Journal of Carcinogenesis
Covering Genesis to Therapeutics
Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 4s, https://carcinogenesis.com/

The Influence of Odor Valence on Long-Term Memory Encoding

Houzhen Guo [1]

[1]Capital Normal University High School

ABSTRACT

Odors can evoke emotional responses and recall memories. It is known that odors with emotional valence, positive or negative, can modulate memory. However, there is a lack of further research that compares the influence of positive, neutral, and negative odors on long-term memory (LTM). In this study, we used sniff sticks with positive, neutral, and negative odors to manipulate odor valence, and memory tasks and distraction tasks to evaluate memory performance. We found that positive odors can enhance memory performance, while negative odors can suppress it, compared to neutral odors. This study has provided additional insight into the mechanism of memory and identified potential factors that influence memory performance.

How to Cite: Houzhen Guo , (2025) The Influence of Odor Valence on Long-Term Memory Encoding, *Journal of Carcinogenesis*, *Vol.24, No.4s*, 756-764

1. INTRODUCTION

Olfaction is one of the most ancient sensory systems. It is distinct from other senses, including audition, vision, pain, and so on, for the olfactory pathway does not go through the thalamus, and is strongly associated with the amygdala and hippocampus, brain regions that are in charge of emotional processing and memory formation (Arshamian A., et al., 2012). Through fMRI scans, scientists discovered that odors with positive valence (eg, vanilla, mint) give rise to the orbital frontal cortex, while odors with negative valence (eg, butyric acid) activate the amygdala (Arshamian A., et al. 2012)（Gottfried, J. A., et al.2004).

Known as the Proustian Phenomenon, olfaction has a more substantial effect on evoking memory (with more details and intense emotions) than other sensory modalities (Toffolo et al., 2012). It has been demonstrated through behavioral experiments that odors help to consolidate memory via emotional encoding, prioritizing the encoding of emotion over details, and are more inaccurate and inexpressible since the olfactory pathway does not pass through the hypothalamus (Herz & Cubchik, 1995). Specifically, negative odors (e.g., 0.5% butyric acid) have been shown to improve memory formation (de Groot, et al., 2012), which is considered to be related to survival and evolution (Stevenson, R. J. 2010). Therefore, it is expected that emotions triggered by the positive odors (PO) and negative odors (NO) can enhance memory encoding.

Although most previous studies suggest that odors have significant improvements on memory retrieval, few studies that have compared the effects of PO and NO on the memory of the same group of people, and the valence-specific effects on long-term memory (LTM) encoding are poorly understood. The aim of this paper is to investigate the effects of PO and NO on LTM encoding through a direct comparison of the memory test results of participants presented with different odors. We hypothesized that PO will improve LTM encoding by activating the reward system through positive emotions, while NO will also enhance LTM encoding by cooperating with the amygdala; furthermore, the concentration of odors is not expected to be a significant factor.

Understanding the effects of odors with different valence on memory encoding is crucial. This research can be applied in education and marketing, utilizing scents to enhance students' retention of knowledge and customers' recall of brands. Meanwhile, getting more knowledge about this topic can promote the treatment of PTSD and neurodegenerative disease screening (Dan X et al.2021) (Audronyte E., et al. 2023)..

2. METHOD

Research Design

This paper presents a quantitative study based on surveys. We designed a correlational and experimental study.

Participants

A total of 22 participants (age 16-17) were recruited via convenience sampling. All participants are native Chinese speakers who have learned English for more than six years. Participants have a normal sense of smell that enables them to identify the valence and concentration of odors presented. We took personal variation in the perception of smell into consideration.

Materials

1. Olfactory stimulus-Sniff sticks: 3 sets of sniff sticks were created and presented in front of the participants. PO include vanilla, jasmine, lemon, etc; NO include butyric acid (smell of vomiting), Trimethylamine (smell of rotten fish); neutral odors include water, and mineral oil.

2. Word lists: 2 unique lists of 20 English nouns were created with no repeated words across lists.

List 1: Oxygen Pyramid Quilt Rainbow Submarine Desk Unicorn Vase Waterfall Phone Yogurt Balloon Carrot Diamond Eagle Mountain Globe Hanger Island Jacket

List 2: Bracelet Ladder Mirror Pencil Rocket Tomato Wallet Yacht Zipper Anchor Broom Dolphin Envelope Guitar Hammock Iceberg Jigsaw Koala Lighthouse Necklace

3. Distraction task: Between vocabulary memorization and recall, simple math tests (four operations within 100) are used to disrupt the effect of working memory, allowing participants to form LTM.

4. Questionnaire:

1) You are aware that the sniff stick used in the experiment may have an unpleasant smell or a pleasant one. If you experienced any physical discomfort, please terminate the experiment immediately (please sign in the blank).

2) How pleasant do you think the smell from the sniff stick in front of you is?

3) What do you think is the intensity of the smell from the sniff stick in front of you? (Degree of stimulation)

4) In the second part, you need to memorize 15 simple nouns. Please note that these words will be used in the subsequent questionnaire. (Present word list 1 or 2)

5) In the third part, you need to complete as many arithmetic problems as possible within 30 seconds. The answer rate and accuracy rate will be recorded. Please calculate carefully (answers will stop automatically after 30 seconds). (Present 10 math problems, 5 problems must be solved as a minimum)

6) In the fourth part, you need to recall and write down as many as possible the 20 simple words from the first part.

Procedure

If there are no existing sniff sticks with target odors, they can be made according to the instructions provided. Something that can reserve liquid and fragrance, such as scented cotton swab sticks used for perfumes and fragrance cards is a great choice.

We used three different solutions to symbolize positive, neutral, and negative odors: 3% vanilla perfume solution for PO, 3% fishy odor agent for NO, and pure water for neutral odor.

One side of the sniff sticks is contacted with these solutions until they are moist from bottom to top. Then, they were dried and stored inside separate bags.

All participants were placed in well-ventilated areas. Sniff sticks were prepared and stored separately in sealable bags. Participants were asked to choose two sets of sniff sticks randomly.

The participants were required to hold a random sniff stick they had chosen around their nose. For each round of the experiment, there are four steps. Firstly, subjects were asked to evaluate odor valence (Do you think this smell is good or bad?) and odor intensity (Is this odor strong for you?) while perceiving the smell of the sniff stick. They were then asked to remember one random list of English words when they were still exposed to the odor. Immediately, they were presented with distraction tasks, which were simple math calculations within 100. Lastly, they were asked to write down anything that they could remember from the previous word list.

Then, the participants were asked to smell mint candy in order to reset their sense of smell. Next, they held the other sniff stick they had chosen and started the next round of the experiment.

3. DATA ANALYSIS

The valence and intensity of different odors reported by the subjects were collected using a Likert scale before memorization. We use the intensity to measure the pungency level of each odor reported by participants to assist the identification of emotions triggered by each odor. The valences of the odors are considered as an independent variable. The memory performance, defined as the correct number of words that can be successfully recalled (0~20), becomes a dependent variable.

To discover the relationship between odor valence and memory performance, we use R to build a Linear Mixed-Effects Model (LMM) to collect and analyze data since each participants have multiple observed values (memory performance), taking random effects and individual variation into consideration.

We used two methods to elaborate our data, subject-rated method (SRM) and experimenter-recorded method (ERM). In the subject-rated method, using valence 1 as the intercept, we analyzed our data based on subjective ratings of odor valence, on the scale of 1 to 5, and memory performance. In the experimenter-recorded method, using unpleasant group as intercept, we categorized valences into three different groups objectively, unpleasant, neutral, and pleasant, and analyzed the correlation based on the categories. The independent variable odor valence will be written as OV, while the dependent variable memory performance will be written as MP.

4. RESULTS

Subject-Rated Method: Using valence 1 as an intercept

We used the REML method in order to consider the random effects of each participant. REML criterion at convergence was 330.9, showing that the model can forecast MP.

The scaled residuals have a minimum of -1.4657, a median of 0.07476, a maximum of 1.70892, a first quartile of -0.63165 and a third quartile of 0.51406. The distribution of residuals is normal and relatively uniform, and no obvious outliers or skewness were found, indicating that the model assumptions are basically satisfied.

Random effects include variance and standard deviation. Participant (intercept) variance is 196.76, standard deviation is 14.027. The residual variance and standard deviation were 93.27 and 9.658. The data shows that there are severe variances and random effects present between participants.

The residual distribution is relatively uniform, and no obvious outliers or skewness were found, indicating that the model assumptions are basically satisfied.

We calculated the mean memory performance, as shown in Figure 1. We found out that there is a minor difference between OV 1 (25) and 3 (22.5). OV 4, with a mean MP of 32.78, is higher than OV 1,2,3 and lower than OV 5, which has the highest mean MP of 35. However, OV 2 is the lowest among all five groups, with a mean MP of 11.67.

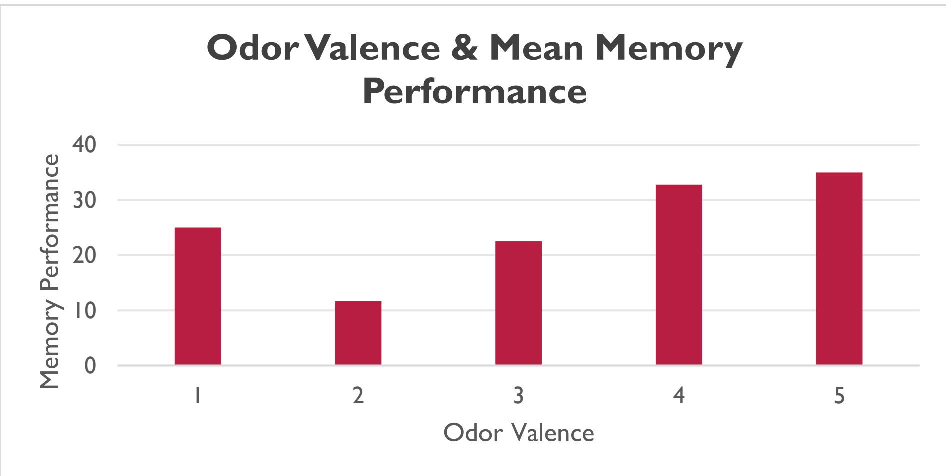


Figure (1) The chart of fixed effects is presented below.

<table>
<tr><th></th><th>Estimate</th><th>Std. Error</th><th>df</th><th>t value</th><th>Pr(>|t|)</th><th></th></tr>
<tr><td>(Intercept)</td><td>22.905</td><td>4.464</td><td>37.994</td><td>5.132</td><td>8.8e-06</td><td>***</td></tr>
</table>

Odor_valence2	-6.716	8.281	25.474	-0.811	0.4249
Odor_valence3	7.824	5.586	23.185	1.401	0.1745
Odor_valence4	5.117	5.268	22.871	0.971	0.3415
Odor_valence5	11.051	4.540	20.178	2.434	0.0243 *

Odor_valence5 has a significant p-value of 0.0243, indicating that OV 5 has a significant positive influence on memory performance. Other groups' p-values are larger than 0.1, meaning that there is no statistically significant influence on memory performance.

As shown in Figure 1, OV 4 and 5 generally have better MP than OV 1,2, and 3. Still, there are no statistical differences. In Figure 2, OV 5 has a higher mean MP than the other groups. Also, the trend line shows that there is a slight trend between higher OV and higher MP.

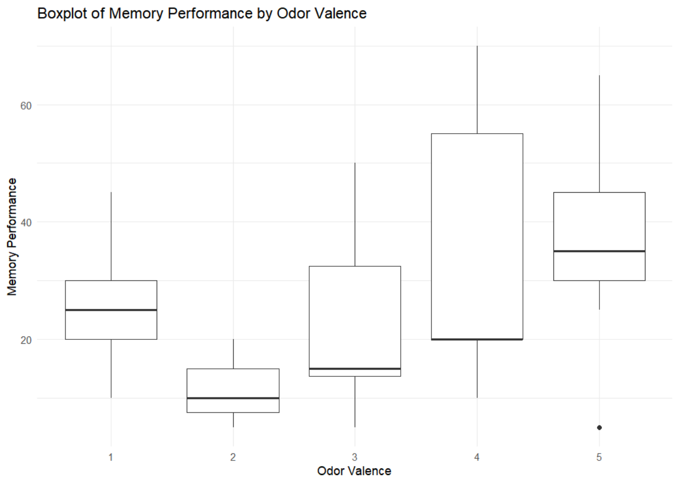


Figure (2)

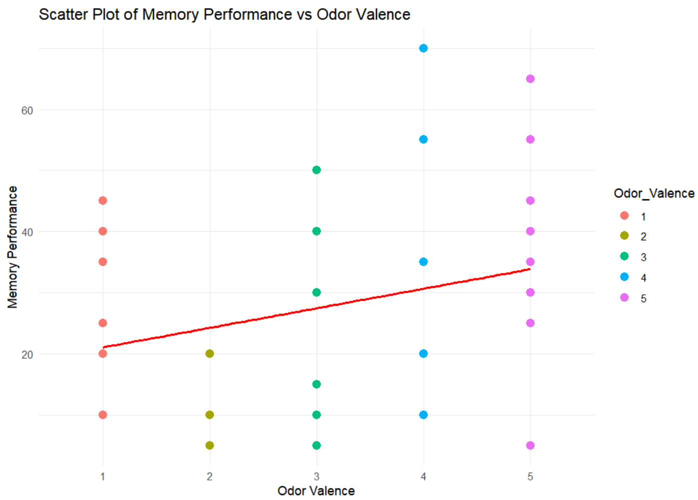


Figure (3)

The chart of correlation of fixed effects is presented below.

	(Intr)	Odr_V2	Odr_V3	Odr_V4
Odor_Valnc2	-0.390			
Odor_Valnc3	-0.450	0.212		
Odor_Valnc4	-0.512	0.438	0.283	

Odor_Valnc5 -0.564 0.366 0.424 0.500

The results show that there is a certain correlation among the fixed effects, but the correlation coefficients do not exceed 0.7, indicating that there are weak and medium correlations between these variables, so the problem of multicollinearity is not serious.

Experimenter-Record Method: Using unpleasant group as an intercept

A LMM was fitted using the REML method, with t-tests employing Satterthwaite's method. The REML criterion at convergence was 344.4.

The scaled residuals have a minimum of -1.42703, a median of 0.05487, a maximum of 1.57200, a first quartile of -0.65307, and a third quartile of 0.47888. The distribution of residuals is normal and relatively uniform, and no obvious outliers or skewness were found, indicating that the model assumptions are basically satisfied.

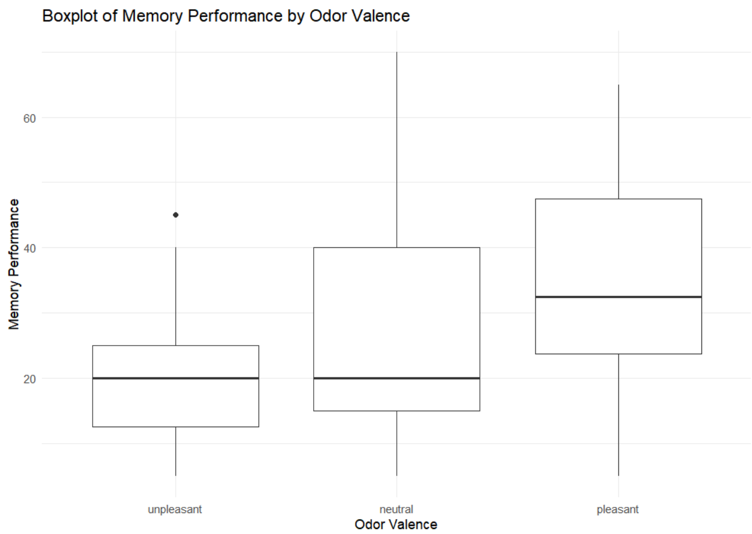
The random effects included the variance and standard deviation for the intercept of the "subject" group, which were 185.47 and 13.619, respectively, while the residual variance and standard deviation were 96.54 and 9.825. There is severe memory performance variation among the participants.

The chart of fixed effects is presented below.

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	22.171	3.985	36.284	5.563	2.6e-06 ***
odor_valence neutral	7.499	4.235	23.520	1.771	0.0896 .
odor_valence pleasant	10.438	3.868	22.403	2.698	0.0130 *

OV neutral has a p-value of 0.0896, which is lower than 0.1 and higher than 0.05. Therefore, OV neutral has a marginally significant influence on MP. OV pleasant has a p-value of 0.0130, which is lower than 0.05, so we are able to say that OV pleasant has a statistically significant effect on MP.

We noticed a trend between the pleasantness of odors and MP through Figure (4). Due to high variance, shown by standard deviation and degrees of freedom, the correlation might not seem as clear as Figure 5. In Figure 5, we are able to recognize the correlation between OV and MP since both OV neutral and OV pleasant have p-values less than 0.1.



Figure(4)

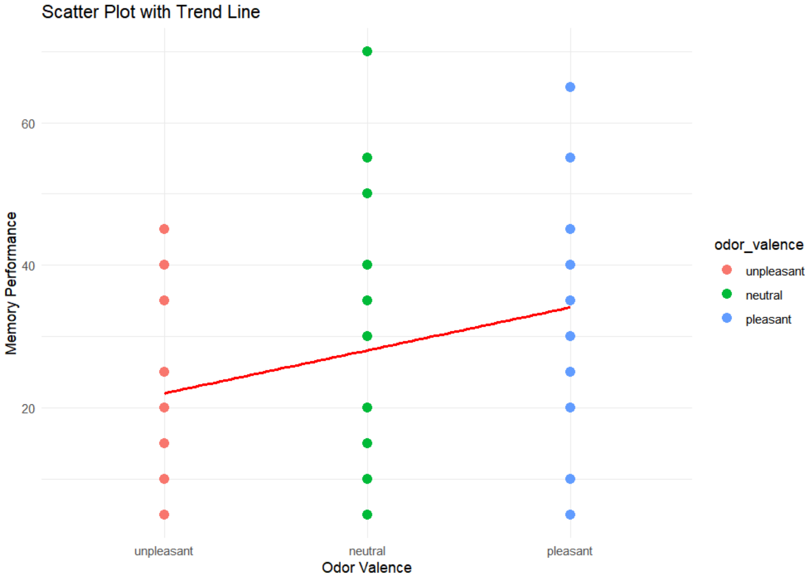


Figure (5)

The chart of correlation of fixed effects is presented below.

	(Intr)	odr_vlncn
odr_vlnc ntr	-0.486	
odr_vlnc pls	-0.506	0.486

The absolute values of correlation coefficients are between 0.3 and 0.7, indicating that there are weak or medium correlations between variables, which can be ignored.

5. DISCUSSION

Through the experiments and data analysis, we can summarize that positive odors can enhance memory performance, while negative odors can suppress memory performance.

In SRM, we can notice that there is a slight trend between odor valence and memory performance, but in ERM, we noticed that there is a positive correlation between these two variables. The outcome is distinct for the reason that, we asked the participants to rate the pleasantness of odors (counted as odor valence, on the scale from 1 to 5) in SRM, and in ERM, we categorize the odors and measure memory performance according to our records of which sniff stick was held by which participant.

The two methods have their own advantages. As we mentioned in the Methods-Participant part, personal variation cannot be removed. The Subject Rating Method will reflect the subjective perception of participants, helping us to choose a proper model for data analysis, the Linear Mixed-Effects Model (LMM). However, a lot of other factors such as stress level, personal preferences, and one's emotions while being tested will interfere the outcome. For the Experimenter Recorded Method, we are able to eliminate the influence of personal preferences and collect data objectively. Recording odors of different experiments can put participants in a standardized odor valence classification. Though it ignores the subjects' perception, it retains the impact of emotions evoked by odors on memory performance. Therefore, applying two approaches of data processing helps us to analyze 'subjective' and 'objective' data at the same time, making the results more well-rounded and enhancing the study's explanatory capacity.

Part of the result, positive odor valence increases memory performance, is aligned with previous behavioral and experimental studies. Positive odors (PO) activate the limbic system and evoke positive emotions. Since the olfaction pathway is closely related to the amygdala, emotional responses will be encoded in hippocampus with stronger and more long-lasting effects of other kinds of stimuli such as vision and audition.

However, we discovered that negative odor valence will decrease memory performance compared to PO, which is distinct from previous studies (Zald D.H. & Pardo J.V., 1997) showing that negative odors (NO) may assist memory performance by activating the amygdala, which helps to identify potential danger.

We infer that properties of negative odors will influence subjects' memory performance. Firstly, NO can evoke stress response and aversion (Hirasawa et al., 2019), so we infer that exposure to NO can enhance the anxiety level of participants, leading to further discussions of the impact of stress and anxiety level on memory performance. Negative odors can develop aversion and avoidance behavior in mice (Kerry Ressler et al., 2024), so there might be similar effects on humans. Secondly, NO can impair cognition and distract subjects from memory tasks. It has been discovered that participants exposed to unpleasant odors had a lower level of attention compared to those exposed to pleasant odors (Nordin et al., 2017), and NO can interfere with emotional states, then impair memory processing (Krusemark et al., 2013). Thirdly, NO will give rise to negative emotions of participants, making it more complicated for us to identify the relationship between odors, emotions, and memory. Therefore, some NO produce negative emotions rather than alertness, which is inconsistent with studies asserting that NO will enhance alertness, and thus memory performance.

Practically, this article helps us to gain better insights of odors and memory by providing a direct comparison of memory performance between NO and PO, which is essential and useful. It provides us with guidance for practical application. For example, libraries and schools can use PO to improve students' mood and memory, producing a better environment for studying. Meanwhile, this study can be used to back up the screening of neurodegenerative disease diseases and the treatment of PTSD.

We have to admit that there are a lot of downsides in our study, but we do our best to refine the experiments and methods of data analysis.

To begin with, due to the diffusion effect of odor molecules, putting sniff sticks in sealable bags is not sufficient to prevent the odors from mixing up with each other, or fading away. During the experiment, some participants reported that they smelled slight vanilla flavor on neutral group sniff sticks, but we examined that the concentration is so low that it can almost be ignored, and some reported that there were slight differences between neutral odor sniff sticks and positive odor sniff sticks. Therefore, we used the Subject-Rated Method and the Experimenter-Recorded Method to help gain a more comprehensive consideration of the results. Further improvements could be made by placing sniff sticks in glass jars and injecting original solutions (3% vanilla perfume solution, 3% fishy odor agent, and water) into them. In this way, we could largely prevent odors from blending together and diminishing, while the intensity of odors should be carefully managed.

In addition, the number of subjects of each valence is uneven due to randomly choosing sniff sticks. Specifically, the number of participants for PO, Neutral, and NO is 15,13,16, respectively. To some extent, this influences the calculation of mean memory performance and the correlation, but it fulfills the requirements of random sampling.

Last but not the least, acknowledging there might be NO presented in the experiment may cause people to refuse to participate. The fear of linguistic clues will affect the outcome. In the future, more effective ways of communicating with potential subjects to gain their confidence and trust should be discovered.

6. CONCLUSION

Olfaction, working as the oldest sensory system of animals, is closely associated with the limbic system, including the amygdala and the hippocampus. This study has pointed out not only the result but also potential factors influencing odor perception and memory performance by using sniff sticks, memory tasks, and distraction tasks. As mentioned above, understanding odor perception and memory performance can be applied to many fields, including education and medical treatment. In future studies, the limitations mentioned above should be refined, using more advanced equipment and technology to discover the mechanisms of this phenomenon, and to find out additional elements impacting the relationship between odor perception and memory performance..

REFERENCES

[1] Nordin, S., Aldrin, L., Claeson, A.-S., & Andersson, L. (2017). Effects of Negative Affectivity and Odor Valence on Chemosensory and Symptom Perception and Perceived Ability to Focus on a Cognitive Task. Perception, 46(3-4), 431-446. https://doi.org/10.1177/0301006616686990 (Original work published 2017)

[2] Royet, J. P., Zald, D., Versace, R., Costes, N., Lavenne, F., Koenig, O., & Gervais, R. (2000). Emotional responses to pleasant and unpleasant olfactory, visual, and auditory stimuli: a positron emission tomography study. The Journal of neuroscience : the official journal of the Society for Neuroscience, 20(20), 7752–7759. https://doi.org/10.1523/JNEUROSCI.20-20-07752.2000

[3] McDonough, M. (2024). The Connections Between Smell, Memory, and Health: The ability of odors to bring to mind past experiences has intriguing scientific and therapeutic implications https://magazine.hms.harvard.edu/articles/connections-between-smell-memory-and-health

[4] Zhen Tong, Xiaorui Liu, Yulong Song, Hongyu Guan, Xinran Wen, Songtao Hu, Mingli Lu, The influence of odors on cognitive performance based on different olfactory preferences, Building and Environment, Volume 271, 2025, 112603, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2025.112603.

[5] Richard J. Stevenson (2010) An Initial Evaluation of the Functions of Human Olfaction, Chemical Senses, Vol. 35, Iss. 1, 2010, p. 3. https://rave.ohiolink.edu/ejournals/article/326829640

[6] Rachel S. Herz, Gerald C. Cupchik, The Emotional Distinctiveness of Odor-evoked Memories, Chemical Senses, Volume 20, Issue 5, 1995, Pages 517–528, https://doi.org/10.1093/chemse/20.5.517

[7] Anderson, A. K., et al. "Dissociated Neural Representations of Intensity and Valence in Human Olfaction." Nature Neuroscience, vol. 6, no. 2, Feb. 2003, pp. 196–202. EBSCOhost, https://doi-org.ezproxy.oberlin.edu/10.1038/nn1001.

[8] Christina Strauch, Denise Manahan-Vaughan, In the Piriform Cortex, the Primary Impetus for Information Encoding through Synaptic Plasticity Is Provided by Descending Rather than Ascending Olfactory Inputs, Cerebral Cortex, Volume 28, Issue 2, February 2018, Pages 764–776, https://doi.org/10.1093/cercor/bhx315

[9] Artin Arshamian, Emilia Iannilli, Johannes C. Gerber, Johan Willander, Jonas Persson, Han-Seok Seo, Thomas Hummel, Maria Larsson, The functional neuroanatomy of odor evoked autobiographical memories cued by odors and words, Neuropsychologia, Volume 51, Issue 1, 2013, Pages 123-131, ISSN 0028-3932, https://doi.org/10.1016/j.neuropsychologia.2012.10.023.

[10] Simon Chu, John J. Downes, Odour-evoked Autobiographical Memories: Psychological Investigations of Proustian Phenomena, Chemical Senses, Volume 25, Issue 1, February 2000, Pages 111–116, https://doi.org/10.1093/chemse/25.1.111

[11] Zhang M, Gong X, Jia J and Wang X (2021) Unpleasant Odors Affect Alerting Attention in Young Men: An Event-Related Potential Study Using the Attention Network Test. Front. Neurosci. 15:781997. doi: 10.3389/fnins.2021.781997

[12] Cook S, Fallon N, Wright H, Thomas A, Giesbrecht T, Field M and Stancak A (2015) Pleasant and Unpleasant Odors Influence Hedonic Evaluations of Human Faces: An Event-Related Potential Study. Front. Hum. Neurosci. 9:661. doi: 10.3389/fnhum.2015.00661

[13] Krusemark, E.A., Li, W. Enhanced Olfactory Sensory Perception of Threat in Anxiety: An Event-Related fMRI Study. Chem. Percept. 5, 37–45 (2012). https://doi-org.ezproxy.oberlin.edu/10.1007/s12078-011-9111-7

[14] Zald, D. H., & Pardo, J. V. (1997). Emotion, Olfaction, and the Human Amygdala: Amygdala Activation during Aversive Olfactory Stimulation. Proceedings of the National Academy of Sciences of the United States of America, 94(8), 4119–4124. http://www.jstor.org/stable/41966

[15] Dan, Xiuli et al. "Olfactory dysfunction in aging and neurodegenerative diseases." Ageing research reviews vol. 70 (2021): 101416. doi:10.1016/j.arr.2021.101416

[16] Nordin, Steven & Aldrin, Lina & Claeson, Anna-Sara & Andersson, Linus. (2017). Effects of Negative Affectivity and Odor Valence on Chemosensory and Symptom Perception and Perceived Ability to Focus on a Cognitive Task. Perception. 46. 301006616686990. 10.1177/0301006616686990.

[17] Audronyte, E., Sutnikiene, V., Pakulaite-Kazliene, G., & Kaubrys, G. (2023). Olfactory memory in mild cognitive impairment and Alzheimer's disease. Frontiers in neurology, 14, 1165594. https://doi.org/10.3389/fneur.2023.1165594

[18] Anderson, A. K., Christoff, K., Stappen, I., Panitz, D., Ghahremani, D. G., Glover, G., Gabrieli, J. D. E., & Sobel, N. (2003). Dissociated neural representations of intensity and valence in human olfaction. Nature Neuroscience, 6(2), 196–202. https://doi.org/10.1038/nn1001

[19] Herz, R. S., & Engen, T. (1996). Odor memory: Review and analysis. Psychonomic Bulletin & Review, 3(3), 300–313. https://doi.org/10.3758/BF03210754

[20] Cahill, L., Haier, R. J., Fallon, J., Alkire, M. T., Tang, C., Keator, D., Wu, J., & McGaugh, J. L. (1996). Amygdala Activity at Encoding Correlated with Long-Term, Free Recall of Emotional Information. Proceedings of the National Academy of Sciences - PNAS, 93(15), 8016–8021. https://doi.org/10.1073/pnas.93.15.8016

[21] Toffolo, M. B. J., Smeets, M. A. M., & van den Hout, M. A. (2012). Proust revisited: Odours as triggers of aversive memories. Cognition and Emotion, 26(1), 83–92. https://doi.org/10.1080/02699931.2011.555475

[22] Yukei Hirasawa, Mika Shirasu, Masako Okamoto, Kazushige Touhara,Subjective unpleasantness of malodors induces a stress response,Psychoneuroendocrinology,Volume 106,2019,Pages 206-215,ISSN 0306-4530, https://doi.org/10.1016/j.psyneuen.2019.03.018.

[23] Learning-Dependent Structural Plasticity in the Adult Olfactory Pathway, Seth V. Jones, Dennis C. Choi, Michael Davis, Kerry J. Ressler, Journal of Neuroscience 3 December 2008, 28 (49) 13106-13111; DOI: 10.1523/JNEUROSCI.4465-08.2008

[24] Li Mai. Proust Effect: The Impact of Odor on Emotional Memory [D]. Hebei: Hebei Normal University,2024.

[25] 李迈. 普鲁斯特效应：气味对情绪记忆的影响[D]. 河北:河北师范大学,2024.

[26] Rachel S. Herz, Gerald C. Cupchik, The Emotional Distinctiveness of Odor-evoked Memories, Chemical Senses, Volume 20, Issue 5, 1995, Pages 517–528, https://doi.org/10.1093/chemse/20.5.517

[27] de Groot, J. H. B., Semin, G. R., & Smeets, M. A. M. (2014). I Can See, Hear, and Smell Your Fear: Comparing Olfactory and Audiovisual Media in Fear Communication. Journal of Experimental Psychology. General, 143(2), 825–834. https://doi.org/10.1037/a0033731

[28] Schiffman, S. S. (1974). Physicochemical Correlates of Olfactory Quality. Science (American Association for the Advancement of Science), 185(4146), 112–117. https://doi.org/10.1126/science.185.4146.112

[29] Cahill, L., Haier, R. J., Fallon, J., Alkire, M. T., Tang, C., Keator, D., Wu, J., & McGaugh, J. L. (1996). Amygdala activity at encoding correlated with long-term, free recall of emotional information. Proceedings of the National Academy of Sciences of the United States of America, 93(15), 8016–8021. https://doi.org/10.1073/pnas.93.15.8016

[30] Hummel, T., Sekinger, B., Wolf, S. R., Pauli, E., & Kobal, G. (1997). 'Sniffin' Sticks': Olfactory Performance Assessed by the Combined Testing of Odor Identification, Odor Discrimination and Olfactory Threshold. Chemical Senses, 22(1), 39–52. https://doi.org/10.1093/chemse/22.1.39.