

Effects of Cognitive Factors on Perceived Odor Intensity in Adaptation/Habituation Processes: from 2 Different Odor Presentation Methods

Takefumi Kobayashi^{1,2}, Nobuyuki Sakai^{2,3}, Tatsu Kobayakawa², Sachiyo Akiyama^{4,2}, Hideki Toda² and Sachiko Saito^{5,3}

¹Department of Human Studies, Bunkyo Gakuin University, 1196 Kamekubo, Fujimino, Saitama 356-8533, Japan, ²National Institute of Advanced Industrial Science and Technology, Tsukuba Central 6, 1-1-1, Higashi, Tsukuba, Ibaraki 305-8566, Japan, ³Department of Living Science, Kobe Shoin Women's University, 1-2-1, Shinoharaobanoyama, Nada, Kobe, 657-0015, Japan, ⁴National Agency for the Advancement of Sports and Health, 3-15-1 Nishigaoka, Kita, Tokyo 115-0056, Japan and ⁵Saito Sachiko Taste and Smell Institute, 410-151, Shimohirooka, Tsukuba, Ibaraki 305-0042, Japan

Correspondence to be sent to: Takefumi Kobayashi, Department of Human Studies, Bunkyo Gakuin University, 1196 Kamekubo, Fujimino, Saitama 356-8533, Japan. e-mail: takefumi@hum.u-bunkyo.ac.jp

Abstract

The purpose of this study, which comprised 2 experiments, was to investigate cognitive effects on odor perception. An odor was presented using an olfactometer. In Experiment 1 ("continuous" presentation), anethole, an odor unfamiliar to most Japanese individuals, was presented continuously for 1 session (20 min), whereas in Experiment 2 ("intermittent" presentation), odor stimuli were presented 60 times for a short duration (0.2 s) over 4 sessions (24 min, including 9 min of inter-session intervals), in which odor duration, temperature, and humidity were strictly controlled and the odor in the nostril was removed immediately after presentation. In each session, participants were asked to continuously evaluate odor intensity. In both Experiments 1 and 2, the participants were informed that the odor was either healthy (healthy-description group) or hazardous (hazardous-description group) prior to the session. The results show that in Experiment 2 (intermittent presentation), the hazardous-description group perceived the odor as more intense than did the healthy-description group, especially during the last 2 sessions. In Experiment 1 (continuous presentation), however, no significant difference in perceived intensity was present between the 2 groups. This study demonstrates the effect of cognitive state on perceived intensity by developing an experimental setting wherein the peripheral adaptation process was reduced and central olfactory processes were emphasized.

Key words: adaptation and habituation, cognitive effects, description, odor, perceived intensity, preference level

Introduction

The mechanisms underlying olfactory adaptation/habituation are poorly understood. Perceived intensity is believed to decrease exponentially with time, and the proportion, extent, and temporal dynamics of recovery are thought to be dependent on the concentration and duration of the odor stimulus (Ekman et al. 1967; Berglund 1974; Cain 1974). When an individual identifies an odor as harmful, toxic, irritating, or familiar, however, perception of the odor is suggested to be influenced by such cognitive or noncognitive factors (Dalton 1996, 2002; Dalton et al. 1997; Smeets and Dalton 2002, 2005; Smeets et al. 2002). These reports indicate that humans may exhibit different adaptation/habituation processes to the same odor depending on how the

odor is presented. Because these studies of olfactory perception have been performed under quite different experimental conditions, they cannot be directly compared. Nevertheless, such studies consistently suggest that habituation or adaptation of perceived intensity to odor stimuli is context dependent. Notable studies were recently performed on the influence of cognitive information about an odor stimulus on olfactory perception (Dalton 1996; Dalton et al. 1997). Dalton reported that belief that an odor stimulus is harmful influences the perceived intensity of the odor and its adaptation/habituation pattern and repeated these studies with the continuous presentation of either isobornyl acetate (Dalton 1996) or acetone (Dalton et al. 1997).

Although it is generally accepted that the adaptation/habituation of odor perception is influenced at both the peripheral (receptor) and central (postreceptor) levels (Dalton 2000), previous studies reporting the effects of cognitive manipulation have not sufficiently controlled experimental conditions with respect to the peripheral and central properties of odor perception. It is extremely difficult to study intrinsic biological processes in olfactory perception in terms of the relative contribution of the peripheral and central processes to the adaptation/habituation of perceived olfactory sensations. Studying these 2 levels in isolation is crucial in achieving a detailed understanding of the adaptation/habituation processes. We have recently focused our attention on central processes, including cognitive effects, in our research of olfactory perception in adaptation/habituation processes.

In this study, we attempted to investigate the effects of odor descriptions using the following 2 presentation methods: “continuous” and “intermittent.” In the continuous presentation method, the odor was presented continuously to a freely breathing participant, as done in previous studies (Dalton 1996; Dalton et al. 1997) (Experiment 1). In Experiment 1, continuous stimulus presentation provided constant exposure of peripheral receptors to the odor. In the intermittent presentation method, by contrast, short-duration odor stimuli were presented intermittently to a participant who was trained to breathe solely by mouth (Experiment 2). In Experiment 2, by strictly controlling the stimulus presentation method, we tried to minimize stagnation of the odor stimulus on the peripheral (receptor) level in order to more specifically study cognitive effects on olfactory perception in adaptation/habituation. Precise control of environmental factors related to olfactory perception is possible with a constant-flow olfactometer (Kobal 1985; Kobal and Hummel 1988), which allows the control of odorant concentration (ratio of bubbled odor and air), temperature, duration, and humidity. We employed this odor presentation technique to examine the influence of cognitive effects on the perceived intensity in the adaptation/habituation processes.

Experiment 1: the continuous presentation method

In Experiment 1, we aimed to investigate the effect of informing subjects that a continuously presented odor was either healthy or hazardous under a relatively natural respiration method on their perceived intensity during adaptation/habituation.

Materials and methods

Participants

Twenty participants (10 females and 10 males) with a mean age of 22 years (standard deviation [SD] = 2.25) took part in this experiment.

Stimulus presentation methods

To present the odor stimulus, anethole, we used a computer-controlled apparatus modified from a constant-flow olfactometer (Sekine et al. 1995). Anethole, a principle component of anise, is unfamiliar to most Japanese individuals (Ayabe-Kanamura et al. 1998; Distel et al. 1999). Ten milliliters of gas, made by bubbling a 100% anethole solution, was diluted with 1 l of air. The flow rate used in the experiment was 1.0 l/min. The stimulus was presented continuously to the participants for 20 min (1 session) through a mask covering the nose and mouth, and a ventilation tube was attached to it to continuously eliminate the odor stimulus. The participants were allowed to breathe freely during the session.

Perceived intensity evaluation

The participants performed a continuous evaluation of the odor stimulus by holding a slide lever attached to the lid of a metal box placed beside them. On the lid of the box, the numbers from 0 to 5 were marked at regular intervals along a 30-cm horizontal line, with the labels “no odor” beneath the line at the left end (0) and “extremely strong” beneath the line at the right end (5). The perceived intensity data were sampled and recorded automatically every 100 ms. For statistical analyses, a maximum perceived intensity value was extracted from every 20 s (1 block) such that the maximum intensity values of 60 blocks were obtained for 1 session.

Procedure

As disclosure of the experiment’s objective to participants before the experiment would have influenced the results, a complete debriefing was performed only after the odor presentation session. The participants were randomly divided into 2 groups—the “healthy” and “hazardous” description groups—and each group consisted of 5 males and 5 females participants. Immediately before the start of the experiment, we described the odor to each group using group-congruent descriptors.

At the beginning of the description, we provided false information regarding the odorant that was provided to both the healthy- and hazardous-description groups: “We would like you to smell a certain substance today. This is a substance developed by our laboratory. The chemical structure of this substance is quite similar to that of a substance called ‘anethole.’ However, it was found in previous experiments that the mental and physiological effects of this substance are different from those of anethole. The objective of the experiment today is to study the detailed mental and physiological effects of this odor.” We then provided, in writing, favorable information regarding the odor stimulus to the healthy-description group: it acts as an antimicrobial and diuretic; it has other positive effects on the digestive system and is therefore expected to be applied in aromatherapy; and smelling the odor at the concentration and for the duration

as in the experiment is expected to bring about aromatherapeutic effects such as stress relief and digestion facilitation. In contrast, the hazardous-description group was provided hazardous information regarding the odor stimulus: the substance is classified as “category number 3, group 3 petroleum, and hazard classification class 3”; it chronically impairs touch in insects; and oral ingestion of large volumes might be fatal in mammals, except for primates such as human beings, other apes, and monkeys. The participants were then told that they could retire from the experiment at any time if they felt sick.

To accustom the participant to the experimental conditions and the operation of the evaluation equipment, they were presented with the odor stimulus continuously for 5 min. During this process, participants were asked to evaluate the perceived intensity in real time. After the experimenter confirmed that the participants were able to perform the perceived intensity evaluation, the experiment began. Continuous odor stimulus was presented for 20 min. During this period, the participants evaluated the perceived intensity in real time, as learned in the training.

After the odor presentation session was completed, the participants evaluated the preference level of the odor by marking on a horizontal line with the numbers from -3 (extremely unpleasant) to $+3$ (extremely pleasant).

Statistical analysis

To statistically analyze the effect of the description (healthy or hazardous) on the perceived intensity, we performed a 2-way analysis of variance (ANOVA) for the description (healthy or hazardous) versus the odor stimulus presentation (60 levels; hereafter referred to as “presentation”) (compound design: “description” is the between-subjects factor and presentation is the repeated factor). To analyze the effects of the description on the preference level, a two-tailed t -test was used. We first included the factor “gender” in the analysis, confirming that the effect of gender was not significant on any measures. Thus, we excluded the gender factor in the analysis to make comparisons of the 2 description groups more distinctive. This study was not originally designed to examine gender differences. The influence of gender on the effects of description on odor perception should be further investigated in an experiment with a more suitable design.

Results

Difference in perceived intensity due to description conditions

The 2-way ANOVA for description versus presentation revealed no significant main effect for description ($F_{1,18} = 0.53$, not significant [NS]) and no significant interaction effect for description and presentation ($F_{59,1062} = 0.90$, NS). The main effect for presentation, however, was significant ($F_{59,1062} = 2.56$, $P < 0.01$). Further post hoc tests by multiple

comparisons by Tukey’s honestly significant difference (HSD) method, however, revealed no significant differences between 1770 comparative pairs among 60 odor presentations. Figure 1 shows the changes in the perceived intensity over the course of the experiment for both the healthy- and hazardous-description groups.

Preference level

We performed a two-tailed t -test on the preference values and found a significant difference between the 2 groups ($t_{18} = 2.46$, $P < 0.05$). The preference profile of the odor stimulus obtained by introspective reports is shown in Figure 2. To create Figure 2, the preference values were mathematically transformed from “ -3 to $+3$ ” into “ -100 to $+100$ ” only to make the visual comparison between the preference results of Experiment 1 and Experiment 2 more comprehensive, as we introduced a visual analogue scale (VAS) (-100 , extremely unpleasant; $+100$, extremely pleasant) in Experiment 2 to allow more precise preference ratings.

Discussion

In Experiment 1, we presented the anethole odor continuously and told the participants to breathe freely during the session, such that peripheral receptors were continuously stimulated by the odor. No significant difference was found between the healthy- and hazardous-description groups in perceived intensity. During the continuous method, peripheral receptors were always exposed to the odor stimulus. The participants may have adapted to the odor stimulus such that the cognitive effects on perceived intensity were less prominent than individual variability. On the other hand, there was a significant difference between the 2 groups in terms of preference level. The hazardous-description group regarded the odor as more unpleasant than the healthy-description group.

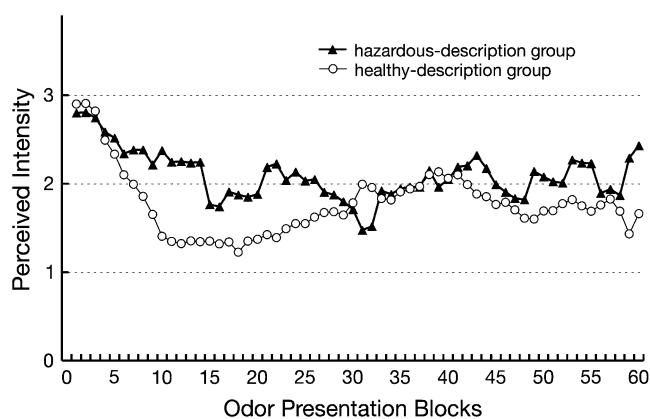


Figure 1 The perceived intensity of the healthy- and hazardous-description groups in Experiment 1 (continuous presentation). The participants were presented with odor stimuli continuously for 20 min. The ordinate represents perceived intensity from 0 (no odor) to 5 (extremely strong odor). The abscissa represents odor presentation blocks. Each triangle/circle represents the maximum perceived intensity within every 20-s block such that there are 60 maximum perceived intensity values per session.

Our tests detected a significant main effect of presentation. We performed post hoc tests for the factor presentation but did not find any significant differences between 1770 pairs of intensity values for 60 odor presentation blocks. According to Figure 1, however, the participants in both the healthy- and hazardous-description groups may have adapted/habituated to the odor soon after the start of continuous odor presentation. The superficial inconsistency between the statistical analysis and what is seen in Figure 1 may be due to individual variability in odor adaptation/habituation, as reported in previous studies (Saito, Iio, et al. 2004; Saito, Kobayakawa, et al. 2004).

Thus, we demonstrated an effect of odor description (healthy or hazardous) on preference level but not on perceived intensity. It was then crucial to investigate whether more salient cognitive effects on perceived intensity could be detected using an intermittent presentation method.

Experiment 2: the intermittent presentation method

In Experiment 2, we tried to strictly control the stimulus presentation methods, as well as the respiration method, to reduce stagnation of the odor stimulus on peripheral receptors, in order to focus more specifically the cognitive effects on olfactory perception of the adaptation/habituation processes.

Materials and methods

Participants

The participants in this experiment comprised 27 females and 6 males. The mean age was 34.42 years (SD = 10.21). No participants had impaired senses of smell, as confirmed

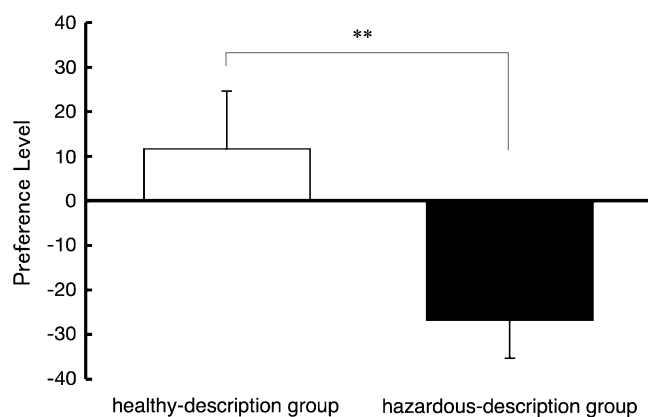


Figure 2 The preference level of the healthy- and hazardous-description groups in Experiment 1 (continuous presentation). Participants in the hazardous-description group regarded the odor as more unpleasant than did those in the healthy-description group. $**P < 0.01$. Vertical bars represent standard error of the mean.

by a stick-type odor identification test (Saito et al. 2006) prior to the experiment.

Stimulus presentation methods

The odor stimulus (anethole) was identical to that used in Experiment 1. The apparatus was a Kobal olfactometer (Kobal 1985; Kobal and Hummel 1988; Hummel and Kobal 1999). As described previously, we strictly controlled the stimulus presentation in Experiment 2. The concentration of anethole was adjusted in this short-duration intermittent stimulus presentation method to be comparable to that used in Experiment 1. Five milliliters of gas, made by bubbling a 100% anethole solution, was diluted with 1 l of air. The flow rate used in the experiment was 3.9 l/min, and the stimuli temperature was adjusted to 40 °C. The stimulus was presented to the left nostril only for 0.2 s at 14.8-s intervals 15 times per session for 4 sessions, for a total of 60 stimulus presentations. Furthermore, participants were required to breathe only by mouth, with closed velopharyngea, to avoid variations in perceived intensity due to breathing. A 3-min interval (intersession interval) was interposed between each session. This intermittent presentation scheme was used to minimize stagnation of the odor at the peripheral (receptor) level. During the intersession interval, the same monitor displayed a movie intended for infants, the content of which was irrelevant to the experiment. In order to remove the odor stimuli immediately after presentation, we placed an aspirating tube carrying twice the purge volume of the stimulus flow volume 5 mm below the nostril receiving the stimuli. During the experiment, white noise was presented through a speaker so that the participants would not hear the sound generated by the olfactometer solenoid valve when switching between the odorless air and the odor stimulus. The overall stimulus presentation procedure in Experiment 2 is shown in Figure 3.

Perceived intensity evaluation

Evaluation of perceived intensity was performed identically to Experiment 1, except that we set a perceived intensity evaluation monitor 1.5 m in front of the participant because the

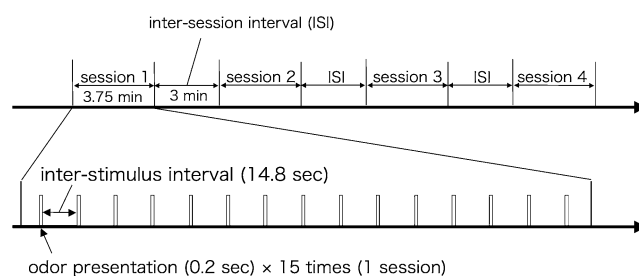


Figure 3 A schematic illustration of odor presentation in Experiment 2. The stimulus was presented to the left nostril for 0.2 s at 14.8-s intervals 15 times per session for 4 sessions, for a total of 60 presentations. A 3-min break (intersession interval) was interposed between each session to further reduce the influence of adaptation at the peripheral (receptor) level.

participants were not able to move their faces due to the aspirating tube attached below the nostril. On the monitor, the numbers 0–5 were marked at regular intervals along a 25-cm horizontal line and the label no odor was placed beneath the line at the left end (0) and the label extremely strong was placed beneath the line at the right end (5). The participants performed a continuous evaluation of the odor stimulus in real time by holding the slide lever and watching the monitor. The perceived intensity data were sampled and recorded automatically every 50 ms.

In evaluating intensity, nearly all participants produced a steep upward curve immediately following each stimulus presentation, followed by a downward curve toward intensity zero, and the intensity values remained at zero until the next odor presentation. We therefore used the maximum perceived intensity value obtained after each stimulus presentation because the maximum value was likely to represent the participants' perceived intensity evaluation for each odor presentation.

Procedure

The general procedure in Experiment 2 was identical to that of the Experiment 1, except for the following. Before the experiment, participants were trained to breathe solely by mouth. After sufficient training, the participants were randomly divided into 2 groups: a healthy-description group (12 females and 3 males participants) and a hazardous-description group (15 female and 3 male participants). Immediately before beginning the experiment, we described the odor to each group using group-congruent descriptions.

To accustom the participant to the experimental conditions and the operation of the evaluation equipment, they were presented with the odor stimuli 5 times. During this process, the participants were asked to evaluate the perceived intensity in real time. After the experimenter confirmed that the participants were able to perform the perceived intensity evaluations, the odor stimuli were presented. The odor stimuli were presented 15 times per session for 4 sessions for a total of 60 presentations. During this period, the participants evaluated the perceived intensity in real time, as in the training.

After the last odor presentation session was completed, odor preference level was evaluated on a VAS (–100, extremely unpleasant; +100, extremely pleasant), as described in the Results section of Experiment 1. At this point, we confirmed that the participants were correctly breathing through their mouths.

Statistical analysis

The procedures for statistical analysis were identical to those in Experiment 1. In addition, we compared differences in the average values of perceived intensity between the healthy- and hazardous-description groups in the first 2 sessions and the last 2 sessions using a two-tailed *t*-test. More details are described in “Change in perceived intensity due to description conditions.”

Results

Difference in perceived intensity due to description conditions

According to the perceived intensity evaluation, participants in the hazardous-description group perceived the odor as more intense than those in the healthy-description group. The 2-way ANOVA for description versus presentation revealed that the main effect of description ($F_{1,31} = 4.55$, $P < 0.05$) and the main effect of presentation ($F_{59,1829} = 2.57$, $P < 0.01$) were both significant. However, further post hoc tests for the factor presentation by multiple comparisons by Tukey's HSD method revealed no significant differences between 1770 comparative pairs among 60 odor presentations. The interaction of the description and the presentation was not significant ($F_{59,1829} = 2.31$, NS). Figure 4 shows changes in perceived intensity over the course of the experiment for both the healthy- and hazardous-description groups.

Change in perceived intensity due to description conditions

Because the interaction between description and presentation was not significant, we calculated the difference in average values of the perceived intensity between the healthy- and hazardous-description groups in the first 2 sessions (30 odor presentations) and the last 2 sessions (30 odor presentations) for each presentation. We then compared the differential values for the stimulus presentations in the first versus the latter sessions by a two-tailed *t*-test and found that the differential values between the healthy- and hazardous-description groups were significantly greater in the last 2 sessions than in the first 2 sessions ($t_{29} = 3.68$, $P < 0.01$) (Figure 5).

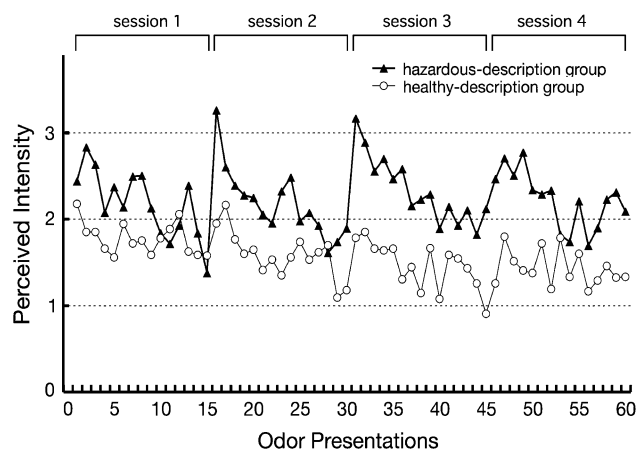


Figure 4 The perceived intensity of the healthy- and hazardous-description groups in Experiment 2 (intermittent presentation). The participants evaluated the intensity of anethole 60 times, and the maximum perceived intensity evaluation values obtained after each stimulus presentation are shown.

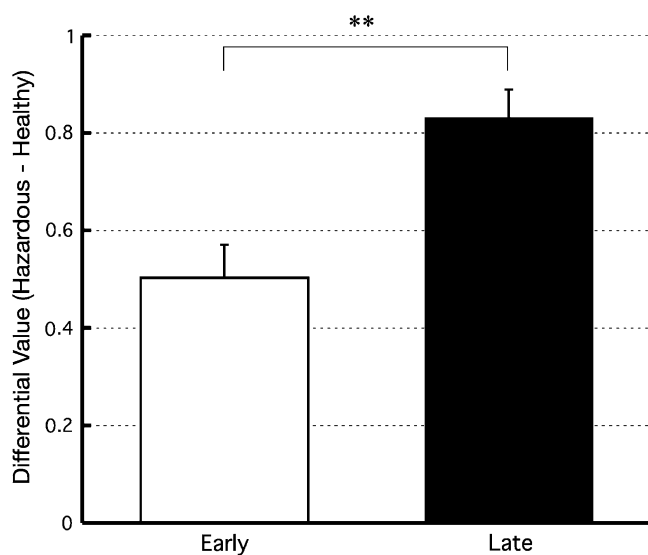


Figure 5 Differences in perceived odor intensity between the healthy- and hazardous-description groups in Experiment 2 (intermittent presentation). Vertical bars represent standard error of the mean. "Early" (left) represents the first 2 sessions (30 odor presentations), and "Late" (right) represents the final 2 sessions (30 odor presentations). $**P < 0.01$.

Preference level

We performed a two-tailed *t*-test on the preference value and found a significant difference between the 2 groups ($t_{31} = 3.74$, $P < 0.01$). The preference profile of the odor stimulus obtained by introspection report is shown in Figure 6.

Discussion

In order to study cognitive effects on the perceived intensity of odors and its change over time, we developed an experimental paradigm that minimized stagnation of an odor stimulus on the peripheral odor receptors (receptor level) by presenting short-duration pulses of intermittent odor stimuli, removing the stimuli immediately after presentation, and training all participants to breathe solely by mouth. We found significant differences between the healthy- and hazardous-description groups both in perceived intensity and preference level, suggesting that participants in the hazardous-description group perceived the odor as more intense and as more unpleasant than did those in the healthy-description group. Furthermore, the difference in the perceived intensity was larger in the last 2 sessions. Thus, with the intermittent presentation method, the cognitive effects of description were more salient than those obtained by the continuous method.

We detected a significant main effect of presentation. We performed post hoc tests for factor presentation but did not find any significant differences between 1770 pairs of the intensity values for 60 odor presentations. According to Figure 4, however, the participants in both the healthy- and hazardous-description groups may have adapted/habituated

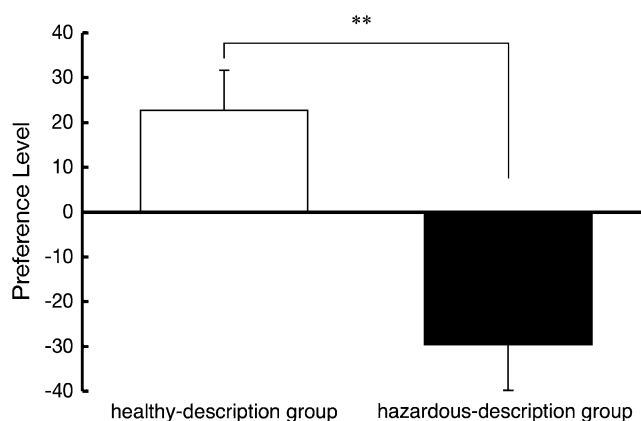


Figure 6 The preference level of the healthy- and hazardous-description groups in Experiment 2 (intermittent presentation). Participants in the hazardous-description group regarded the odor as more unpleasant than did those in the healthy-description group. $**P < 0.01$. Vertical bars represent standard error of the mean.

to the odor within each session but recovered from the adaptation/habituation during the 3-min recess interposed between the sessions. This superficial inconsistency in perceived intensity, as seen in Experiment 1, may also be due to individual variability in odor adaptation/habituation, as reported in previous studies (Saito, Iio, et al. 2004; Saito, Kobayakawa, et al. 2004).

General discussion

The continuous and intermittent odor presentation methods

In this study, we investigated the effect of an odor's description (healthy or hazardous) on odor perception using both continuous and intermittent presentation methods. In this study, the continuous method represents a relatively natural state with free respiration and continuous odor presentation, whereas the intermittent method utilizes a controlled state in which the odor presentation and respiration method were both strictly controlled to avoid the continuous stimulation of peripheral receptors with the odor. In Experiment 1, we continuously presented the anethole odor to participants who were breathing freely, thus stimulating the peripheral receptors for the duration of the trial, and detected no significant difference in perceived intensity between the healthy- and hazardous-description groups. With such methods, the peripheral receptors likely exhibit considerable adaptation to the odor, such that the effect of description on the perceived intensity was statistically undetectable and not significant relative to individual variability.

This result appears to conflict with previous findings (Dalton 1996; Dalton et al. 1997). Here, a comparison between the previous study (Dalton 1996) and the current study should be made carefully, taking note of the statistical analysis results. The previous studies did not find a significance effect of group (description: healthy/hazardous in the current

study). Dalton (1996) performed a 2-way ANOVA on the intensity ratings as a function of exposure time and description group, and the study did not detect a main effect for the group (description) but did detect a main effect for time (presentation in the current study) and a significant interaction between time (presentation) and group (description). In Experiment 1 of the current study, the main effect of presentation was significant, whereas the main effect of description and the interaction between description and presentation were not significant. We assume that the effect of description (healthy/hazardous) was not strong enough to have a statistically significant effect on the perceived intensity, which would be compatible with the lack of main effect of group (description) seen previously. One apparent difference in statistical analysis between the previous study and ours lies in the interaction between time (presentation) and group (description). Dalton found a significant interaction between presentation and description as described above, indicating that the hazardous-description group did not adapt/habituate to the odor, whereas the healthy-description group did. This finding is important in showing a significant effect of description on perceived intensity. However, the report by Dalton did not study the simple main effect after determining the significant interaction. The analysis of simple main effects is of critical importance in showing significant differences between the healthy- and the hazardous-description groups. Thus, it is difficult to closely contrast the results of these 2 studies, though the procedural differences between the 2 studies can be examined. First, we used the odor stimulus anethole, which is unfamiliar to most Japanese people, whereas the odor used in Dalton's study was isobornyl acetate, which is a known flavoring agent in toiletries and soaps. Perceived intensity evaluation has been shown to vary according to the odor stimulus (Dalton et al. 1997; Dalton 2002; Smeets and Dalton 2002; Smeets et al. 2002), indicating that the intensity is also influenced by preexisting familiarity. Second, in the perceived intensity evaluation, the current study employed a continuous rating method, whereas the study by Dalton prompted participants to make ratings every minute. The real-time evaluation system in the current study did not distract subjects from the odor stimulus, whereas occasional ratings may have disturbed their focus on the odor stimulus. These 2 procedural differences may account for the inconsistency between the current study and the previous study (Dalton 1996).

Another study (Dalton et al. 1997) also failed to find a significant effect of group (description) using different odor stimuli (acetone and phenylethyl alcohol), though the effect was close to the level of significance ($P < 0.07$). Thus, no statistically significant effect of description (cognitive bias) on perceived intensity was found, as in previous reports, upon careful examination of statistical analyses (Dalton 1996; Dalton et al. 1997). This indicates a general difficulty in detecting significant cognitive effects on perceived intensity using the continuous presentation method.

In Experiment 2, on the other hand, we found that participants reported a stronger intensity of the anethole odor when it had been described as hazardous rather than healthy. Furthermore, the perceived intensity of the odor remained higher for the hazardous-description group throughout the experiment and the difference in perceived intensity between groups increased in significance during the later sessions.

These results demonstrate that when an unfamiliar odor is described as hazardous and then presented in short intermittent bursts, it is perceived as more intense and adaptation/habituation to it occurs more slowly. Because the intermittent presentation method minimizes peripheral stagnation of the odor stimulus, this cognitive effect on perceived intensity is likely mediated by central mechanisms.

Preference level

When asked to rate the preference level for the anethole odor in this study, participants in both Experiments 1 and 2 behaved very differently depending on whether the odor had been described as healthy or hazardous. This suggests that, relative to perceived intensity, preference rating is a measure that is easily influenced by cognitive biases, at least under certain experimental conditions as in the current study.

The fact that the same odor stimulus elicited such differences in perception reflects a significant influence of cognitive effects on olfactory perception. The fact that we used an unfamiliar odor stimulus probably contributed to the significant effect described above. The familiarity of an odor is strikingly culture dependent. This study clearly shows that when presented with an unfamiliar odor, the qualitative response of a participant to the odor depends tremendously on prior, non-odor-related information given to them about the odorant. For our experiment, in which we needed to provide distinct nonolfactory descriptions of a stimulus against a completely naive background, it was crucial to avoid any preconceptions regarding the odor stimulus. Because the odor of anethole is "typically European" and not familiar to Japanese people (Ayabe-Kanamura et al. 1998; Distel et al. 1999) and the percentage of people who can identify the substance is assumed to be low, we believed it to be a suitable stimulus. Familiar odors are accompanied by the experience and memory of the participant, and many studies have indicated the importance of preexisting knowledge, perceived risks, biases, and exposure history in odor perception (Dalton et al. 1997; Dalton 2002; Smeets and Dalton 2002, 2005; Smeets et al. 2002). Although an experimenter can attempt to manipulate the cognitive associations of an odor stimulus by providing descriptions of the odorant, the influence of prior experience of the participants cannot be avoided. In our experiment, we provided descriptions that were carefully constructed so as not to be affected by the participants' preconceptions, even if they were in fact familiar with the odor. We stated that the chemical structure of the odorant was quite

similar to that of anethole but that its perceptual and physiological effects are quite different. Our use of a relatively unfamiliar odorant allowed us to gauge the effects of our cognitive manipulations upon a relatively clean background.

Advantages of the intermittent method

Differences in adaptation to an odorant may arise from differences in the physical and chemical characteristics of the odorant itself or from differences in perineural clearance mechanisms, such as blood flow in the submucosal tissues in the nostril, clearance by the nostril mucosal cilia, and removal by exhalation (Dalton 2000). To study the influence of cognitive effects on the odor stimulus, it was necessary to control these peripheral factors. We achieved this in Experiment 2 by a short-duration, intermittent stimulus presentation method, as well as respiration control, to reduce the load to the periphery. Hummel and Kobal (1999) demonstrated that perceived intensity of odorant stimuli decreases when the stimulation intervals are shorter than 40 s. We expected “changes” in perceived intensity in the process of adaptation/habituation, so the interstimulus interval needed to be shorter than 40 s. Changes in perceived intensity may result from both peripheral and central processes, so we decreased the former (peripheral) process. Furthermore, we attempted to reduce participants’ physical/mental fatigue by making the session duration as short as possible in the restricted experimental setting and set the interstimulus interval to 14.8 s and the intersession interval to 3 min. One complication with analyzing olfactory stimuli is that they continue to stimulate receptors even after removal (Dalton 2000). In order to minimize this complication, we placed an aspiration tube below the nostril to promote prompt removal of the odor stimulus. This stimulus protocol, especially compared with the long-duration stimuli employed previously and in Experiment 1, minimized persistent peripheral activation and enabled the analysis of central processes in relative isolation.

We did not statistically contrast the results using the continuous and intermittent presentation methods, making it difficult to contrast these 2 methods directly. However, we considered it inappropriate to include the presentation method as an experimental factor because differences between the 2 experiments are present not only in the presentation method (continuous vs. intermittent) but also in other elements that are not addressed by this study (e.g., the position where the odor was presented, the varying times that the 2 experiments took place, and the three 3-min recesses in Experiment 2 but not in Experiment 1). Furthermore, our primary focus was to find a significant difference in perceived intensity due to the description alone. Therefore, we first confirmed in Experiment 1 (using the continuous method) that it is difficult to detect a significant effect of description on the perceived intensity in a relatively natural state where the odor was presented continuously and the participants were able to breathe freely. We subsequently found in Exper-

iment 2 (using the intermittent method) that a significant effect of description on the perceived intensity could be detected under a controlled environment where stagnation of the odor around peripheral receptors was minimized.

Although there is currently no means to examine peripheral and central processes in perfect isolation, we believe that the current study design permitted us to conclude that the differences in perceived intensity in adaptation/habituation of the olfactory response between the healthy- and hazardous-description groups reflects central processes.

Funding

The Experimental Research Budget for Pollution Prevention and National Environmental Conservation.

Acknowledgements

The authors are grateful to Sandra C. A. Vermeulen for her valuable comments on this manuscript.

References

- Ayabe-Kanamura S, Schicker I, Laska M, Hudson R, Distel H, Kobayakawa T, Saito S. 1998. Differences in perception of everyday odors: a Japanese-German cross-cultural study. *Chem Senses*. 23:31–38.
- Berglund U. 1974. Dynamic properties of the olfactory system. *Ann N Y Acad Sci*. 237:17–27.
- Cain WS. 1974. Perception of odor intensity and the time-course of olfactory adaptation. *ASHRAE Trans*. 80:53–75.
- Dalton P. 1996. Odor perception and beliefs about risk. *Chem Senses*. 4:447–458.
- Dalton P. 2000. Psychophysical and behavioral characteristics of olfactory adaptation. *Chem Senses*. 25:487–492.
- Dalton P. 2002. Odor, irritation and perception of health risk. *Int Arch Occup Environ Health*. 75:283–290.
- Dalton P, Wysocki CJ, Brody MJ, Lwley HJ. 1997. The influence of cognitive bias on the perceived odor irritation and health symptoms from chemical exposure. *Int Arch Occup Environ Health*. 69:407–417.
- Distel H, Ayabe-Kanamura S, Martinez-Gomez M, Schicker I, Kobayakawa T, Saito S, Hudson R. 1999. Perception of everyday odors—correlation between intensity, familiarity and strength of hedonic judgement. *Chem Senses*. 24:191–199.
- Ekman G, Berglund B, Berglund V, Lindval T. 1967. Perceived intensity of odor as a function of time of adaptation. *Scand J Psychol*. 8:177–186.
- Hummel T, Kobal G. 1999. Chemosensory event-related potentials to trigeminal stimuli change in relation to the interval between repetitive stimulation of the nasal mucosa. *Eur Arch Otorhinolaryngol*. 256:16–21.
- Kobal G. 1985. Pain-related electrical potentials of the human nasal mucosa elicited by chemical stimulation. *Pain*. 22:151–163.
- Kobal G, Hummel T. 1988. Olfaction: chemosensory evoked potentials in patients with olfactory disturbances. *Rhinology*. 26 (suppl):1–18.
- Saito S, Ayabe-Kanamura S, Takashima Y, Gotow N, Nito N, Nozawa T, Mise M, Deguchi Y, Kobayakawa T. 2006. Development of a smell identification test using a novel stick-type odor presentation kit. *Chem Senses*. 31:379–391.

- Saito S, Iio K, Kobayakawa T, Gotow N. 2004. Variation in intensity curves during odor exposure. *J Jpn Assoc Odor Environ.* 35:17–21. [in Japanese].
- Saito S, Kobayakawa T, Gotow N, Iio K. 2004. Variety of time intensity curves during offensive odor exposure and its relation with perceptual and cognitive aspects. *ECRO Congr.* p. 107. [abstract].
- Sekine M, Saito S, Iio S. 1995. Response properties of metal-oxide-semiconductor gas sensor to odor presented continuously. *J Odor Res Eng.* 26:122–127. [in Japanese].
- Smeets M, Dalton P. 2002. Perceived odor and irritation of isopropanol: a comparison between naive controls and occupationally exposed workers. *Int Arch Occup Environ Health.* 75:541–548.
- Smeets M, Dalton P. 2005. Evaluating the human response to chemicals: odor, irritation and non-sensory factors. *Environ Toxicol Pharmacol.* 19:581–588.
- Smeets M, Maute C, Dalton P. 2002. Acute sensory irritation from exposure to isopropanol (2-propanol) at TLV in workers and controls: objective versus subjective effects. *Ann Occup Hyg.* 46:359–373.

Accepted October 11, 2007