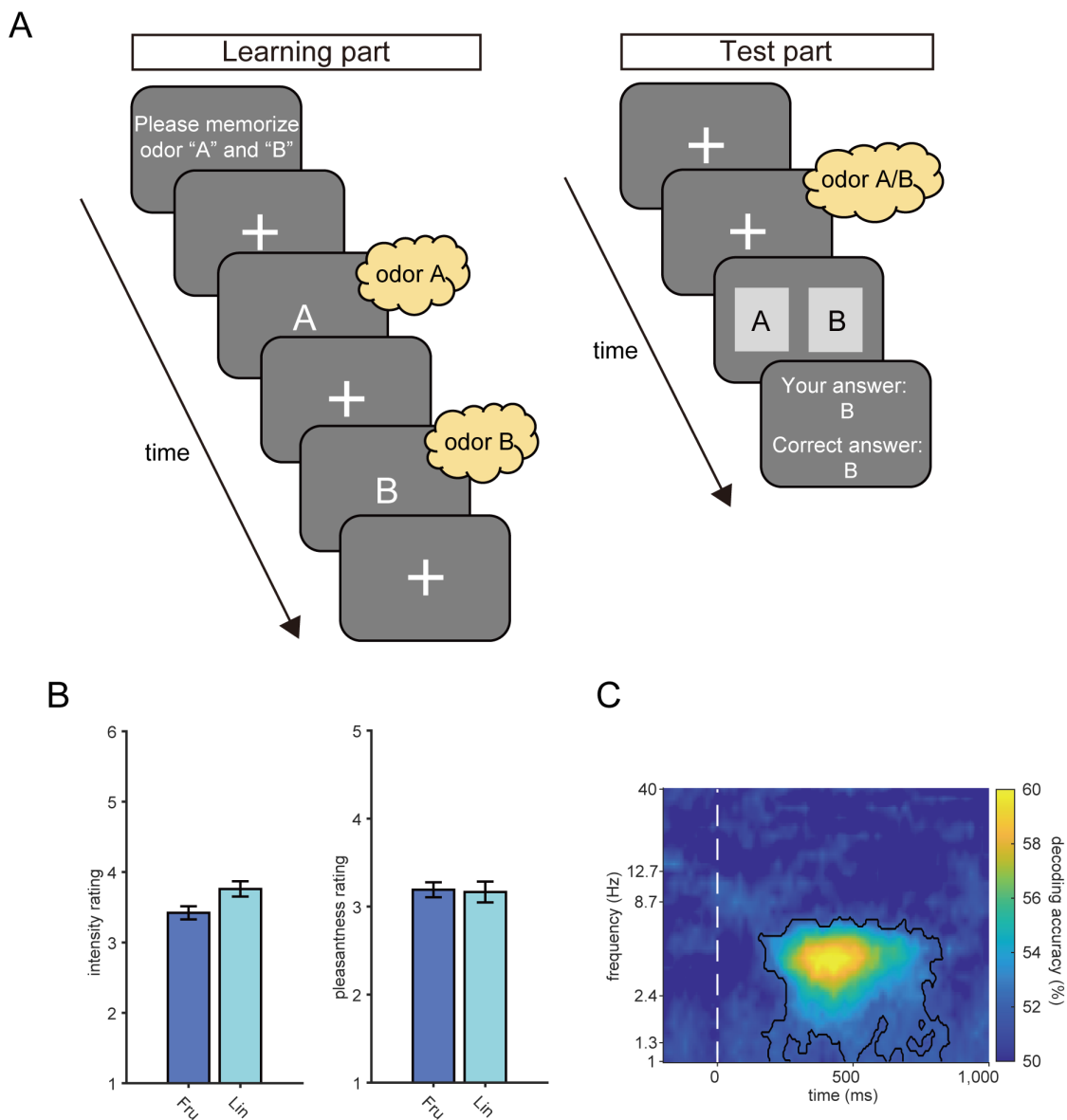


Figure S6. Experiment design, sensory evaluation, and decoding outcomes of Exp. 2

(A) Trial timelines for the learning part (left) and test part (right) of the odor memorization session. (B) Intensity and pleasantness ratings for each odor for all participants ($n = 42$; mean $\pm$ SEM). The data from one participant could not be obtained due to time constraints. (C) Time frequency map of the grand mean decoding accuracy classifying odors A and B. Only correctly answered trials were used as training data, and both correctly and incorrectly answered trials were used as test data. Black contour lines indicate statistical significance ($n = 24$, one-sided, one-sample Student's t -test, $p < 0.05$, cluster-based permutation correction). Peak decoding accuracy was observed in a similar time and frequency window as in Exp. 1 for the corresponding odor pair (Fig. S2B, red arrow).