PAPER

Increasing the Strength of Odors Produced by an Odor-Emitting Technology Using Odor Capsules

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SUMMARY We have developed an odor-emitting apparatus for application of odor to information technology. This apparatus consists of a chemical capsule cartridge including chemical capsules of odor ingredients and valves to control odor emission using an artificial metal muscle. In this method, multiple valves can be opened using the current for a single artificial muscle because the expansion and contraction time constant for the artificial muscles is large. We have developed a new multi-valve sequence mode that uses multiple odor capsules to increase odor strength, and we have been able to increase the strength produced by a factor of two. In addition, we evaluated the change in odor strength using a mock-up of the back seat of an automobile, and all of the ten test subjects reported sensing a stronger odor.

key words: *odor-emitting apparatus, multi-valve sequence mode, odor capsule, back seat of an automobile*

1. Introduction

It is well known that odor can contribute to promoting refreshment and relaxation, as typified by aromatherapy and the benefits of fresh, forest air. Compared with vision and hearing, an understanding of the fundamental mechanisms of the sense of smell has been late in arriving, but significant advances have been made recently. A major difference between the sense of smell and others of the five senses is that it is transmitted through the cerebral limbic system, containing the hypothalamus, which regulates autonomic nerves and hormones, and the hippocampus, which governs memory. Because of this, presenting information to the sense of smell promises new possibilities not available with vision and hearing, and various new devices for presenting information to the sense of smell are being developed [1], [2].

However, since the sense of smell is a chemical process, the distance between the substance producing the smell and the nose is a significant issue. There are devices such as a wearable olfactory display [3], that can deliver an odor when the user is in a particular location as one of the elements of virtual reality, and on the other hand, others that do not require the user to carry anything, but that can deliver an odor through an air nozzle directed at their nose area [4]. There are two types of visual display device that provide a fixed-type olfactory display in addition to the visual display: the inkjet method [5], and the solenoid valve method [6]. Both of these use odor-generating materials in liquid form, which is likely to be troublesome because these materials might leak and for which the waterproof structure is necessary. Also, methods that generate odors using functional high-polymers that have a high potential to change gel-sol state with temperature have been reported [7]. However, none of these methods is able to meet all four conditions that we consider essential for an olfactory presentation technology: (1) Able to use of many odor components, (2) Compact, (3) Able to adjust the intensity of the odor, and (4) Able to generate stable odors over a long period of time. We have developed an odor-emitting apparatus which uses odor capsules, satisfies all of these conditions and can be used as olfactory technology to be integrated into visual and auditory information systems [8]–[10]. This odor-emitting apparatus uses odor capsules made of a polysaccharide alginate membrane enclosing natural fragrances that are essential oils. It is compact and can use up to nine types of odor capsule to present different odors, and the strength of the odors can be controlled by using the characteristics of a type of artificial muscle to control the valves.

In earlier development, we have achieved control of the intensity of odors with a dynamic range of about 160 with modes of operation including changing the drive voltage of the artificial muscle, changing the temperature of the odor capsules, and changing the sequence of the valves. However, with earlier odor generating technologies using odor capsules, the generated odor was highest within five millimeters of the odor capsule substance. Depending on the scenario of use, even stronger odors may need to be produced, with higher dynamic range. For example, to generate odors using equipment built into an automobile, it will not always be possible to position the odor-emitting apparatus near the noses of persons seated in the seats of the automobile. As such, in this paper, we report on studies of a new multi-valve sequence mode, which is able to increase the intensity of odor produced by simultaneously opening multiple valves using only the current required to drive a single artificial muscle. This is done by taking advantage of the large time-constant property of expansion and contraction of the artificial muscles which drive the valves.

2. Materials and Methods

2.1 Odor-Emitting Apparatus with Chemical Capsule Cartridge

An external view of the odor-emitting apparatus is shown in

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Fig. 1 Photograph of odor-emitting apparatus.

Fig. 1 for Ref. [8]–[10]. This apparatus consists of valves, a chemical capsule cartridge, and chemical capsules. The size of the apparatus is $50 \times 80 \times 80$ mm, and nine chemical capsules are inside. One component is a valve with artificial metal "muscles", which contracts and returns to original length by turning on and off electricity. The turning on of electricity results in the contraction of the "muscles", opening of the valves, and the emitting of odors from the chemical capsules. On the other hand, the turning off of electricity returns the "muscles" to original length and leads to the closing of the valves. An important feature of the odor-emitting apparatus is that neither vibration nor noise occurred during opening and closing of the valves compared with other types of valves. This particular feature is important when combining olfactory information with vision and oral information. The temperature of the chemical capsules is controlled between room temperature and 80°C with a 100-W cartridge heater and a temperature control unit.

2.2 Chemical Capsules

Chemical capsules contain different natural fragrances. These fragrances were encapsulated by alginic acid polymer, which was a dietary fibers in polysaccharide. The size of the chemical capsules was about 5 mm in diameter and 30 mg in weight. The production of the chemical capsules was performed using the coacervation method.

In order to measure the odor strength from the chemical capsules, we used a portable odor monitor OMX-SR of Shinei Technology Co., Ltd. (Kobe-shi, Hyogo, Japan). The values acquired using semiconductor devices showed the relative strength of odor, not the actual odor strength and odor concentration. Sampling of order strength was done once every second.

3. Results and Discussion

Earlier, we proposed a mode of operation which used the large time-constant of expansion and contraction of the artificial muscles that drive the valves, varying the timing of opening and closing to weaken the intensity of odors emitted by the apparatus, and showed that this method was effective. In this research, we have studied modes of operation that increase the dynamic range significantly and are able to intensify the odors.

The basic approach is to insert multiple of the same type of odor capsule in the capsule cartridge and to create a more intense odor by opening more than one capsule at a time. A key point when doing so is that the large expansion and contraction time constant of the artificial muscle can be used. Using separate currents for each of the artificial muscles controlling the valves makes it easy to open multiple valves, but the current required for a single artificial muscle is about 500 mA, resulting in quite a large current if more than one artificial muscle is operated at the same time. However, since the expansion and contraction time constant for the artificial muscles we are using is large, multiple valves can be opened using the current for a single artificial muscle by using a sequence like that described below (hereafter called the multi-valve sequence).

<Multi-valve sequence concept>

① Pass current through artificial muscle A, opening valve A.
② Stop the current through artificial muscle A.
③ Pass current through artificial muscle B, opening valve B.
④ Stop the current through artificial muscle B.
⑤ Pass current through artificial muscle C, opening valve C.
⑥ Stop the current through artificial muscle C.

An example of the multi-valve sequence is shown in Fig. 2 (a). Current at 13 V is passed through the artificial muscles for three valves, applied for five-second intervals at five-second offsets repeatedly. A single valve stays open for about 10 seconds due to the five-second current, so all three valves stay opened continuously, as shown in Fig. 2 (b) (the region marked by the dashed line).

In order to show that the above concept is valid, we performed the following experiment. Based on the assumption that there is no difference between individual odor capsules, and using the three rows and three columns of odor capsules in the odor capsule cartridge, we studied whether the odor strength generated using three odor capsules could be explained in terms of the sum of strengths produced by a single cartridge. We used peppermint odor capsules for this experiment.

First, we studied the case when three odor capsules in a horizontal row were used. The standard odor profile (change in odor strength over time) is shown in Fig. 3, and

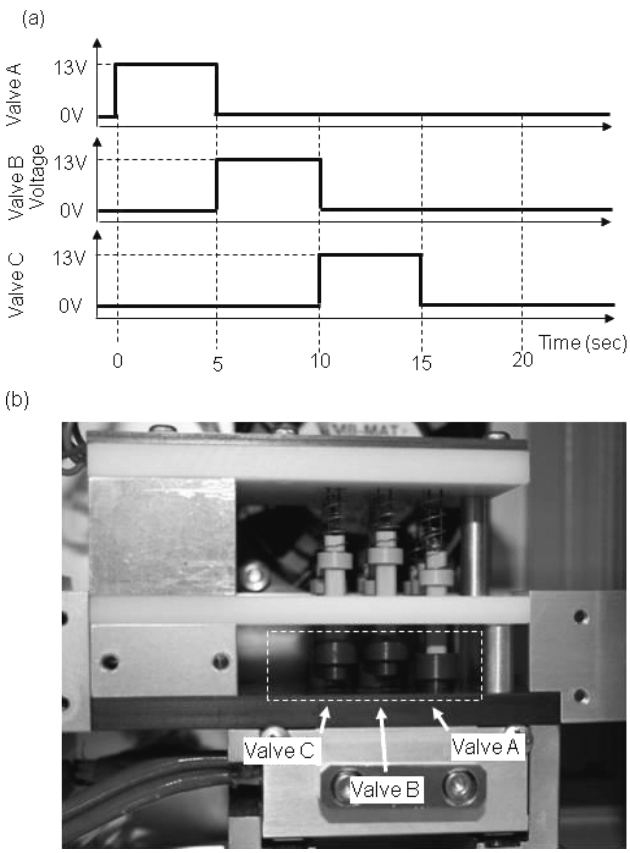

Fig. 2 (a) Multi-valve sequence mode. (b) Photograph of inside when three valves open.

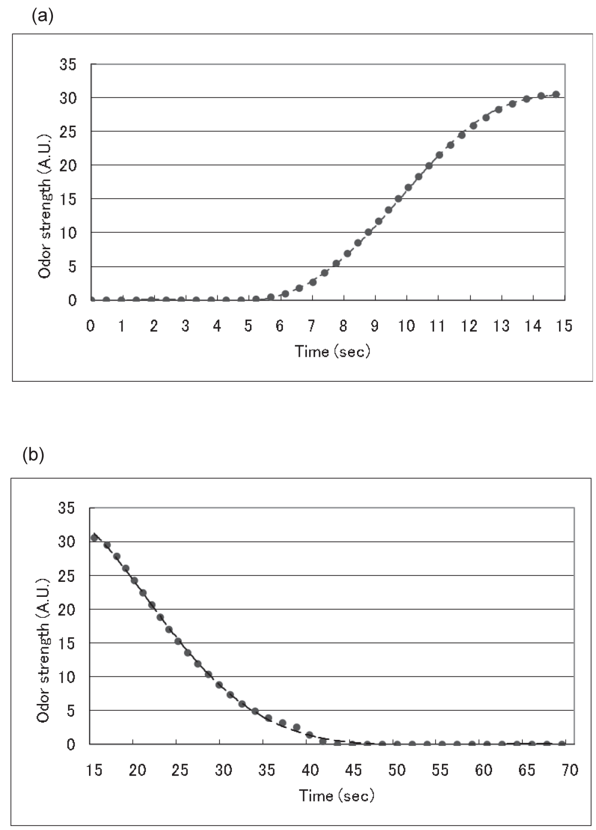

Fig. 3 Basic odor profile in a horizontal row (a) $0 < t \leqq 15$ sec. (b) $15 < t < 70$ sec. Observed curve is a dotted line and approximated curve is a dashed line.

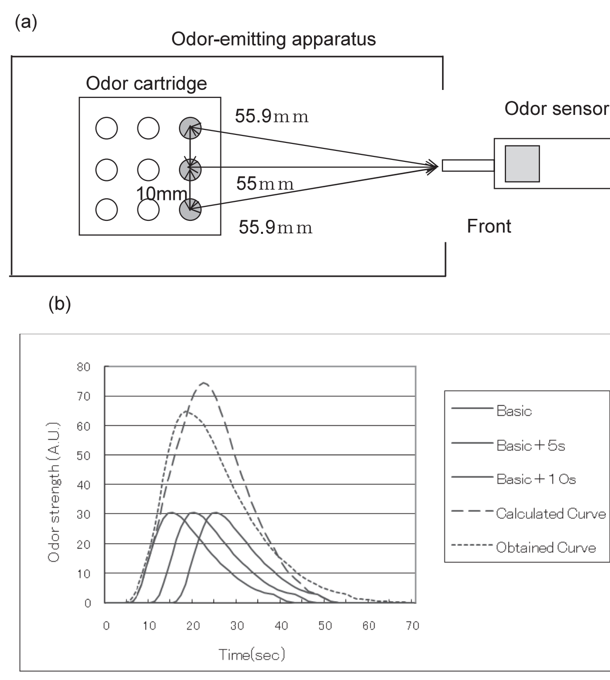

Fig. 4 (a) Setup of three odor capsules in a horizontal row. (b) Odor profile in multi-valve sequence mode in a horizontal row.

with a boundary at 15 s, the peak can be approximated by the two six-degree polynomials, $f_1(t)$, below.

$0 < t \leqq 15$ s

$$f_1(t) = 0.0001t^6 - 0.0052t^5 + 0.0926t^4 - 0.7236t^3 + 2.6095t^2 - 4.0815t + 2.1151$$

$15 < t < 70$ s

$$f_1(t) = -2 \times 10^{-8}t^6 + 3 \times 10^{-6}t^5 - 0.0003t^4 + 0.0103t^3 - 0.1446t^2 - 0.8927t + 32.234$$

The correlation coefficient for both of these is 0.99.

As shown in Fig. 4, for the horizontal row of three capsules, an odor monitor using semiconductor sensors was placed 55 mm from the center odor capsule as a measurement system. In this case, the distances to the odor capsules on either side were 55.9 mm. As a result, we can give an approximate expression the odor profile emitted by the three odor capsules as $f_2(t)$.

$$f_2(t) = \sum (f_1(t) + f_1(t+5) + f_1(t+10))$$

The actual measurement results, compared with the results of the above expression are shown in Fig. 4. The results of calculation using the standard profile $f_1(t)$ are shown with a broken line, and it is nearly the same as the measured results shown with a dotted line.

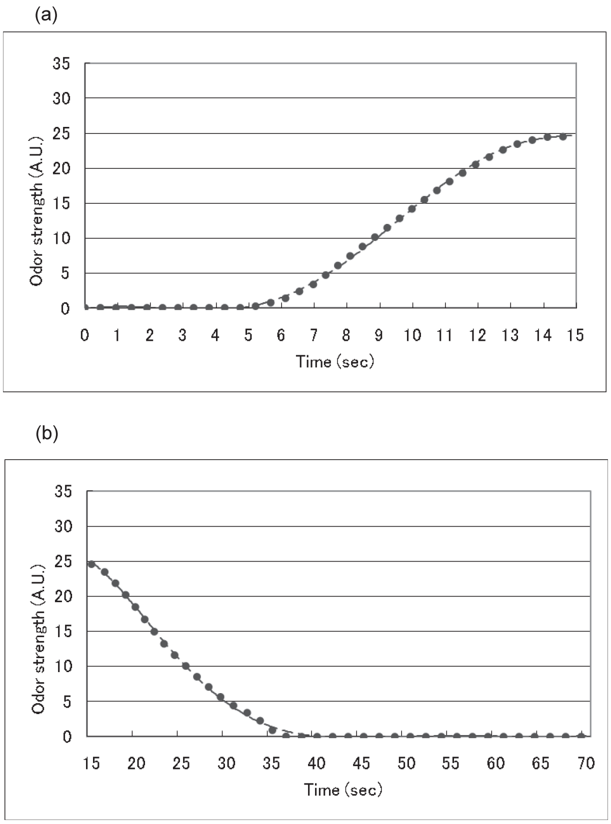

Fig. 5 Basic odor profile in a vertical row (a) $0 < t \leqq 15$ sec. (b) $15 < t < 70$ sec. Observed curve is a dotted line and approximated curve is a dashed line.

Next, we studied the case where three odor capsules were arranged in a vertical row. Taking the odor profile of the capsule nearest to the odor monitor, as shown in Fig. 5, as the base, the odor profile can be divided at the 15 s boundary and approximated by $f_3(t)$ defined with two six-degree polynomials as was done earlier.

$$0 < t \leqq 15\,\mathrm{s}$$
$$f_3(t) = 3 \times 10^{-5}t^6 - 0.0014t^5 + 0.0174t^4 - 0.0392t^3 - 0.3319t^2 + 1.3747t + 1.1188$$
$$15 < t < 70\,\mathrm{s}$$
$$f_3(t) = -2 \times 10^{-8}t^6 + 4 \times 10^{-6}t^5 - 0.0003t^4 + 0.0115t^3 - 0.1626t^2 - 0.597t + 25.573$$

The correlation coefficient for both of these is 0.99.

When the odor capsules are arranged vertically, their distances from the odor monitor are 55, 65 and 75 mm respectively. Considering diffusion in a gas, the strength of the odor from the farther capsule should be weaker. Figure 6 shows the dependence of odor strength on the distance between odor capsule and odor monitor. As the distance becomes larger, the odor strength decreases. From this result, and if we take the strength of the odor from the closest odor capsule to the odor monitor (55 mm) to be one (1.00), the strength at distance 65 mm is 0.76 (α) and at 75 mm it is 0.52 (β). Accordingly, the odor profile, $f_4(t)$, produced by

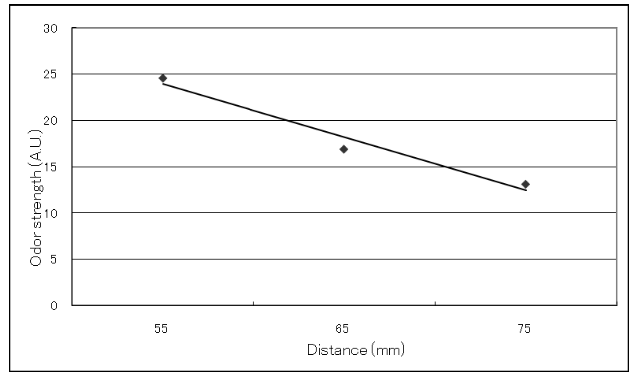

Fig. 6 Odor strength at different distance.

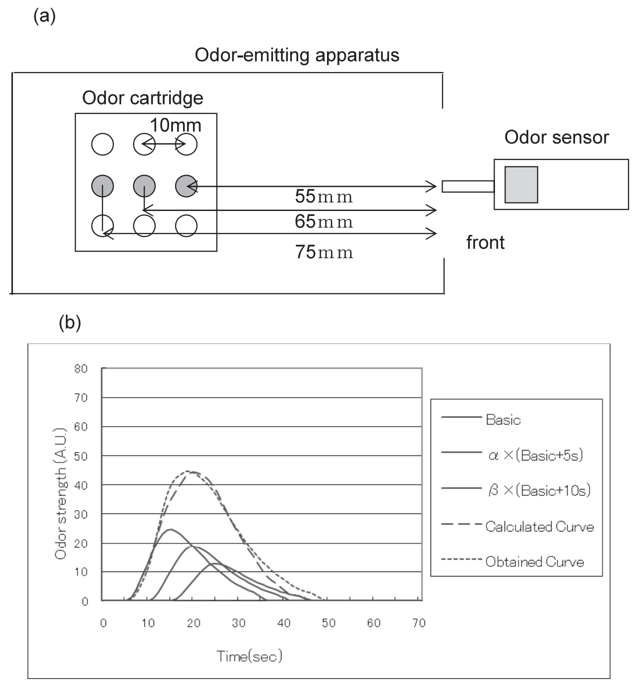

Fig. 7 (a) Setup of three odor capsules in a vertical row. (b) Odor profile in multi-valve sequence mode in a vertical row.

the three capsules aligned vertically can be approximated by the expression:

$$f_4(t) = \sum (f_3(t) + \alpha f_3(t+5) + \beta f_3(t+10))$$

Measured and calculated values are compared in Fig. 7, showing that they are almost the same.

We now discuss the odor profiles for the two capsule arrangements above. We have confirmed that for cases using multiple valves, the profiles for both vertical and horizontal rows of three odor capsules could be explained in terms of the sum of the profiles of the individual capsules. We have also shown that through the multi-valve sequence mode, three valves can be opened at the same time using only the current required for a single artificial muscle. As a result, using either the vertical or horizontal configuration, odor strength of up to twice that of using only a single odor

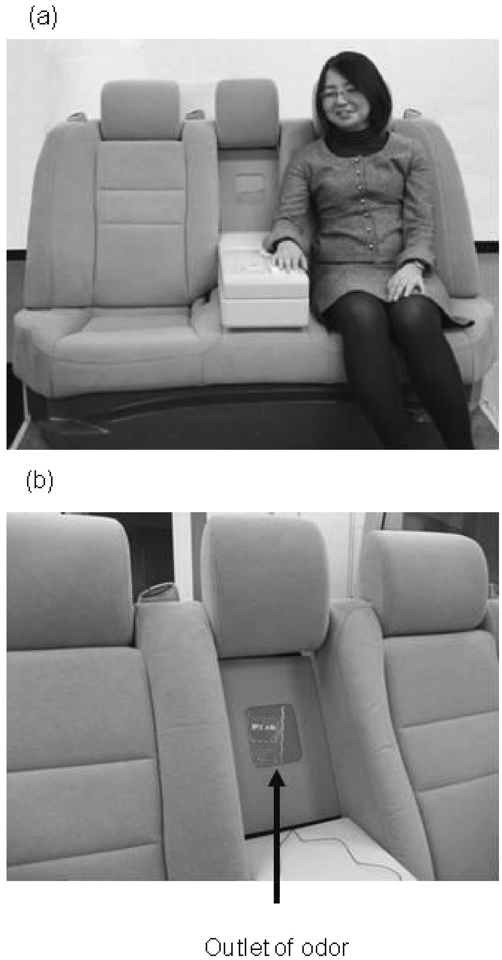

Fig. 8 (a) Photograph of mock-up of automobile rear seat. (b) Photograph of outlet of odor.

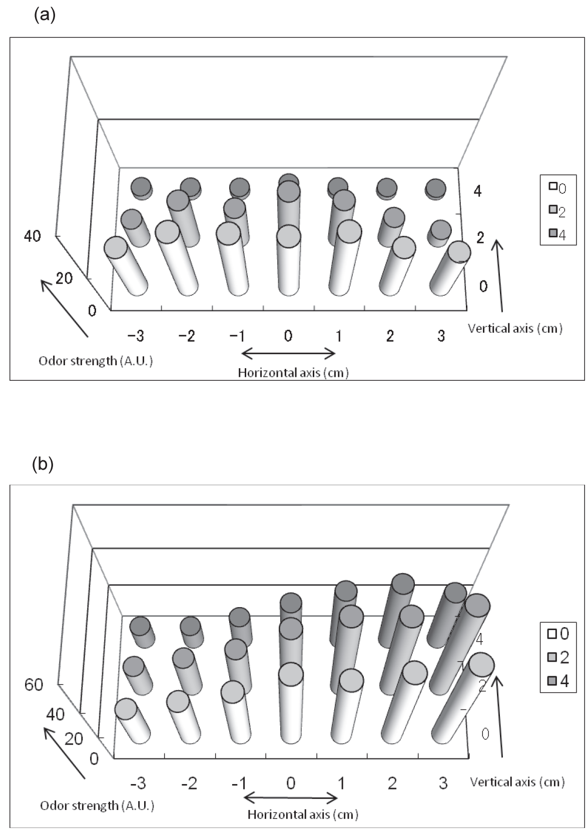

Fig. 9 3-dimensional graph of odor distribution (a) front (b) right side.

capsule can be achieved, and the multi-valve sequence mode is effective in increasing odor strength in this way. Note that with the horizontal configuration, the distances to the odor monitor were less, so odor strength was greater than with the vertical configuration.

Within our group, we have already shown that we can adjust odor strengths by a factor of about 160 using three operating modes that we have reported on earlier, including the valve drive-voltage, temperature and valve-sequence modes [8]–[10]. Using the multi-valve sequence mode discussed here, we can achieve double the odor strength, so combined with the previous three modes, we can achieve changes in strength by factors up to 320. Note that we are currently still studying the conditions for multi-valve sequencing using four or more capsules.

There are various possible applications for odors, but one of these is to build an odor-emitting apparatus into the seats of trains or cars as a means to create a refreshing and relaxing, comfortable space. As such, we have created a mock-up of an automobile rear seat equipped with olfactory presentation technology as shown in Fig. 8. Mesh panels are situated between the two seats and the odor emitting equipment is built into it. The odor-emitting apparatus is also able to rotate relative to the mesh panel. With this arrangement, the odor can diffuse through the mesh from the emitting component into the automobile, and with the rotating structure, a stronger odor can be delivered to either the right or left seat. In order to evaluate diffusion of the odors into the automobile through the mesh, we studied the odor distribution directly outside the mesh panel. The results for cases when the odor-emitting apparatus faced the mesh directly and when it was rotated by 30 degrees are shown in Fig. 9. As expected, in the former case the odor was strongest in the central area, and for the later, the strongest region moved toward the right side. When actually presenting odors in the rear seats of the automobile, passengers will be seated in the seats to the right and left of the odor emitting component, so adjusting the angle of the component can be used effectively to adjust the odor strength distribution.

In order to evaluate use of the multi-valve sequence mode in the rear seats of an automobile, we studied the ability of ten subjects (five each of male and female aged between 20 and 60) seated in the rear seats of the automobile to perceive the strength of odors produced with the multi-valve sequence mode. Specifically, each person was asked to smell the odor from a single peppermint odor capsule for five seconds, and then five minutes later, to smell the odor from three peppermint capsules (in a horizontal row) emitting in the multi-valve sequence mode. The five-minute intermission was taken in order to avoid the olfac-

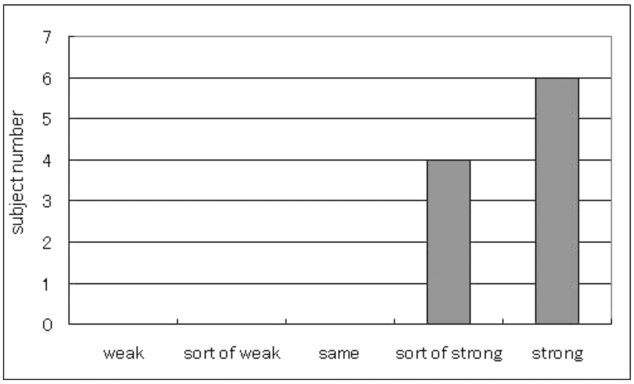

Fig. 10 Evaluation of odor in multi-valve sequence mode.

tory adaptation effects, whereby sensitivity to a given smell decreases with continuous exposure. The conditions were evaluated on a five-level scale, with each subject being asked whether the multi-valve sequence mode case was "Weaker", "Somewhat weaker", "The same", "Somewhat stronger", or "Stronger" than the single-mode case. In the results show in Fig. 10, four of the ten subjects answered "Somewhat stronger" and six answered "Stronger", showing that they were able to recognize the doubled strength of the odor emitted by the multi-valve sequence.

In the future, we hope to make use of this sort of characteristic for a broad range of applications, including uses in automobiles such as changing the type and strength of fragrance to suit the surrounding landscape or to increase passenger alertness as they approach their destination by gradually changing the strength.

4. Conclusion

We have developed a new multi-valve sequence mode which uses multiple odor capsules as a way of increasing odor strength, and have been able to increase the strength produced by a factor of two. Using this mode, we evaluated the change in odor strength using a mock-up of the back seat of an automobile, and all of the ten test subjects reported sensing a stronger odor. In the future, we plan to expand applications of olfactory presentation in automobiles and passenger trains.

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