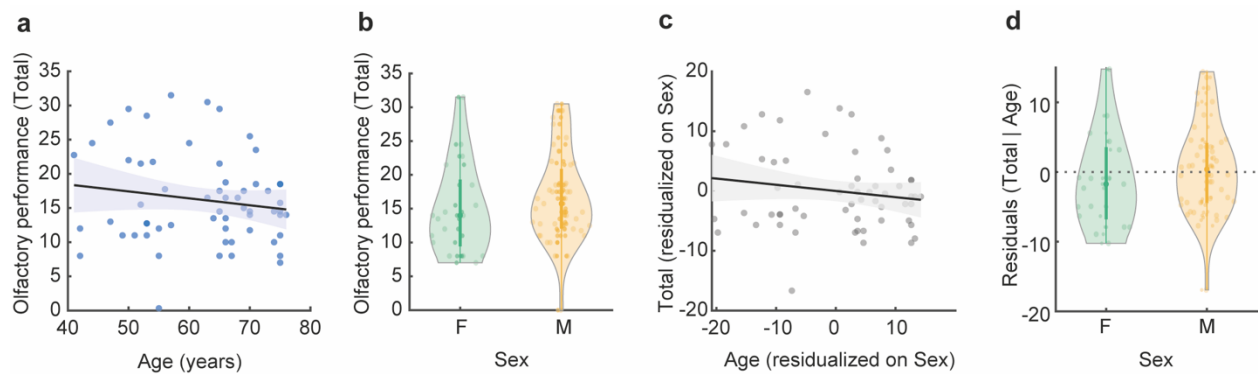
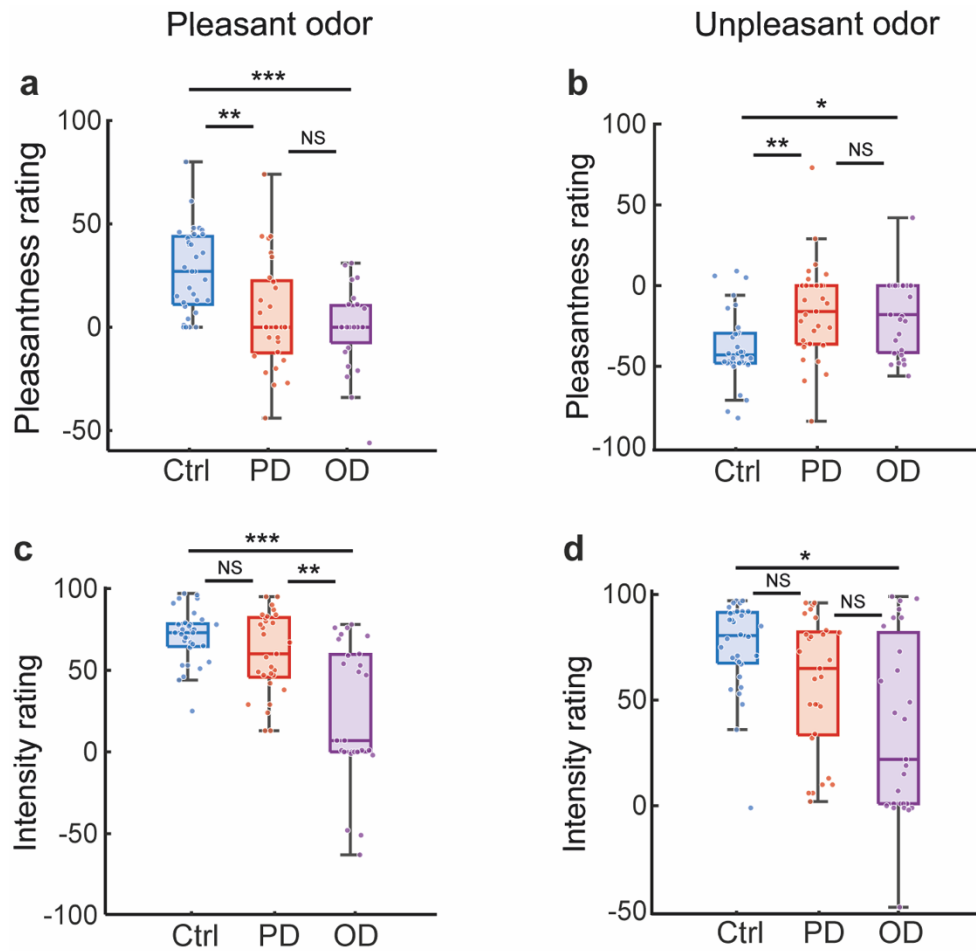


Supplementary Materials



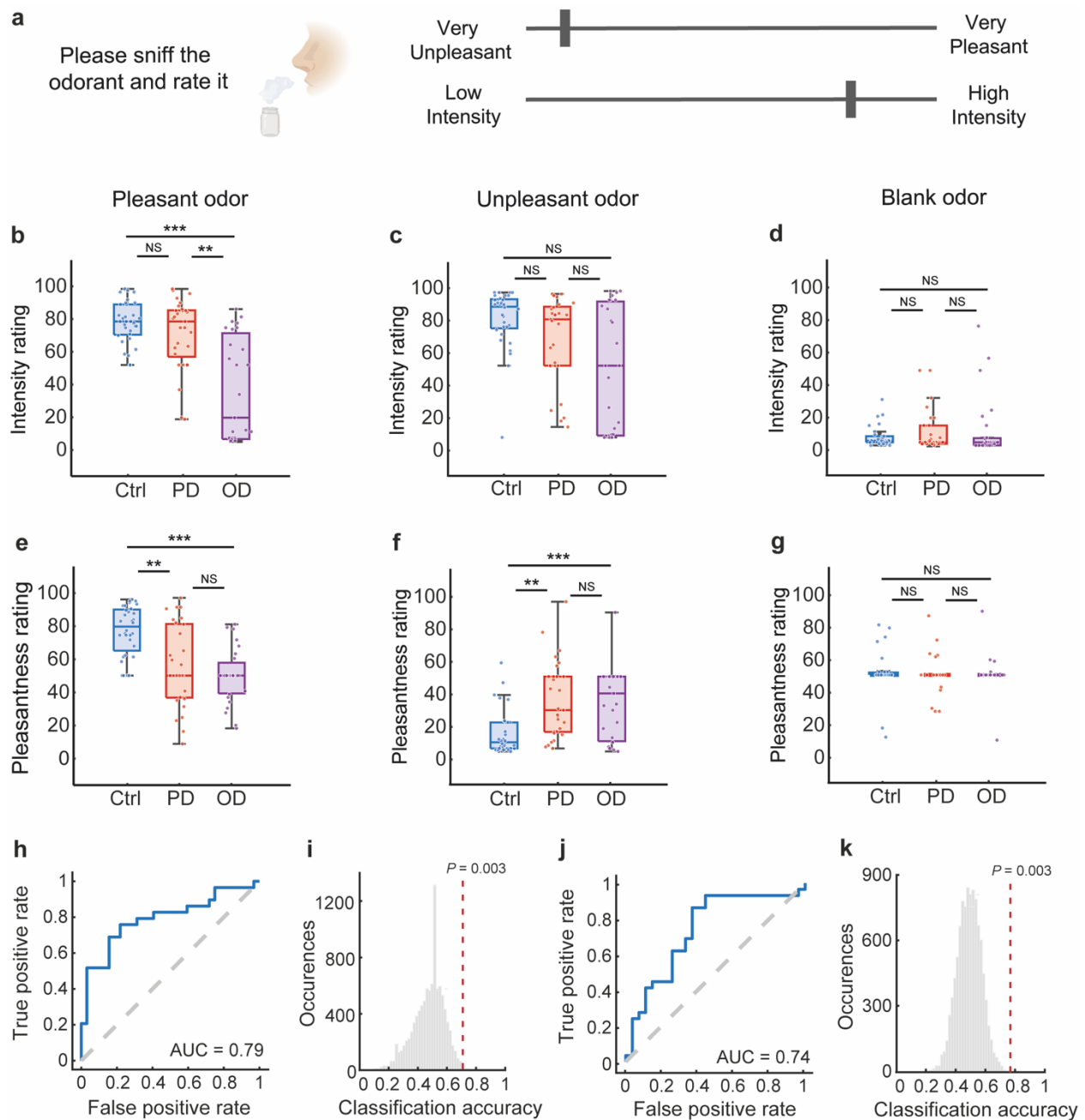
Supplementary Fig. 1: Sex- and age-related variation in olfactory performance (PD and OD only)

a, Scatter of Sniffin' Sticks Total score vs. age (years) with a least-squares fit (black line) and 95% CI (light-blue band); each circle is one participant. **b**, Violin plots of Sniffin' Sticks Total score by sex (female = green, male = orange) with individual points overlaid. **c**, Added-variable (partial regression) plot presenting the relation between model residuals of Sniffin' Sticks Total score (after removing sex) and age residualized on sex; black line represents the fit, grey band the 95% CI; each circle is one participant. **d**, Violin plots of age-residualized Total by sex (female = green, male = orange) with individual points overlaid.



Supplementary Fig. 2: Pleasantness ratings in PD and OD normalized by ratings of blank

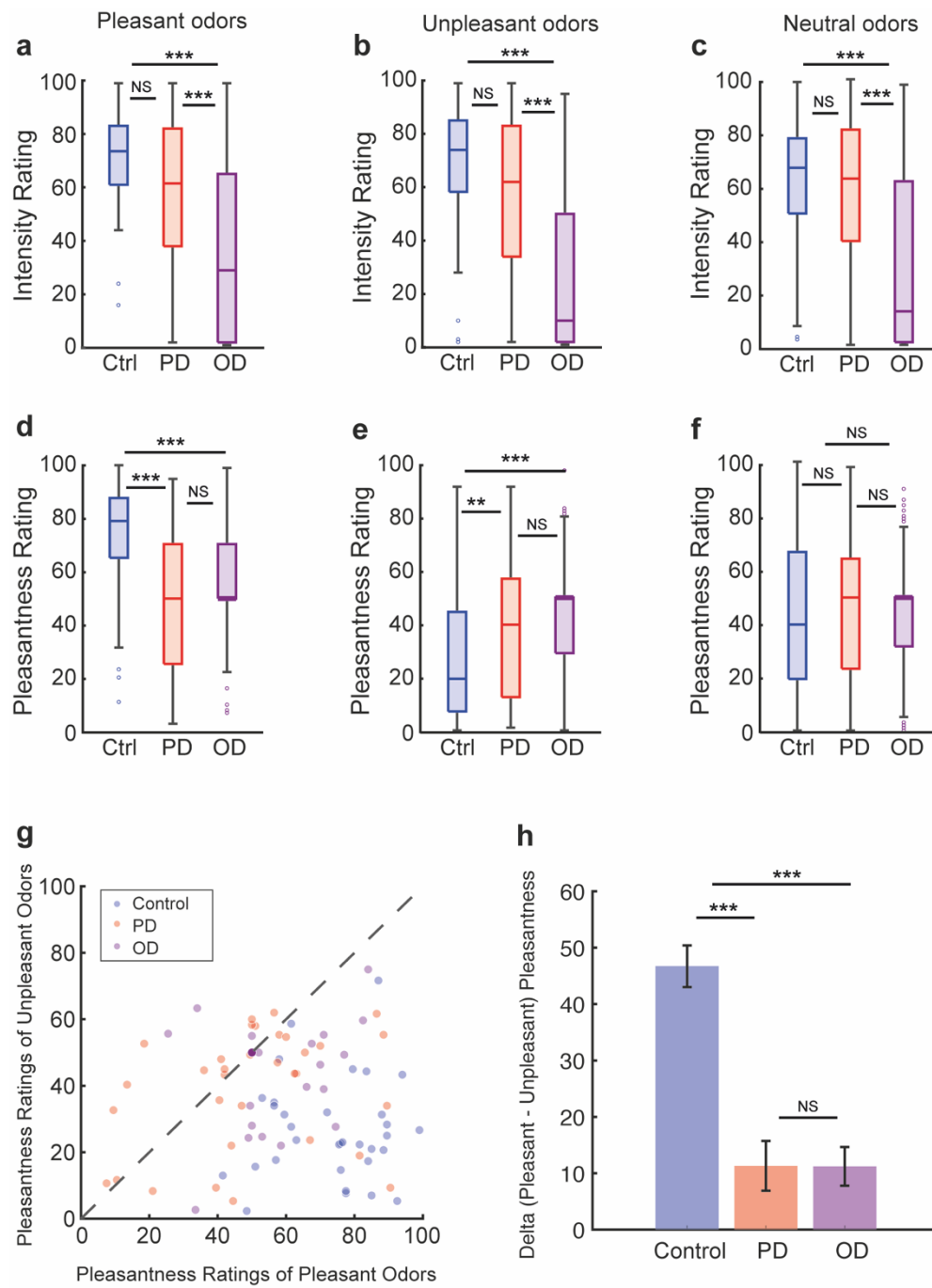
a-d, Box plots presenting subjective ratings (VAS scale, 1-100), normalized by subtraction to blank, of pleasantness (a,b) and intensity (c,d) for pleasant (a,c) and unpleasant (b,d) odorants in PD (red, $n = 29$), OD (purple, $n = 27$), and control (blue, $n = 32$) group. Central lines indicate median, top and bottom edges of the box indicate 75th and 25th percentiles, respectively. Whiskers reflect 1.5 times the interquartile range. Each circle represents a participant. * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.



Supplementary Fig. 3: Shifted primary axes of olfactory perception in Parkinson's disease

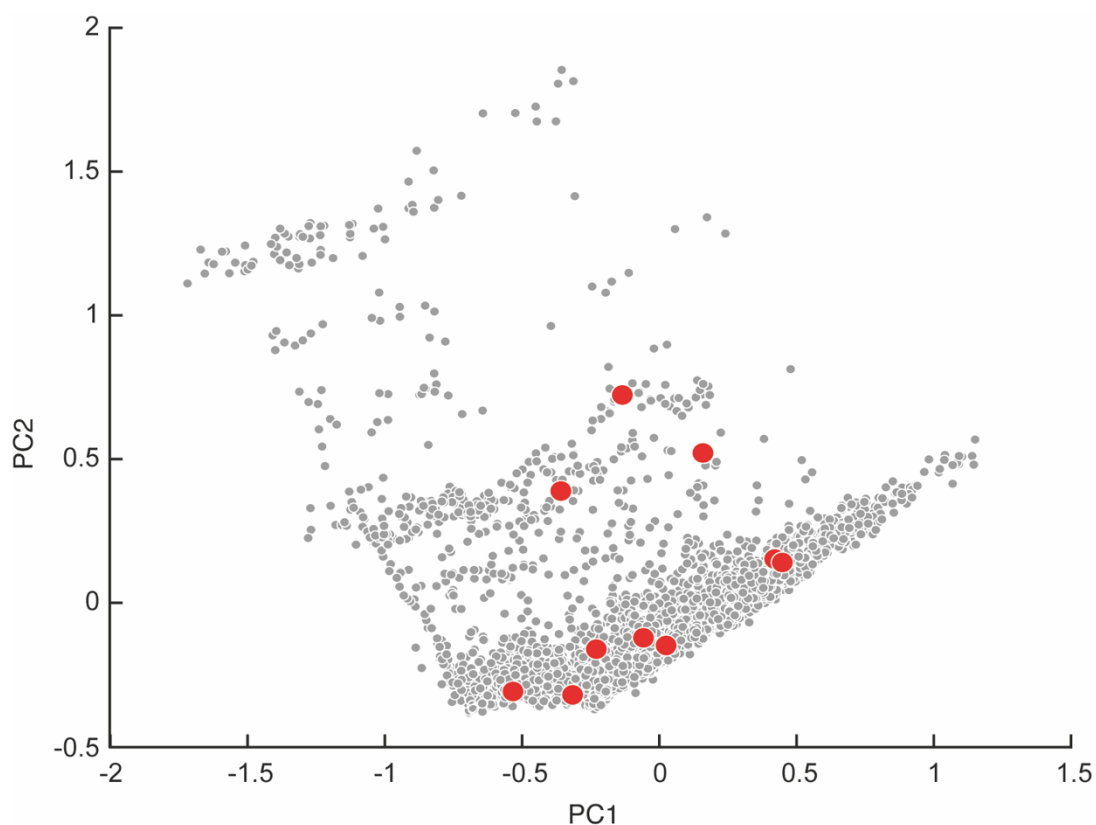
a, Illustration of task procedure. **b-g**, Box plots displaying subjective ratings (VAS scale, 1-100) of intensity (b,c,d) and pleasantness (e,f,g) for pleasant (b,e), unpleasant (c,f), and blank (d,g) odorants in PD (red, $n = 29$), OD (purple, $n = 27$) and healthy controls (blue, $n = 32$). Central lines indicate median, top and bottom edges of the box indicate 75th and 25th percentiles, respectively. Whiskers reflect 1.5 times the interquartile

range. Each circle represents a participant. $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$. **h, j**, ROC curves for detecting PD from healthy controls (h) and for detecting PD from OD participants (j) using an SVM classifier on pleasantness and intensity ratings. **i, k**, Histogram of classification accuracy using an SVM classifier for shuffled labels data of PD and controls (i) and PD and OD (k) with actual classification accuracy marked by red dashed line. P-values are marked on top of the line.



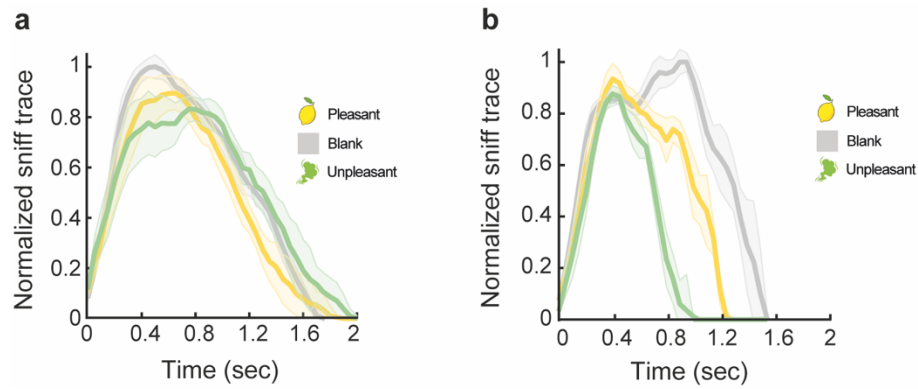
Supplementary Fig. 4: Intensity and pleasantness ratings for 10 odorants

a-f, Box plots illustrating subjective ratings (VAS scale, 1-100) of intensity (a-c) and pleasantness (d-f) for pleasant (a,d), unpleasant (b,e), and blank (c,f) odorants in PD (red, $n = 33$), OD (purple, $n = 28$) and healthy controls (blue, $n = 33$) groups. Central lines indicate median, top and bottom edges of the box indicate 75th and 25th percentiles, respectively. Whiskers reflect 1.5 times the interquartile range. Each circle represents a participant. **g**, Scatter plot displaying pleasantness ratings of pleasant vs. unpleasant odorants in Control (blue), PD (red), and OD (purple) groups. Each circle represents a participant. **h**, Bar graph (mean $\pm$ SEM) illustrating the difference (delta) between pleasantness ratings of pleasant and unpleasant odorants in each participant. $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$.



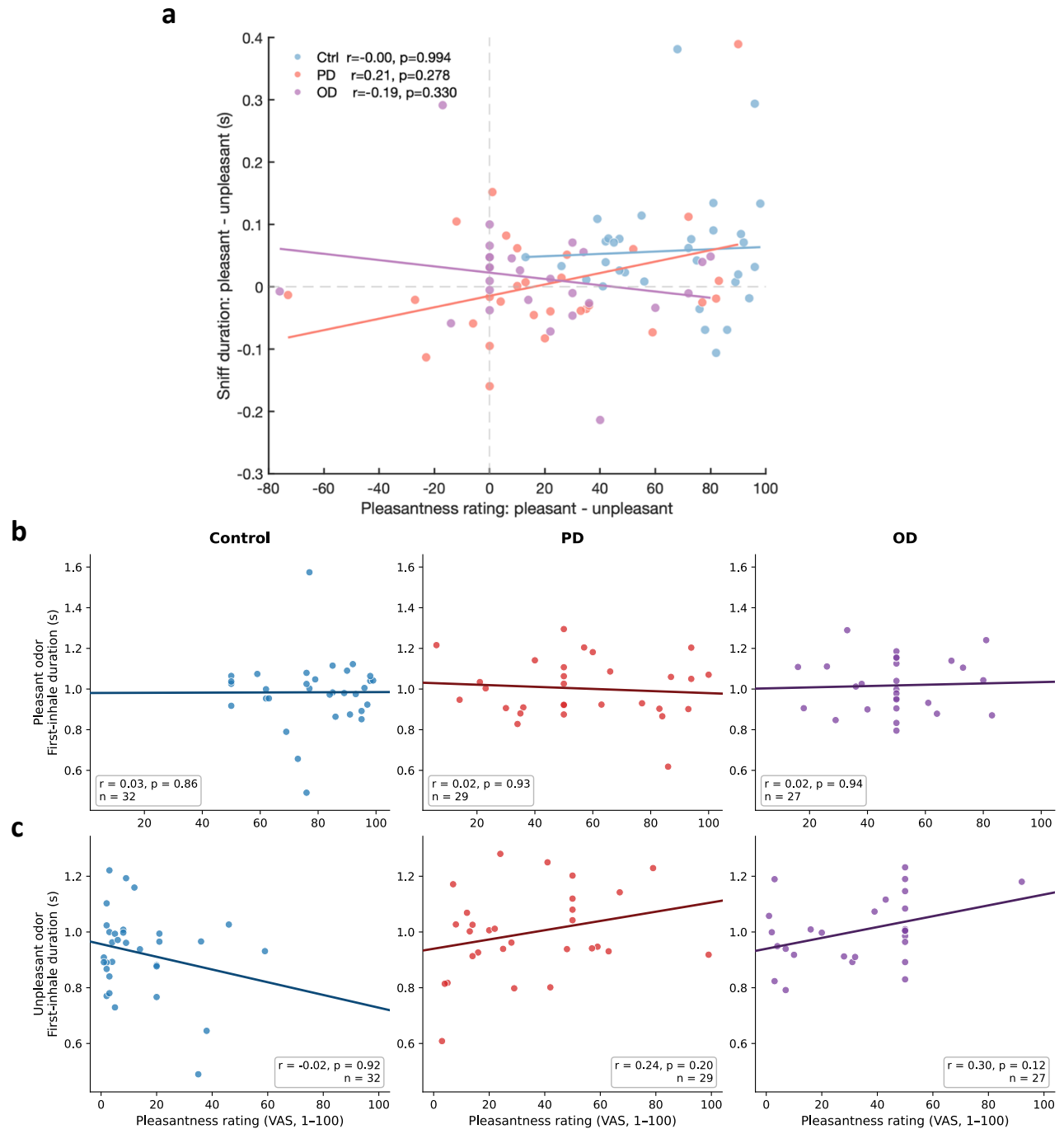
Supplementary Fig. 5: Selected monomolecules in physicochemical space

monomolecules used in the study (red circles) depicted within the first and second principal components of a representative physicochemical space containing 4886 odorant molecules (grey circles). The 10 monomolecules are: Fenchone (CAS 7787-20-4), Isoamyl acetate (CAS 123-92-2), 3-Propylidene phthalide (CAS 17369-59-4), Cuminaldehyde (CAS 122-03-2), Strawberry glycidate 1 (CAS 77-83-8), Nonanal (CAS 124-19-6), Citral (CAS 5392-40-5), Skatole (CAS 83-34-1), Hexanol (CAS 111-27-3), 6-Methylquinoline (CAS 91-62-3). All monomolecules were rated across 11 descriptors: “Pleasantness”; “Intensity”; “Garlicky”; “Sweet”; “Fruity”; “Chemical”; “Bitter”; “Burnt”; “Spicy”; “Clean-Dirty”; “Fresh-Rotten.”



Supplementary Fig. 6: Individual examples of sniff-response patterns

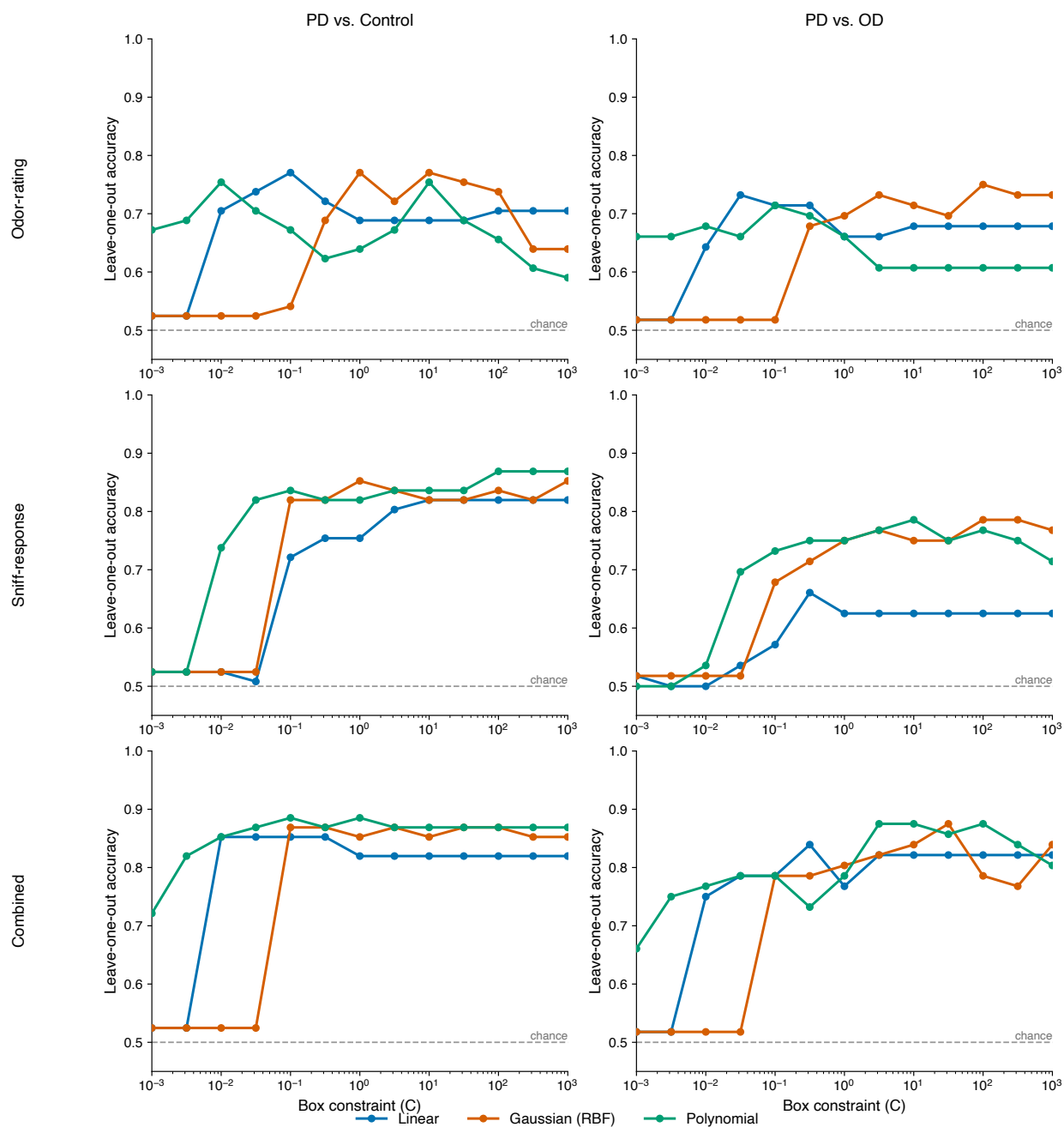
a, Example traces of altered sniff response from participant with PD 009, sniff trace was normalized to the participant's maximal peak value. Normalized sniff duration (mean $\pm$ s.d.): pleasant (yellow), 0.92 ± 0.14 NDU (10 repetitions); unpleasant (green), 1.0 ± 0.14 NDU (9 repetitions); blank (grey), 1.0 ± 0.14 NDU (10 repetitions). **b,** Example traces of intact sniff response from healthy control 004, sniff trace was normalized to the participant's maximal peak value. Normalized sniff duration: pleasant (yellow), 0.87 ± 0.11 NDU (10 repetitions); unpleasant (green), 0.7 ± 0.08 NDU (10 repetitions); blank (grey), 1.06 ± 0.11 NDU (10 repetitions). Traces are presented as mean (line) and SEM (shaded areas).



Supplementary Fig. 7: Explicit pleasantness ratings do not predict sniff-duration modulation.

a, For each participant, we calculated a pleasantness contrast as pleasant odor rating minus unpleasant odor rating, and a sniff-duration contrast as pleasant odor sniff duration minus unpleasant odor sniff duration. Scatter plots present the association between these contrasts within each group: healthy controls, PD, and OD. **b-c**, Scatter plots present, for each group (healthy controls, PD, and OD), first-inhale sniff duration as a function of pleasantness rating, for the pleasant odor (b) and for the unpleasant odor (c). Each point represents one participant (controls $n = 32$, PD $n = 29$, OD $n = 27$). Lines indicate linear fits for

visualization only; statistics were based on Spearman correlations and indicated. No significant association was observed in any group or condition.



Supplementary Fig. 8: Classifier accuracy is stable across SVM hyperparameters.

Leave-one-out cross-validation accuracy as a function of the SVM box constraint (regularization parameter C ; log-spaced 10^{-3} – 10^3) for each classifier (rows: odor-rating, sniff-response, combined) and each pairwise comparison (columns: PD vs. control; PD vs. non-PD olfactory dysfunction, OD). Within each panel, lines represent the three candidate kernels: linear (blue), Gaussian/RBF (orange), and polynomial (green); for the Gaussian kernel each point is the best accuracy across the swept kernel-scale values, and for the

polynomial kernel the best across orders 2–3. The dashed line indicates chance (0.5). For every classifier the reported accuracy lies on a broad plateau that is stable across two-to-three orders of magnitude of C and comparable across kernels.

Supplementary Table 1: Post-hoc comparisons, effect-size estimates, and confidence intervals.

Analysis	Outcome / condition	Group values, median $\pm$ SD	Comparison	Test statistic	Corrected P	Cliff's δ	95% CI
Sniffin' Sticks	Threshold	Control = 7.5 ± 2.7 ; PD = 2.7 ± 2.4 ; OD = 1 ± 1.4	Control vs. PD	Z = 4.6	5.4×10^{-5}	0.65	0.41 to 0.80
		Control = 7.5 ± 2.7 ; PD = 2.7 ± 2.4 ; OD = 1 ± 1.4	Control vs. OD	Z = 6.2	7.9×10^{-9}	0.9	0.78 to 0.96
		Control = 7.5 ± 2.7 ; PD = 2.7 ± 2.4 ; OD = 1 ± 1.4	PD vs. OD	Z = 2.7	NS	0.4	0.10 to 0.64
	Discrimination	Control = 11 ± 2.7 ; PD = 8 ± 2.6 ; OD = 6 ± 2.9	Control vs. PD	Z = 3.9	9.4×10^{-4}	0.57	0.31 to 0.75
		Control = 11 ± 2.7 ; PD = 8 ± 2.6 ; OD = 6 ± 2.9	Control vs. OD	Z = 4.3	1.8×10^{-4}	0.64	0.38 to 0.81
		Control = 11 ± 2.7 ; PD = 8 ± 2.6 ; OD = 6 ± 2.9	PD vs. OD	Z = 1.13	NS	0.17	-0.13 to 0.40
	Identification	Control = 13 ± 2.0 ; PD = 5 ± 2.7 ; OD = 5 ± 4.1	Control vs. PD	Z = 6.2	5.9×10^{-9}	0.88	0.70 to 0.96
		Control = 13 ± 2.0 ; PD = 5 ± 2.7 ; OD = 5 ± 4.1	Control vs. OD	Z = 4.3	2.2×10^{-4}	0.63	0.31 to 0.82
		Control = 13 ± 2.0 ; PD = 5 ± 2.7 ; OD = 5 ± 4.1	PD vs. OD	Z = 0.2	NS	0.03	-0.30 to 0.30
	Total score	Control = 30.5 ± 5.5 ; PD = 16.5 ± 5.9 ; OD = 12.4 ± 7.2	Control vs. PD	Z = 6.1	1.2×10^{-8}	0.88	0.72 to 0.95
		Control = 30.5 ± 5.5 ; PD = 16.5 ± 5.9 ; OD = 12.4 ± 7.2	Control vs. OD	Z = 5.6	2.8×10^{-7}	0.83	0.64 to 0.93
		Control = 30.5 ± 5.5 ; PD = 16.5 ± 5.9 ; OD = 12.4 ± 7.2	PD vs. OD	Z = 1.9	NS	0.3	-0.03 to 0.60
Intensity rating	Pleasant odor	Control = 78 ± 13.5 ; PD = 78 ± 22.6 ; OD = 16 ± 33.1	Control vs. PD	Z = 0.7	NS	0.1	-0.19 to 0.39
		Control = 78 ± 13.5 ; PD = 78 ± 22.6 ; OD = 16 ± 33.1	Control vs. OD	Z = 4.8	1.7×10^{-5}	0.7	0.48 to 0.86

		Control = 78 ± 13.5 ; PD = 78 ± 22.6 ; OD = 16 ± 33.1	PD vs. OD	Z = 4.05	4.5×10^{-4}	0.6	0.36 to 0.80
	Unpleasant odor	Control = 89.5 ± 19.8 ; PD = 81 ± 28.7 ; OD = 50 ± 41.4	Control vs. PD	Z = 1.9	NS	0.3	-0.004 to 0.54
		Control = 89.5 ± 19.8 ; PD = 81 ± 28.7 ; OD = 50 ± 41.4	Control vs. OD	Z = 2.6	NS	0.4	0.07 to 0.64
		Control = 89.5 ± 19.8 ; PD = 81 ± 28.7 ; OD = 50 ± 41.4	PD vs. OD	Z = 1.6	NS	0.26	-0.07 to 0.50
	Blank	Control = 4 ± 6.8 ; PD = 3 ± 13.6 ; OD = 3 ± 19.9	Control vs. PD	Z = 0.2	NS	0.02	-0.26 to 0.30
		Control = 4 ± 6.8 ; PD = 3 ± 13.6 ; OD = 3 ± 19.9	Control vs. OD	Z = 1.5	NS	0.2	-0.08 to 0.50
		Control = 4 ± 6.8 ; PD = 3 ± 13.6 ; OD = 3 ± 19.9	PD vs. OD	Z = 1.3	NS	0.2	-0.10 to 0.50
	Pleasantness rating	Control = 81.5 ± 15.9 ; PD = 50 ± 26.2 ; OD = 50 ± 17.6	Control vs. PD	Z = 3.3	0.006	0.5	0.21 to 0.71
		Control = 81.5 ± 15.9 ; PD = 50 ± 26.2 ; OD = 50 ± 17.6	Control vs. OD	Z = 5.0	3.9×10^{-6}	0.7	0.54 to 0.88
		Control = 81.5 ± 15.9 ; PD = 50 ± 26.2 ; OD = 50 ± 17.6	PD vs. OD	Z = 1.0	NS	0.15	-0.15 to 0.43
	Unpleasant odor	Control = 7 ± 14.8 ; PD = 28 ± 24.9 ; OD = 39 ± 23.0	Control vs. PD	Z = -3.9	6.7×10^{-4}	-0.60	-0.76 to -0.33
		Control = 7 ± 14.8 ; PD = 28 ± 24.9 ; OD = 39 ± 23.0	Control vs. OD	Z = -3.3	0.009	-0.50	-0.71 to -0.19
		Control = 7 ± 14.8 ; PD = 28 ± 24.9 ; OD = 39 ± 23.0	PD vs. OD	Z = 0.3	NS	0.04	-0.26 to 0.34
	Blank	Control = 50 ± 14.0 ; PD = 50 ± 12.5 ; OD = 50 ± 12.1	Control vs. PD	Z = 1.06	NS	0.13	-0.11 to 0.36
		Control = 50 ± 14.0 ; PD = 50 ± 12.5 ; OD = 50 ± 12.1	Control vs. OD	Z = 0.67	NS	0.08	-0.14 to 0.30

		Control = 50 ± 14.0 ; PD = 50 ± 12.5 ; OD = 50 ± 12.1	PD vs. OD	Z = -0.6	NS	-0.07	-0.30 to 0.17
Normalized sniff duration	Pleasant vs. unpleasant, Control	Pleasant = 1.12 ± 0.30 NDU; Unpleasant = 0.98 ± 0.26 NDU	Pleasant vs. unpleasant	Z = 4.4	1.0×10^{-4}	0.29	0.15 to 0.42
	Pleasant vs. unpleasant, OD	Pleasant = 1.32 ± 0.33 NDU; Unpleasant = 1.17 ± 0.28 NDU	Pleasant vs. unpleasant	Z = 4.3	1.7×10^{-4}	0.21	0.12 to 0.30
	Pleasant vs. unpleasant, PD	Pleasant = 1.18 ± 0.31 NDU; Unpleasant = 1.20 ± 0.33 NDU	Pleasant vs. unpleasant	Z = -1.5	NS	-0.002	-0.16 to 0.16
	Pleasant–unpleasant delta	Control = -0.12 ± 0.20 NDU; PD = 0.02 ± 0.20 NDU	Control vs. PD	Z = -4.3	4.3×10^{-5}	-0.65	-0.82 to -0.36
	Pleasant–unpleasant delta	OD = -0.09 ± 0.20 NDU; PD = 0.02 ± 0.20 NDU	OD vs. PD	Z = 4.3	4.5×10^{-5}	0.67	0.39 to 0.84
	Blank vs. unpleasant, Control	Blank = 1.14 ± 0.35 NDU; Unpleasant = 0.98 ± 0.26 NDU	Blank vs. unpleasant	Z = 4.5	5.4×10^{-5}	0.43	-0.16 to 0.60
Absolute sniff duration	Blank	Healthy = 1.136 ± 0.354 s; PD = 1.240 ± 0.332 s; OD = 1.257 ± 0.313 s	Healthy vs. PD	Z = -1.581	NS	-0.237	-0.497 to 0.062
		Healthy = 1.136 ± 0.354 s; PD = 1.240 ± 0.332 s; OD = 1.257 ± 0.313 s	Healthy vs. OD	Z = -1.346	NS	-0.206	-0.478 to 0.102
		Healthy = 1.136 ± 0.354 s; PD = 1.240 ± 0.332 s; OD = 1.257 ± 0.313 s	PD vs. OD	Z = 0.115	NS	0.019	-0.281 to 0.316
	Pleasant odor	Healthy = 1.119 ± 0.343 s; PD = 1.184 ± 0.312 s; OD = 1.322 ± 0.333 s	Healthy vs. PD	Z = -1.755	NS	-0.263	-0.515 to 0.032
		Healthy = 1.119 ± 0.343 s; PD = 1.184 ± 0.312 s; OD = 1.322 ± 0.333 s	Healthy vs. OD	Z = -2.533	0.034	-0.387	-0.621 to -0.089
		Healthy = 1.119 ± 0.343 s; PD = 1.184	PD vs. OD	Z = -0.705	NS	-0.111	-0.400 to 0.198

		± 0.312 s; OD = 1.322 ± 0.333 s					
	Unpleasant odor	Healthy = 0.977 ± 0.258 s; PD = 1.206 ± 0.332 s; OD = 1.170 ± 0.284 s	Healthy vs. PD	Z = -3.574	0.0011	-0.534	-0.730 to -0.259
		Healthy = 0.977 ± 0.258 s; PD = 1.206 ± 0.332 s; OD = 1.170 ± 0.284 s	Healthy vs. OD	Z = -2.792	0.0157	-0.426	-0.650 to -0.134
		Healthy = 0.977 ± 0.258 s; PD = 1.206 ± 0.332 s; OD = 1.170 ± 0.284 s	PD vs. OD	Z = 0.771	NS	0.121	-0.187 to 0.408

Values are reported as median $\pm$ SD where applicable. Post-hoc P-values are corrected for multiple comparisons where applicable. NS = non-significant. CI = confidence interval. NDU = normalized duration unit.

Metric	Raw (as reported)	Standardized
Sensitivity	0.79	0.76
Specificity	0.79	0.82
Accuracy	0.79	0.79

Supplementary Table 2: The perceptual-fingerprint classifier is robust to feature standardization.

Leave-one-out sensitivity, specificity, and accuracy of the 11-descriptor perceptual-fingerprint (majority-vote logistic-regression) classifier for PD vs. control, computed on the raw 1–100 visual-analogue-scale ratings (as reported) and after standardizing (z-scoring) the features within each training fold. PD is the positive class.

Classifier	Comparison	Kernel	Box constraint (C)	Kernel scale	Polynomial order	LOO accuracy
Odor-rating	PD vs. Control	Linear	1.0×10^{-3}	0.13	-	0.77
Odor-rating	PD vs. OD	Gaussian (RBF)	4.5×10^{-2}	76.3	-	0.71
Sniff-response	PD vs. Control	Gaussian (RBF)	0.99	0.33	-	0.85
Sniff-response	PD vs. OD	Gaussian (RBF)	2.2×10^{-2}	3.54	-	0.8
Combined	PD vs. Control	Gaussian (RBF)	3.8×10^{-2}	5.42	-	0.89
Combined	PD vs. OD	Gaussian (RBF)	2.60×10^{-2}	1.76	-	0.88
Combined (age/sex-matched)	PD vs. OD	Polynomial	47.5	275	3	0.94

Supplementary Table 3: SVM hyperparameters selected by Bayesian optimization, per classifier.

For each classifier and pairwise comparison, the kernel, box constraint (C), kernel scale, and (where applicable) polynomial order selected by Bayesian optimization (expected-improvement acquisition, 75 evaluations) within leave-one-out cross-validation, together with the resulting leave-one-out accuracy. Box constraint and kernel scale were searched over 10^{-3} – 10^3 on a log scale. Kernel scale is not applicable to the linear kernel (–). Leave-one-out accuracies reproduce the values reported in the main text.