愛媛大学教育学部紀要 第72巻 132-138 2025

How do olfactory stimuli and learning methods influence academic performance?

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（Received September 1, 2025; accepted November 27, 2025）

Introduction

In episodic memory, contextual information - such as time, location, and one's physical and mental state - is encoded alongside the target information. Among these contextual elements, physical environmental factors, such as the room in which encoding and retrieval occur, are referred to as environmental context (Yamada & Chujo, 2009). Previous research has demonstrated that when the environmental context at encoding matches that at retrieval, the likelihood of successfully recalling the target information increases. This phenomenon is known as the environmental context-dependent effect (Godden & Baddeley, 1975).

In Japan, Yamada has conducted a series of studies on environmental context-dependent memory. In one such study (Yamada, 2008), the relationship between the salience of olfactory environmental cues and the occurrence of context-dependent effects was examined. Participants were assigned to one of four conditions: (1) odor presented during both encoding and retrieval, (2) no odor presented during either phase, (3) odor presented only during encoding, and (4) odor presented only during retrieval. A free recall task was administered under each condition. The results showed that recall performance was highest when the same odor was present during both encoding and retrieval. These findings suggest that salient environmental stimuli, such as odors, can elicit context-dependent memory effects, thereby demonstrating the role of olfactory cues in enhancing memory retrieval.

Yamada and Chujo (2009) investigated the occurrence of environmental context-dependent effects in a word completion task, an implicit memory paradigm, by manipulating the modality of stimulus presentation during encoding and retrieval. In this study, environmental context was varied by conducting the experiment in different laboratories. Two modality conditions were employed: a congruent condition in which stimuli were presented visually during both encoding and retrieval, and an incongruent condition in which stimuli were presented auditorily during encoding and visually during retrieval. The results revealed that environmental context-dependent effects emerged only under the incongruent modality condition. These findings suggest that when more effective item-specific cues are available, environmental context effects may be masked. Thus, environmental context-dependent memory effects are more likely to manifest under conditions in which the effectiveness of item cues is reduced.

Yamada and Chujo (2010) examined the occurrence of environmental context-dependent effects in a word completion task, focusing on the retention interval between encoding and retrieval. Using odor as an environmental context cue, they manipulated its presence during encoding and retrieval across two experiments. In Experiment 1, a one-week retention interval was employed, while Experiment 2 used a 10-minute interval. The results revealed that environmental context-dependent effects emerged in the word completion task only when the retention interval was long. In contrast, when the interval was short, the effectiveness of item-specific cues during retrieval appeared to mask the influence of environmental context cues. These findings suggest that environmental context-dependent effects are more likely to manifest under conditions where the effectiveness of item cues is diminished.

Thus, Yamada has conducted a series of investigations that systematically explore the conditions under which environmental context-dependent memory effects occur. However, no studies have examined the environmental context-dependent effect under conditions where both the modality of stimulus presentation (matched vs. mismatched) and the presence or absence of olfactory stimuli are manipulated during encoding and retrieval.

Based on these considerations, the present study aims to supplement Yamada's series of investigations by examining the influence of olfactory environmental context on word completion performance. Specifically, the study compares the salience of environmental context-dependent effects under conditions of matched and mismatched stimulus presentation modalities, with and without olfactory stimuli, to investigate the impact of scent-present and scent-absent contexts as environmental cues.

Method

Participants

The participants consisted of 68 undergraduate and graduate students (58 women, 10 men; $M = 20.93$, $SD = 1.41$).

Experimental Conditions

This study employed a between-subjects design, in which participants were randomly assigned to one of the following four conditions:

1. **Modality-Matched / No Scent Condition**
   Stimuli were presented visually during both encoding and retrieval phases, and the experiment was conducted in a scent-free laboratory.
2. **Modality-Matched / Scent Condition**
   Stimuli were presented visually during both encoding and retrieval phases, and the experiment was conducted in a laboratory with olfactory stimuli.
3. **Modality-Mismatched / No Scent Condition**
   Stimuli were presented auditorily during encoding and visually during retrieval, and the experiment was conducted in a scent-free laboratory.
4. **Modality-Mismatched / Scent Condition**
   Stimuli were presented auditorily during encoding and visually during retrieval, and the experiment was conducted in a laboratory with olfactory stimuli.

Experimental Stimuli

Word Completion Task A total of 160 high-familiarity Japanese nouns (five-character hiragana words) were selected from the familiarity ratings reported by Fujita, Saitō, and Takahashi (1991), with familiarity scores ranging from 3.51 to 5.00 (mean familiarity = 4.07). Two encoding word lists and two retrieval word lists were created using these words. Each encoding list consisted of 40 unique words. Each retrieval list contained 100 words, including 20 words from

one of the encoding lists and 80 additional words not included in the encoding lists. The same set of 80 additional words was used across both retrieval lists. For the retrieval phase, fragment stimuli corresponding to the 120 words (40 encoded + 80 additional) were used, based on materials developed by Fujita (1997) from the original ratings by Fujita et al. (1991). Among these 120 fragment stimuli, 40 words from the encoding lists and 60 of the 80 additional words had a correct response rate of 0.10 or higher. The remaining 20 additional words had a correct response rate between 0.01 and 0.10. During encoding, in the modality-matched conditions, stimuli were presented visually using Microsoft PowerPoint, with one word per slide. In the modality-mismatched conditions, auditory recordings of the word lists were played. During retrieval, stimuli were presented visually using Microsoft PowerPoint in all conditions, with one fragment per slide.

Environmental Context This study examines "odor" as an environmental context. Previous research by Yamada on context-dependent effects of odor consistently employed the scent of hinoki (Japanese cypress), based on evidence that this fragrance evokes a high degree of familiarity among Japanese adults. In contrast, the present study aims to investigate how odor-based environmental context influences participants' performance on a word-completion task (learning outcomes). Accordingly, the selection of odor was guided not by "familiarity" but by its potential to enhance "concentration," which is critical for learning. Based on the survey conducted by the Aroma Environment Association of Japan (AEAJ) (2014), we adopted rosemary fragrance and aromatherapy, which demonstrated the strongest effect in the category of "mind: concentration.". Specifically, Rosemary Camphor essential oil produced by Tree of Life Co., Ltd. was used. The scent was diffused using an ultrasonic aroma diffuser manufactured by MUJI Co., Ltd., filled with 200 ml of water and four drops (approximately 0.20 ml) of essential oil. The diffuser was activated 15 minutes prior to the start of the experiment. During the experiment, the experimenter did not mention the scent, and participants' awareness of the scent was assessed through introspective reports after all experimental sessions had concluded.

The same room was used for both encoding and retrieval phases. Participants were seated and viewed the stimuli on a screen placed on a desk. During the task, the experimenter remained out of the participants' line of sight. All experimental sessions—including encoding, retrieval after 10 minutes, and retrieval after one week—were conducted by the same experimenter.

Procedure

Participants were recruited through in-class announcements and individual invitations. All sessions were conducted individually in private rooms on the university campus to ensure confidentiality. Prior to the experiment, participants were randomly assigned to one of the four experimental conditions, resulting in 17 participants per condition. The experiment consisted of three sessions: (1) encoding, (2) retrieval 10 minutes after encoding, and (3) retrieval one week after encoding. These sessions were conducted across two separate days. All sessions were administered individually.

In the modality-matched conditions, where stimuli were presented visually during both encoding and retrieval, participants were instructed as follows: "We are currently preparing auditory stimuli for a future experiment. Please read aloud each word that appears on the screen at a pace of one word every five seconds." Participants then read aloud 40 words displayed one at a time on a screen, with each word shown

for five seconds. A voice recorder was placed on the desk to record their responses.

In the modality-mismatched conditions, where stimuli were presented auditorily during encoding and visually during retrieval, participants were instructed: "Please listen to the audio and rate how clearly you can hear each word." Participants listened to a recording of 40 words presented at a pace of one word every five seconds and repeated each word aloud. Their responses were also recorded.

After completing the encoding session in both modality conditions, participants were asked two questions to mark the end of the task and to assess regional dialects: "Please tell us the place where you have lived the longest.", "How many years have you lived there?". Participants then moved to a waiting room for a 10-minute break before returning to the experimental room.

In the retrieval session 10 minutes after encoding, all participants completed a word completion task with visual presentation, regardless of modality condition. No verbal instructions were given; instead, the following message was displayed on the screen: "You will see one word fragment at a time containing a blank (□). Please say aloud the first five-character hiragana noun that comes to mind. Words will appear every two seconds. If you cannot respond in time, proceed to the next word." Each fragment was shown for two seconds. If participants failed to respond within the time limit, the task continued automatically. Responses were recorded, and participants completed an introspective report afterward.

In the retrieval session one week after encoding, the same word completion task was administered using the same procedure as the 10-minute retrieval session. After completing the task, participants again provided introspective reports, including whether they had noticed any scent in the experimental room.

Ethical Considerations

Participants were informed both verbally and in writing that participation was voluntary, that refusal to participate would not result in any disadvantage, and that the study was unrelated to any coursework. They were also informed that they could withdraw at any time, even during the task, and that no personally identifiable data would be disclosed or used externally. Informed consent was obtained through signed consent forms.

Results

Statistical Software

All analyses were conducted using HAD version 16.000 (Shimizu, 2016).

OLD and NEW Items

Of the 100 words included in the retrieval word list, 20 words that were also presented during the encoding session were classified as OLD items, while the remaining 80 words not presented during encoding were classified as NEW items. For OLD items, a correct response was defined as the reproduction of the encoded word. For NEW items, a correct response was defined as the completion of the fragment with an existing word. The correct response rates for OLD and NEW items were calculated separately. The difference between the correct response rate for OLD items and that for NEW items was used as an index of priming effect, which served as the dependent variable in subsequent analyses.

Analysis 1: Descriptive Statistics

To exclude participants for whom the olfactory stimulus did not function as an environmental context, introspective reports were collected after the one-week retrieval session to assess awareness of the scent in the experimental room. Eleven participants (3 in the Modality-

Table 1

The mean of the priming effect

	N	the priming effect	
		after 10 minutes	after one week
Modality-Matched / No Scent Condition	*17*	0.21 (0.14)	0.18 (0.11)
Modality-Matched / Scent Condition	*14*	0.13 (0.09)	0.15 (0.09)
Modality-Mismatched / No Scent Condition	*17*	0.07 (0.07)	0.09 (0.09)
Modality-Mismatched / Scent Condition	9	0.09 (0.12)	0.07 (0.09)

Matched/Scent condition, 8 in the Modality-Mismatched/Scent condition) either did not notice the scent or reported perceiving a different scent than the one used, and were therefore excluded from the analysis. The final sample consisted of 57 participants (49 females, 8 males; $M = 21.98$, $SD = 1.42$). The number of participants in each condition, as well as the mean of the priming effect at both the 10-minute and one-week retrieval sessions, are presented in Table 1.

Analysis 2: Two-Way ANOVA on Presentation Modality and Environmental Context

A two-way ANOVA was conducted with the priming effect at the 10-minute retrieval session as the dependent variable, and presentation modality (matched vs. mismatched) and environmental context (scent vs. no scent) as independent variables. The main effect of environmental context was not significant, indicating that the presence or absence of olfactory stimuli did not significantly affect the priming effect in the word completion task. In contrast, the main effect of presentation modality was significant ($F(1, 53) = 8.03$, $p < .01$).

Additionally, the interaction between presentation modality and environmental context showed a marginal trend toward significance ($F(1, 53) = 2.83$, $p = .098$). Simple effects analysis revealed a marginally significant effect of environmental context within the Modality-Matched condition ($F(1, 53) = 3.49$, $p = .067$), with the No Scent condition yielding a greater priming effect than the Scent condition. In the Modality-Mismatched condition, the simple effect of environmental context was not significant.

Furthermore, within the No Scent condition, the simple effect of presentation modality was significant ($F(1, 53) = 13.01$, $p < .01$), with the Modality-Matched condition producing a greater priming effect than the Modality-Mismatched condition. In contrast, within the Scent condition, the simple effect of presentation modality was not significant.

A similar two-way ANOVA was conducted for the priming effect at the one-week retrieval session. The main effect of environmental context was again not significant. However, the main effect of presentation modality remained significant ($F(1, 53) = 9.87$, $p < .01$). The interaction between presentation modality and environmental context was not significant.

Discussion

The present study aimed to examine the influence of olfactory environmental context on word completion performance by comparing the salience of context-dependent effects under

conditions of matched and mismatched stimulus presentation modalities during encoding and retrieval. Specifically, the study investigated whether the presence or absence of olfactory stimuli would affect memory performance as an environmental context cue.

An analysis of the modality-matched and modality-mismatched conditions revealed that, at the 10-minute retention interval, the priming effect was greater in the no-scent condition than in the scent-present condition within the modality-matched group. This indicates that when item-specific cues are effective, memory performance is enhanced in environments without olfactory stimuli. Furthermore, within the no-scent condition, the modality-matched group showed a greater priming effect than the modality-mismatched group, whereas no such difference was observed in the scent-present condition. These findings suggest that the presence of olfactory stimuli may diminish the effectiveness of item-specific cues. Thus, rosemary scent may interfere with the facilitative effects of modality-based item cues. These results do not support the findings of Yamada and Chujo (2010).

Additionally, at the one-week retention interval, no significant difference in priming effect was found between the scent-present and no-scent conditions. This indicates that even when the influence of item-specific cues is reduced due to the extended retention interval, the presence or absence of olfactory stimuli does not affect memory performance. These findings also do not support Yamada (2008).

This study aimed to investigate the influence of olfactory environmental context on memory performance by comparing the susceptibility to context-dependent effects of odor stimuli under conditions of modality match and mismatch during encoding and retrieval in a word completion task. The results demonstrated that, with a 10-minute retention interval, item-specific cues were more salient in the odor-absent condition. In contrast, the presence of odor appeared to attenuate the effectiveness of modality-based item cues. These findings suggest that when modality-specific item cues are available, encoding and retrieval processes are more effective in environments without strong olfactory stimulation. Accordingly, it may be argued that everyday living spaces, which typically lack distinctive or intense odors, provide optimal conditions for focused learning.

However, the results of this study did not support the series of results reported by Yamada. One notable difference between this study and Yamada and Chujo (2010) as well as Yamada (2008) lies in the type of olfactory stimulus employed. In this study, we deliberately focused on “concentration,” which is essential for learning, and therefore selected rosemary scent instead of the hinoki scent used in Yamada’s research. Consequently, the results of this study may reflect effects specific to rosemary fragrance, and the manifestation of context-dependent effects could differ when other odor stimuli are used. Future research should re-examine the phenomenon using the hinoki scent adopted in Yamada’s studies. Additionally, it will be necessary to conduct a preliminary experiment to obtain ratings of odor stimuli, select the stimulus for the main experiment, and further investigate the relationship between odor characteristics and the occurrence of context-dependent effects.

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Note

This paper is based on Hiyori NISHIKUNI's undergraduate thesis, which was completed under the supervision of the author and submitted to the Faculty of Education at Ehime University in the 2023 academic year, and has since been revised and expanded.