Measurement of Olfactory Characteristics for Two Kinds of Scent in a Single Breath

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Abstract. This study describes a presentation technique of scent designed for users to recognize multiple scents during a very short time period. We measured the olfactory characteristics of subjects when two kinds of scents were presented in a single breath. We defined and measured the minimum ejection interval in which subjects could discriminate the two individually emitted pulses of scent, which we term "separable detection threshold", and the minimum ejection interval in which they could specify both kinds of scents, "separable recognition threshold". Further, "response time" and "duration of scent perception" were measured. As a result, we found the duration of scent perception and the separable recognition threshold were positively correlated. Knowledge of this olfactory characteristic brings us closer to being able to provide a greater sense of realism in multimedia environments, by describing more than one object by scent at the same time as the objects are seen on screen.

Keywords: Olfactory Information, Olfactory Display, Pulse Ejection, Olfactory Characteristics

1 Introduction

Information and communication via computers tends to be limited to visual information and audio information. However, in the real world, humans gather external information via the five senses of sight, hearing, touch, smell and taste, allowing them to react appropriately to local circumstances. Accordingly, the conveyance of such information and its communication via the five senses has lately attracted much attention [1]. Olfactory information presented to match visual information has been shown to have a dramatic effect on deepening the viewer's understanding of the image content [2]. In addition, in the case of viewers watching a movie accompanied by scent emission, the relation between the scent and the viewer's feelings has been analyzed by measuring the viewer's brain waves and estimating his or her psychological state [3]. The presentation of olfactory information is considered to be an effective means for enhancing the sense of reality, similarly to the use of three-dimensional images and sounds [4]. Therefore, trials on the transmission of olfactory information together with that of audio/visual information are currently being conducted in the field of multimedia.

In order to transmit scent together with other media, it is necessary to control the presentation of scent in accordance with changes in the images/sounds over time. However, existing techniques have not yet overcome the problem of emitting too much odor over a continuous period, which causes various problems such as olfactory adaptation and the lingering of odors in the air, making it difficult to synchronize scents with the ever changing images and sounds. In efforts to resolve these problems, we have focused on reducing the amount of scent emitted by using pulse ejection for a very short period of time [5]. In the viewing of movie scenes especially, it is thought that the sense of realism is increased by delivering scent adapted to the specific images being viewed. Frequently, multiple objects are shown at the same time in scenes, but a technique for presenting multiple scents during a very short time period has not been reported to date.

During measurement of olfactory characteristics using a pulse ejection technique which was designed to avoid scent remaining in the vicinity of the user and thus prevent olfactory adaptation, we found that humans can recognize a switch between two kinds of scents in a single breath. Therefore, in this study, in efforts to develop a presentation technique of multiple scents in a single breath, we measure the olfactory characteristics when two kinds of scents are presented in a single breath, and report the results here.

2 Related Work

Trials on the transmission of olfactory information together with audio/visual information are ongoing. Work first started in the 1950s when Heilig developed Sensorama [6], the first virtual reality (VR) system that presented olfactory information together with audio/visual information. The recently developed virtual space system, Friend Park [7], 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 [8] describes some systems that add scent to web content, and computer controlled olfactory displays such as iSmell [9] and Osmooze [10] 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 also been proposed [11].

In research on the transmission of olfactory information, Nakamoto et al. [12] 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 in order to reproduce the target scent. However, the system can not yet handle arbitrary scents.

A wearable olfactory display with a position sensor has also been developed [13]. 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 the olfactory information obtained.

AROMA [14] 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. [3] measured the viewer's mental state by his or her brainwaves, and analyzed the relation between the scent and the viewer's feelings while watching. A movie that adds olfactory information to the visual/audio information has been created, but since the synthetic scent did not consistently accord with the image and the scent was not deodorized, the movie could not be widely distributed.

3 Characteristics of Olfaction

A fragrance substance is a compound that stimulates the olfactory cells in the nasal cavity. Fragrance substances can be inorganic substances such as hydrogen sulfide and ammonia, although most are organic compounds. It is said that of the approximately two million kinds of organic compounds in existence, about four hundred thousand of these have an odor [15]. However, humans perceive and recognize about five thousand scents routinely. The characteristics of human olfaction are now briefly described.

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 [16], usually expressed in units of mol (concentration) and mass percentage. However, because the olfactory threshold is a measure of the lowest olfactory stimulus intensity at which an individual can perceive scent, this value does not reflect the intensity (strength and weakness) of the scent perceived.

- *Detection threshold*: the smallest density at which scent can be detected and where the user does not need to recognize the kind of smell.
- *Recognition threshold*: 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.
- *Differential threshold*: 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. In the case of olfaction, it differs with different kinds of scent, but is in the range of about 13-33%.

3.2 Adaptation

Adaptation is the phenomenon where sensory nerve activity is decreased by continuous stimulation by odor molecules. Adaptation itself and the speed of recovery from adaptation differ according to the kind of scent. Adaptation is gradually strengthened over time, but is restored for a short time (3-5 minutes) by eliminating the scent.

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

4 Olfactory Characteristics in Relation to Two Kinds of Scent in a Single Breath

Previously, while testing a pulse ejection method that ensures scent does not remain in the vicinity of the user, we found that humans can recognize a switch between two kinds of scents in a single breath. Therefore, the purpose of this study was to develop a presentation technique that enables users to recognize multiple scents during a very short time period by measuring the olfactory characteristics of subjects.

Using the pulse ejection technique, the ejection time interval between two pulse ejections was about 1 second. It is known that a typical person breathes about 12 times/min and inhales for an average of 2 sec at rest [17]. This means that a third pulse ejection is not presented during inspiration in most cases, so many people cannot perceive the scent presented. Therefore, we limited the scents presented in a single breath to two kinds, and measured the time characteristics of olfaction. Figure 1 depicts the two pulse ejections of scent individually emitted in a single breath, where the ejection time interval of two pulse ejections is defined as T_i.

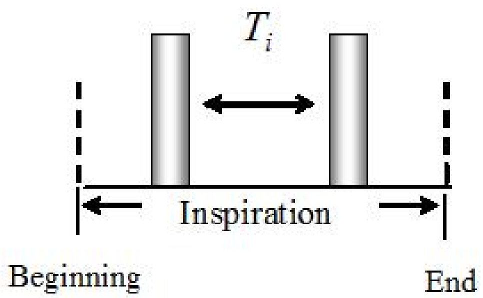

Fig. 1. Ejection time interval of two pulse ejections "T_i"

When scent is emitted as depicted in Figure 1, humans cannot discriminate the two individually emitted pulses of scent when the interval T_i is small. Naturally, this applies in the case of the emission of two different scents, one at each pulse. Thus, we defined the minimum ejection time interval in which the subject could discriminate the two individually emitted pulses of different kinds of scent as the “separable detection threshold” and the minimum ejection time interval in which the subject could specify both kinds of scents as the “separable recognition threshold”, and measured them.

The separable detection threshold of scent was defined on the basis of the separable detection threshold of pain. When touching two nearby points on the skin with a sharp tipped object, at a certain distance we perceive the two points at just one location and beyond this point we perceive them at separate locations. This minimum distance to perceive pain at two locations is known as the separable detection threshold of pain.

When this separable detection threshold is defined as “the threshold at which a subject can perceive two concomitant stimuli of pain (via the sense of touch) as separate stimuli”, the separable detection threshold in regard to other senses can be also defined. The separable detection threshold is classified into spatial distance and temporal distance: the above separable detection threshold of pain is spatial while that of smell is temporal. Therefore, we defined the separable detection threshold in regard to the sense of smell as “the time interval in which a subject can discriminate two individually ejected pulses of different scents”.

During measurements of the separable detection threshold and separable recognition threshold in regard to the sense of smell, 100-msec, stable pulse ejections of the scents were presented. Measurements were then made to determine the “response time” and “duration of scent perception”, which were defined respectively as follows: the time period from when the olfactory display started pulse ejection until when the subject started to perceive the scent, and the time period from when the subject started to perceive the emitted scent until when he or she no longer perceived it.

5 Olfactory Display and Performance Evaluation

5.1 Olfactory Display

We developed an olfactory display in conjunction with Canon Inc. Figure 2 shows the prototype olfactory display. This display is ink-jet in order to produce a jet which is broken into droplets from the small hole in the ink tank. Ejection control is possible for a unit of 100 msec.

Figure 3 is a plain view of the olfactory display. 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 256 minute holes in the head connected to the large tank and 128 in the head connected to the small tank. The display can emit scent from multiple holes for a period of 100-msec, and the ejection concentration can be varied using between 0 to 255 holes for the large tank and 0 to 127 holes for the 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 during a 100-msec ejection period as “the number of simultaneous ejections (NSE)”.

Fig. 2. Olfactory display

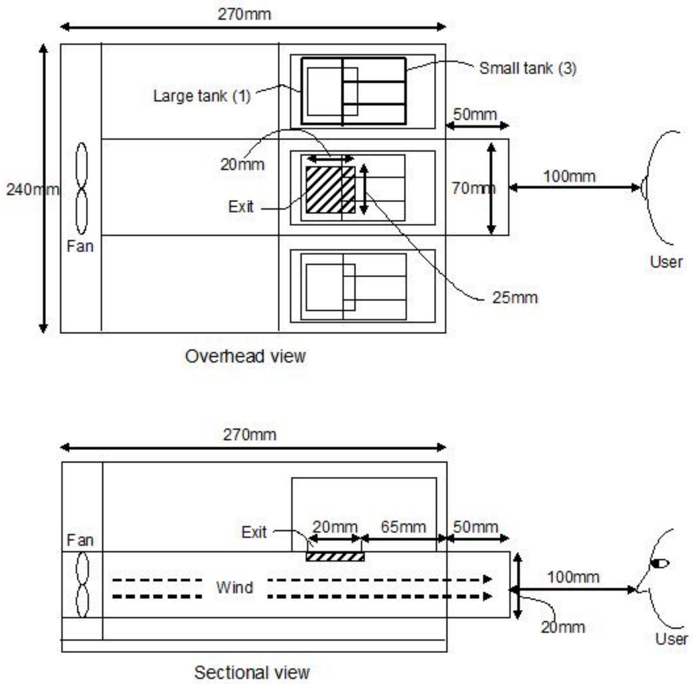

Fig. 3. Plain view of the olfactory display

For all measurements, we used only the small tanks. The scents used were lavender, lemon and peppermint. The UAEQ from the small tanks is 4.7 pl for lavender scent, 3.7 pl for lemon scent and 4.7 pl for peppermint scent. Examination at Canon Inc. 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 the 100-msec period in the range of 1 to 150 times, which we denote the "volume". In this study, the volume was set to 150 times without variation. Therefore, the ejection quantity in the 100-msec period (EQ) is calculated as follows.

$$\text{EQ (pl)} = 4.7 \text{ or } 3.7 \text{ (pl: UAEQ)} \times 0\text{-}127 \text{ (NSE)} \times 150 \text{ (times: Volume)} \quad (\mathbf{1})$$

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

$$\text{Scent quantity (pl)} = \text{EQ (pl)} \times 0.05 \quad (\mathbf{2})$$

The display is equipped with a fan and there are 10 phases of wind velocity control in the range of 0.8 m/sec to 1.8 m/sec. The scent presentation hole is a rectangle of 2 cm height and 24 cm width.

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

Fig. 4. Use of the olfactory display

5.2 Continuance Time of Pulse Ejection

If more than the required amount of scent is emitted, it remains in the air and can cause adaptation. Therefore, it is desirable that the continuance time of pulse ejection is the shortest for which an individual can sense the scent without adaptation. As the shortest ejection continuance time of the olfactory display is 100-msec and all 20 subjects we recruited could recognize pulse ejection of 100-msec, we set the pulse ejection to 100-msec in this study.

5.3 Recognition Threshold

Measurements to determine the recognition threshold were conducted using 100-msec pulse ejections of three kinds of scent (lavender, lemon and peppermint) with 6 subjects.

Measurement was undertaken for between 5 and 40 simultaneous ejections which determine ejection concentration, in decrements of 5. Using the paired comparison method [18], we measured the recognition threshold of each scent. The olfactory display presented scented and unscented ejections to each subject, and we instructed the subject to indicate which of the two was the scented one and the kind of the scent. Ejection concentration was decreased until the subject could no longer recognize the scent.

Table 1. Recognition threshold (in 127 phases)

Kind of scent	Average	Maximum	Minimum
Lavender	23.3	30	15
Lemon	19.2	30	10
Peppermint	17.5	10	5

Table 1 shows the measurement results of the recognition threshold. The maximum recognition threshold of 6 subjects was an ejection concentration of 30 NSE for three scents. Thus, all subjects could recognize a scent when the ejection concentration is set at more than 30. Therefore, NSE in the following measurement was set to 30.

6 Measurement of the Temporal Characteristics of Olfaction

6.1 Response Time and Duration of Scent Perception

We measured the olfactory characteristics of pulse ejection with regard to “response time” and “duration of scent perception” in a single breath, with 24 subjects. Olfactory ejection was presented at the beginning of inspiration for each subject. In order to measure “response time”, subjects were instructed to click a mouse when they perceived the scent. For each subject we measured the time from starting the ejection of scent to the mouse click three times for each scent, and recorded the average value for each scent. In order to measure “duration of scent perception”, subjects were instructed to click a mouse when they could no longer perceive a scent. Similarly to the measurement of response time, for each subject we measured the time from starting the ejection of scent to the mouse click three times for each scent and recorded the average value for each scent. We then calculated the response time and the duration of scent perception as follows.

$$\text{Response time} = \text{Average time to beginning to perceive the scent} \quad (\mathbf{3})$$

$$\text{Duration of scent perception} = \text{Average time to no longer perceiving the scent} - \text{Average time to the beginning to perceive the scent} \quad (4)$$

Table 2. Response time and duration of scent perception

Kind of scent	Response time		Duration of scent perception	
	Average (sec)	Standard deviation	Average (sec)	Standard deviation
Lavender	1.08	0.14	1.26	0.48
Lemon	1.09	0.12	1.21	0.46
Peppermint	1.04	0.13	1.26	0.48
Average	1.07	0.13	1.24	0.47

Table 2 shows the measurement results for the response time and the duration of scent perception. In order to examine the effect of differences among scents and among individuals on the response time and the duration of scent perception, the results were analyzed using a two-way ANOVA (kind of scent, individual). The results for response time showed no significant differences for the interaction of the two factors ($F(46)=1.45$, $P>0.05$) or for the main effect of kind of scent ($F(2)=3.06$, $P>0.01$). However, a significant difference was found for the main effect of individual ($F(23)=1.60$, $P<0.01$); however, the individual difference was small since the average of the standard deviation was as small as 0.13 (variation coefficient 12.0%). The results for duration of scent perception showed no significant differences for the main effect of kind of scent ($F(2)=3.20$, $P>0.05$). A significant different was found for the main effect of individual ($F(23)=1.77$, $P<0.01$) , which was large since the average of the standard deviation was as large as 0.47 (variation coefficient 37.7%).

6.2 Separable Detection Threshold and Separable Recognition Threshold

We measured the “separable detection threshold” and the “separable recognition threshold” with 24 subjects in the same manner as described above. “Scent scenarios” were presented in a single breath. The scent scenarios prepared were six scent patterns (ejection of different combinations of two of the total three scents) and six dummy patterns (three patterns where the scent of the two pulse ejections was the same and three patterns where the number of pulse ejections was only one). The measurement range of the interval between the two pulse ejections was set between 0.2 and 2.0 sec by 0.2 sec.

Measurement was performed as follows. A scent scenario with a given ejection interval was randomly chosen from 12 scenarios, and the scenario was executed by synchronizing the first pulse ejection with the beginning of inspiration. When each scent scenario was completed, subjects answered two questions: “*1. How many times did you notice the scent?*” and “*2. What was the kind of the scent?*” The first question was an open question and we judged that the subject could separate and detect the smells when answering “two times”, and the second question was a closed question. When both questions were answered correctly, we judged that the subject could separate and recognize the two scents presented. Measurement was repeated for all six of the scent patterns while changing the ejection interval. The measurement was finished when the result was stabilized (i.e. when the subject answered correctly more than twice for scent presentation at the ejection interval that was considered the shortest one) and we then recorded the shortest ejection interval at which each subject could detect as well as recognize the two distinct kinds of scent.

Table 3. Separable detection threshold and separable recognition threshold

Scent scenario		Separable detection threshold		Separable recognition threshold	
First	Second	Average (sec)	Standard deviation	Average (sec)	Standard deviation
Lavender	Lemon	0.78	0.41	1.02	0.49
Lavender	Peppermint	0.61	0.34	0.94	0.45
Lemon	Lavender	0.87	0.36	1.09	0.35
Lemon	Peppermint	0.60	0.29	0.81	0.46
Peppermint	Lavender	0.83	0.43	1.04	0.42
Peppermint	Lemon	0.80	0.36	0.95	0.35
Average		0.75	0.37	0.98	0.42

Table 3 shows the measurement results of the separable detection and separable recognition thresholds. To examine the effects of the differences among scent scenarios and individuals on the separable detection threshold, the results were analyzed using a two-way ANOVA (kind of scent, individual). There was no significant difference for the main effect of kind of scent ($F(2)=2.29$, $P>0.01$). However, a significant difference was found for the main effect of individual ($F(23)=1.62$, $P<0.01$), which was large since the average of the standard deviation was as large as 0.37 (variation coefficient 48.9%).

In the case of the separable recognition threshold, some subjects could not separate and recognize two scents even if the ejection interval was set to the maximum time of 2.0 sec. Therefore, Table 3 shows the value determined excluding data from those subjects. Since the number of data items was not equal, the results were analyzed using a one-way ANOVA (kind of scent, individual). For the separable recognition threshold, there was no significant difference for kind of scent ($F(2)=2.29$, $P>0.05$), but a significant difference for individual ($F(23)=1.63$, $P<0.01$), which was large since average of the standard deviation was 0.42 (variation coefficient 43.1%).

6.3 Discussion

This study revealed that the kind of scent used had no influence on the measurement results obtained. On the other hand, differences were found in the measurement results among individuals, particularly with regard to duration of scent perception and separable recognition threshold. Therefore, we examined the correlation of these two values. A weak correlation (0.56) was found between duration of scent perception and separable recognition threshold. Figure 5 is the correlation diagram showing individual values and an approximate curve. There are some outliers, but a positively correlation is seen.

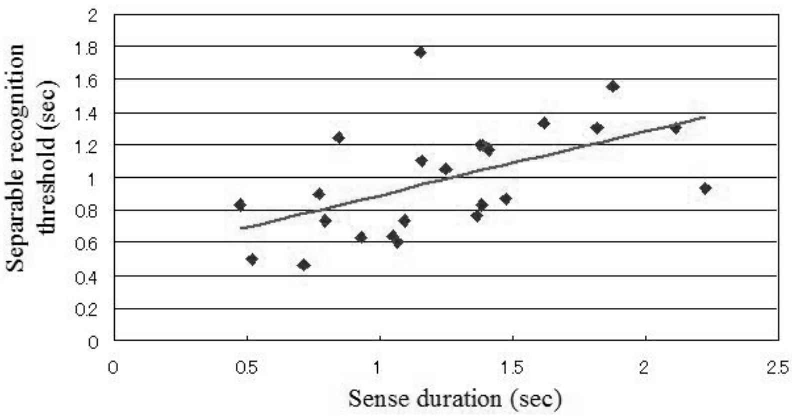

Fig. 5. Correlation diagram between duration of scent perception and separable recognition threshold

To consider this aspect in detail, we divided the 24 subjects into 3 groups of 8 based on the results of duration of scent perception: the short group, medium group, and long group. Figure 6 shows the duration of scent perception histogram for the 3 groups.

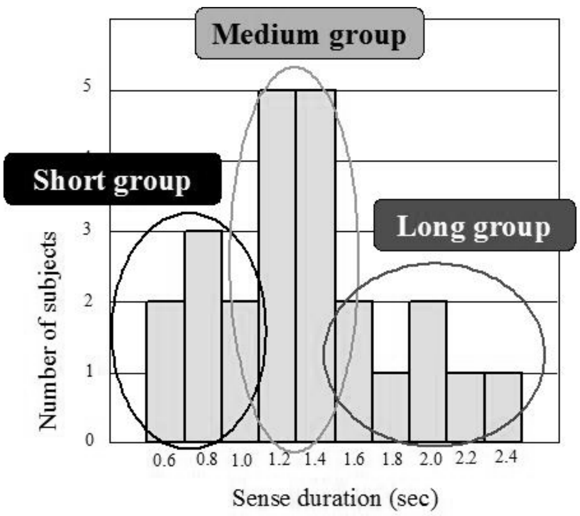

Fig. 6. Duration of scent perception histogram

Figure 7 shows the sensory perception results for subjects in the short and long groups. The horizontal axis represents time and the vertical axis represents the amount of scent perceived. The gray bars represent pulse ejections and the curve represents the change in the amount of scent perceived. This curve is drawn on the basis of results estimated by an olfactory model reported in an earlier study [19]. Overall, there were little individual differences in response time, and all subjects began to perceive the scent around 1 sec after pulse ejection started. Furthermore, as shown by the second curve in each graph, the subjects began to perceive the second scent just after they stopped perceiving the first scent.

There were several subjects for whom the two curves overlapped or were separated only slightly. The interval time between the two pulse ejections is the separable recognition threshold, and it appears that when pulse ejections were presented at an interval shorter than the subject's separable recognition threshold, he or she could not distinguish the two scents because the two curves overlapped greatly.

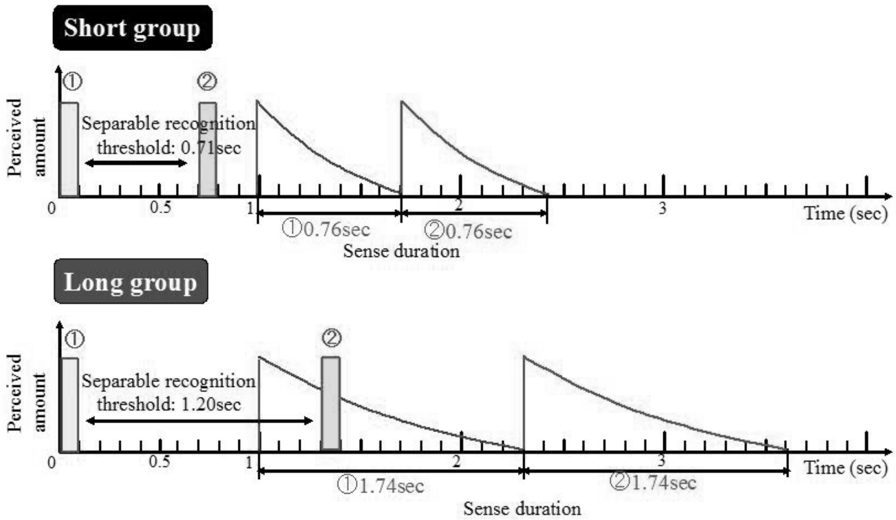

Fig. 7. Sensory perception differences for each group

7 Conclusion

In order to realize a scent presentation technique that enables users to recognize multiple scents during a very short time period, we measured olfactory characteristics when two kinds of scents were presented by pulse ejection in a single breath. We measured "response time" and "duration of scent perception" in relation to the pulse ejections of scent. We were able to define and measure the "separable detection threshold" and the "separable recognition threshold" that was the interval between two pulse ejections. As a result, we found large individual differences in the duration of scent perception and the separable recognition threshold; however, these values were positively correlated. In general, it is said that the presentation technique could not handle well some large individual differences in olfactory characteristics, but the temporal characteristics of smell measured in this study did show a correlation among individuals.

By advancing the measurement of olfactory characteristic in future, we will be able to use scent easily. For example, olfactory displays could be customized in accordance with such characteristics. In addition, by setting the interval of pulse ejections based on the separable recognition threshold of the long group, all users should be able to perceive two kinds of scent in a single breath. Such technology brings us closer to being able to provide a greater sense of realism in multimedia environments by describing more than one object by scent at the same time as the objects are seen on screen.

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