

**Examining Odor Memorability: The Role of Pleasantness, Intensity, and
Individual Differences in Olfactory Memory Among Adults**

By

Vicky Zhang

August, 2025

A paper submitted in partial fulfillment of the requirements for the
Master of Arts degree in the
Master of Arts Program in the Social Sciences

Faculty Advisor: Dr. Wilma A. Bainbridge

Preceptor: Dr. Amanda Ceniti

Abstract

This study examined whether odors possess intrinsic memorability and tested how perceived pleasantness and intensity influence recognition accuracy and confidence. Nineteen adults incidentally encoded six of twelve intensity-matched monomolecular odorants and later completed a yes-no recognition test containing all twelve odors. Corrected recognition scores and confidence ratings were analyzed at both participant and odor levels. Memorability varied markedly across odors: some were reliably recognized (corrected recognition ≈ 0.90), whereas others were near chance or negative, indicating stimulus-specific mnemonic strength. Perceived pleasantness did not predict recognition accuracy or confidence, and a one-way ANOVA showed no accuracy differences across rounded pleasantness categories. In contrast, perceived intensity correlated positively with confidence and showed a weak, nonsignificant trend with accuracy. Confidence and corrected recognition were themselves positively related. These results indicate that (i) odor memorability is largely stimulus-driven and consistent across individuals, and (ii) subjective intensity, rather than hedonic valence, enhances metacognitive certainty with minimal impact on objective accuracy. Future work should use larger samples, broader hedonic ranges, and neuroimaging to test whether stimulus-level mnemonic differences map onto distinct activation patterns in olfactory and limbic regions and to assess potential sex-specific effects.

Introductoin

Memorability refers to an intrinsic, measurable quality of a stimulus that determines how likely it is to be remembered later, regardless of personal experience. Since it is quantifiable, it can be identified and analyzed using data from various memory or perception experiments (Bainbridge & Rissman, 2018). While certain stimulus features such as distinctiveness and emotionality have been proposed to affect memorability, the evidence is mixed. In some

domains, prototypical items are remembered better than distinctive ones (Kramer et al., 2023), and emotionality shows little or inconsistent association with memory performance (Davis & Bainbridge, 2023). These findings highlight that the determinants of memorability remain an open empirical question. Visual stimuli with clear semantic content or strong emotional impact tend to be more memorable, a finding supported by neuroimaging studies showing distinct neural activations during the encoding and retrieval of such stimuli (Bainbridge et al., 2017; Bainbridge & Rissman, 2018). Sound memorability is similarly predicted by factors like causal uncertainty, visualizability, and valence, which are strong indicators of a sound's likelihood to be remembered (Ramsay, Ananthabhotla, & Paradiso, 2018; Revsine et al., 2025). Thus, memorability is largely determined by these higher-order perceptual properties (Bainbridge, 2019). All of these properties are further supported by studies which show that memorability is consistent across individuals, reflecting that these properties are fundamental characteristics of the stimulus itself rather than being purely subjective (Isola et al., 2011). This consistency across observers underscores the robustness of memorability as an intrinsic stimulus attribute influencing memory performance in various contexts (Bainbridge, 2017). While much of the research on memorability has focused on visual and auditory aspects, such as images, videos, and sounds, less attention has been given to olfactory stimuli.

The lack of studies on odor memorability or odor memory may be due to the difficulty of empirically studying olfactory recall. Unlike pictures or words, odors have no straightforward verbal or graphic "output" that participants can reproduce on demand. Most people struggle to name even common smells, and there is no equivalent of drawing a remembered scene or repeating a spoken list. As a result, researchers must rely on indirect measures such as yes-no recognition or similarity ratings, which capture memory only coarsely and make it harder to

quantify recall accuracy (Herz, 1996). To date, adequate cognitive olfactory studies mostly based on the Proust phenomenon have explored factors such as odor-evoked autobiographical memories and odor recognition using naturalistic cross-modal experiments (Herz & Schooler, 2004). The Proust phenomenon suggests that odors can trigger vivid and emotionally charged autobiographical memories of the past. Subsequent studies have shown that odor-evoked memories, compared to those triggered by verbal, visual, or auditory stimuli, do not necessarily retrieve more vivid details but tend to elicit stronger emotional responses (Herz & Schooler, 2002; Herz & Schooler, 2004). This is supported by the link between emotional impact and the unique olfactory pathway, which connects directly to the amygdala-hippocampal complex, the neural substrate for emotional memory (Aggleton & Mishkin, 1986; Cahill et al., 1995). Additionally, emotional engagement has long been recognized as a dominant feature in odor perception and stimulation (Brauchli, Ruegg, Etzweiler, & Zeier, 1995; Vernet-Maury, Alaoui Ismaili, Dittmar, Delhomme, & Chanel, 1999). While odor-evoked memories may not enhance the accuracy of autobiographical details, their strong emotional potency underscores the critical role of emotional engagement in odor memorability. Additionally, given that pleasantness itself rarely predicts memorability in vision or audition (Isola et al., 2011; Revsine et al., 2025), it remains unclear whether hedonic value will play a stronger role in the olfactory modality. Therefore, this emotional potency, whether pleasant or unpleasant, warrants further exploration as a key factor influencing how well odors are remembered.

Besides, Cabanac and Bonniot-Cabanac (2011) found that odors that evoke strong pleasure or displeasure tend to trigger more emotional responses, which are closely tied to memory formation, retrieval, and performance. Their experiments showed that odors rated as either highly pleasant or highly unpleasant were more accurately recalled than those rated as

neutral. This suggests that emotional intensity, whether positive or negative, plays a pivotal role in how well an odor is remembered, highlighting the unique role of bipolar hedonic content in enhancing both recall and recognition accuracy. Building on this foundation, previous studies of odor memory have highlighted the importance of the hedonic dimension, the perceived pleasantness or unpleasantness of an odor, in shaping recall and autobiographical vividness (Cabanac & Bonniot-Cabanac, 2011). However, those studies typically focused on emotionally charged or familiar scents and did not test whether odors possess an intrinsic, stimulus-driven memorability independent of personal relevance, nor did they disentangle the relative contributions of pleasantness and perceived intensity under controlled conditions. Therefore, it is crucial to explore odor memorability specifically through the lens of odor pleasantness.

Supporting this, Khan and Sobel (2007) demonstrated that odor pleasantness can be predicted by the physicochemical properties of odor molecules. They argued that pleasantness is not solely a learned response but is also deeply rooted in biological and structural characteristics (Khan & Sobel, 2007). Their work established odor pleasantness as a primary axis of olfactory perception, showing that certain molecular structures are universally perceived as pleasant, regardless of cultural differences. Arshamian et al. (2022) further support this, finding that the perception of odor pleasantness is largely universal, with minimal cultural influence and strongly predicted by the physicochemical properties of odor molecules. Although Kermen et al. (2011) showed that odors with greater molecular complexity are often perceived as more pleasant and provide richer olfactory experiences, we chose monomolecular odorants for the present study because this is our first investigation of odor memorability.

Since existing research on memorability has primarily focused on visual and auditory stimuli, with less attention given to the olfactory domain, this proposed study addresses this

critical gap by exploring how odor memorability can be studied and quantified, similar to other sensory modalities. Additionally, it examines the correlation between odor pleasantness and odor memorability, shedding light on what factors could affect odor memorability. As memorability is an intrinsic, measurable quality of a stimulus, studying olfactory stimuli through the lens of odor pleasantness allows us to explore whether intensity and emotionality, which are well-established predictors of visual and auditory memorability, also apply to smells. The present study also focuses on which characteristics of specific odors are more likely to be remembered and mechanisms that may influence odor retention. Since olfactory stimuli evoke strong emotional responses due to their unique neural connections with the amygdala-hippocampal complex, studying odor memorability offers a rich avenue for understanding the role of emotional intensity, which is hedonicity, in olfactory memory processes. This research not only expands current knowledge on olfactory cognition but also contributes to a more comprehensive framework for multisensory memorability, addressing how intrinsic properties of stimuli, including pleasantness, determine their likelihood to be remembered. The findings could have practical implications in areas such as marketing, education, and clinical therapies, where the strategic use of memorable odors could enhance engagement and retention.

Research Question

Are certain odors consistently more memorable across a sample of adults, or is odor memorability highly individual-specific? Given that pleasantness generally does not predict visual or auditory memorability (Isola et al., 2011; Revsine et al., 2025), does smell differ due to its strong link to emotion and memory? Specifically, to what extent does the perceived pleasantness of an odor correlate with its memorability, and does variation in subjective (perceived) odor intensity influence recognition accuracy and confidence?

Hypothesis

Based on prior research indicating the emotional potency of olfactory stimuli (Cabanac & Bonniot-Cabanac, 2011), we hypothesize that odors rated as highly pleasant or highly unpleasant will be more memorable, leading to higher recognition accuracy and greater confidence levels compared to neutral odors. Furthermore, we predict that perceived odor intensity will enhance recognition accuracy and confidence, reflecting the role of arousal and perceptual salience in supporting episodic memory (Cabanac & Bonniot-Cabanac, 2011).

Methods

Participants

Nineteen healthy adult participants between the ages of 18 and 45 were recruited through the University of Chicago SONA participant pool and local advertisements. All participants provided informed consent in accordance with procedures approved by the University of Chicago Institutional Review Board (protocol IRB19-1395). Participants were screened using a pre-experiment health and behavior questionnaire to ensure eligibility. Inclusion criteria required that participants be non-smokers, with no current or prior history of neurological, respiratory (e.g., asthma, chronic bronchitis), or olfactory (e.g., anosmia) disorders, including nasal trauma or surgery. Participants currently experiencing symptoms such as nasal congestion, sore throat, fatigue, or recent loss of smell or taste were excluded. Additionally, individuals who reported using medications that may impair olfaction, or were uncertain of their effects, were not enrolled. They were also instructed not to wear any fragrances (e.g., perfume, cologne, body spray, aftershave, scented lotions or deodorants) on the day of participation. Participants who reported typically wearing scented products were asked to specify the type and brand for documentation, and confirmed they had not applied any on the test day.

Subjects were randomly assigned to one of two experimental groups (Group A = 10, Group B = 9), with each group exposed to a different subset of six odorants drawn from a total of twelve. During the encoding phase, participants were presented with a series of olfactory stimuli that varied in pleasantness (ranging from unpleasant to pleasant across 9 levels). No indication of a subsequent memory test was given, allowing assessment of incidental encoding of olfactory information. Given existing literature suggesting sex-based differences in olfactory sensitivity, particularly increased sensitivity in females during ovulation (Mair et al., 1978) as well as evidence that cortisol may influence memory formation differently in males (Andreano & Cahill, 2006), participant sex was recorded and considered in exploratory analyses. However, data from male and female participants were pooled for all primary analyses.

Location and Materials

Twelve monomolecular odorants were selected based on the Sobel pleasantness scale and odor similarity, considering both chemical structure and perceived valence (Khan et al., 2007). Odorants were stored in airtight, light-shielding glass jars and categorized according to their predicted pleasantness scores (Khan & Sobel, 2007), which ranged from -35.06 (highly unpleasant) to 41.51 (highly pleasant). Of the twelve odorants selected, four had pleasantness scores greater than 10, five ranged between 0 and 10, and three had values below -15. Positive values indicate increasing pleasantness, while negative values reflect increasing unpleasantness. All odorants were obtained from Aldrich Chemicals (St. Louis, MO) at the highest purity available. To ensure both participant safety and consistency in perceived intensity across odor stimuli, all odorants were pre-diluted in dipropylene glycol (DPG). Initial dilution concentrations were determined with reference to the maximum usage levels permitted in commercial perfumery (IFRA, 2023), and did not exceed the established safety thresholds for human

inhalation exposure, as listed in PubChem, the Laboratory Chemical Safety Summary (LCSS), and Sigma-Aldrich Safety Data Sheets (NIH, 2024; Sigma-Aldrich, 2023).

To balance recognizability and experimental control, the twelve monomolecular odorants spanned a broad range of everyday and less familiar smells. Several molecules are readily identifiable in daily life, including methyl anthranilate (grape or jasmine), allyl cinnamate (cinnamon), furfuryl mercaptan (fresh-roasted coffee), and eucalyptol (eucalyptus). Others, such as adoxal (marine -ozonic), diphenyl oxide (soapy/metallic), and methoxynaphthalene (amber-woody), are common perfumery bases yet seldom encountered in isolation by naïve observers. Finally, acetaldehyde (pungent green/solvent) and undecylenic acid (fatty, slightly sweaty) provided sharp, less pleasant anchors at the negative end of the valence scale. Pilot testing indicated that fewer than one-quarter of participants could confidently name any of the odorants before the experiment, ensuring that recognition judgments in Phase B reflected episodic memory rather than pre-existing semantic knowledge.

Each odorant was first diluted by the experimenter to a conservative and perceptually appropriate level based on pilot olfactory evaluation. Intensity matching was carried out in two sessions, spaced one week apart, using a separate panel of seven pilot participants who did not take part in the subsequent memory test. During each session, odors were presented individually in sealed, unlabeled glass jars. Immediately before a trial, the experimenter opened the jar beneath the participant's nose; participants were free to sniff as often as they want. Each jar contained a cotton strip fixed to the underside of the lid with laboratory tape, onto which a pre-measured aliquot of diluted odorant had been applied; no liquid remained in the jar itself, eliminating cueing from visual or auditory hints. After sampling, participants completed a Qualtrics survey in which they (i) ranked the perceived intensity of the odor on a 0-10 slider

anchored at “no odor” and “extremely strong,” (ii) rated pleasantness on a 9-point Likert scale, and (iii) provided a free-text description of what the scent smelled like. Ratings were analyzed after each session. First, the odorant perceived as the weakest was identified. Then, all remaining odorants were gradually diluted until their perceived intensities matched that of the weakest reference odor, as judged by the panel. This procedure, consistent with prior research in olfactory psychophysics (Khan et al., 2007), ensured that all stimuli were both perceptually equivalent and within safe exposure limits for human subjects.

Experiments were conducted in a designated testing room located in the Biopsychological Research Building at the University of Chicago. The room was specifically modified for olfactory testing and equipped with ceiling-mounted ventilation ducts and an active air filtration system to ensure controlled airflow, minimize ambient odor contamination, and reduce olfactory fatigue (Herz & Schooler, 2004). Odorants were stored in a temperature-controlled, light-protected environment between sessions and replaced on a monthly basis to prevent degradation. Participant responses and confidence ratings were recorded using Qualtrics survey software presented on a desktop monitor.

Procedure

This study followed a two-phase, between-subjects design to investigate how odor pleasantness affect recognition memory and confidence judgments. Odor pleasantness was estimated in advance using the Sobel Pleasantness Scale (Khan & Sobel, 2007), which assigns a predicted pleasantness score based on chemical structure and perceptual descriptors. To minimize individual differences in perceived strength and ensure consistency across stimuli, odor intensity levels were determined by researchers prior to testing based on physicochemical parameters (e.g., sorption coefficients and detection thresholds), following methods from Khan

& Sobel (2007). Final stimulus intensity was further refined through empirical matching procedures involving pilot participants.

Prior to each testing session, the experimenter sanitized the testing room using isopropyl alcohol wipes and ensured that all odor jars were freshly prepared and arranged behind a cardboard barrier to prevent visual bias. Participants were instructed during scheduling to abstain from food or drink (except water) for at least 30 minutes prior to the session and to avoid wearing any scented products. Upon arrival, participants completed a Qualtrics-based screening form assessing current symptoms (e.g., congestion, fatigue), recent food or beverage intake, and fragrance use. Participants also completed two self-assessment items rating their ability to detect and identify odors using 7-point Likert scales (1 = very poor, 7 = excellent). These subjective ratings were recorded to provide individual baseline olfactory profiles and explore their potential relation to performance. They were then randomly allocated to Group A or Group B using an alternating scheme (e.g., odd-numbered IDs to Group A, even-numbered to Group B). The experiment consisted of two distinct phases.

Phase A: Odor Encoding (Memory) Phase

Participants completed an incidental encoding task in which they were presented with 6 monomolecular odorants unique to their group (i.e., Group A and Group B each received a non-overlapping subset of 6 from the full set of 12). The odorants were selected to represent a range of predicted pleasantness values. Odors were presented one at a time in sealed, unlabeled glass jars, which were opened under the participant's nose by the experimenter. Each odorant had been pre-applied onto a small cotton strip affixed to the underside of the jar lid using a tape loop; the strip was the sole carrier of the scent, and no liquid was present inside the jar. Each odor was available for 30 seconds, during which participants were instructed to sniff normally without

picking up the jar. Following each presentation, participants rated the odor's perceived pleasantness on a 9-point Likert scale (1 = extremely unpleasant, 9 = extremely pleasant), and intensity using a continuous visual analog 0-10 slider on Qualtrics ranging from "no odor" to "extremely strong." A 30-second interval separated each trial to reduce the risk of olfactory fatigue and support memory consolidation (Herz & Schooler, 2004). After completing all six odor presentations, participants were given a 10-minute break during which they could relax, read, or use the restroom. During this time, the experimenter rearranged the odor jars to eliminate positional memory cues and reset the survey system.

Phase B: Odor Recognition Phase

Following the break, participants began a surprise recognition task. In this phase, they were presented with all 12 odors which contains 6 "old" odors encountered in Phase A and 6 "new" foils they had not previously smelled. The foils were chosen to be comparable to the old odors in both perceived pleasantness and matched intensity, ensuring that recognition decisions reflected memory rather than salient perceptual differences. Each odor was again presented for 30 seconds, followed by a 30-second response interval. For each trial, participants were instructed to indicate whether they had encountered the odor earlier in the session ("Yes" or "No") and to rate their confidence in this judgment using a 7-point Likert scale (1 = Not confident at all; 7 = Extremely confident). All responses were recorded in Qualtrics.

Data Analysis

To prepare the dataset for recognition memory analyses, behavioral responses from both the encoding (Phase 1) and recognition (Phase 2) phases were processed and aggregated at both the participant and odor levels. Group assignment determined odor exposure: Group A encountered odors 2, 3, 6, 10, 11, and 12, whereas Group B was exposed to odors 1, 4, 5, 7, 8,

and 9. Responses to recognition trials were categorized as “hits” (correctly identified old odors), “misses” (old odors judged as new), “false alarms” (new odors judged as old), or “correct rejections” (new odors correctly rejected).

Table 1 summarizes individual participant-level performance. For each participant, the number of hits, misses, false alarms, and correct rejections was computed based on their specific group-assigned odor set. From these, hit rate and false alarm rate were derived as proportion scores. A corrected recognition score was then computed as hit rate minus false alarm rate, yielding a bias-adjusted index of memory accuracy. This metric accounts for individual variability in response tendencies (e.g., liberal or conservative criteria) and was used as the dependent variable in several analyses. Additionally, the specific odors corresponding to each response category (e.g., “Hit Odors” or “False Alarm Odors”) were retained for later memory matrix construction. This table captures both recognition accuracy and response bias at the individual level.

Table 2 presents odor-level aggregates. For each of the 12 odorants, hit rate was calculated by dividing the number of participants who correctly identified the odor by the number who had smelled it. Likewise, false alarm rates were computed for each odor based on incorrect “yes” responses from participants not previously exposed. Corrected recognition was again computed at the odor level as the difference between hit rate and false alarm rate. In parallel, odor-level averages were computed for three subjective measures: perceived pleasantness (Phase 1), perceived intensity (Phase 1), and confidence (Phase 2). These measures formed the basis for subsequent correlation, regression, and ANOVA analyses examining the relationship between perceived odor attributes and memory performance.

Together, these participant- and odor-level summary tables enabled targeted examination of the central research questions: whether certain odors are intrinsically more memorable, whether perceived pleasantness or intensity influence memory accuracy and confidence, and whether recognition performance varies systematically across different levels of odor valence.

Results

Nineteen healthy adults completed the experiment (mean age \approx 26 years, range 18–44). Age distribution was 40 % in the 18–24 bracket, 55 % in 25–34, and 5 % in 35–44. Five participants (26 %) identified as female. Group assignment was balanced, with 10 participants in Group A and 9 in Group B.

Odor Memorability: Consistency Across Individuals

To investigate whether certain odors are intrinsically more memorable across individuals, or whether olfactory memorability is primarily participant-specific, we constructed a binary odor \times participant matrix capturing recognition outcomes. Each cell in the matrix reflects whether a participant accurately identified a previously encountered odor as “old” during the recognition phase (hit = 1, miss = 0, NaN = not exposed). Group-based odor assignments (Group A: odors 2, 3, 6, 10, 11, 12; Group B: odors 1, 4, 5, 7, 8, 9) were used to ensure that only responses to actually encountered odors were included. As shown in Figure 1, certain odors such as Odor 8 elicited near-uniform hits among exposed participants, whereas Odors 6 and 7 were frequently missed. These patterns suggest that memorability may not be random or entirely participant-specific, but instead reflect inherent differences in the odors themselves.

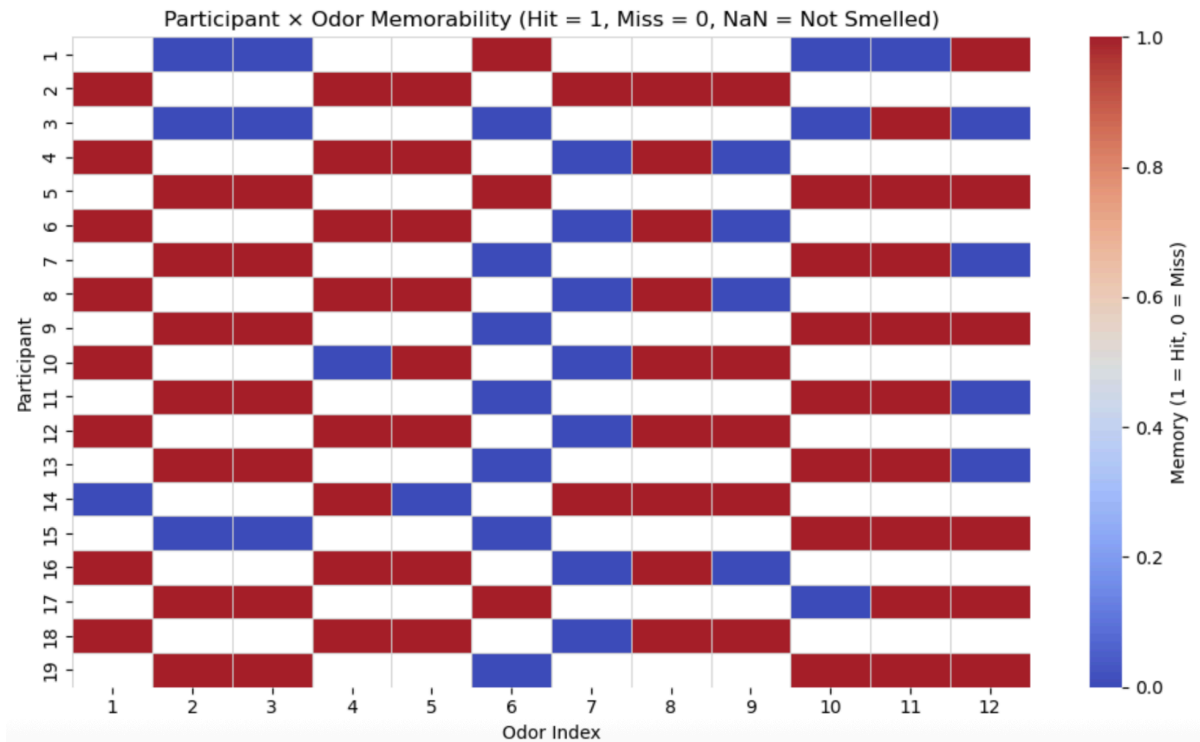


Figure 1. Odor memorability matrix across participants.

A participant-by-odor heatmap showing recognition memory performance for each of the 12 odors. Each cell represents the memory response of a given participant to a given odor. Red cells (value = 1) indicate correctly recognized odors (Hits), blue cells (value = 0) indicate missed targets, and white cells denote odors not presented to the participant (due to group assignment). Rows represent individual participants ($N = 19$), and columns represent odor indices (1–12). Odors were non-overlapping between groups A and B, with each participant exposed to only six of the twelve odorants in Phase A. The figure reveals odor-specific consistency in recognition performance across subjects. Notably, odors such as #8 were reliably recognized by nearly all exposed participants, whereas odors such as #6 and #7 were frequently missed. This pattern suggests stimulus-intrinsic differences in memorability.

To quantitatively evaluate odor-specific memorability while correcting for individual response biases, we computed a corrected recognition score for each odor. This measure, calculated as the difference between hit rate and false alarm rate (Correct Recognition = Hit Rate – False Alarm Rate), accounts for the baseline tendency of participants to falsely endorse unfamiliar odors as previously encountered. Unlike raw hit rates, which can be inflated by liberal response styles, corrected recognition provides a more conservative and theoretically grounded estimate of true memory signal (Macmillan & Creelman, 2005).

Figure 2 displays the corrected recognition scores across the 12 odorants. Substantial variability was observed: Odors 7 and 10 yielded the highest corrected recognition (≈ 0.90), indicating strong memorability with minimal confusability. In contrast, Odors 6 and 9 showed negative values (e.g., Odor 6: -0.07 ; Odor 9: -0.09), meaning they were more likely to elicit false alarms than hits, suggesting low discriminability in memory. Several odors (e.g., Odors 1, 3, and 8) fell within a moderate range, with corrected recognition scores between 0.25 and 0.50.

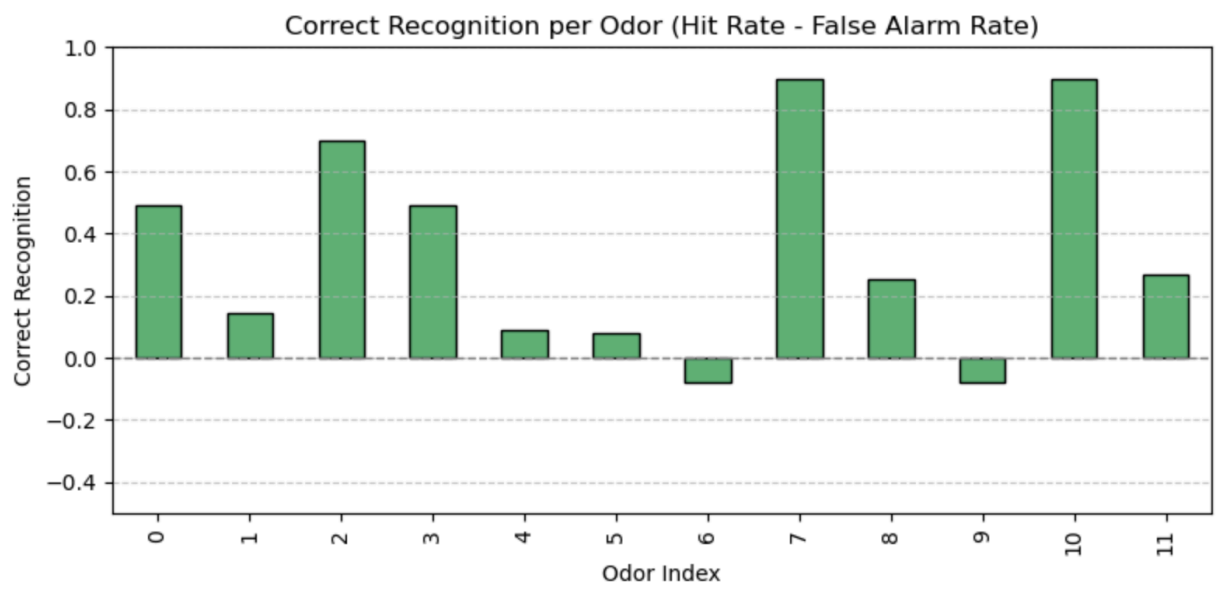


Figure 2. Correct recognition score per odorant.

Bar plot displaying corrected recognition accuracy for each of the 12 odors, computed by subtracting the false alarm rate (i.e., proportion of incorrect “yes” responses from participants not exposed to the odor) from the hit rate (i.e., proportion of correct “old” responses among exposed participants). This measure provides a bias-adjusted estimate of recognition performance that better reflects true memory discriminability. Values above zero indicate odors that were recognized more often than falsely endorsed, whereas values near or below zero reflect weak or misleading memory signals. Odors 7 and 10 showed the highest corrected recognition (≈ 0.90), whereas odors 6 and 9 had negative scores, indicating poor discriminability. These findings support the hypothesis that certain odors exhibit intrinsically higher memorability, independent of exposure frequency or participant-level variability.

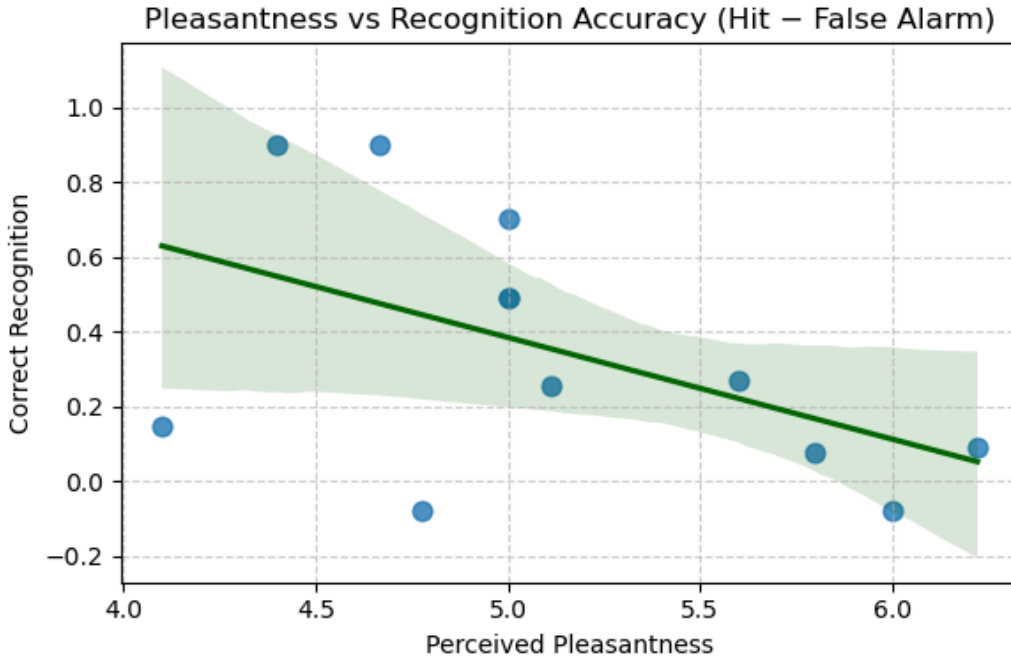
This performance variability occurred despite controlled presentation conditions and matched exposure frequency, reinforcing the interpretation that odor memorability reflects intrinsic properties of specific odorants. The corrected recognition metric thus offers stronger

inferential value than hit rate alone by isolating memory performance from guessing tendencies. Collectively, the individual \times odor matrix and corrected recognition distribution provide converging evidence for intrinsic memorability in olfaction, paralleling similar findings in visual memory (Isola et al., 2011), and highlight the importance of adjusting for response bias in recognition memory paradigms.

Relationship Between Perceived Pleasantness and Odor Recognition or Confidence

To evaluate the extent to which the perceived pleasantness of an odor predicts its memorability and the confidence associated with its recognition, we conducted correlation and regression analyses using correct recognition (defined as hit rate minus false alarm rate) instead of hit rate alone. This metric better accounts for individual response biases, particularly the tendency to incorrectly endorse novel odors as previously encountered. Ratings were aggregated across participants for each of the 12 odorants.

Descriptive statistics revealed moderate variability in pleasantness ratings ($M = 5.14$, $SD = 0.65$), spanning a 9-point Likert scale from 4.10 to 6.22. Confidence ratings ranged from 3.56 to 6.05, with a mean of 4.43 ($SD = 0.68$). Correct recognition scores varied from -0.11 to 0.90 across odors. To examine the predictive relationship between pleasantness and memory performance, Spearman correlation coefficients was computed between perceived pleasantness and correct recognition. As shown in Figure 3a, correct recognition was negatively correlated with pleasantness (Spearman's $\rho = -0.527$, $p = 0.0786$), suggesting that odors perceived as less pleasant tended to be recognized more accurately, though the relationship did not reach conventional significance thresholds.



3a. Relationship Between Perceived Pleasantness and Recognition Accuracy. Scatterplot showing the relationship between perceived pleasantness and recognition accuracy, operationalized as correct recognition (hit rate minus false alarm rate) for each odor. Each point represents one of the 12 odors. The negative slope suggests that less pleasant odors tended to be recognized more accurately, though this relationship did not reach significance (Spearman's $\rho = -0.527$, $p = 0.0786$).

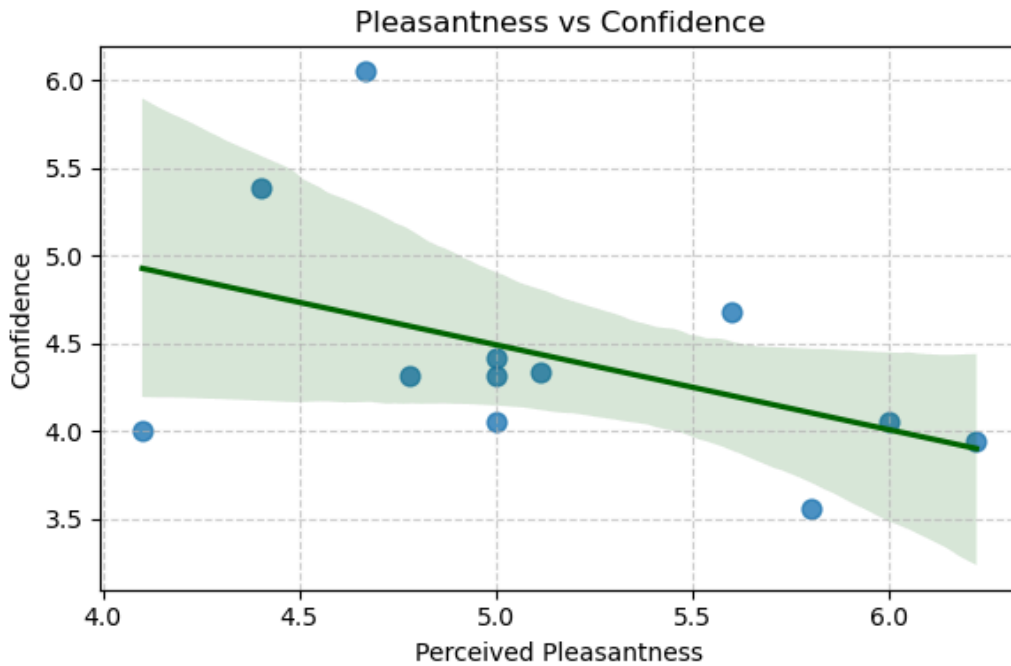


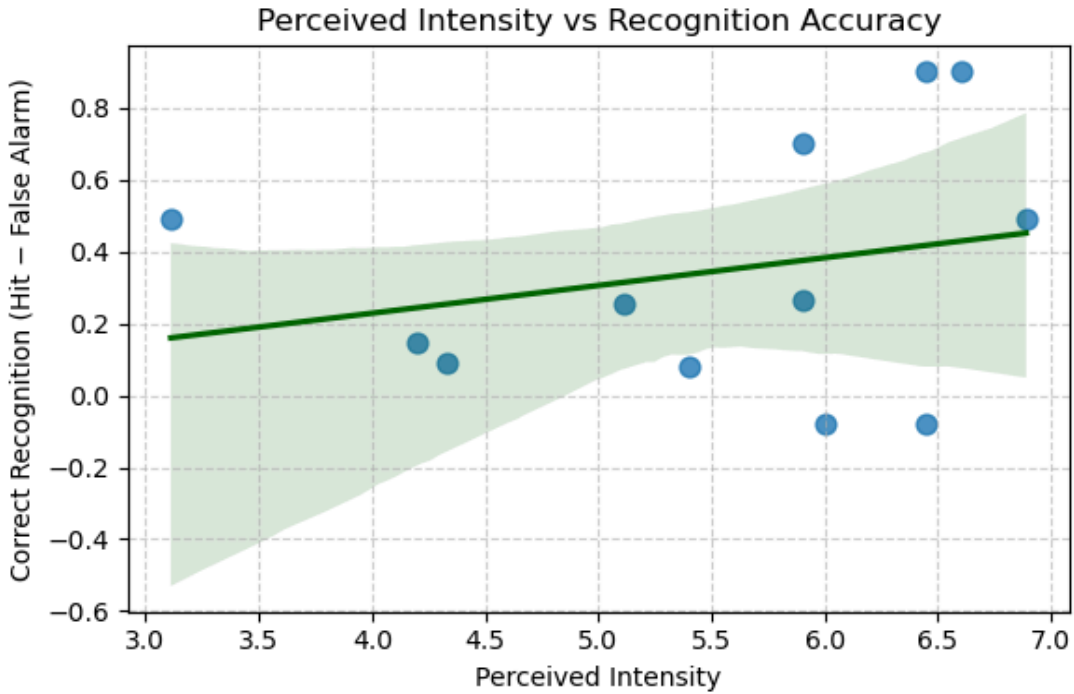
Figure 3b. Relationship Between Perceived Pleasantness and Confidence Ratings.

Scatterplot illustrating the relationship between perceived pleasantness and confidence ratings. A negative trend indicates that unpleasant odors were associated with slightly greater confidence in recognition responses, although this association was not statistically significant (Spearman's $\rho = -0.423$, $p = 0.1703$).

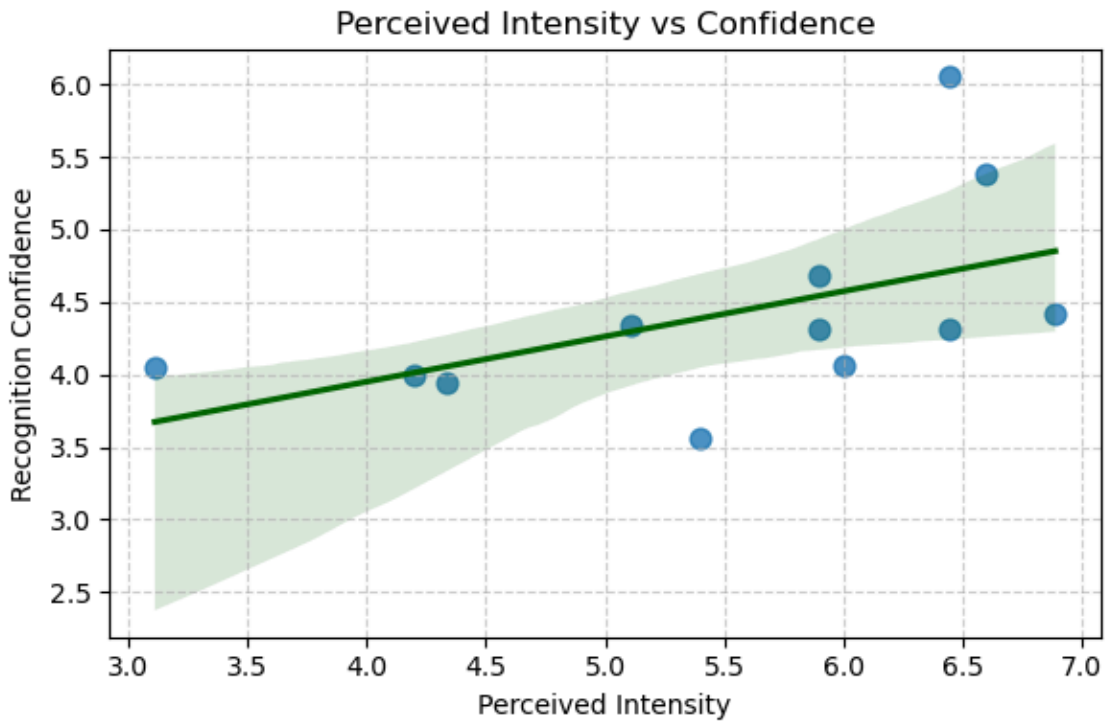
A similar analysis was performed for confidence ratings. As shown in Figure 3b, the correlation between perceived pleasantness and confidence was also negative (Spearman's $\rho = -0.423$, $p = 0.1703$), indicating that mildly unpleasant odors elicited somewhat higher recognition confidence. However, this trend also failed to reach statistical significance.

Relationship Between Perceived Intensity and Odor Recognition or Confidence

To explore whether the perceived strength of an odor influences its memorability or associated confidence, we conducted correlational analyses between odor-level intensity ratings, correct recognition scores (calculated as hit rate minus false alarm rate), and self-reported confidence. Intensity ratings were collected during the encoding phase (Phase 1), while recognition and confidence data were derived from the recognition phase (Phase 2). Ratings were averaged across participants for each of the 12 odorants. Figure 4a and 4b visualize the relationships between perceived intensity and both recognition accuracy and confidence. A weak positive association was observed between intensity and correct recognition (Spearman's $\rho = 0.266$, $p = 0.4036$), though the relationship did not reach statistical significance. This suggests that stronger-smelling odors may be slightly more likely to be remembered correctly, but the effect is small and inconsistent across odors.



4a. Relationship Between Perceived Intensity and Correct Recognition. Scatterplot with linear regression line showing the relationship between perceived intensity and correct recognition (hit rate minus false alarm rate) across the 12 odors. The trend is positive but not statistically significant (Spearman's $\rho = 0.266$, $p = 0.4036$).



4b. Relationship Between Perceived Intensity and Confidence.

Scatterplot with linear regression line showing the relationship between perceived intensity and confidence. A stronger and statistically significant positive correlation is observed, indicating that more intense odors tend to be remembered with greater confidence (Spearman's $\rho = 0.689$, $p = 0.0132$).

By contrast, intensity showed a moderately strong and statistically significant correlation with recognition confidence, particularly in the Spearman analysis (Spearman's $\rho = 0.689$, $p = 0.0132$). As shown in Figure 4b, participants reported higher confidence in their recognition decisions for odors perceived as more intense. This pattern aligns with theoretical frameworks suggesting that perceptual salience enhances metacognitive certainty. These findings highlight a dissociation between objective recognition performance and subjective confidence: while odor intensity had minimal impact on correct memory retrieval, it reliably increased participants' confidence in their judgments. Even so, confidence was not divorced from accuracy altogether. Across the twelve odors, corrected recognition showed a significant positive association with mean confidence (Spearman $\rho = 0.668$, $p = 0.0176$; Figure 5). In other words, odors that were remembered more accurately also elicited greater metacognitive certainty, even though intensity, not pleasantness, emerged as the main perceptual factor boosting that confidence.

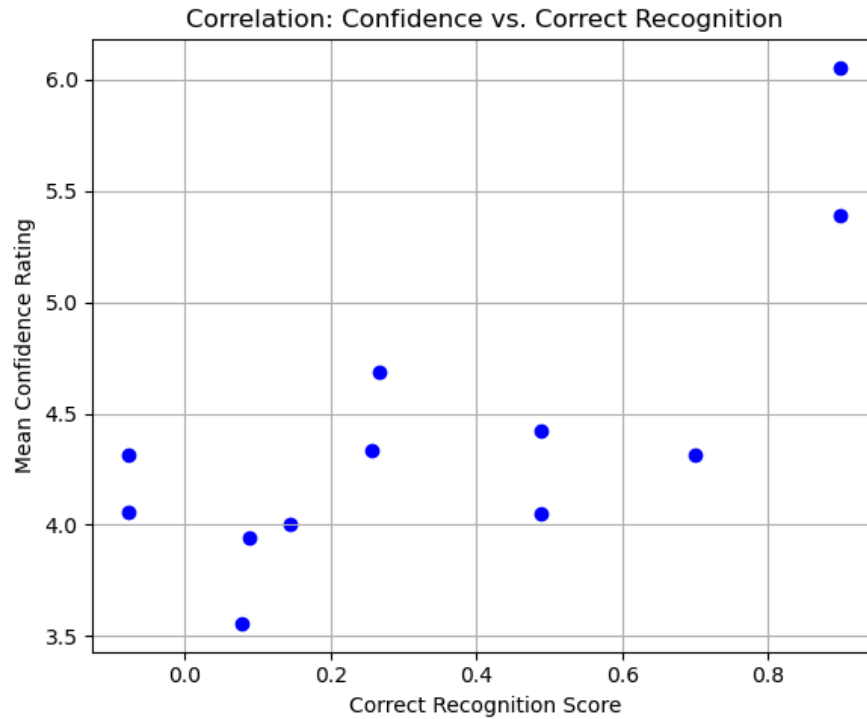


Figure 5. The Relationship Between Objective Accuracy and Metacognitive Confidence.

Scatter-plot of mean confidence rating (y-axis, 7-point scale) versus corrected recognition score (x-axis, hit rate – false-alarm rate) for each of the twelve odors. The monotonic trend is captured by a Spearman correlation of $\rho = 0.668$, $p = 0.0176$, indicating that odors remembered more accurately also elicited greater self-reported confidence.

Recognition Accuracy Across Levels of Odor Pleasantness

To determine whether recognition accuracy varies meaningfully across different levels of perceived odor pleasantness, we performed a one-way ANOVA using correct recognition scores (i.e., hit rate minus false alarm rate) as the dependent variable and rounded pleasantness ratings (on a 9-point scale) as a categorical predictor. Odors were grouped into three levels based on their integer-rounded pleasantness scores: 4 (unpleasant), 5 (neutral), and 6 (mildly pleasant). As visualized in Figure 6, odors rated as unpleasant (score = 4) exhibited the greatest variability in correct recognition scores (median = 0.50), with values ranging from –0.10 to 0.90. In contrast, neutral odors (score = 5) displayed more moderate and consistent recognition (median ≈ 0.37),

and mildly pleasant odors (score = 6) tended to elicit the lowest correct recognition scores overall (median ≈ -0.05), with most values clustered near or below zero. These descriptive differences suggest a possible non-linear trend in how odor pleasantness affects recognition accuracy.

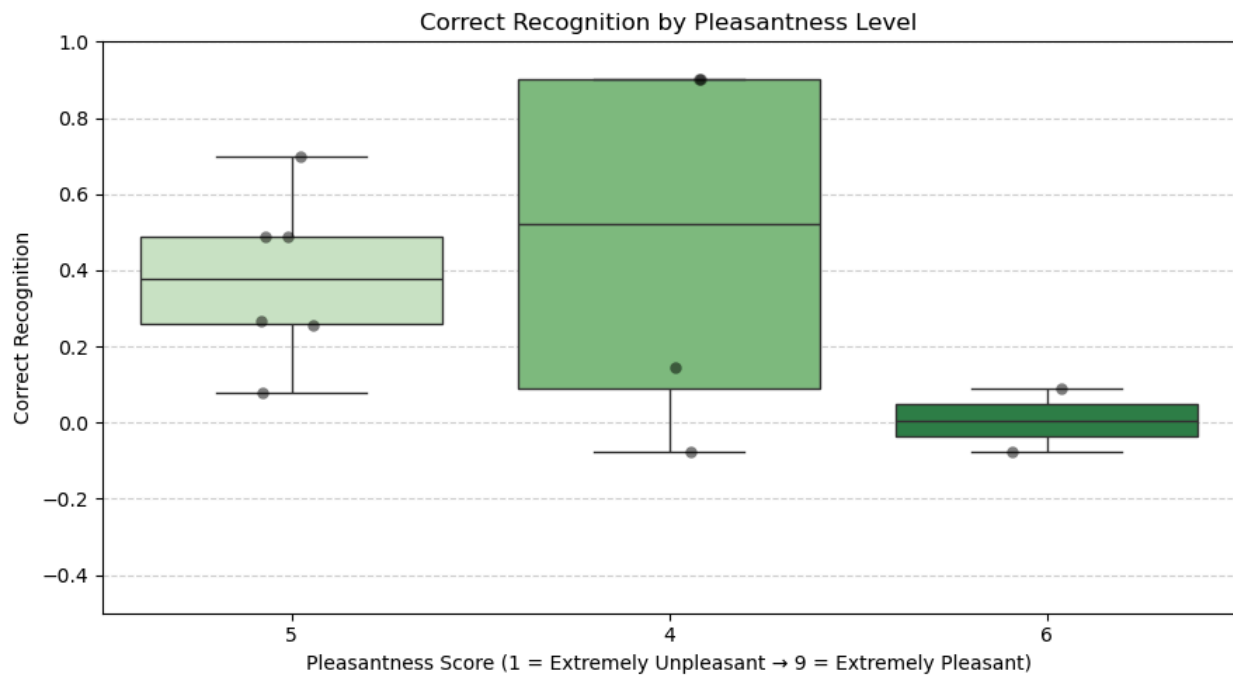


Figure 6. Boxplot showing correct recognition accuracy (hit rate minus false alarm rate) for odors grouped by rounded perceived pleasantness scores. Odors rated as unpleasant (score = 4) exhibited the highest variability and generally higher recognition performance, while mildly pleasant odors (score = 6) tended to have lower correct recognition scores. Neutral odors (score = 5) showed moderate and relatively stable performance. Individual odor values are overlaid as jittered points. Although visual differences emerged across groups, a one-way ANOVA revealed no significant effect of pleasantness level on correct recognition, $F(2, 9) = 1.29, p = 0.322$.

However, statistical analysis did not reveal significant group-level differences. The ANOVA yielded $F(2, 9) = 1.29, p = 0.322$, indicating that the observed variance in correct recognition across pleasantness categories was not statistically reliable. Despite the apparent dip in recognition for mildly pleasant odors, these results suggest that perceived hedonic value, at

least within this moderate range, does not exert a strong categorical influence on olfactory memory accuracy.

Discussion

This study investigated whether odor memorability is stimulus-specific and whether perceived pleasantness and intensity modulate olfactory recognition accuracy and confidence. The results partially support the stimulus-specific hypothesis: despite group-based exposure constraints, certain odors were consistently well recognized while others were frequently forgotten, indicating stable, intrinsic mnemonic potential. Overall, odor memorability was more strongly linked to perceived intensity than to pleasantness within the controlled range tested here.

Regarding pleasantness, neither correlational nor ANOVA analyses revealed a reliable link between hedonic valence and recognition accuracy or metacognitive confidence. This null effect challenges the common assumption, derived from affective-memory research, that emotionally pleasant (or unpleasant) stimuli are preferentially remembered. Indeed, we observed only a slight, non-significant tendency for unpleasant odors to yield stronger memory traces, underscoring the importance of using bias-corrected metrics (e.g., corrected recognition) to temper spurious effects driven by false alarms. Turning to intensity, the data showed a modest but significant positive association with confidence and a weak, nonsignificant trend with accuracy. Participants were more certain about judgments involving odors they had rated as more intense during encoding, revealing a dissociation between objective performance and subjective certainty. This pattern aligns with perceptual-fluency accounts, where stimulus salience serves as a heuristic for familiarity even when actual memory strength is unchanged.

These findings raise the possibility that recognition may follow a non-linear or U-shaped function across a broader hedonic spectrum. Future work should therefore employ more extreme

valence ratings or larger, more heterogeneous odor sets to determine whether pleasantness (or unpleasantness) facilitates memory under different conditions. At the same time, individual sensory ability remains an underexplored moderator. Participants self-rated their odor detection and identification skills, but these data were not analyzed here; objective threshold tests and interaction terms for acuity could refine predictive models of odor memorability.

Several methodological considerations temper our conclusions. The modest sample size (N = 19) limited statistical power and precluded comprehensive examination of interaction effects, so larger and more diverse samples are needed. Although the use of intensity-matched, monomolecular odors provided precise perceptual control, it may limit ecological validity; incorporating complex blends with learned associations would test whether hedonic influences emerge more clearly in real-world contexts. Nonetheless, strengths of the present design include the between-subjects exposure scheme, minimization of cross-trial interference, and reliance on corrected recognition scores to enhance measurement validity.

For future direction, neuroimaging could determine whether mnemonic differences among odors correspond to differential activation in olfactory and limbic regions such as the piriform cortex, orbitofrontal cortex, and amygdala. Well-documented sex differences in olfactory sensitivity and memory likewise warrant investigation to see whether neural and behavioral markers of odor memorability vary by sex and display sex-specific activation patterns or perceptual weightings. Finally, computational frameworks that jointly model physicochemical features, hedonic ratings, perceptual salience, and demographic moderators (e.g., sex, olfactory acuity) promise a more comprehensive, mechanistic account of what makes certain smells linger in memory.

References

- Aggleton, J. P., & Mishkin, M. (1986). The amygdala: Sensory gateway to the emotions. In R. Plutchik & H. Kellerman (Eds.), *Emotion: Theory, research, and experience* (Vol. 3, pp. 281–299). Academic Press.
- Andreano, J. M., & Cahill L. (2006). Glucocorticoid release and memory consolidation in men and women. *Psychological Science*, 17, 466-470.
<http://dx.doi.org/10.1111/j.1467-9280.2006.01729.x>
- Arshamian, A., Ohla, K., Mälberg, M., et al. (2022). The perception of odor pleasantness is shared across cultures. *Proceedings of the National Academy of Sciences*, 119(10), e2121879119. <https://doi.org/10.1073/pnas.2121879119>
- Bainbridge, W. A. (2017). The memorability of people: Intrinsic memorability across transformations of a person's face. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 43, 706–716.
- Bainbridge, W. A. (2019). Memorability: How what we see influences what we remember. *Psychology of Learning and Motivation*, 70, 1-24.
<https://doi.org/10.1016/bs.plm.2019.02.001>
- Bainbridge, W. A., Dilks, D. D., & Oliva, A. (2017). Memorability: A stimulus-driven perceptual neural signature distinctive from memory. *NeuroImage*, 149, 141–152.
- Bainbridge, W. A., & Rissman, J. (2018). Dissociating neural markers of stimulus memorability and subjective recognition during episodic retrieval. *Scientific Reports*, 8, 8679.
- Brauchli, P., Ruegg, P. B., Etzweiler, F., & Zeier, H. (1995). Electrocortical and autonomic alteration by administration of a pleasant and an unpleasant odor. *Chemical Senses*, 20(5), 505–515. <https://doi.org/10.1093/chemse/20.5.505>

- Cabanac, M., & Bonniot-Cabanac, M. C. (2011). Hedonicity and memory of odors. *Frontiers in Psychology*, 2, 171. <https://doi.org/10.3389/fpsyg.2011.00171>
- Cahill, L., Babinsky, R., Markowitsch, H. J., & McGaugh, J. L. (1995). The amygdala and emotional memory. *Nature*, 377(6547), 295–296. <https://doi.org/10.1038/377295a0>
- Chu, S., & Downes, J. J. (2000). Odour-evoked autobiographical memories: Psychological investigations of Proustian phenomena. *Chemical Senses*, 25(1), 111–116. <https://doi.org/10.1093/chemse/25.1.111>
- Davis, T. M., & Bainbridge, W. A. (2023). Memory for artwork is predictable. *Proceedings of the National Academy of Sciences*, 120(28), e2302389120.
- Herz, R. S. (2004). A naturalistic analysis of autobiographical memories triggered by olfactory, visual, and auditory stimuli. *Chemical Senses*, 29(3), 217–224. <https://doi.org/10.1093/chemse/bjh025>
- Herz, R. S., & Engen, T. (1996). Odor memory: Review and analysis. *Psychonomic Bulletin & Review*, 3(3), 300–313.
- Herz, R. S., & Schooler, J. W. (2002). A naturalistic study of autobiographical memories evoked by olfactory and visual cues: Testing the Proustian hypothesis. *The American Journal of Psychology*, 115(1), 21–32. <https://www.jstor.org/stable/1423672>
- Hudon, G., Guy, C., & Hermia, J. (2000). Measurement of odor intensity by an electronic nose. *Journal of the Air & Waste Management Association*, 50(10), 1750–1758. <https://doi.org/10.1080/10473289.2000.10464202>
- International Fragrance Association. (2023). *IFRA Standards*, 51st Amendment. Retrieved from <https://ifrafragrance.org>

- Isola, P., Parikh, D., Torralba, A., & Oliva, A. (2011). Understanding the intrinsic memorability of images. *Advances in Neural Information Processing Systems*, 24 (*NeurIPS 2011*).
<https://proceedings.neurips.cc/paper/2011/file/3a5db0b7a31fcd5569a5a6c3e2c0884a-Paper.pdf>
- Isola, P., Xiao, J., Parikh, D., Torralba, A., & Oliva, A. (2014). What makes a photograph memorable. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 36(7), 1469–1482.
- Kermen, F., Chakirian, A., Sezille, C., Jousain, P., Le Goff, G., Padey, B., Bertrand, B., Bensafi, M. (2011). Molecular complexity determines the number of olfactory notes and the pleasantness of smells. *Scientific Reports*, 1, 206. <https://doi.org/10.1038/srep00206>
- Khan, R. M., Luk, C.-H., Flinker, A., Aggarwal, A., Lapid, H., Haddad, R., & Sobel, N. (2007). Predicting odor pleasantness from odorant structure: Pleasantness as a reflection of the physical world. *Journal of Neuroscience*, 27(37), 10015–10023.
<https://doi.org/10.1523/JNEUROSCI.1158-07.2007>
- Kramer, M. A., Hebart, M. N., Baker, C. I., & Bainbridge, W. A. (2023). The features underlying the memorability of objects. *Science advances*, 9(17), eadd2981.
- Mair, R. G., Bouffard, J. A., Engen, T., & Morton, T. H. (1978). Olfactory sensitivity during the menstrual cycle. *Sensory Processes*, 2, 90–98.
- National Center for Biotechnology Information. (2024). *PubChem Compound Summary*. Retrieved from <https://pubchem.ncbi.nlm.nih.gov/>
- Ramsay, D. B., Ananthabhotla, I., & Paradiso, J. A. (2018). The intrinsic memorability of everyday sounds. *arXiv*. <https://doi.org/10.48550/arXiv.1811.07082>

Revsine, C., Goldberg, E., & Bainbridge, W. A. (2025). The memorability of voices is predictable and consistent across listeners. *bioRxiv*.

<https://doi.org/10.1101/2024.02.08.579540>

Sigma-Aldrich. (2023). *Safety Data Sheets (SDS)*. Retrieved from <https://www.sigmaaldrich.com>

Vernet-Maury, E., Alaoui Ismaili, O., Dittmar, A., Delhomme, G., & Chanel, J. (1999). Basic emotions induced by odorants: A new approach based on autonomic pattern results.

Journal of the Autonomic Nervous System, 75(2), 176–183.

[https://doi.org/10.1016/S0165-1838\(98\)00108-0](https://doi.org/10.1016/S0165-1838(98)00108-0)

Appendix

Participant	Group	Hits	Hit Odors	Misses	Miss Odors	False Alarms	False Alarm Odors	Correct Rejections	Correct Rejection Odors	Hit Rate	False Alarm Rate
1	A	2	[6, 12]	4	[2, 3, 10, 11]	2	[1, 9]	4	[4, 5, 7, 8]	0.333333	0.333333
2	B	6	[1, 4, 5, 7, 8, 9]	0	[]	2	[2, 10]	4	[3, 6, 11, 12]	1.000000	0.333333
3	A	1	[11]	5	[2, 3, 6, 10, 12]	4	[1, 4, 5, 7]	2	[8, 9]	0.166667	0.666667
4	B	4	[1, 4, 5, 8]	2	[7, 9]	1	[10]	5	[2, 3, 6, 11, 12]	0.666667	0.166667
5	A	6	[2, 3, 6, 10, 11, 12]	0	[]	2	[1, 5]	4	[4, 7, 8, 9]	1.000000	0.333333
6	B	4	[1, 4, 5, 8]	2	[7, 9]	1	[2]	5	[3, 6, 10, 11, 12]	0.666667	0.166667
7	A	4	[2, 3, 10, 11]	2	[6, 12]	1	[5]	5	[1, 4, 7, 8, 9]	0.666667	0.166667
8	B	4	[1, 4, 5, 8]	2	[7, 9]	3	[2, 10, 12]	3	[3, 6, 11]	0.666667	0.500000
9	A	5	[2, 3, 10, 11, 12]	1	[6]	2	[4, 5]	4	[1, 7, 8, 9]	0.833333	0.333333
10	B	4	[1, 5, 8, 9]	2	[4, 7]	2	[2, 10]	4	[3, 6, 11, 12]	0.666667	0.333333
11	A	4	[2, 3, 10, 11]	2	[6, 12]	3	[5, 8, 9]	3	[1, 4, 7]	0.666667	0.500000
12	B	5	[1, 4, 5, 8, 9]	1	[7]	1	[12]	5	[2, 3, 6, 10, 11]	0.833333	0.166667
13	A	4	[2, 3, 10, 11]	2	[6, 12]	2	[5, 9]	4	[1, 4, 7, 8]	0.666667	0.333333
14	B	4	[4, 7, 8, 9]	2	[1, 5]	2	[10, 12]	4	[2, 3, 6, 11]	0.666667	0.333333
15	A	3	[10, 11, 12]	3	[2, 3, 6]	3	[4, 5, 7]	3	[1, 8, 9]	0.500000	0.500000
16	B	4	[1, 4, 5, 8]	2	[7, 9]	2	[6, 10]	4	[2, 3, 11, 12]	0.666667	0.333333
17	A	5	[2, 3, 6, 11, 12]	1	[10]	3	[1, 5, 7]	3	[4, 8, 9]	0.833333	0.500000
18	B	5	[1, 4, 5, 8, 9]	1	[7]	3	[2, 6, 10]	3	[3, 11, 12]	0.833333	0.500000
19	A	5	[2, 3, 10, 11, 12]	1	[6]	1	[4]	5	[1, 5, 7, 8, 9]	0.833333	0.166667

Table 1. Individual Recognition Performance Summary

For each participant, the table lists group assignment (A or B), raw counts of hits, misses, false alarms, and correct rejections, the specific odor numbers associated with each response category, and the derived hit rate and false-alarm rate. Hit rate is calculated as hits / (hits + misses); false-alarm rate as false alarms / (false alarms + correct rejections). Participants in Group A had been exposed to odors 2, 3, 6, 10, 11, 12 during encoding, whereas Group B had encountered odors 1, 4, 5, 7, 8, 9. These proportions provide a bias-corrected basis for comparing recognition accuracy across individuals.

Odor	Hit Rate	False Alarm Rate	Perceived Pleasantness	Intensity	Confidence
1	0.888889	0.400000	5.000000	3.111111	4.052632
2	0.700000	0.555556	4.100000	4.200000	4.000000
3	0.700000	0.000000	5.000000	5.900000	4.315789
4	0.888889	0.400000	5.000000	6.888889	4.421053
5	0.888889	0.800000	6.222222	4.333333	3.941176
6	0.300000	0.222222	5.800000	5.400000	3.555556
7	0.222222	0.300000	4.777778	6.444444	4.315789
8	1.000000	0.100000	4.666667	6.444444	6.052632
9	0.555556	0.300000	5.111111	5.111111	4.333333
10	0.700000	0.777778	6.000000	6.000000	4.055556
11	0.900000	0.000000	4.400000	6.600000	5.388889
12	0.600000	0.333333	5.600000	5.900000	4.684211

Table 2. Item-Level Odor Recognition Accuracy and Subjective Ratings

For each of the twelve odorants the table reports (i) hit rate, (ii) false-alarm rate, (iii) mean perceived pleasantness (9-point scale), (iv) mean perceived intensity (0–10 slider, rescaled 0–10), and (v) mean confidence rating given during the recognition task (7-point scale). Hit and false-alarm rates were computed across only those participants who had encountered or not encountered the odor, respectively; all subjective ratings were averaged over the same subsets of participants. These values provide the basis for item-level correlations among pleasantness, intensity, confidence, and recognition accuracy presented in Figures 3 and 4.