Adaptation process of human olfactory under continues exposure to odor of ethyl acetate based on subjective estimation of odor intensity

H. Nagatsugu[1], T. Yamanaka[1], K. Sagara[1], H. Kotani[1], Y. Momoi[1] and A. Takemura[2]

[1] *Department of Architectural Engineering , Graduate School of Engineering , Osaka University , Japan*

[2] *Department of Odor and Aroma Design , School of Informatics , Daido University , Japan*

Abstract

This study was aimed at making a model which predicted olfactory sensation. Firstly, it was conducted the experiment, which odor was exposed to subjects constantly and subjects evaluated odor, to investigate the olfactory adaptation process. As a result, it was turned out odor intensity decreasing exponentially as time. Secondly, validity of the previous theoretical model (Osako,1991) was investigated by comparing the evaluation. As a result, it was found out that the validity of the previous model might be better in the case discriminating the adapting intensity from the after adapted.

Keywords: Odor, Subjective evaluation, Adaptation model

1. Introduction

Olfactory adaptation is well known as the decrease phenomenon of olfactory sensitivity by continuous smelling. In order to predict momentary evaluation accurately in our life, it is necessary to consider the unsteady variation of olfaction, because the adaptation and the recovery are repeated according to the variation of odor concentration as our movement. For example, even if there is odor visitors cannot accept, occupants never sense the odor due to the olfactory adaptation in the office. Therefore, it is also important to take account of the occupants' olfactory response in the case of being exposed to unsteady odor concentration.

However, it is necessary to know the response of olfaction under constant exposure to odor before the case of exposed unsteady state response. Thus, the purpose of this study is to clarify the adaptation response of human olfactory in time series by means of perceived intensity under continuous exposure to the odor with the constant concentration. In this study, the experiment was conducted to measure the odorous sensitivity by the subjective evaluation of the odor intensity on continuous scale. As an odor, ethyl acetate was used because it was controlled by Odor Control Law in Japan. As subjects were exposed to the odor for a long time, therefore the odor must have little effect on health. The safe odor concentration was determined accounting for the health effect.

The subjective was applied for examining the theoretical models for perceived intensity. One is the model presented by Osako which is based on the rate of increasing number of odorant-receptor combination, and the other is the model by Overbosch based on the power law. In this paper, the investigation about the former model by Osako is examined.

2. Methods

Subjects

A total of five subjects (one male student and four female students) from the age of 22 through 23 years old participated in the experiment.

Method

The experiments were conducted from May 13 to June 11, 2010 in the laboratory whose interior was decorated with stainless steel plates (Fig.1). In the tests, the sufficient ventilation rate was maintained by keeping the windows open to some extent. The temperature was ranged from 19.2 to 24.9^{o}C, the humidity ranged from 27.0 to 76.0%. Ethyl acetate was used as the odor for the tests. The subjects were exposed to the odor continuously. Fig.2 shows the odor presentation device. The method of presenting the odor was as follows. Firstly, the air in the next room where the temperature controlled was extracted by the fan. Secondly, the supplied air became odorless air after passing through the active carbon deodorant device. Thirdly, ethyl acetate was injected to the odorless air. Forth, the subjects in the laboratory (the right side in Fig.1) start to smell the mixed air supplied through the flexible duct made of aluminum. Before the experiments, the subjects were exercised the test once.

The time schedule is shown in Fig. 3. At first, the subjects were given the instruction before the start of the experiment. Then they smelled the odorless air for 5minutes. After that, subject were asked to evaluate the intensity of the odor every 30s. In total, the subjects evaluate the odor intensity for 21 times. There are two methods of breathing for the subjects. Table 1 shows the odor concentration and the breath methods. One is the method that the subjects are inhale and exhale only through nose. The other is the method that the subjects inhale through nose and exhale through mouth. They were instructed to breathe naturally in either method. he divided time spans can bring better accuracy than using overall time span.

3. Results and Discussion

3.1 Experimental Results

Fig.5 shows the relation between the exposing time and the odor intensity for each trial, under the condition of exposed concentration and the breath method. In this figure, the evaluation results by five subjects are listed in each graph. The evaluation by subject A seems different from the results by other subjects. This difference is considered to reflect that subject A has different perception of the intensity scale in comparison with the other subjects. It is considered, therefore, the evaluation by subject A should be excluded from the following discussions in this paper.

Fig.6 shows the relation between the exposing time and the average of odor intensity under each condition. In this figure, the mean value of the evaluations and the range of $\pm\sigma$ (standard deviation) at each exposing time is listed. In the case of the ethyl acetate of 1.0ppm, the odor intensity decreases to “No odor” within 3 minutes. In the case of 7.0ppm, the odor intensity decreases and becomes around “Weak” in not more than 5 minutes. In the case of 20ppm, the odor intensity also decreases, but it seems to take more time than the cases of the other small concentration to reach about “Weak”. These results indicate that, so-called adaptation may be caused at any odor concentrations. In the previous studies, also the same tendency as this one was presented, therefore, obtained data can be applied to the past theoretical model of olfactory adaptation. In this study, the model presented by Osako (1991) was selected. The model is hereafter called “Osako model”.

3.2 The olfactory model

Osako model is based on the rate of odorant-receptor combination with the odorant molecules. The combination of the odorant molecules (S) with the receptors (P) were expressed as the following equation 1, which expresses the state of equilibrium.

$$S + P \underset{k_2}{\overset{k_1}{\rightleftarrows}} \boxed{(SP)_{act} \rightarrow (SP)_{inact}} \qquad \text{(Eq.1)}$$

The dotted line on the right side in Eq.1 shows that the active compound $(SP)_{act}$ becomes inactive compound $(SP)_{inact}$ after transmitting the electric pulses In addition, considering the actual breathing method, it is supposed that the odorant molecules will be combined with receptors during inhalation, but they may leave during exhalation. The variation of the number of combined odorant molecules with the receptors $x(t)$ is presented in Fig.7. Based on this assumption, the equations about the combination rate can be derived. Using $x'_{(t)}$ as the combination rate of the odorant molecules with the receptors during inhalation of n times from the start of exposing, Eq.2 can be written for the inhalation period. In similar way, Eq.3

can be derived for the period of exhalation. It is assumed that people exhales through their nose. Fig. 8 shows the fluctuation of combination rate calculated by the Eq.2 and 3.

$$x'_{(t)} = k_1 CN \exp\left[-\left(k_1 C + k_2\right)\left\{t + t_k - n\left(t_A + t_B\right)\right\}\right] \qquad \text{(Eq.2)}$$

$$x'_{(t)} = -k_1 x'_{\left[(A+1)t_A + At_B\right]} \exp\left[-k_2 \left\{t - \left(A+1\right)t_A - At_B\right\}\right] \qquad \text{(Eq.3)}$$

$$I = \alpha x'_{(t)} \qquad \text{(Eq.4)} \qquad\qquad I = In\left[\alpha x'_{(t)}\right] \qquad \text{(Eq.5)}$$

Odor intensity can be determined in two different ways. The one way is to assume the linearity as Eq.4, the other way is to apply Weber-Fechner's law as Eq.5. If the parameters (α, t_A, t_B, k_1, k_2, N and C) in Eq.2, Eq.3 and Eq.4 can be identified by regression based on the experimental data, it is possible to establish the olfactory prediction model. In the previous report (Nagatsugu et al., 2010), t_A and t_B were fixed at 1s because t_A and $t_{B,}$ that is, the time intervals have little effect on the calculated odor intensity using this model. Additionally, in order to simplify the calculation, α was assumed to be 1.0 and N was estimated to be 10000. Furthermore, C, which means the concentration of the mucus on olfactory epithelium, was regarded to be equal to the odorant concentration in the experiment. By regarding the rest parameters (k_1 and k_2) variables, these variables were identified by least-square method using experimental data. In this calculation, "No odor" was substituted by 0, and "Overpowering" was substituted by 1.

Fig.9 demonstrated the comparison between the change of calculated odor intensity based on Eq.4 and the experimental values, which is the mean value of five subjects except subject A.

The experimental data and the regression line seems to be almost conformable, however, there can be seen a little discrepancy at the start and end of exposing time. Therefore, in order to get better conformance of the model, it was tried to shorten the time span for regression. Fig.10 shows the result of the changing the time span for regression obtained by both of exponential model (Eq.4) and the logarithmic model (Eq.5), and Table 2 shows the residuals of both equations for each condition. From this table, it was made clear that the exponential model is more applicable than the logarithmic ones. Therefore, future investigations will be made by means of the exponential model (Eq.4).

In Osako model, actual breathing method was taken into account. However, it seems not necessary to distinguish inhaling process from exhaling process. That is, it is possible to apply simpler exponential model as Eq.6.

$$x'_{(t)} = \alpha \exp\left[\beta t\right] \qquad \text{(Eq.6)}$$

Fig.11 shows the comparison between Osako model and the simple exponential model. There is little difference between them. Additionally, Fig.12 presents the comparison between the two exhaling method, nose exhaling and mouth exhaling. It can be said that there is also little difference between them. Thus, it is concluded that detailed Osako model is not needed to predict the decreasing process of odor intensity due to adaptation caused by continuous exposure to odor.

In Fig.13, two kinds of regression results obtained from the data in divided time spans and overall time span are drawn using simple exponential equation (Eq.6). It is found that the divided time spans can bring better accuracy than using overall time span.

Conclusions

As a result of the experiment of exposing subjects to odor constantly, it was made clear that adaptation is caused quickly, and adaptation will take longer time if the odorous concentration is higher.

Applying Osako model to the experimental data was successful, but exponential model brought better applicability than Weber-Fechner's law.

Additionally, simpler model ignoring breathing process was investigated. Consequently, it is concluded that Osako model is not needed to predict the decreasing process of odor intensity due to adaptation caused by continuous exposure to odor.

References

1. M.Osako(1991):Study on evaluation of environmental odor based on modeling of olfaction", Ph.D thesis Kyoto university (in Japanese)

2. Collegium Odor Control Law: Handbook Odor Control Law, Ver.4, 2005

3. P.Overbosch: A theoretical model for perceived intensity in human taste and smell as a function of time, Chemical Senses, Vol.11, no.3, pp.315-329, 1986

4. H.Nagatsugu, T.Yamanaka, K.Sagara, K,Hisashi, Y,Momoi and T,Takemura: Olfactory Adaptation in Odor Subjective Evaluation (Part2)Application of Olfactory Adaptation Model to Time Variation Properties of Odor Intensity, Summaries of technical papers of annual meeting of AIJ, prepublished 2010 (in Japanese)

5. U. Berglund: Dynamic properties of the olfactory system, Ann.N.YAcad.Sci., 237, pp.17-27, 1974

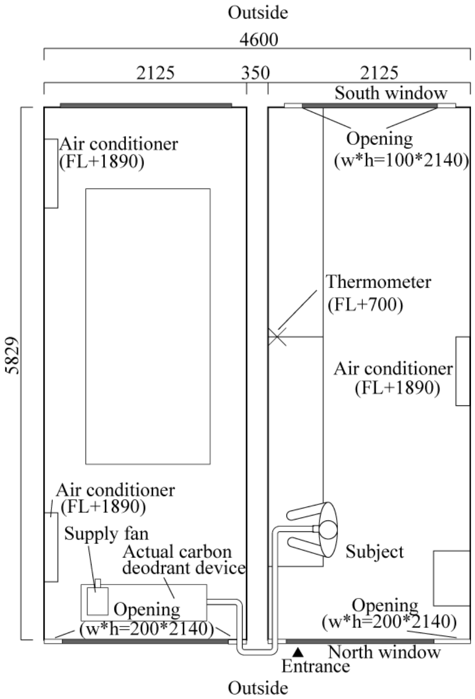

Fig.1 Laboratory plan

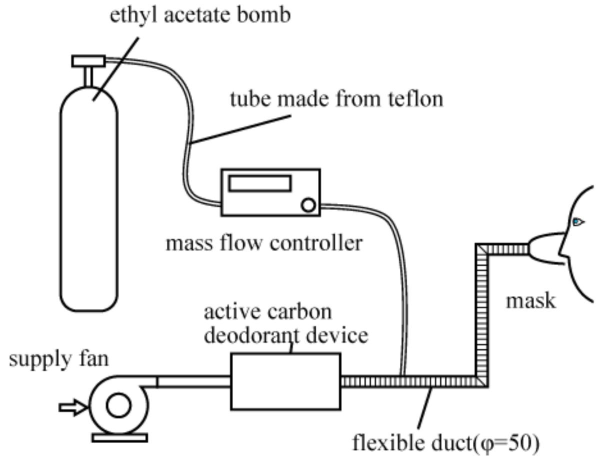

Fig.2 Odor presentation device

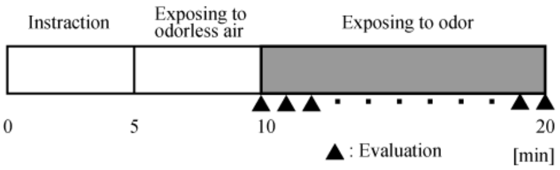

Fig.3 Time schedule

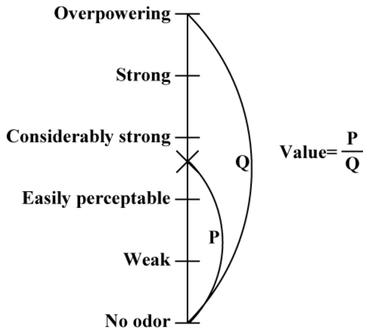

Fig.4 Scale of odor intensity and evaluation value of intensity

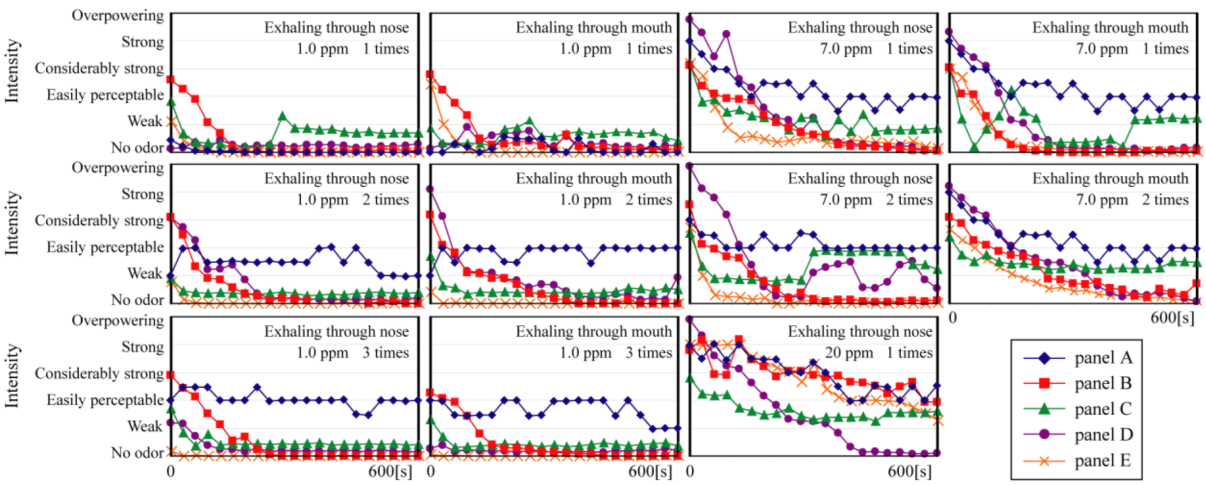

Fig. 5 Relation between exposing time and odor intensity for each trial, under condition of exposed concentration and breathing method

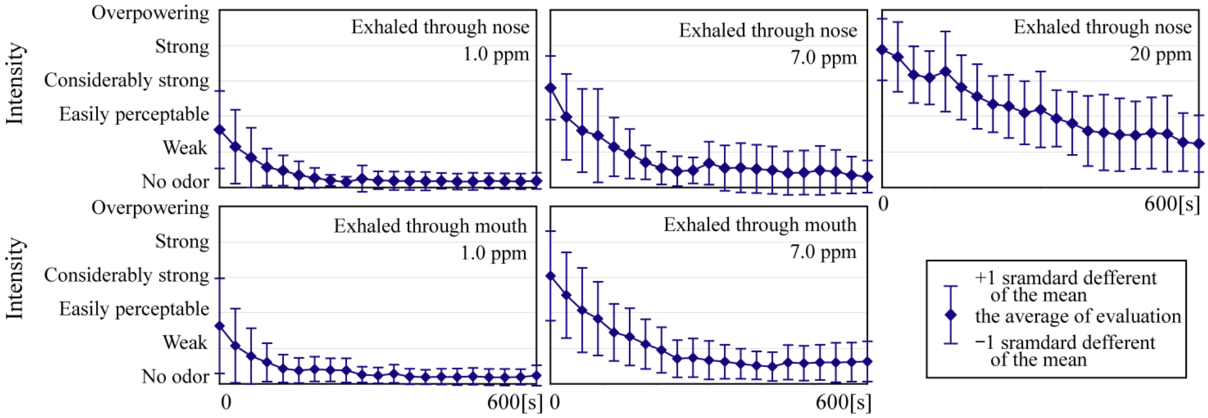

Fig.6 Relation between exposing time and average of odor intensity under each condition

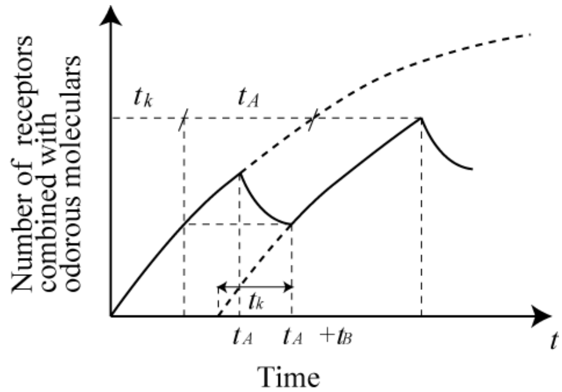

Fig.7 Conceptual graph of the number of the concentration for the Osako model

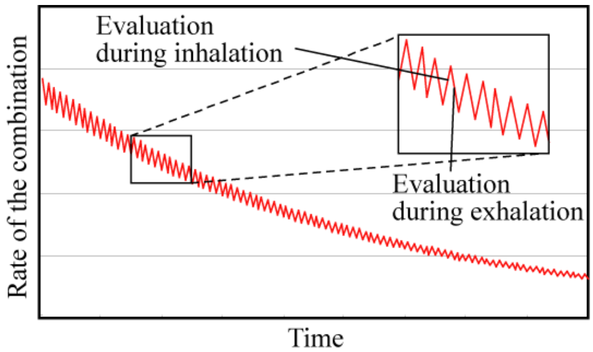

Fig.8 fluctuation of combination rate calculated by the Eq.2 and Eq.3 by Osako model

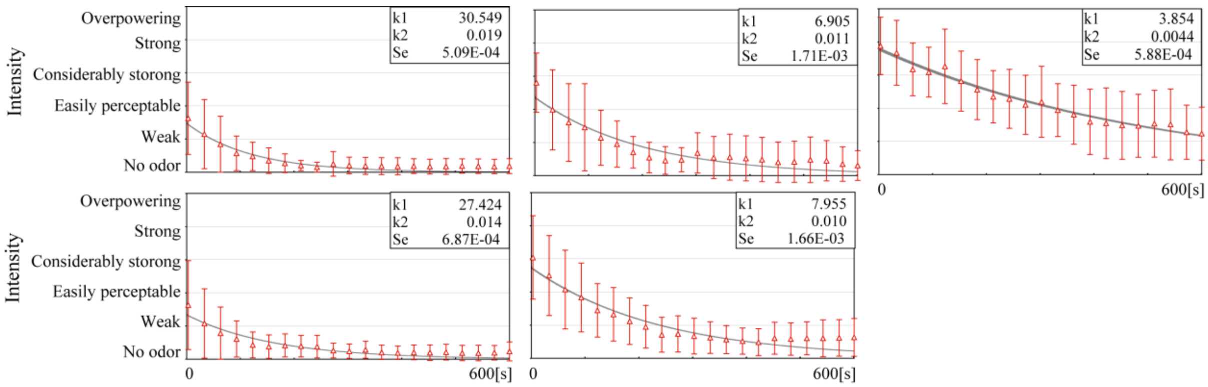

Fig.9 Comparison between change of calculated odor intensity based on Eq.4 and experimental values, which is mean value of five subjects except subject A

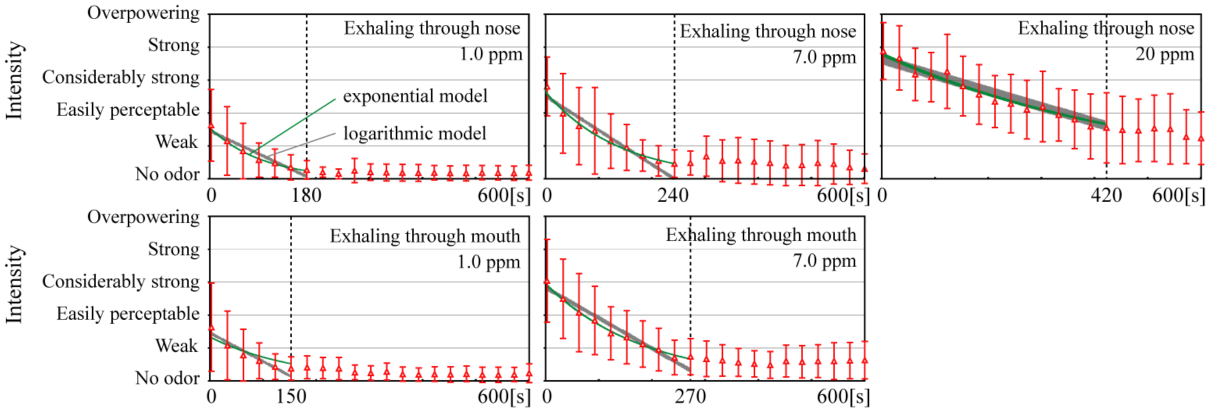

Fig.10 Result of changing time span for regression obtained by both of exponential model (Eq.4) and logarithmic model (Eq.5)

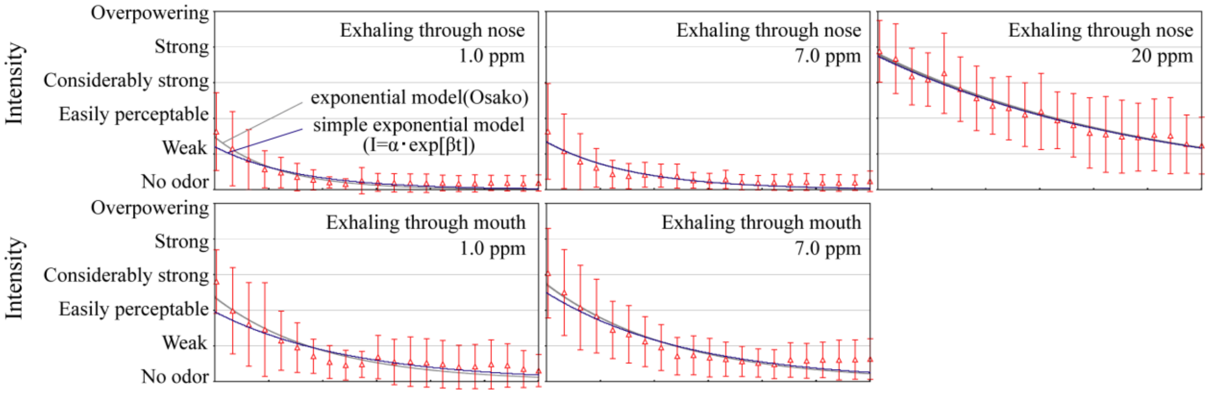

Fig.11 Comparison between Osako model and simple exponential model

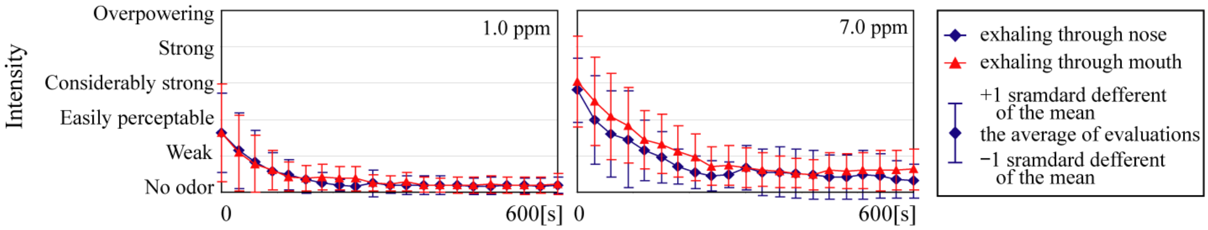

Fig.12 Comparison between two nose exhaling and mouth exhaling

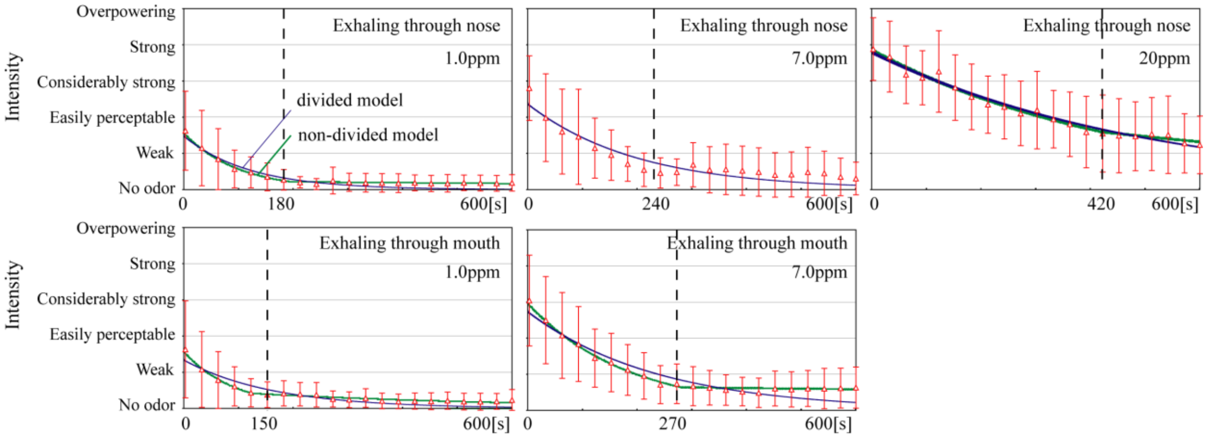

Fig.13 Two kinds of regression results obtained from data in divided time spans and overall time span using simple exponential equation (Eq.6)

Table 1 Odor concentration and the breathing methods

the method of the breath	Odor Concentration		
	1.0ppm	7.0ppm	20ppm
Exhaling through mouth	3 trials	2 trials	1 trial
Exhaling through nose	3 trials	2 trials	0 trial

Table 2 Residuals of regression lines

Concetration	Exhaling method	Exponential	Logarithmic
1.0ppm	nose	2.10E-05	6.45E-03
	mouth	1.26E-03	8.41E-03
7.0ppm	nose	2.11E-04	4.27E-02
	mouth	8.76E-05	2.41E-02
20ppm	nose	6.11E-04	1.07E-01