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## Effects of odor-induced autobiographical memory recall interventions on the mental health of individuals with problem drinking behaviors

Kohsuke Yamamoto<sup>1</sup>✉ & Tomonari Irie<sup>2</sup>

The number of alcohol use disorders (AUD) worldwide has increased; therefore, understanding and preventing alcohol addiction is of utmost importance. The objective of this study was to examine the influence of memory recall interventions using the odor of alcohol on mental health and drinking behavior. We used three different studies, two online and one in a laboratory, where participants with and without problematic drinking behaviors were asked to recall autobiographical memories evoked by the odor of alcohol. They were asked to complete questionnaires to measure their autobiographical memory and mental health. The results revealed that participants without problematic drinking behaviors recalled more positive memories and exhibited better mental health than those with such behaviors. Furthermore, in both groups, recalling positive memories increased positive mood, while recalling negative memories decreased positive mood. Additionally, for participants with problematic drinking behaviors, recalling positive memories increased their planned alcohol consumption, whereas recalling negative memories decreased it. The results suggest that interventions focused on recalling emotional autobiographical memories may influence the mental health and behavior of individuals with problematic drinking behaviors.

**Keywords** Odor, Autobiographical memory, Alcohol, Olfaction, Addiction

### The relationship between problematic drinking behaviors and memory

While 20% of the Japanese population, which translates to more than 25 million people, consider themselves habitual drinkers who consume at least 1 unit of alcohol per drinking day for at least 3 days a week<sup>1</sup> without developing problematic behaviors, an estimated 100,000 of these individuals suffer from alcohol use disorders (AUD); notably, the number could be even higher<sup>2</sup>. Hence, understanding and preventing AUD is of utmost importance.

Previous research suggests that given individual and genetic factors, those with and without problematic drinking behaviors may display psychological and behavioral differences<sup>3</sup>. Numerous studies have examined problem drinkers' cognitive processes, focusing particularly on their memory<sup>4–6</sup>. Kessler et al.<sup>6</sup> reported that alcohol-related cognitive biases affect both attentional and working memory, and demonstrated that frequent drinkers exhibit an attentional bias toward alcohol-related stimuli and a working memory advantage for these stimuli over neutral ones. These findings suggest that alcohol use influences not only immediate attention but also the encoding and retrieval of alcohol-related information. Recently, research has focused on autobiographical memory, which is the memory of past events<sup>7–10</sup>. For example, Nandrino et al.<sup>10</sup> reviewed previous studies examining the association between problematic drinking behaviors and autobiographical memory and highlighted that individuals with AUD exhibit significant impairments in the maintenance of autobiographical memory. They emphasized that autobiographical memory is closely linked to affect regulation, as it plays a crucial role in processing and integrating emotional experiences. Specifically, deficits in autobiographical memory in individuals with AUD have been associated with difficulties in retrieving specific emotional events, reduced emotional intensity in recalled memories, and an increased tendency toward overgeneralized autobiographical recall. These impairments may stem from dysfunctions in neural circuits responsible for both

<sup>1</sup>Faculty of Science and Engineering, Hosei University, Tokyo, Japan. <sup>2</sup>Department of Psychology and Counseling, School of Education and Culture, Hokusho University, Ebetsu, Japan. ✉email: kyamamoto@hosei.ac.jp

memory consolidation and emotional regulation, such as the prefrontal cortex and limbic system. Given that chronic alcohol consumption disrupts these brain regions, the ability to construct and maintain coherent self-narratives becomes compromised, further exacerbating emotional dysregulation and reinforcing problematic drinking behaviors. Thus, appropriate maintenance of autobiographical memory is essential for emotional well-being, and its impairment in AUD may contribute to the persistence of maladaptive affective states and the cycle of alcohol dependence.

The fading affect bias (FAB) refers to the tendency for unpleasant emotions associated with past events to fade more rapidly over time than pleasant emotions. This bias is considered a healthy coping mechanism that enhances overall positive affect and emotional well-being. Given the association between those with problem drinking behavior, FAB might reinforce maladaptive behaviors like alcohol consumption by causing unpleasant emotions associated with these behaviors to fade quickly. Meanwhile, individuals who recall negative memories more readily might be at higher risk of developing AUD.

Nandrino<sup>10</sup> proposes the Autobiographical Memory and Alcohol Use Disorders (AMAUD) model based on traditional studies related to alcohol dependence and autobiographical memory. The AMAUD model explains how autobiographical memory is disrupted in individuals with alcohol dependence. According to this model, those with AUD face issues such as interference with emotion regulation, decreased executive functions, and overgeneralization in their autobiographical memories. Interference with emotion regulation indicates a diminished ability to appropriately adjust emotions, leading to a lack of crucial emotional context when forming autobiographical memories in individuals with AUD, which undermines the specificity and depth of those memories. The decrease in executive functions is significant as these functions are essential for forming and maintaining autobiographical memories; however, AUD impairs these functions, hindering the ability to recall detailed episodic information. Particularly, decision-making, goal-setting, and planning become challenging, obstructing the construction of rich memories. These executive function issues also relate to memory suppression. For example, a study by de Almeida-Antunes et al.<sup>11</sup> using memory suppression paradigms like the Think/No-Think (TNT) task suggests that AUD patients demonstrate a reduced ability to suppress unwanted memories or intrusive thoughts. Therefore, interventions focusing on sustained suppression of intrusive thoughts<sup>12</sup> or using reconsolidation techniques<sup>13</sup> are being explored for efficacy<sup>14</sup>. Furthermore, overgeneralization refers to a tendency to rely on general experiences or broad events rather than recalling specific past occurrences, which results in the absence of concrete experiences that are essential for identity formation. This tendency may be a strategy to avoid emotional trauma, but in the long term, it can reinforce negative self-image and hinder self-identity development. Individuals with AUD lack the sensory details and emotional richness when recalling memories, diminishing their ability to vividly remember past events. This leads to a loss of the sensory enhancement typically associated with memory experiences, making it difficult to reflect on specific memories. Autobiographical memory is deeply connected to personal identity. In patients with AUD, there is a tendency toward the generalization of negative self-defining memories, creating ambiguity in personal identity and future outlooks. Consequently, self-evaluations often decline, and depressive symptoms can emerge, which is seen as a factor contributing to the vicious cycle of alcohol consumption. According to this model, it is predicted that individuals with problematic drinking behaviors will not experience general functional alcoholic behavior, and negative self-image-associated autobiographical memories are more likely to be recalled.

However, empirical findings regarding the presence or absence of FAB in individuals with problematic drinking behaviors remain mixed. On the one hand, several studies suggest that individuals with problematic alcohol consumption exhibit diminished FAB, meaning that negative memories are retained more strongly compared to non-problematic drinkers. For instance, Contractor et al.<sup>7</sup> and De Groote et al.<sup>8</sup> reported that individuals with problematic drinking behaviors tend to recall negative memories more frequently and vividly than those without such behaviors, which may contribute to emotional distress and perpetuate maladaptive drinking patterns. On the other hand, although there is a limited number of studies, Gibbons et al.<sup>9</sup> examined FAB in individuals with problematic drinking behaviors. They found that this bias was present during both low-alcohol consumption periods and high-alcohol consumption events. These findings contrast with previous reports and suggest that the relationship between FAB and problematic drinking may not be straightforward. Given these inconsistencies in the literature, further research is needed to clarify how FAB functions in the context of AUD. The present study aimed to address this gap by investigating the mechanisms underlying FAB in individuals with problematic drinking behaviors and exploring its potential role in AUD.

### Odor-induced autobiographical memory

In recent years, many empirical studies have been conducted on olfaction and autobiographical memory in the field of cognitive psychology<sup>15–19</sup>. These studies suggest that odor-induced memories are highly emotional, vivid, specific, rare, and relatively old. Memories evoked by odor cues are rated as more pleasant than those evoked by other cues, but are reflected upon and discussed less frequently. Subsequent studies have found that autobiographical memory elicited by odors is more emotional and vivid than memories elicited by verbal labels or other modality cues. Moreover, it is associated with a stronger sense of being transported back in time to when the event occurred<sup>20–24</sup>.

Previous studies have indicated that emotion is a key feature of odor-induced autobiographical memory. According to Engen<sup>25</sup>, smell is strongly linked to emotion, which can be considered an emotional judgment. Research has found that smells are potent emotion inducers that elicit mood<sup>26</sup>. Furthermore, neuropsychological studies have demonstrated a relationship between the olfactory cortex and amygdala-hippocampal complex<sup>27</sup>. The amygdala is involved in processing emotional experiences and emotional or general memories. Thus, autobiographical memory evoked by odor is expected to have significant affective functions. Recalling memories based on odor may evoke positive emotions and help individuals cope with negative emotions<sup>28,29</sup>. Moreover, olfactory memory retrieval may influence subjective well-being<sup>30</sup>.

## Autobiographical memories and emotions evoked by the odor of alcohol

A small number of studies have been conducted on memories evoked by the odor of alcohol<sup>31–33</sup>. These studies examine alcohol as one of the four major “shikohin” (luxury and indulgent products: alcohol, tea, coffee, and tobacco) in Japan. For instance, Yamamoto et al.<sup>31</sup> investigated the characteristics of autobiographical memories evoked by the odor of “shikohin” by using a method where participants recorded the features of memories evoked by the odor of “shikohin” in their daily lives in a diary. The results reported that autobiographical memories evoked by the odor of alcohol had higher scores on the factor related to coping with negative emotions, including items such as “trying to forget the recalled event,” compared to those evoked by tea or coffee. Additionally, Yamamoto and Yokomitsu<sup>33</sup> developed a questionnaire to measure the characteristics of memories evoked by “shikohin.” Using this questionnaire, they reported that autobiographical memories evoked by the odor of alcohol elicited more negative emotions and were less likely to evoke positive emotions compared to memories evoked by other indulgences (tea, coffee, and tobacco). These results suggest that a higher incidence of problematic behaviors, such as failures due to excessive drinking, is more prevalent with alcohol use compared to that of tea, coffee, and tobacco. In other words, the occurrence of the fading affect bias is not confirmed here. Additionally, Johnstone et al.<sup>34</sup> found that individuals with problematic drinking behaviors tend to recall more negative memories, which are associated with depressive symptoms and motivations to cope with problematic behaviors. Such motivations are associated with the endorsement of alcohol-related words in negative emotional situations<sup>35</sup>. Therefore, it is considered necessary for individuals with problematic drinking behaviors to appropriately address the negative emotions that often accompany memory recall.

## Study goal

Previous studies<sup>28,29</sup> have demonstrated that when experiments or surveys are conducted on the general population, asking participants to recall autobiographical memories using everyday odors as cues and evaluate the emotional qualities of those memories, relatively more positive memories are recalled than negative ones. Since these prior studies have involved generally healthy individuals, it is likely that non-problematic drinkers are also included. Thus, based on this finding, it can be predicted that the odor of alcohol may also evoke positive memories and participant’s mental health might improve. However, when focusing on participants with problematic drinking behavior, the opposite results may also occur. That is, as indicated by previous studies<sup>34,35</sup>, participants with problematic drinking behavior may, conversely, recall more negative memories than positive ones due to the smell of alcohol, potentially harming their mental health. Individuals with problematic drinking behaviors often use alcohol as a coping mechanism for stress, and it is conceivable that drinking may temporarily evoke positive memories and emotions, improving their mood<sup>10</sup>. Additionally, since alcohol promotes the release of dopamine, the pleasure hormone, it is also possible that enjoyable experiences and moods are reinforced after drinking<sup>36,37</sup>.

To date, several studies have been conducted on autobiographical memory and mental health in clinical populations. For example, in patients with posttraumatic stress disorder (PTSD), it has been reported that traumatic autobiographical memories lack coherence or are disordered<sup>38</sup>. Additionally, research on anxiety and depression disorders and autobiographical memory has shown that the recall of positive autobiographical memories is beneficial for healthy individuals, while it may not have the expected effects for those experiencing depression<sup>39</sup>. Furthermore, regarding alcohol consumption patterns and mental health, research has been conducted by Massin and Kopp<sup>40</sup>. In this study, the Russia Longitudinal Monitoring Survey was utilized to explore the relationship between alcohol consumption over the past 30 days and life satisfaction based on data from 17,953 individuals. The results indicated that, while there were differences in patterns between genders, overall, low or moderate drinking was associated with higher life satisfaction, whereas excessive consumption was linked to lower life satisfaction.

However, the characteristics of autobiographical memories evoked by the odor of alcohol among individuals with problematic drinking behaviors and their impact on mental health remain unexplored. Furthermore, psychological effects differ between individuals with and without problematic drinking behaviors<sup>3</sup>. Accordingly, it is hypothesized that the characteristics of recalled memories and their impact on mental health might vary between these groups.

To investigate this hypothesis, this study conducted three separate studies targeting individuals with and without problematic drinking behaviors. The objective was to examine the influence of memory recall interventions using the smell of alcohol on mental health and drinking behavior. In Study 1, the autobiographical memory characteristics evoked by the odor of alcohol were compared between individuals with and without problematic drinking behaviors to examine the occurrence of FAB and differences in memory characteristics. Mental health indicators and planned alcohol consumption were also measured to gather foundational data for subsequent intervention studies. Studies 2 and 3 built on the results of Study 1, implementing interventions where participants were asked to recall specific autobiographical memories. Changes in mental health indicators and planned alcohol consumption were examined through online and laboratory experiments, respectively.

## Study 1 Methods

### Participants

To identify individuals with and without problematic drinking behaviors, we adopted the Japanese version of the Alcohol Use Disorders Identification Test (AUDIT) developed by Hiro and Shima<sup>41</sup>. This test’s original version was developed by Babor et al.<sup>42</sup>. The AUDIT comprises 10 items rated on a 5-point Likert scale (e.g., How often do you drink alcohol-containing beverages?). A score of 8 or more on the AUDIT indicated problematic drinking behaviors. From a Japanese research firm’s database, we recruited 711 participants aged 20–59

without problematic drinking behaviors (i.e., scoring 1–7 on the AUDIT) and 332 participants aged 20–59 with problematic drinking behaviors. Through screening, we asked the participants to subjectively assure the researchers that they did not have colds, nasal rhinitis, allergies, or smell aversions. Following the research firm's regulations, the participants were rewarded with points that could be exchanged for goods/services.

## Data collection

### Odor-evoked autobiographical memory questionnaire (OEAMQ)

The OEAMQ developed by Yamamoto and Sugiyama<sup>43</sup> measures the characteristics and functions of odor-evoked autobiographical memory. It has been evaluated as reliable and valid. It comprises the following seven factors: emotion ( $\alpha = 0.93$ ), retrospective recollection ( $\alpha = 0.94$ ), clarity ( $\alpha = 0.91$ ), time information ( $\alpha = 0.89$ ), future actions ( $\alpha = 0.95$ ), perceptual experience ( $\alpha = 0.71$ ), and nostalgia ( $\alpha = 0.84$ ). The questionnaire comprises 21 items rated on a 7-point scale (e.g., “How much emotion was aroused by smelling the odor?” [1 = “not at all”; 7 = “very much”]).

### Function of the autobiographical memory evoked by shikohin scale (FAMS)

The FAMS developed by Yamamoto and Yokomitsu<sup>33</sup> measures the function of autobiographical memory evoked when a *shikohin* product (alcohol, tea, coffee, tobacco) is consumed. The FAMS has been evaluated as reliable and valid. It comprises the following four factors: evoking positive emotions ( $\alpha = 0.85$ ), directing action ( $\alpha = 0.89$ ), coping with negative emotions ( $\alpha = 0.93$ ), and nostalgia ( $\alpha = 0.88$ ). The questionnaire comprises 32 items rated on a 7-point Likert scale (1 = “not at all”; 7 = “very much”).

### Japanese version of the positive and negative affect schedule (J-PANAS)

Watson et al.<sup>44</sup> developed the original version of the Positive and Negative Affect Schedule (PANAS). We used the Japanese version (J-PANAS)<sup>45</sup> to assess the degree of the participants' positive or negative mood during memory recall induced by the odor of alcohol. The J-PANAS comprises two factors (negative,  $\alpha = 0.82$  and positive,  $\alpha = 0.90$ ), with 16 items rated on a 5-point Likert scale (1 = “not at all”; 5 = “very much”).

### Japanese version of the EQ-5D-5 L (J-EQ-5D-5 L)

The original version of the EQ-5D-5 L (EuroQol five dimensions with five levels) scale was developed by Brooks and EuroQol Group<sup>46</sup>. Our study used the Japanese version<sup>47</sup> to assess the participants' quality of life. This scale comprises five items (mobility, personal care, usual activities, pain/discomfort, and anxiety/blockedness) rated on a 5-point Likert scale (1 = “no problem walking”; 5 = “unable to walk”).

### Japanese version of the world health organization 5 well-being index (J-WHO-5)

The WHO's Psychiatric Research Unit, Mental Health Centre North Zealand<sup>48,39</sup>, developed the original version of the WHO-5. We used the short Japanese version<sup>49</sup> to assess the participants' mental health ( $\alpha = 0.89$ ). This scale comprises five items (e.g., “I am in a thoughtful and joyful mood”) rated on a 4-point Likert scale (1 = “not at all”; 4 = “always”).

### Japanese version of the satisfaction with life scale (J-SWLS)

Diener et al. (1985)<sup>50</sup> developed the original version of the SWLS. Our study used the Japanese version (J-SWLS)<sup>51,42</sup> to assess the degree of participants' life satisfaction ( $\alpha = 0.80$ ). This scale comprises five items (e.g., “For the most part, my life is close to ideal”) rated on a 4-point Likert scale (1 = “not at all”; 4 = “absolutely”).

## Procedure

This study was conducted entirely in the participants' homes based on Yamamoto and Sugiyama's<sup>28</sup> online research methods. The instructions were provided online. First, the survey stated, “What changes occurred within you when you were reminded of past events by smelling alcoholic drinks? Please prepare the alcoholic drinks that you usually consume. The term ‘alcohol’ here refers to all drinks containing alcohol, such as beer, happoshu, sake, shochu, awamori, shochu-hai, cocktails, wine, whiskey, brandy, gin, vodka, and plum wine. Please smell them and try to remember past events while smelling them. Please do this in a calm and quiet place, such as your home, where no one else is around.”

When the participants recalled their autobiographical memory related to the smell of alcoholic drinks, they were asked to indicate the specific type of alcoholic drink that elicited the memories. Further, they were asked to rate the intensity of the odor, degree of preference, emotional intensity, pleasant and unpleasant emotions, and familiarity with the alcoholic drink on a 5-point scale. Thereafter, the participants were asked to indicate how many alcoholic drinks they planned to consume according to the AUDIT criteria (e.g., 1 large beer = 2.5 drinks). Finally, they were asked to respond to the OEAMQ and FAMS to assess their recalled autobiographical memory, followed by the J-PANAS, J-EQ-5D-5 L, J-WHO-5, and J-SWLS to understand their mental health.

## Ethical considerations

This study was conducted in accordance with the revised version of the Declaration of Helsinki. All procedures in Studies 1–3 were approved by the ethical committee of the Osaka Sangyo University, Japan (reference number: human 2022-02). We presented an explanation of the survey contents to potential participants at the time of recruitment and just before they began the online survey, and informed them of their right to cease participation even after their initial agreement to participate; all participants provided informed consent by selecting a check button displayed on the computer screen.

## Results

The participants who could not complete the entire procedure or who answered inappropriately (e.g., all answers had the same number) were excluded by the research firm. The final analysis included 635 participants in the non-problematic drinking group (272 men, 363 women; mean age = 45.06, standard deviation [*SD*] = 9.10) and 283 participants in the problematic drinking group (192 men, 91 women; mean age = 46.96, *SD* = 9.10). The analyses were performed using SPSS statistical software (Version 27). The data were compared using *t*-tests and correlation analyses.

First, the *t*-test results revealed that individuals without problematic drinking behaviors ( $M = 1.06$ ,  $SD = 1.34$ ) had lower total AUDIT scores than those with problematic drinking behaviors ( $M = 9.87$ ,  $SD = 5.70$ ), confirming the validity of the grouping manipulation ( $t [916] = 36.75$ ,  $p < .001$ ). In examining several sub-items of the AUDIT, regarding the question, “How much do you typically drink when you drink?” the most common response among non-problem drinkers was 1–2 drinks (2 drinks are about 500 ml of beer), with 506 respondents selecting this option. Conversely, among problem drinkers, the most common response was 3–4 drinks, with 122 individuals indicating this amount. Furthermore, when asked, “How often do you consume 6 or more drinks on one occasion?” the predominant response among non-problem drinkers was “never,” with 407 respondents choosing this option. In contrast, among problem drinkers, the most frequent response was “once a month,” with 78 individuals selecting this frequency. Moreover, planned alcohol consumption was analyzed by group. Individuals with problematic drinking behaviors ( $M = 1.63$ ,  $SD = 1.00$ ) drank more alcohol than those without problematic drinking behaviors ( $M = 2.81$ ,  $SD = 2.00$ ). The *t*-test results also revealed that individuals with problematic drinking behaviors had a higher mean age than those without problematic drinking behaviors ( $t [916] = 2.93$ ,  $p < .05$ ).

Second, we examined the group differences for each factor of the OEAMQ. As presented in Table 1, individuals with problematic drinking behaviors had significantly higher scores on the OEAMQ emotional factor than those without problematic drinking behaviors. The sub-item results revealed a significant difference in memory valence ( $t [916] = 2.68$ ,  $p < .01$ ), indicating that individuals without problematic drinking behaviors ( $M = 5.30$ ,  $SD = 1.54$ ) tended to recall more positive memories than those with problematic drinking behaviors ( $M = 4.99$ ,  $SD = 1.73$ ).

Third, we analyzed the FAMS. As presented in Table 1, individuals without problematic drinking behaviors had significantly higher scores on the FAMS factors of “coping with negative emotions” and “evoking positive emotions” than individuals with problematic drinking behaviors.

Fourth, we analyzed the mental health indicators. As presented in Table 1, individuals without problematic drinking behaviors had lower negative factor scores on the PANAS and higher total scores on the J-EQ-5D-5 L, J-WHO-5, and J-SWLS than individuals with problematic drinking behaviors. This indicates that individuals without problematic drinking behaviors had better mental health than individuals with problematic drinking behaviors.

	Non-problematic drinking group	Problematic drinking group	t(df = 916)	d
OEAMQ				
F1 Emotion	5.17(1.36)	4.90(1.45)	2.77**	1.39
F2 Retrospective recollection	4.30(1.51)	4.26(1.45)	0.38	1.49
F3 Clarity	5.01(1.38)	4.88(1.45)	1.24	1.40
F4 Time information	5.13(1.60)	5.12(1.71)	0.11	1.64
F5 Future action	3.68(1.48)	3.66(1.42)	0.18	1.46
F6 Perceptual experiences	4.59(1.35)	4.47(1.33)	1.26	1.34
F7 Nostalgia	4.57(1.40)	4.38(1.50)	1.92†	1.43
FAMS				
F1 Coping with negative emotions	30.50(14.38)	34.22(15.02)	3.57****	14.58
F2 Nostalgia	37.71(11.92)	37.39(11.81)	0.37	11.89
F3 Directing action	21.82(8.57)	22.05(8.09)	0.38	8.42
F4 Evoking positive emotions	22.04(7.49)	20.75(7.87)	2.37*	7.60
Mental health				
PANAS Positive	23.38(7.54)	22.75(7.75)	1.16	7.60
PANAS Negative	18.31(8.24)	19.86(8.71)	2.57**	8.39
J-EQ-5D-5 L	0.92(0.12)	0.88(0.14)	4.46****	0.13
J-WHO-5	14.19(6.13)	12.54(5.82)	3.83****	6.04
J-SWLS	18.70(7.40)	17.78(7.13)	1.76†	7.32

**Table 1.** Means (*SDs*) of the OEAMQ, FAMS, and mental health scores by group. Note: † $p < .10$ , \* $p < .05$ , \*\* $p < .01$ , \*\*\*\* $p < .001$ . Abbreviations: OEAMQ = Odor-evoked Autobiographical Memory Questionnaire, FAMS = Function of the Autobiographical Memory Evoked by Shikohin Scale, PANAS = Positive and Negative Affect Schedule, J-EQ-5D-5L = Japanese version of the EQ-5D-5L, J-WHO-5 = Japanese version of the World Health Organization 5 Well-Being Index, J-SWLS = Japanese version of the Satisfaction with Life Scale.



Table 2 summarizes the correlation analysis results between memory valence and the mental health indices. The results suggest that the more positive the recalled memories, the higher the mental health indices in both groups. The results revealed a weak but significant correlation between the memory valence rating and mental health index in both groups, suggesting that positive memory recall is related to mental health.

Study 2

Study 1 suggests that recalling positive memories triggered by the odor of alcohol might enhance mental health. In this study, an online experiment was conducted to examine the effects of recalling positive or negative memories induced by the odor of alcohol on drinking behavior and mental health indicators among individuals with and without problematic drinking behaviors.

Experimental design

The study used a three-factor 2 (problematic drinking behavior: present, absent, between-subjects) × 2 (memory type: positive, negative, between-subjects) × 2 (time: pre, post, within-subjects) mixed-design.

Participants

The participants were 610 individuals aged 20–59, screened using the AUDIT from a survey company’s registered members. The groups were as follows:

- Non-problematic drinkers, positive memory group: 214 (97 men, 117 women; mean age = 44.78, SD = 9.08).
- Non-problematic drinkers, negative memory group: 210 (87 men, 123 women; mean age = 45.73, SD = 8.36).
- Problematic drinkers, positive memory group: 90 (60 men, 30 women; mean age = 47.07, SD = 9.02).
- Problematic drinkers, negative memory group: 96 (68 men, 28 women; mean age = 46.96, SD = 9.00).

The participants were rewarded with points for their cooperation according to the survey company’s regulations.

Survey instruments

Four scales used in Study 1 were employed as mental health indicators, along with a section for the participants to record their planned alcohol consumption.

Procedure

The experiment was conducted online. The participants were first asked to rate four mental health indicators and their planned alcohol consumption. They were then instructed to prepare a frequently consumed alcoholic beverage, smell it, and recall either a positive or negative past event associated with the smell, rating the pleasantness or unpleasantness of the memory on a 7-point scale. To ensure that participants followed the instructions correctly, they were required to press a confirmation button on the webpage after each instruction. Additionally, they were asked to provide detailed reports on the alcoholic beverages they prepared and the events they recalled. Based on this procedure, we considered that participants had followed the instructions to a certain extent. Afterward, the participants rated the same mental health indicators and their planned alcohol consumption again.

Results

To check the manipulation, a t-test was conducted on the pleasantness/unpleasantness of the memories recalled under the positive and negative conditions. The results showed that in the positive condition,  $M = 5.55$  ( $SD = 1.60$ ) and in the negative condition,  $M = 4.00$  ( $SD = 2.18$ ). The positive condition elicited more positive memories than the negative condition, confirming the appropriateness of the manipulation ( $t(608) = 10.02, p < .001, d = 0.81$ ).

Table 3 presents the means and SDs of the questionnaires for each group. A three-factor mixed ANOVA revealed that, for the PANAS, there was a significant interaction between the pre–post factor and the positive–negative memory recall factor for both positive and negative moods ( $F(1, 606) = 6.19, p < .05, \eta^2 = 0.01$ ;  $F(1, 606) = 11.57, p < .001, \eta^2 = 0.02$ , respectively). Specifically, both the group with problematic drinking behaviors and the group without them experienced an increase in positive mood after the positive memory recall intervention and a decrease in positive mood after the negative memory recall intervention. Additionally, recalling negative memories increased negative mood. Regarding planned alcohol consumption, only the main effect of the groups was significant ( $F(1, 606) = 194.42, p < .01, \eta^2 = 0.24$ ), indicating no significant effect of the intervention.

	PANAS Positive	PANAS Negative	J-EQ-5D-5 L	J-WHO-5	J-SWLS
Non-problematic drinking group	0.19*	– 0.10*	0.11*	0.21*	0.22*
Problematic drinking group	0.19*	– 0.17*	0.18*	0.25*	0.17*

**Table 2.** Results of the correlation analysis between memory Valence rating and mental health indices by group. Note: \* $p < .01$ . Abbreviations: PANAS = Positive and Negative Affect Schedule, J-EQ-5D-5 L = Japanese version of the EQ-5D-5 L, J-WHO-5 = Japanese version of the World Health Organization 5 Well-Being Index, J-SWLS = Japanese version of the Satisfaction with Life Scale.

	Non-problematic drinking group				Problematic drinking group			
	Positive		Negative		Positive		Negative	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
EOD	1.25(0.98)	1.25(1.03)	1.29(0.98)	1.24(1.13)	3.48(2.63)	3.41(2.78)	3.24(2.79)	3.14(2.81)
PANAS-P	19.73(7.74)	20.03(8.48)	19.29(7.65)	18.51(8.54)	20.70(7.79)	21.56(8.89)	19.86(7.96)	19.48(8.35)
PANAS-N	13.47(6.94)	13.52(7.13)	13.18(6.82)	13.35(8.18)	14.04(7.17)	14.08(7.73)	15.04(8.39)	17.13(8.88)
J-EQ-5D-5 L	0.94(0.09)	0.95(0.09)	0.94(0.10)	0.95(0.10)	0.92(0.11)	0.92(0.10)	0.90(0.15)	0.91(0.15)
J-WHO-5	18.14(7.16)	18.54(7.70)	18.92(7.12)	19.05(7.59)	18.47(8.00)	18.58(8.71)	17.23(6.75)	17.45(6.94)
J-SWLS	12.97(5.81)	18.13(5.99)	13.59(5.97)	18.45(6.40)	12.06(6.01)	17.63(6.45)	12.24(5.52)	17.21(5.63)

**Table 3.** Means (SDs) of the mental health scores by group. Abbreviations: EOD = Estimated amount of drinking, PANAS-P = Positive and Negative Affect Schedule – Positive factor, PANAS-N = Positive and Negative Affect Schedule – Negative factor, J-EQ-5D-5 L = Japanese version of the EQ-5D-5 L, J-WHO-5 = Japanese version of the World Health Organization 5 Well-Being Index, J-SWLS = Japanese version of the Satisfaction with Life Scale.

### Study 3

To replicate the results of Study 2 in a more controlled laboratory environment, the following methodology was used.

#### Experimental design

The study used a three-factor mixed design with 2 (problematic drinking behavior: present, absent, between-subjects)  $\times$  2 (memory type: positive, negative, between-subjects)  $\times$  2 (time: pre, post, within-subjects).

#### Participants

The participants were 132 individuals aged 20–59, screened using the AUDIT from a survey company's registered members. The groups were as follows:

- Non-problematic drinkers, positive memory group: 34 (14 men, 20 women; mean age = 37.18,  $SD = 10.92$ ).
- Non-problematic drinkers, negative memory group: 34 (17 men, 17 women; mean age = 40.15,  $SD = 10.42$ ).
- Problematic drinkers, positive memory group: 33 (17 men, 16 women; mean age = 41.09,  $SD = 10.65$ ).
- Problematic drinkers, negative memory group: 31 (15 men, 16 women; mean age = 41.35,  $SD = 10.44$ ).

The participants were rewarded with points for their cooperation according to the survey company's regulations.

#### Experimental stimuli

Based on the results of Study 2, five fragrances frequently used as recall cues were chosen: beer, red wine, white wine, sake, and whiskey (manufactured by Takasago International Corporation). Each fragrance was used at a quantity of 5  $\mu$ L. Cotton wool was placed in small bottles, and the fragrances were absorbed into the cotton.

#### Survey instruments

The same scales and measures as in Study 2 were used.

#### Procedure

The experiment was conducted with small groups of up to 12 participants. Initially, the participants rated four mental health indicators and their planned alcohol consumption. Next, they smelled the fragrances at their own pace, recalling either positive or negative past events associated with each smell. They rated the pleasantness or unpleasantness of these memories on a 7-point scale. Subsequently, the participants rated the mental health indicators and their planned alcohol consumption again. The ratings were collected via Google Forms, which the participants completed on their smartphones.

#### Supplementary verification (follow-up study)

If an intervention effect was observed, its persistence was examined by asking the participants to complete the same mental health and planned alcohol consumption indicators online three and six months after the experiment. They were also asked to rate how often they had recalled past events when smelling alcohol since the laboratory experiment using a 5-point scale (1 = “never recalled”; 2 = “rarely recalled”; 3 = “recalled a few times”; 4 = “often recalled”; 5 = “recalled every time they drank”).

#### Results

To check the manipulation, a t-test was conducted to compare the pleasantness/unpleasantness ratings of the memories recalled under the positive and negative conditions. The results indicated that in the positive condition, the mean (M) was 6.40 with a standard deviation (SD) of 0.82, while in the negative condition, the mean (M) was 2.34 with a standard deviation (SD) of 1.39. These findings demonstrate that the positive condition elicited significantly more positive memories compared to the negative condition, thereby confirming the effectiveness

	Non-problematic drinking group				Problematic drinking group			
	Positive		Negative		Positive		Negative	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
EOD	1.53(1.32)	1.60(1.39)	3.05(2.08)	2.92(2.35)	4.70(2.42)	5.03(2.41)	6.08(3.35)	5.30(3.42)
PANAS-P	25.59(5.98)	26.79(7.55)	25.79(6.12)	23.58(7.81)	26.39(5.75)	27.39(8.37)	26.47(3.70)	23.59(5.77)
PANAS-N	13.24(4.83)	11.06(4.04)	14.12(6.62)	16.88(8.80)	14.33(5.75)	12.06(6.43)	14.22(5.02)	14.44(6.08)
J-EQ-5D-5 L	0.93(0.09)	0.94(0.08)	0.94(0.10)	0.92(0.11)	0.97(0.07)	0.97(0.06)	0.97(0.06)	0.96(0.07)
J-WHO-5	19.88(5.60)	20.62(6.76)	19.48(5.19)	18.76(6.83)	22.21(4.78)	22.72(5.08)	21.22(4.99)	20.91(6.03)
J-SWLS	19.94(4.69)	20.62(5.09)	19.94(4.74)	19.18(5.52)	20.00(4.68)	20.36(4.90)	20.28(3.01)	20.50(3.48)

**Table 4.** Means (SDs) of the mental health scores by group. Abbreviations: EOD = Estimated amount of drinking, PANAS-P = Positive and Negative Affect Schedule – Positive factor, PANAS-N = Positive and Negative Affect Schedule – Negative factor, J-EQ-5D-5 L = Japanese version of the EQ-5D-5 L, J-WHO-5 = Japanese version of the World Health Organization 5 Well-Being Index, J-SWLS = Japanese version of the Satisfaction with Life Scale.

	Non-problematic drinking group				Problematic drinking group			
	Positive		Negative		Positive		Negative	
	Three month follow-up	Six month follow-up	Three month follow-up	Six month follow-up	Three month follow-up	Six month follow-up	Three month follow-up	Six month follow-up
EOD	1.18(0.99)	1.35(1.45)	3.14(2.75)	3.00(3.07)	4.46(2.32)	4.11(2.78)	5.86(2.93)	5.74(3.63)
PANAS-P	23.53(9.12)	24.83(8.32)	25.03(6.25)	24.58(8.15)	24.63(6.78)	24.96(6.60)	26.52(7.25)	24.62(8.50)
PANAS-N	13.87(6.63)	15.23(7.48)	16.73(8.01)	14.55(7.06)	15.07(7.05)	17.26(8.65)	13.10(6.19)	14.57(6.74)
J-EQ-5D-5 L	0.94(0.09)	0.94(0.09)	0.93(0.11)	0.93(0.11)	0.98(0.05)	0.98(0.05)	0.96(0.08)	0.96(0.08)
J-WHO-5	19.30(6.67)	19.17(6.75)	17.39(5.83)	18.27(7.22)	21.48(5.65)	21.19(6.36)	20.05(5.58)	20.67(6.93)
J-SWLS	20.00(5.02)	19.23(5.22)	19.09(4.24)	18.85(5.55)	19.78(4.81)	19.78(5.49)	20.24(4.36)	19.62(5.49)

**Table 5.** Means (SDs) of the mental health scores at follow-up periods. Abbreviations: EOD = Estimated amount of drinking, PANAS-P = Positive and Negative Affect Schedule – Positive factor, PANAS-N = Positive and Negative Affect Schedule – Negative factor, J-EQ-5D-5 L = Japanese version of the EQ-5D-5 L, J-WHO-5 = Japanese version of the World Health Organization 5 Well-Being Index, J-SWLS = Japanese version of the Satisfaction with Life Scale.

of the manipulation ( $t(130) = 20.43, p < .001, d = 0.87$ ). This statistical analysis provides insight into the emotional impact of the recalled memories.

Table 4 presents the means and SDs of the questionnaires for each group. A three-factor mixed ANOVA revealed significant interactions between the pre–post factor and the positive–negative memory recall factor for the PANAS positive ( $F(1, 128) = 16.54, p < .01, \eta^2 = 0.14$ ), PANAS negative ( $F(1, 128) = 18.37, p < .001, \eta^2 = 0.13$ ), EQ-5D-5 L ( $F(1, 128) = 4.68, p < .05, \eta^2 = 0.04$ ), and WHO-5 ( $F(1, 128) = 7.06, p < .01, \eta^2 = 0.05$ ). For both groups with and without problematic drinking behaviors, values related to positive mood and mental health increased after recalling positive memories, while these values decreased after recalling negative memories. Additionally, unlike in the online experiment, the planned alcohol consumption also showed a similar interaction, with a significant three-way interaction between the problematic drinking behavior group, positive–negative memory recall factor, and pre–post factor ( $F(1, 128) = 6.70, p < .05, \eta^2 = 0.05$ ). The subgroup analysis indicated that in the group with problematic drinking behaviors, the planned consumption amount increased after recalling positive memories and decreased after recalling negative memories. This result was not observed in the group without problematic drinking behaviors. Thus, it suggests that the impact of memories on drinking behavior may differ depending on the presence or absence of problematic drinking behaviors.

Furthermore, a three-factor mixed ANOVA was conducted on the data obtained from the follow-up survey three and six months after the experiment, considering the period as four levels (pre, post, three-month follow-up, six-month follow-up). Excluding the 12 participants who withdrew from the survey at either the three-month or six-month follow-up, 111 participants who completed all surveys were analyzed. The results showed no significant differences, indicating that the effect of the memory recall intervention in the laboratory experiment was not maintained over time (Table 5).

Additionally, regarding the experience of recalling past events when smelling alcohol after the laboratory experiment, about 60% of participants responded that they had never or rarely recalled such events, and less than 10% responded that they frequently or always recalled such events when drinking (Table 6). This suggests that the habit of odor-induced recall is not maintained in the long term, making it difficult for the intervention effect to be sustained.



	Three month follow-up		Six month follow-up	
	N	%	N	%
1: I have never recalled it.	36	32.43	50	45.05
2: I rarely recall it.	30	27.03	23	20.72
3: I recall it a few times.	33	29.73	31	27.93
4: I often recall it.	10	9.01	5	4.50
5: I remember it every time I drink.	2	1.80	2	1.80

**Table 6.** Percentage of frequency of memory recall at follow-up periods.

Discussion

In this study, we focused on groups with and without problematic drinking behaviors to examine the relationship between autobiographical memories evoked by the odor of alcohol, mental health, and drinking behavior. Based on these findings, we evaluated the effects of memory recall interventions.

Study 1 revealed that while both groups exhibited FAB, the group without problematic drinking behaviors showed a higher degree of the FAB than the group with such behaviors. This result suggests that although individuals with problematic drinking behaviors exhibit more problematic drinking patterns, they do not experience AUD; therefore, issues with maintaining autobiographical memories are relatively mild, leading to a certain degree of FAB. Future comparisons with AUD individuals are necessary to further investigate this point.

Studies 2 and 3 suggest that interventions involving the recall of positive memories associated with the smell of alcohol could potentially promote mental health in both groups. This implies that even individuals with problematic drinking behaviors might benefit from interventions that encourage the recall of positive memories to maintain and promote mental health. However, it was also found that among individuals with problematic drinking behaviors, recalling positive memories increased planned alcohol consumption, while recalling negative memories decreased it. This result was not observed in the group without problematic drinking behaviors, indicating that memory recall interventions may impact mental health but not drinking behavior in this group. Given that there are varying levels of problematic drinking behaviors, it may be beneficial for individuals with mild problematic drinking behaviors to recall positive memories to enhance mental health. Contrarily, for those with severe problematic drinking behaviors, recalling negative memories may be necessary to suppress drinking behavior.

However, follow-up surveys conducted as a supplementary verification in Study 3 revealed that memory recall interventions do not have long-term effects. Therefore, memory recall interventions aimed at improving or promoting mental health and suppressing drinking behavior among drinkers require further examination. At this point, they cannot be actively supported based on their effectiveness in clinical settings. A factor contributing to the lack of a maintained effect was that less than 10% of the participants reported frequently recalling memories evoked by the smell of alcohol three and six months after the laboratory experiment. This suggests that to achieve long-term effects, the intervention needs to be repeated periodically without long intervals.

As mentioned previously, the AMAUD model<sup>10</sup> suggests that chronic alcohol consumption impairs not only executive function, which maintains the construction of autobiographical memory, but also emotional control. The impairment of emotional control and executive function reduces motivation to construct detailed memories and subjective reliving, affects anterograde amnesia and negative self-defined memory, and makes it difficult to generate complex autobiographical memory and self-images. In Study 1, no group differences were observed for clarity; however, we compared clarity values for positive (valence rating = 1–3) and negative (valence rating = 5–7) memories among the group with problematic drinking behaviors; the results indicated that positive memories ( $M = 5.30$ ,  $SD = 1.23$ ) had significantly higher clarity values than negative memories ( $M = 4.25$ ,  $SD = 1.79$ ;  $t [229] = 4.76$ ,  $p < .001$ ). In other words, we found that negative memories were less vivid than positive memories among participants with problematic drinking behaviors, confirming a previous study’s finding<sup>10</sup>.

Our findings have clinical applications for this field. Previous research on addiction has already shown that persuading people to stop drinking to improve problem drinking, including alcohol use disorders, can be counterproductive rather than ineffective<sup>52</sup>. An effective psychotherapy for problems related to substance use, including AUD, is cognitive behavioral therapy (CBT), which focuses on the function of drinking behavior on the environment surrounding the individual and aims to modify it<sup>53</sup>. One of the most problematic functions of drinking behavior is experiential avoidance<sup>54</sup>. Experiential avoidance through drinking behavior refers to the consumption of alcohol in response to negative emotions as a means of temporarily escaping from them. However, drinking behavior maintained by such negative reinforcement has been shown to lead to increased alcohol consumption and an elevated risk of developing AUD<sup>55</sup>. The drinking pattern demonstrated in this study, which involves consuming alcohol while recalling positive memories triggered by odors, may serve as a strategy not only to prevent drinking in response to negative cognitive processes but also to establish drinking behavior based on positive reinforcement, as it is accompanied by positive emotions. In other words, it is a strategy aimed at altering the function of drinking through the retrieval of autobiographical memories triggered by odors. Although the effects are limited and the long-term impact remains unclear, the findings also suggest that this strategy may contribute to improvements in various indicators of mental health. Furthermore, from the perspective of clinical applications, the findings of this study are relevant to harm reduction, which has

recently attracted considerable attention in addiction research. Harm reduction, which originally emerged from treatment and practice related to substance use, is defined as policies, programs, and practices that aim to minimize the negative health, social, and legal impacts associated with drug use, drug policies, and drug laws<sup>56</sup>. As it prioritizes the various health risks posed by these substances and behaviors, it reduces the impact of these risks. Indeed, harm reduction strategies reportedly reduce peak alcohol use<sup>57</sup>. However, consistent results have not been obtained on well-being—a positive psychological aspect of alcohol use<sup>58</sup>. This study's results are the first to address this issue with a focus on autobiographical memory recall. As mentioned above, this study contributes not to aiming for the cessation of drinking but to proposing drinking strategies that, while allowing continued alcohol consumption, prevent the worsening of the problem. In the future, based on this study's results, clarifying how mental and physical health problems and well-being are specifically related to positive and negative memories among problem drinkers is important. Such findings would allow for the further elaboration of psychotherapeutic and harm reduction approaches for problem drinkers.

While this study presents some new findings, certain limitations must be acknowledged. The study included examinations through experiments with strict settings but lacked strict manipulation during the long-term verification phase. Consequently, as mentioned above, fewer than 10% of participants reported a frequent recall of memories evoked by the smell of alcohol at three and six months after the laboratory experiment. This suggests that the results concerning the long-term effects of memory recall interventions may be influenced by a biased sample. One way to address this issue is through ecological momentary assessment (EMA). EMA involves the repeated sampling of individuals' behaviors and experiences in real-time, within their natural environments. Compared to global, lab-based self-report measures, EMA is believed to substantially improve the accuracy of reporting and is recommended for recalling long-term events in studies of AUD<sup>59</sup>. Additionally, EMA typically notifies participants through a device (e.g., smartphone), with reminders for measurement. Such reminders have been reported to be effective in modifying behaviors in the treatment of AUD<sup>59</sup>. Therefore, EMA could help address the limitations of this study and contribute to its development into a psychotherapeutic approach. This study experimentally examined the effects of memory recall interventions using the smell of alcohol and demonstrated certain effects. Future studies should consider the implementation of specific preventive programs in actual clinical settings. The results of the long-term effect examination conducted in supplementary Study 3 suggest that the effect may diminish after three months, even if there is an effect immediately after the intervention. Therefore, it is necessary to develop a program that continuously conducts interventions after certain intervals.

Additionally, a traditional method for recovery from alcohol dependence used in abstinence groups involves forcibly recalling negative memories, such as experiences of failure due to alcohol. This study suggests that recalling such negative memories may suppress drinking behavior, supporting the validity of traditional methods. However, as indicated in this study, recalling negative memories, while suppressing drinking behavior, carries the risk of harming mental health. As suggested by this study, it is necessary to develop and examine medium- to long-term recovery and preventive programs that maintain and promote mental health through positive memory recall interventions, depending on the patient's situation. In this study, subjective characteristics of memories were measured using ratings to examine features such as positivity and negativity. While this method is commonly used in autobiographical memory research where encoding times cannot be specified, it is crucial to note that the results of this study are limited to the retrieval phase. Although the study included only a small number of participants with severe AUD, these individuals are likely to have had more negative alcohol-related experiences. Future research should focus on participants with severe AUD and conduct prospective studies to explore both aspects of encoding and retrieval. From the perspective of controlling these two aspects, examining context-dependent memory becomes important. Context-dependent memory refers to the phenomenon where recall is enhanced the more similar the conditions are at the time of encoding and retrieval<sup>60</sup>. In this study, based on this phenomenon, odors presented during encoding were provided again at retrieval to elicit those memories. Previous research has indeed shown that odors have contextual effects<sup>61</sup>, but it is also known that other factors, such as emotions, are involved in context-dependent memory. Future work needs to investigate these factors as well to clarify more detailed mechanisms. Furthermore, in this study, Research 1 and Research 2 were conducted in an online environment, with participants preparing the alcoholic drink themselves as the experimental stimulus. This indicates a high ecological validity, as the experiment is conducted in a context very similar to everyday life. However, this also means that various biases might have occurred, such as visual stimuli from the packaging of alcoholic beverages or proximity behaviors toward alcohol. While factors such as these were controlled in Study 3 conducted in a laboratory, efforts should be made to minimize these aspects as much as possible in future online experiments.

## Data availability

Since sensitive data are included, data are available from the authors (kyamamoto@hosei.ac.jp) if there are reasonable grounds.

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## Author contributions

K.Y. and T.I. : conceptualization, data curation, funding acquisition, and investigation. K.Y.: formal analysis, project administration, and writing – original draft. I.T : writing – review and editing. Both authors contributed to the article and approved the submitted version.

## Declarations

## Competing interests

The authors declare no competing interests.

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## Additional information

**Correspondence** and requests for materials should be addressed to K.Y.

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