# Effective Presentation Technique of Scent Using Small Ejection Quantities of Odor

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## ABSTRACT

Trials on the transmission of olfactory information together with audio/visual information are currently underway. However, a problem exists in that continuous emission of scent leaves scent in the air causing human olfactory adaptation. To resolve this problem, we aimed at minimizing the quantity of scent ejected using an ink-jet olfactory display developed. Following the development of a breath sensor for breath synchronization, we next developed an olfactory ejection system to present scent on each inspiration. We then measured human olfactory characteristics in order to determine the most suitable method for presenting scent on an inspiration. Experiments revealed that the intensity of scent perceived by the user was altered by differences in the presentation method even when the quantity of scent was unchanged. We present here a method of odor presentation that most effectively minimizes the ejection quantities.

**Keywords:** Olfactory information, Human Olfactory Characteristics, olfactory display, ink-jet, pulse ejection, breath sensor

**Index Terms:** H5.2 [INFORMATION INTERFACES AND PRESENTATION]: User Interfaces—User-centered design ; H.1.2 [MODELS AND PRINCIPLES]: User/Machine Systems—Human factors

## 1 INTRODUCTION

Information transmission and communication tends to be limited to visual information and audio information. However, transmission of information via all five senses (sight, hearing, touch, smell and taste) has lately attracted much attention [1, 2]. Olfactory information recognized by the olfactory organs differs from the information recognized via the other four senses. The sense of smell powerfully affects humans since olfactory information is directly transmitted to the cerebral limbic system that governs emotions. Although the information we receive through the nose is much less than that through the eyes or ears, olfactory information has a major influence on how we feel [3]. For example, feelings are intensified by adding olfactory information to images and sound. Therefore, olfactory information is expected to further enrich communication media. However, problems exist in the amount of scent emitted to enhance the multimedia experience; too much scent emitted over a continuous period leaves scent in the air and causes human adaptation to the scent. Thus the goal of transmission of olfactory information is not reflected in the actual human response. To resolve this problem, we aimed at reducing the ejection quantity of scent as much as possible.

First, we developed an olfactory ejection system to present scent on each inspiration. When humans breathe in, they inhale smell molecules in the air. When a smell molecule binds to a receptor organ in the nose, we detect a scent. Therefore, the emission of scent can be perceived only on inspiration, and not on expiration and scent molecules are left in the air. By using the olfactory ejection system, we reduced the ejection quantity of scent on each expiration. We next measured human olfactory characteristics in order to determine the most suitable method for presenting scent on an inspiration. Experiments revealed that the intensity of scent perceived by the user was altered by differences in the presentation method even when the quantity of scent was unchanged. Therefore, we determined the optimal conditions of the presentation method for minimizing ejection quantity of odor. This study reports the presentation method which most effectively provides odor in small ejection quantities while maintaining continuous perception of odor.

## 2 RELATED WORK

Trials on the transmission of olfactory information together with audio/visual information are currently being conducted. Work first started in the 1950s when Heilig developed Sensorama [4], the first virtual reality (VR) system that presented olfactory information together with audio/visual information. The recently developed virtual space system, Friend Park [5], provides users with an increased sense of reality by generating the aroma of a virtual object or environment, where the aroma is defined as the area in which a scent can be perceived. Kaye's article [6] describes some systems that add scent to web content, and computer controlled olfactory displays such as iSmell [7] and Osmooze [8] are utilized in these systems. Another type of display, the air cannon olfactory display that generates toroidal vortices of scent in order to present it in restricted space, has been proposed in [9].

Nakamoto et al. [10] designed a smell synthesis device that presents the scent of a virtual object remotely. The system analyzes the smell to be transmitted and presents the analyzed data as the composition ratio of the scent elements. On the receiver side, a feedback control changes the ratio of the scent elements owned by the receiver to reproduce the target scent.

A wearable olfactory display with a position sensor has also been developed [11]. By controlling the density of odor molecules, it can present the spatiality of olfaction in an outdoor environment. The olfactory information transmitting system consists of the aforementioned display, a sensing system using three gas sensors, and matching database. The user can experience a real sense of smell through the system by translating obtained olfactory information.

AROMA [12] tries to introduce the olfactory modality as a potential alternative to the visual and auditory modalities for messaging notifications. Experimental findings indicate that while the olfactory modality was less effective in delivering notifications than the other modalities, it had a less disruptive effect on user engagement in the primary task.

The addition of a scent to image media such as movies has been proposed by a number of researchers. Okada et al. [13] measured the viewer's mental state by his/her brainwaves, and analyzed the relation between the scent and the viewer's feelings while watching.

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## 3 CHARACTERISTICS OF OLFACTION

### 3.1 Olfactory Threshold

The olfactory threshold is the value used as a standard to express the strength and weakness of a scent. Three kinds of values are generally used for the olfactory threshold: the detection threshold, the recognition threshold, and the differential threshold [14], usually expressed in units of mol (concentration) and mass percentage.

The detection threshold is the smallest density at which scent can be detected and where the user does not need to recognize the kind of a smell. The recognition threshold is the smallest density at which the kind of scent can be recognized, and its value reflects the ability of the user to express quality and characteristics of the scent. The differential threshold is the density at which the user can distinguish the strength of a scent, where its value reflects the ability of the user to detect changes in the stimulus and to quantify the change. Generally such changes are expressed as the % change of stimulation quantity of the original. The differential threshold is around 1-2% in the case of light. and in the case of sounds is around 0.3% at 200Hz. In the case of olfaction, it differs with different kinds of scent, but is in the range of about 13-33%. But the threshold is a rough guide of the strength perceived by the user and cannot know the strength and weakness of how to feel about smells from this value.

### 3.2 Adaptation

Adaptation is the phenomenon where sensory nerve activity is decreased by continuous smell stimulation. Adaptation itself and the speed of recovery from adaptation differ with different kinds of scent. Adaptation is gradually strengthened over time but is dissipates over a short interval(3-5 minutes) by eliminating the scent.

In addition, there are various patterns of adaptation, influenced by the kind of scent and recognition factors.

### 3.3 Measurement of Adaptation

In 2003, Saito et al. [15] measured the strength of adaptation directly and found that the subject no longer continued to detect the smell when the smell was presented for a long time. When they classified the results of the measurement, adaptation could be divided into several patterns in relation to time dependence. They reported that strength of the smell decreased under the exponential function. When the ratio of each pattern of a participant was observed, the exponential function type was about 30%. For most patterns, subjects could once again detect a scent when the strength of smell was reduced. In addition, there were very few participants who consistently showed the same adaptation pattern, and individual participants did not always show the same adaptation pattern for the same smell. Such variety suggests that there exist factors influencing the recognition of different smells for each participant.

### 3.4 Olfaction and Breathing

Honma et al. [18] measured human air intake in a study of telemedicine. Air intake was found to decrease over time. Figure 1 shows the average air intake during human inspiration.

## 4 OUTLINE OF THE PROPOSED METHOD

When humans breathe in, they inhale smell molecules in the air. When a smell molecule binds to a receptor organ in the nose, we detect a scent. This is the recognition mechanism of a scent [16, 17]. Therefore, the emission of scent can be perceived only on inspiration, and not on expiration and scent molecules are left in the air. The conventional olfactory presentation method continues emitting scent at high densities for a long time. As such, this presentation method creates various problems of olfactory adaptation and scent lingering in the air. To overcome such issues, this study aimed at minimizing the quantity of scent ejected by realizing finely tuned control of the ejection of scent, and considering the olfactory characteristics of humans.

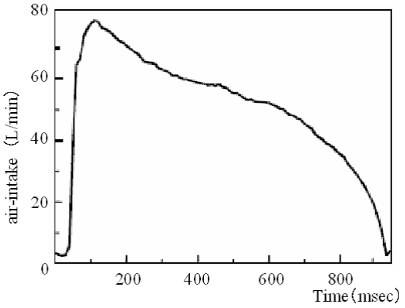


Figure 1: Change in air intake during inspiration over time

In order to realize such finely tuned control, first we developed an olfactory ejection system to present scent on each inspiration. We developed an ink-jet olfactory display that achieves high-precision emission control of scent by providing stable pulse emission of scents. The pulse ejection presented by this olfactory display emits scent for just a very short period of time. Kadowaki et al. showed that scent did not remain in the vicinity of the receiver when presented by such pulse ejection with the wind velocity above a certain level [19]. We then developed a breath sensor that could record breathing data in real time and detect the beginning of inspiration. We combined the breath sensor and the ink-jet olfactory display, and created an olfactory ejection system that presents scent on each inspiration.

We next determined a scent ejection method in a single breath cycle. Kadowaki et al. showed that the effect of adaptation was reduced by decreasing the quantity of scent available to breathe in [20]. For determining the most suitable method to present a scent in an inspiration, we must consider carefully the olfactory characteristics of humans in relation to pulse ejection. However, to date, as comparatively little information has emerged concerning such characteristics, we examined these characteristics. We determined whether the perceived intensity of scent was changed by altering the presentation method to the user in a condition where the quantity of scent available for breathing in is the same.

## 5 OLFACTORY PRESENTATION SYSTEM

### 5.1 Olfactory Display

The prototype olfactory display developed is shown in figure 2. This display is ink-jet in order to produce a jet which is broken into droplets from the small hole in the ink tank.

Figure 3 shows the olfactory display in ground plan. The display can set up 3 scent ejection heads. Since each head can store one large tank and 3 small tanks, the display can present, in total, 12 kinds of scents utilizing 3 large tanks and 9 small tanks. There are 255 minute holes in the head connected to the large tank and 127 in the head connected to the small tank. Moreover, the display can emit scent from multiple holes at 100 msec, so the ejection concentration is adaptable to 1-255 (large tank), 1-127 (small tank). We denote the average ejection quantity from each minute hole as the ”unit average ejection quantity (UAEQ),” and the number of minute holes emitting at 100 msec as ”the number of simultaneous ejections (NSE).”

The unit average ejection quantity from two tanks is 4.7 picoliters(pl) for lavender scent and 3.7 picoliters for lemon scent. We confirmed the quantity to be approximately constant without depending on the residual quantity of ink. In addition, the user can set the number of ejection times from one hole in 100 msec to 1-150 times, which we denote the ”volume”. In this study, we always set

Figure 2: Olfactory display

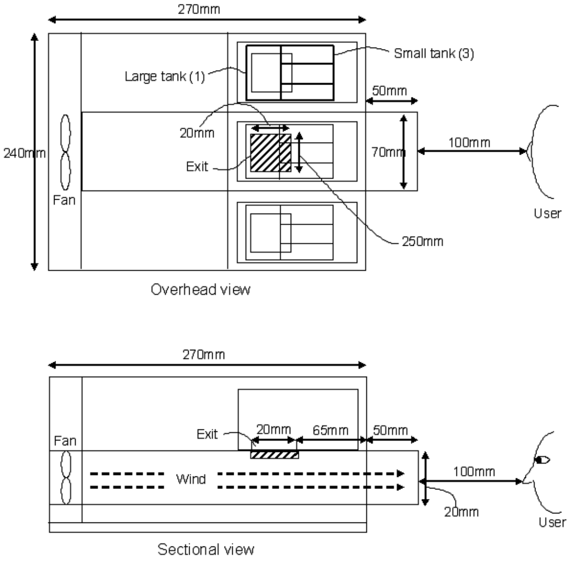


Figure 3: Plain view of the olfactory display

the volume to 150 times. Therefore, the ejection quantity in 100 msec (EQ) is calculated as follows.

$$EQ\ (pl/100msec) = 4.7or3.7\ (pl : UAEQ) \times 1 - 255\ (NSE) \times 150\ (times : Volume) \quad (1)$$

The scent is diluted by 5% with ethanol and water.

$$Scent\ quantity\ (pl/100msec) = EQ\ (pl/100msec) \times 0.05 \quad (2)$$

Ejection control is possible for a unit of 100 msec. To ensure there is no delay, ejection continuance time is more than 100 msec and the ejection interval time is more than 100 msec. Also, the display is equipped with a fan and there are 10 phases of wind velocity control in the range of 0.8 m/sec-1.8 m/sec. The scent presentation hole is a rectangle of 2 cm length and 24 cm width.

Figure 4 is a photograph showing the factory display. The user places the chin on the chin rest, fixing the distance from the olfactory ejection point to the nose at 225 mm.

Figure 4: Use of the olfactory display

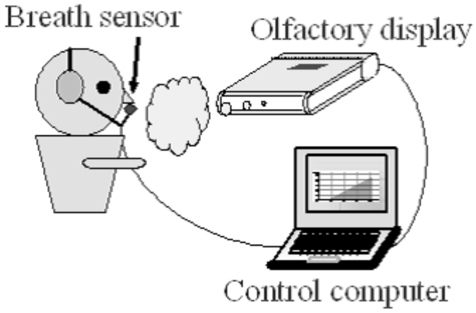


Figure 5: Olfactory ejection system synchronized with breathing

### 5.2 Olfactory Ejection with Breathing Synchronization

As mentioned above, when we inhale, we detect scent molecules. To match the timing of pulse ejection with breathing, we developed an olfactory ejection system that synchronized with breathing. Figure 5 shows a schematic of the system.

The user wearing a breath sensor sits in front of the olfactory display and is presented with scent. The system acquires the user's breath data by the breath sensor and transfers the value to a control computer. The control computer runs a program to monitor breath data constantly and to detect the beginning of inspiration. At the point the program judges the beginning of inspiration, a signal of scent presentation is sent to the olfactory display, which then presents scent to the user. The above represents the process of smell presentation by the olfactory ejection system.

The breath sensor (Figure 6) we developed acquires breath information by sensing temperature change in air breathed through the nose. The temperature detection element is the NTC (Negative Temperature Coefficient) thermistor. An Op-Amp amplifies each sensing data, an A/D converter converts it to a digital signal, and the value is transferred to a computer. The NTC thermistor is widely used as a temperature detection element and has a negative temperature characteristic that resistance falls when temperature rises.

The data transfer rate of the output voltage level acquired from the breath sensor is 10 sample/sec and the analysis software "TracerDAQ" records the data. Figure 7 shows a wave pattern of the recorded breath data from which the beginning of inspiration is detected. Since temperature of a thermistor falls when air flows due to inspiration, the resistance and the output voltage fall. Conversely, the output voltage rises during expiration. Based on this behavior, the timing when the wave pattern of breath data begins to fall is judged as the beginning of inspiration.

Characteristics such as breathing intervals differ from person to person, and each user must therefore calibrate the breathing sensor before use.

Figure 6: Breath sensor

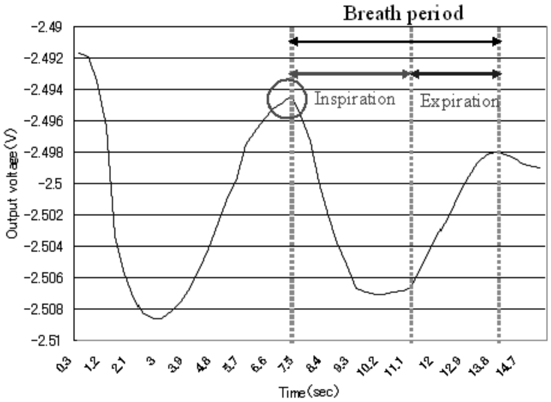


Figure 7: Breath data measured with the breath sensor

### 5.3 Experiment 1: System Verification Experiment

We verified whether the above olfactory ejection system detected inspiration and presented scent accurately. Twenty participants participated in the verification experiment.

In each experiment, the system monitored about 10 cycles of the participant's breath and presented scent at the beginning of each inspiration. Lavender scent was presented by pulse ejection. The ejection concentration was 50 of lavender scent. We asked participants to click a mouse button when they began to inhale. After the experiment, we compared the timing of scent presentation with that of clicking the mouse button. From the result we verified the performance of olfactory ejection system by judging whether the scent presentation was synchronized with the beginning of inspiration. Each participant performed this experiment two times.

We defined two following values and calculated them from the result of the verification experiment.

$$Detection\ rate\ (\%) = NSDC \div NPI \times 100 \tag{3}$$

$$\begin{aligned} False\ detection\ rate\ (\%) &= NSDW \div TNSD \\ &\quad \times 100 \end{aligned} \tag{4}$$

$NSDC$ : $Number\ of\ times\ system\ detected\ correctly$
$NPI$ : $Number\ of\ participant's\ inspiration$
$NSDW$ : $Number\ of\ times\ system\ detected\ wrongly$
$TNSD$ : $Total\ number\ of\ times\ system\ detected$

The detection rate of this system was 93.9%, and the false detection rate was 11.3%.

As a result, we confirmed that this olfactory presentation system could detect the beginning of inspiration with a probability of more than 90% and present scent synchronized with breathing. The detection rate is able to increase close to 100%, but the false detection rate increases with it at present. Because of this increase in the false detection rate, there is wasteful ejection and an excess quantity of scent is emitted. Depending on the purpose of system usage, it is necessary to adjust the balance between the detection rate and the false detection rate.

## 6 MEASUREMENT OF HUMAN OLFACTORY CHARACTERISTICS

### 6.1 Preliminary Experiment

#### 6.1.1 Detection Threshold

The experiment to determine the detection threshold was conducted using 100 msec pulse ejections of lavender scent and lemon scent with 14 participants. Olfactory ejection was synchronized with the timing of breathing of each participant. The participants were instructed to respond when they detected a scent. With the following pair comparison method [21], we measured the detection threshold of the scent. The olfactory display presented scented and unscented ejections to each participant, and we instructed the participant to indicate which of the two was the scented ejection. Ejection concentration was decreased until the participant selected the distractor. Two kinds of scent were emitted in turn in order to avoid the problem of adaptation which occurs when smelling the same scent successively.

As a result, the average detection threshold of 14 participants was an ejection concentration of 6.8 NSE(the number of simultaneous ejections) for lavender scent and of 8.2 NSE for lemon scent. Then the maximum detection threshold of 14 participants was an ejection concentration of 15 NSE for both scent. These findings reveal that all participants can detect a scent when the ejection concentration is set by more than 15(NSE).

#### 6.1.2 Effective Area in Inspiration

Our previous experiment confirmed that users cannot detect a scent at the end of inspiration. Therefore, it is necessary to examine the range of detection during inspiration to avoid wasteful olfactory ejection. Figure 8 shows how we determined a value to measure this experimentally. The limiting point is the latest time that the user can detect scent in the end phase of inspiration. The effective area is the time range between the start of inspiration and the limiting point.

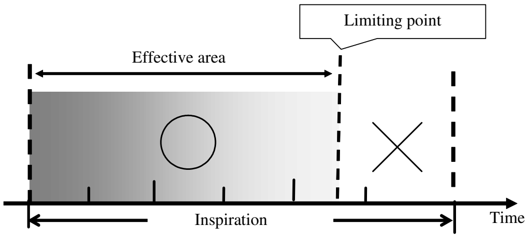


Figure 8: Effective area and limiting point

It is known that able-bodied people breathe about 12 times/min at rest. In breathing, the ratio of inspiration to expiration is 1 to 1.5 [22], meaning that they inhale for an average of 2 sec at rest. Therefore, we measured the effective area of 10 participants when they inhale for 2 sec. The breathing of the participants was regulated by sound cues to ensure inspiration time was 2 sec.

As a result, The average value of limiting point of the participants was 1.5 sec and the minimum value was 1.2 sec. These findings reveal that the scent ejected in the ranges from the start of inspiration to 1.2 sec was detected for all participants. The effective area therefore ranges from the start of inspiration to 1.2 sec.

### 6.1.3 Two-point Threshold in the Sense of Smell

When the two pulse ejection of scent is individually emitted in a single breath cycle as shown in Figure 9, humans can not discriminate the two individually emitted pulses of scent when the interval "$T_t$" of two pulse ejections is small. For example, when experiencing pain, when we touch two nearby points on the skin with an object with a sharp tip, at a certain distance we perceive the two points at just one location and beyond this point we perceive them at separate locations. In general, the minimum distance to perceive pain at two locations is defined as the two-point threshold, and refers to the perception of spatial distance. By the same token, the minimum interval time in which a subject could discriminate the two individually emitted pulses of scent was defined here as the two-point threshold in regard to the sense of smell and was measured.

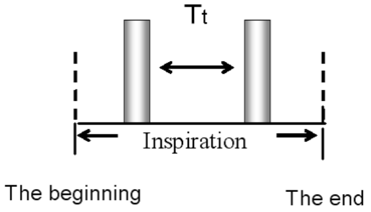


Figure 9: Two-point Threshold "$T_t$"

We measured the two-point threshold of 10 participants using lavender scent and lemon scent. The average two-point threshold of 10 participants was 1.1 sec for lavender scent and 1.0 sec for lemon scent. Then, the minimum two-point threshold of 10 participants was 0.6 sec for lavender scent and 0.8 sec for lemon scent. These findings reveal that when the interval time of two pulse ejections is within 0.6 sec, all participants feel the two pulse ejections as one ejection.

### 6.1.4 Deciding the Ejection Condition of Scent

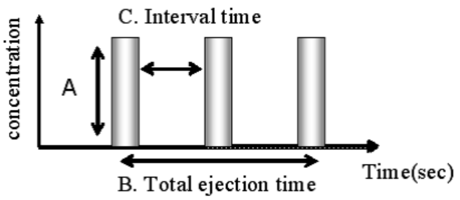


Figure 10: Ejection Condition of Scent

The preliminary experiments enabled us to decide the ejection condition of scent. In Figure 10, the x axis shows time, and the vertical axis shows concentration of ejection in 100 msec. The ejection concentration of Figure 10-A was set by more than 15(NSE). The total ejection time of Figure 10-B did not exceed 1.2 sec. And the interval time of two pulse ejections of Figure 10-C did not exceed 0.6 sec.

According to this ejection condition of scent, all scent presented was perceived and participants perceived just one ejection of scent.

## 6.2 Experiment 2: Same Quantity of Scent Available to Breathe in

In this experiment, we measured whether the perceived intensity of scent was changed by altering the presentation method of scent in a condition where the quantity of scent available to breathe in was the same. According to the ejection condition of scent, we developed four scent presentation methods for same quantity of scent in total, as shown in Figure 11. We compared the perceived intensity of lavender scent and lemon scent when presented by the four patterns of scent presentation.

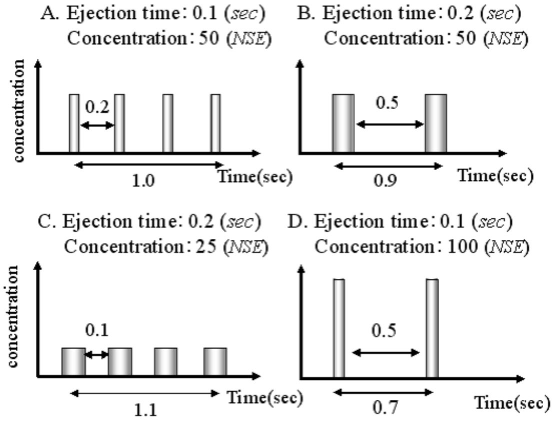


Figure 11: Four presentation methods of scent

However, participants likely cannot precisely judge the intensity of scent due to the influence of olfactory adaptation. For example, when we breathe in scent of the same density two times consecutively, we perceive the intensity of former scent to be stronger than that of the subsequent one. To account for such a effect, we used the pair comparison method [23], a basic measure of the human senses, and determined the perceived intensity of the four ejection pattern methods.

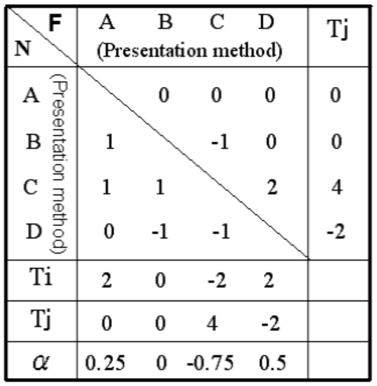
One trial was performed between two breaths. The breathing cycle of the participants was regulated by sound cues to ensure inspiration time was 2 sec and expiration time was 3 sec. Scent was presented for each of the four patterns in a random manner on the beginning of each of the two inspirations. The participants compared the intensity of former scent with that of next. The participants compared the intensity of scent for a combination (total 4*3=12) of the presentation method of the four patterns. The participants did not know which presentation method was being used, and rated the intensity of the two kinds of scent on a scale of -2 to +2, as shown in Table 1.

Table 1: Scores used for judgment of scent intensity

| Score | Judgment of the intensity |
|---|---|
| +2 | Former is considerably stronger than the next |
| +1 | Former is slightly stronger than the next |
| 0 | Intensity of the former is the same as that of the next |
| -1 | Former is slightly weaker than the next |
| -2 | Former is considerably weaker than the next |

Eight participants participated in a total of 24 trials for each combination of four presentation methods and kind of scent. Table 2 shows an example of the scores of the perceived intensity of lavender scent for the four presentation methods. For example, when participants perceived the scent from presentation method A before the scent from presentation method B, the intensity score was +1(Former is slightly stronger than the next). Conversely, when participants perceived the scent from presentation method C before the scent from presentation method D, the intensity score was -1(Former is slightly weaker than the next). For each the presenta-

Table 2: An example of the experimental result
(F:the former, N:the next)



| N \ F | A | B | C | D | Tj |
|---|---|---|---|---|---|
| | (Presentation method) | | | | |
| A (Presentation method) | | 0 | 0 | 0 | 0 |
| B | 1 | | -1 | 0 | 0 |
| C | 1 | 1 | | 2 | 4 |
| D | 0 | -1 | -1 | | -2 |
| Ti | 2 | 0 | -2 | 2 | |
| Tj | 0 | 0 | 4 | -2 | |
| $\alpha$ | 0.25 | 0 | -0.75 | 0.5 | |

tion method we calculated $T_i$ by summing the vertical row of scores and $T_j$ by summing the horizontal row of scores. $T_i$ denotes the intensity scores for the former of the two presentation methods. A high $T_i$ score reflects the participants perceived the scent presented by that method to be strong. Conversely, $T_j$ denotes the intensity scores for the second of the two presentation methods, and a low $T_j$ score reflects the participants perceived the scent presented by the method to be strong. The estimate scores "$\alpha$" of scent intensity were calculated as follows.

$$\alpha = (T_i - T_j) \div 8 \tag{5}$$

Table 3 shows average "$\alpha$" of the scent intensity for the four presentation methods.

Table 3: Average "$\alpha$" of the scent intensity for the four presentation methods

| Presentation method | A | B | C | D |
|---|---|---|---|---|
| lavender | 0.14 | -0.31 | -0.48 | 0.66 |
| lemon | 0.23 | -0.34 | -0.45 | 0.56 |
| average | 0.19 | -0.33 | -0.47 | 0.61 |

The results were analyzed using a two-way analysis of variance (ANOVA) (factor of kind of scent and factor of presentation method) and no significant differences were found for the main effect of kind of scent (F(1,7)=3.98, P>0.05). However, a significant different was found for the main effect of presentation method (F(3,7)=2.50, P<0.01). Tukey's HSD multiple comparison test (P<0.05) showed significant differences between presentation method D and the other methods(P<0.05), between presentation method A and the other methods(P<0.05). There was no significant difference between presentation methods B and C(P>0.05).

These results indicate that the perceived intensity of scent was changed by the presentation method even when the quantity of scent available for breathing in was the same. Ranking of the four methods presenting scent in terms of strength was as follows: D > A > B = C. Thus, we hypothesize the following to be features of those presentation methods that were judged to produce strong scent.

- Concentration of pulse ejection
- Number of pulse ejections

We next measured each of these factors, and determined the optimal conditions of the presentation method for minimizing ejection quantity of odor while being continuously perceived.

### 6.2.1 Experiment 3: Concentration of pulse ejection

The experiment described in Section 6.2 revealed that in the perceived intensity of scent there were significant differences between three presentation methods, D, A, and C. We therefore assume that differences in the concentration of pulse ejection in 100 msec had the greatest effect on the perceived intensity of scent. Next, we developed four scent presentation methods that decreased the emitted concentration stepwise on a logarithmic scale, as shown in Figure 12. The quantity of the four scent presentation methods was kept the same, at was 240.

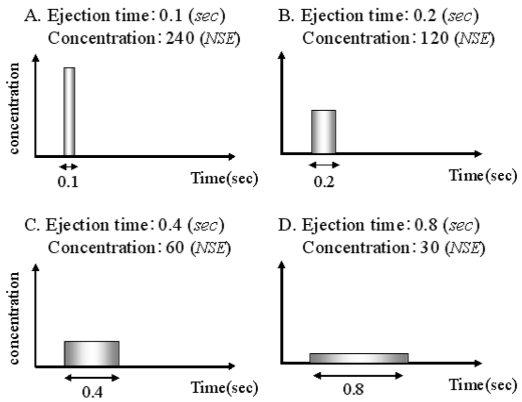


Figure 12: Concentration of pulse ejection

In an experimental method similar to that described in Section 6.2, using the pair comparison method we compared the perceived intensity of lavender scent and of lemon scent when presented by four patterns of scent presentation method. Participants rated the intensity of the two kinds of scent on a scale of -2 to +2, and the estimate scores "$\alpha$" of scent intensity were calculated. Table 4 shows the average "$\alpha$" for the 21 participants.

Table 4: Average "$\alpha$" of scent intensity for the four presentation methods varying concentration of pulse ejection

| Presentation method | A | B | C | D |
|---|---|---|---|---|
| lavender | 0.77 | 0.15 | -0.33 | -0.60 |
| lemon | 0.64 | 0.05 | -0.20 | -0.51 |
| average | 0.71 | 0.10 | -0.26 | -0.55 |

The results were analyzed using a two-way ANOVA (factor of kind of scent and factor of presentation method) and showed no significant differences for the main effect of kind of scent (F(1,20)=3.90, P>0.05). A significant difference was seen between the main effect of presentation method (F(3,20)=2.66, P<0.01). Tukey's HSD multiple comparison test (P<0.05) showed significant difference between all pairs (P<0.05).

For four presentation methods, the estimate scores "$\alpha$" of scent intensity decreased in a linear manner with a logarithmic decrease in the concentration of pulse ejection. These results indicate that the perceived intensity of scent was changed when the concentration of two pulse ejections differed by more than 30 (NSE).

### 6.2.2 Experiment 4: Number of pulse ejections

The experiment presented in Section 6.2.1 revealed that the perceived intensity of scent becomes stronger when the concentration of pulse ejection is increased above a constant value. In the experiment of Section 6.2, the perceived intensity of scent presented by method A was different from that presented by method B, while the concentration of pulse ejection of A was the same as of B. Therefore, the feature of concentration of pulse ejection of the presentation method was not the only feature influencing the perception of scent as strong.

Therefore, we assumed that differences in the number of pulse ejections had an effect the perceived intensity of scent. We developed three scent presentation methods which varied the number of ejections between 1, 2 and 4, as shown in Figure 13. The quantity of scent used for all three scent presentation methods was the same, at 200.

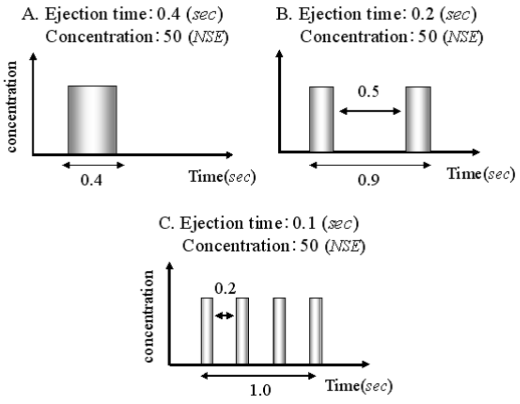


Figure 13: Number of pulse ejections

In an experimental method similar to that described in Section 6.2, using the pair comparison method we compared the perceived intensity of lavender scent and of lemon scent when presented by three patterns of scent presentation method. Participants rated the intensity of the two kinds of scent on a scale of -2 to +2, and the estimate scores ”$\alpha$” of scent intensity were calculated. Table 5 shows the average ”$\alpha$” for the 21 participants.

Table 5: Average ”$\alpha$” of scent intensity for the three methods varying number of pulse ejections

| Presentation method | A | B | C |
|---|---|---|---|
| lavender | -0.02 | -0.44 | 0.45 |
| lemon | 0.02 | -0.48 | 0.45 |
| average | 0 | -0.46 | 0.45 |

The results were analyzed using a two-way ANOVA (factor of kind of scent and factor of presentation method) and showed no significant differences for the main effect of kind of scent (F(1,20)=3.92, P>0.05). A significant difference was seen between the main effect of presentation method (F(2,20)=3.07, P<0.01). Next, Tukey’s HSD multiple comparison test (P<0.05) showed a significant difference between A and B and C(P<0.05).

When the three presentation methods of scent at a quantity of 200 in total were ranked in order of strength as follows: C > A > B. But, each the number of pulse ejections was 4 and 1 and 2. This experiment revealed that the perceived intensity of scent was not related to the number of pulse ejections.

However, the perceived intensity of each scent was changed, while both the total quantity of scent available to breathe in and the concentration of pulse ejection remained the same. In the difference of the three presentation methods of scent, there was pulse ejection which occurred at around 0.3-0.7 sec from the start of inspiration. Thus, we hypothesize the following to be features of those presentation methods that were judged to produce strong scent.

- Timing of pulse ejection

We next measured this factor.

### 6.2.3 Experiment 5: Timing of pulse ejection

In the experiment of Section 6.2.2, the perceived intensity of each scent was changed, while both the total quantity of scent available to breathe in and the concentration of pulse ejection remained the same. However, the number of pulse ejections was found not to be a feature influencing the perception of scent. So, we measured the relation between the estimate scores ”$\alpha$” of scent intensity and the timing of pulse ejection.

As already mentioned, it is known that air intake decreases over time. So, we assumed that the difference in the timing for breathing in scent affected the perceived intensity of the scent. We developed four scent presentation methods that delayed the timing of pulse ejection (Ejection time : 0.1 sec, Concentration : 100 NSE) every 0.3 seconds on inspiration, as shown in Figure 14.

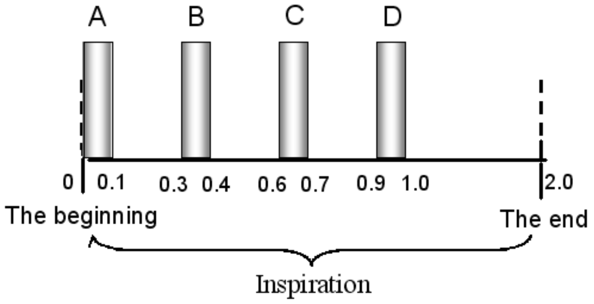


Figure 14: Timing of pulse ejection

In this experiment, the start time for breathing was accurately synchronized with the start time for pulse ejection using the breath sensor. In this experimental method, which is similar to that described in Section 6.2, the pair comparison method was used to compare the perceived intensity of lavender scent and lemon scent when presented by four patterns of scent presentation method. Participants rated the intensity of the two kinds of scent on a scale of -2 to +2, and the estimate scores ”$\alpha$” of scent intensity were calculated. Table 6 shows the average ”$\alpha$” for the 21 participants.

Table 6: Average ”$\alpha$” of scent intensity for four methods varying timing of scent ejection

| Presentation method | A | B | C | D |
|---|---|---|---|---|
| lavender | 0.09 | 0.43 | 0.01 | -0.54 |
| lemon | 0 | 0.45 | 0.04 | -0.47 |
| average | 0.04 | 0.44 | 0.02 | -0.50 |

The results were analyzed using a two-way ANOVA (factor of kind of scent and factor of presentation method) and showed no significant differences for the main effect of kind of scent (F(1,20)=3.90, P>0.05). They did show a significant difference between the main effect of presentation method (F(3,20)=2.66, P<0.01). Tukey’s HSD multiple comparison test (P<0.05) revealed no significant difference between A and C(P>0.05), but did show a significant difference between the other pairs (P<0.05).

These results revealed that the scent presented during 0.3-0.4 sec from the beginning of inspiration worked most effectively. The perceived intensity of scent presented during 0-0.1 sec was the same as that of scent presented during 0.6-0.7 sec, and that of scent presented during 0.9-1.0 sec was the weakest. Scent was perceived

125 msec after the start of presentation because the distance from the olfactory ejection point to the nose was fixed at 225 mm(Figure 3) and the wind velocity of olfactory display was set at 1.8 m/s. Thus, scent breathed in around 0.4-0.5 sec after the start of inspiration worked most effectively.

These experiment results enable us to explain the reason for the result of Section 6.2.2; the perceived intensity of the presentation method C was most strongest because the timing of pulse ejection occurred at 0.3-0.4 sec from the start of inspiration. Moreover, presentation method C presented scent during the first second and the interval of time between the two pulse ejections was very short. Therefore, the participants breathed in the scent around 0.4-0.5 sec even if the start time for breathing was not synchronized exactly with the start time for ejection (e.g., the participant breathed from 0.2 sec after ejection started). Conversely, the reasons for the perceived intensity of presentation method B being the weakest were that the timing of pulse ejection did not occur within 0.3-0.4 sec. In regard to the presentation method A, while the timing of pulse ejection occurred at 0.3-0.4 sec, total ejection time of presentation method A occurred within 0.4 sec and was very short. Therefore, it is thought that the lack of complete synchronization between the start time for inspiration and the start time for ejection did exert an influence.

## 7 CONCLUSION

In order to use olfactory information in multimedia, the disparities between its transmission and receipt must be overcome. This requires resolution of the problem of scent remaining in the air which results in adaptation. To overcome such issues, this study aimed at minimizing the quantity of scent ejected by realizing finely tuned control of the ejection of scent from one second to the next, and considering the olfactory characteristics of humans.

We built an olfactory ejection system developed that realizes high-precision emission control of scent by providing stable pulse emission of scents. The pulse ejection presented by this olfactory display emits scent for just a very short period of time. Then we developed a breath sensor that could record breathing data in real time and detect the beginning of inspiration. We combined the breath sensor and the ink-jet olfactory display to create an olfactory ejection system that presents scent on each inspiration. In experimental tests, we confirmed that this olfactory presentation system can detect the beginning of inspiration with a probability of more than 90% and present scent synchronized with breathing.

We next determined a scent ejection method in a single breath cycle. For determining the most suitable method to present a scent in an inspiration, we measured human olfactory characteristics. The perceived intensity of scent was altered by differences in the presentation method even when the quantity of scent available to breathe in was unchanged. We then determined that the scent presentation method by pulse ejection with a short ejection time and high concentration of scent works more effectively than the method by pulse ejection with a long ejection time and low concentration of scent, and that the scent breathed in around 0.4-0.5 sec after inspiration worked most effectively. Using our olfactory system, a presentation method that presents high concentration scent in pulse ejections at 0.3-0.4 sec after the beginning of inspiration works most effectively.

In the future, to advance the transmission of olfactory information together with audio/visual information, the various aspects of our proposed method we describe here will make it possible to finely control scent presentation. As a result, the synchronization between media is expected to become easier.

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