Olfactory adaptation model based on change of odor threshold using impulse response function

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ABSTRACT

It is well known that the olfactory sensitivity changes with exposure time and concentration of odor under continuous exposure to odor in the air. This decrease of odorous sensitivity, the increase of odorous threshold in other words due to continuous exposure to odor is called olfactory adaptation.

The object of this study is to make an olfactory model which can be applied for predicting the olfactory sensation. Firstly, the experiment was conducted to obtain the data of psychological response of odor intensity using a continuous scale of odor intensity under the odor concentration with step change on time serious. Ethyl acetate was used as the target odor.

Twelve panels (subjects) were employed for this experiment. These subjects smelled the odorous air blown out of a duct carrying the air injected with ethyl acetate with a controlled generation rate. As a result, it was turned out the odor intensity decreases exponentially as time due to olfactory adaptation.

Secondly, the theoretical olfactory model is constructed. This model is based on the impulse response function. By regression analysis on the varying odor intensity, two parameters of the exponential response function are identified. One parameter is the amplitude of response to unit impulse, and the other parameter is exponential constant. Odor intensity can be predicted under any variation of odor concentration by this theoretical model of response function. The accuracy of this olfactory model is examined by comparing the measured odor intensity with predicted odor intensity under odor concentration varying with steps in time series.

Lastly, this model is applied to some typical odor concentration variations, and the possibility of controlling ventilation rate to keep the intensity of body odor inside a room less than a certain level in order to save energy will be noted. In addition, calculation method of varying ventilation rate to control the odor will be presented.

Additionally, the model applicability was tested under recovery process of olfactory adaptation using instantaneous exposure of odor under recovering state with fresh air.

It is turned out that this theoretical olfactory model is quite useful to predict the odor intensity under adapting state rather than recovering process.

KEYWORDS

Odor, Olfactory adaptation, Response function, Olfactory threshold, Odor intensity

1 INTRODUCTION

There is no doubt that the odor sensation is the most important sensation for us to judge the indoor air quality. It is, however, olfactory adaptation prevents us from sensing the change of indoor air quality during the stay indoors. There are many researches on the olfactory adaptation (Ekman et al., 1967) (Cain, 1974) (Berglund, 1974) (Berglund et al., 1978)

(Overbosch, 1986) (Osako et al. , 1991), but due to the difference of adaptation depending on the chemical compounds and it’s concentration, there is no method to predict the odor intensity of the people under adapted situation inside the rooms. In order to control the ventilation rate to keep the indoor air quality to be good for occupants, a prediction method of odor intensity is essential, but the practical method with wide applicability has not yet provided to architectural engineers.

The authors, therefore, try to construct the practical olfactory model which can be used by engineers to predict the odor intensity under the concentration input of an odor. For the applicability to the varying odor concentration, the impulse response model of the increment of odor threshold concentration is adopted, that is, the linearity of adaptation is assumed.
In this paper, the result of experiments to measure the change of odor intensity under step change of concentration of ethyl acetate will be presented and applicability of the olfactory model to the adaptation and recovery process will be investigated.

A part of this paper is republished from the previous paper by the authors (Yamanaka et al., 2014).

2 EXPERIMENT FOR OLFACTORY ADAPTATION TO ETHYL ACETATE

2.1 Experimental Set-Up

In Figure 1, the outline of experimental apparatus is shown. Panel means an observer who sniffs the odorous air from the diffuser and votes the odor intensity using a scale for evaluation (Figure 2). The voted odor intensity is normalized by the maximum value “overpowering” according to the length on the scale. As an odor, ethyl acetate was used. The concentration of ethyl acetate is set at 1.5 ppm, 4.0 ppm and 10.7ppm. The experiment took 30 minutes as shown in Figure 3. There are two kind of exposures after the refreshment period, while panels are exposed to odorless air made by deodorization unit containing activated carbon for five minutes. During the first and second exposures, air with a couple of constant concentrations is supplied from the diffuser to a nose of panel in turn.

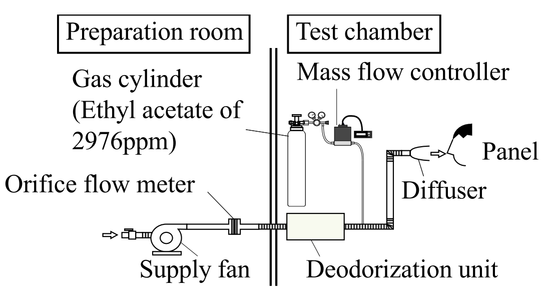

Figure 1: Experimental apparatus

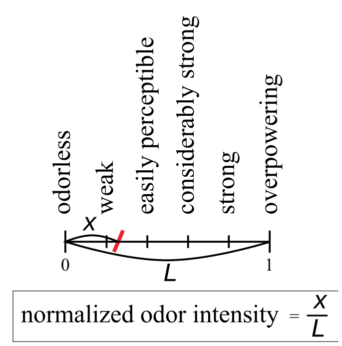

Figure 2: Scale for odor intensity

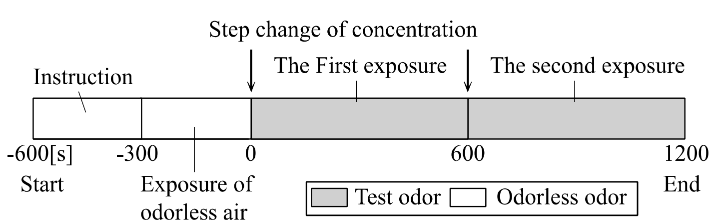

Figure 3: Time schedule of experiment

The combinations of ethyl acetate concentration in the first and the second exposure are listed in Table.1. Six cases are applied for the experiment. As the threshold concentration of ethyl acetate is 0.3ppm, the concentration ratio to the threshold ranges from 5 to 36. At the time of changing the concentration, that is, 0, and 600 seconds in Figure 3, the panel are told to stop breathing for a while to wait the concentration becomes stable. Each panel voted odor intensity using the scale intermittently every 30 minutes. 13 panels (7 male and 8 female students) participated in the test one by one. The age of panels are from 20 to 23 years old with normosmia, which is tested by 5 standard week odors (T&T olfactometer). The test was conducted in a small chamber located outside with good ventilation.

Table 1: Cases for cousing ncentration change of ethyl acetate

Case Number	**First Exposure Concentration [ppm]**	**Second Exposure Concentration [ppm]**
No.1	1.5	4.0
No.2	1.5	10.7
No.3	4.0	1.5
No.4	4.0	0.7
No.5	10.7	1.5
No.6	10.7	4.0

2.2 Results on Odor Intensity

The result of voted odor intensity are shown in Figure 4. Odor intensities of 13 panels are drawn in the graphs. Most of odor intensity decay exponentially in the first exposure period, and then rapid increase can be seen in the case that the second exposure concentration is larger than the first exposure concentration. In most cases, the large variation depending on panels is confirmed. After around 5 minutes from the first exposure, some panels lose odor sensation, but other panels senses odor to some extent. From a analysis of the variation pattern of individual intensity variation, it was turned out that there are three types of panels, that is, variation type, decay type and middle type. This individual variation is quite difficult to explain, so the average value is important and also the target value for the olfactory model to predict.

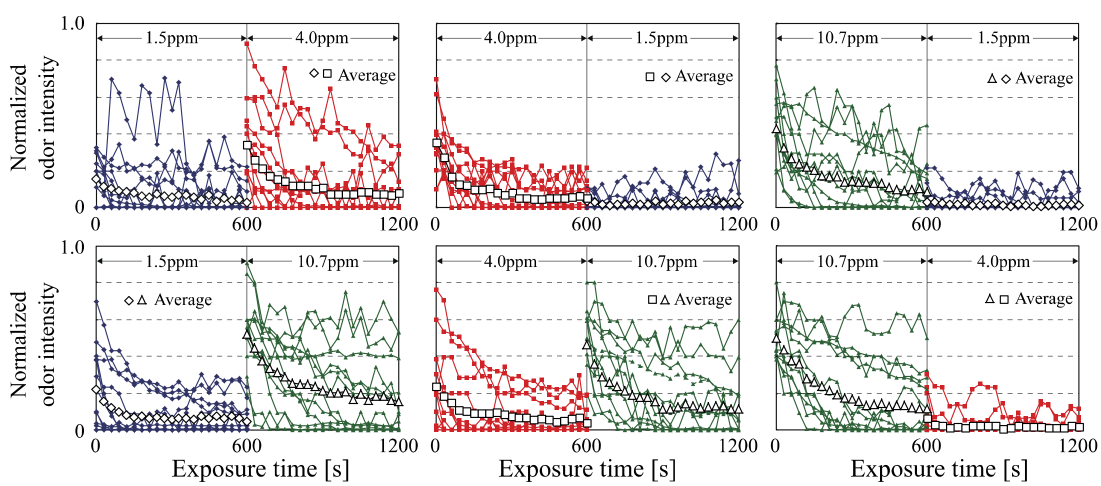

Figure 4: Variation of odor intensity under six conditions

2.3 Olfactory Adaptation Model Based on Impulse Response Function

Here, with a purpose of constructing an olfactory model to predict the odor intensity taking account of olfactory adaptation, the following theory are presented. At first, it is assumed that Weber-Fechner's law is consistent even under the adaptation process.

Using Weber-Fechner's law, the following Equation (1) can be written.

$$I_{(t)} = k_c \log_{10} \frac{C_{(t)}}{C_{th0} + \Delta C_{th(t)}} \tag{1}$$

Here, $I_{(t)}$ is normalized odor intensity at time t, $C_{(t)}$ is the concentration of odorous compound at time t, C_{th0} is the threshold concentration of target odor, $\Delta C_{th(t)}$ is the increment of threshold concentration, and k_c is a constant.

From Equation (1), Equation (2) can be written.

$$I_{(t)} = k_c \log_{10} C_{(t)} - k_c \log_{10} C_{th0} \tag{2}$$

In Figure 5, the relationship between the concentration of ethyl acetate and odor intensity is shown using the initial odor intensity data at the initial time at 0 of the first exposure. From the regression line, the value of k_c and C_{th0} were identified as 0.321 and 0.411[ppm] for ethyl acetate.

If $C^*_{th(t)}$ is defined as an impulse response function for unit impulse at time of zero, $\Delta C_{th(t)}$ can be calculated from the following Equation (3).

$$\Delta C_{th(t)} = \int_0^\infty C_{(t-\tau)} C^*_{th(t)} d\tau \tag{3}$$

From some trials by means of various functions, the exponential decay function is turned out to be quite valid to fit the calculated odor intensity to the measured odor intensity. $C^*_{th(t)}$ is ,therefore, defined as follows (see Figure 6).

$$C^*_{th(t)} = \alpha \cdot e^{-\beta t} \tag{4}$$

Here, α and β are constants suitable for the kind of odor. If α and β are known, odor intensity in time series can be calculated using Equation (5).

$$I_{(t)} = k_c \log_{10} \frac{C_{(t)}}{C_{th0} + \int_0^\infty C_{(t-\tau)} \cdot \alpha \cdot e^{-\beta\tau} d\tau} \tag{5}$$

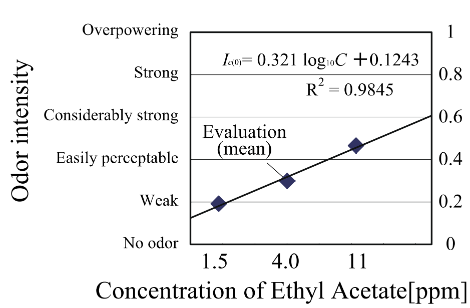

Figure 5: Relationship between ethyl acetate concentration and odor intensity

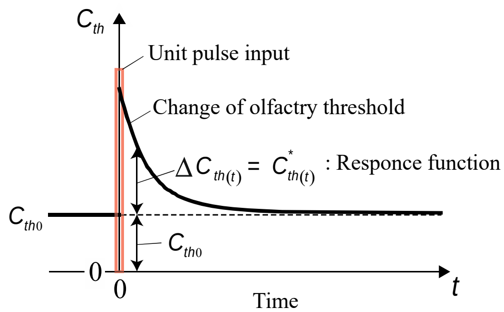

Figure 6: Relationship between ethyl acetate concentration and odor intensity

Using the data of the first exposure, the least square method was applied to obtain the most appropriate values of α and β were identified. As a result of identification, $2.03\square10^{-3}$[1/s] for α and $5.38\square10^{-3}$ [1/s] for β were obtained.

The correlation between measured normalized odor intensity and predicted normalized odor intensity is shown in Figure 7. As a coefficient of determination of 0.885 was obtained, the validity of the model parameters are considered to be confirmed.

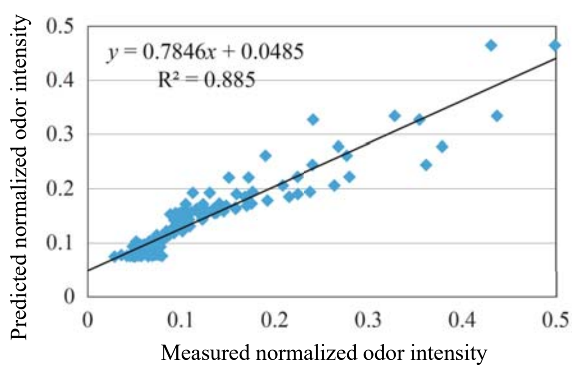

Figure 7: Comparison between measure odor intensity and predicted odor intensity during the first exposure of ethyl acetate by means of olfactory adaptation model based on impulse response function

By using identified value for values for four constants (k_c=0.321, C_{th0}= 0.411[ppm], α= $2.03\square10^{-3}$[1/s] for and β= $5.38\square10^{-3}$ [1/s] for the first exposure), the calculated odor intensity and the measured odor intensity were shown in Figure 8.

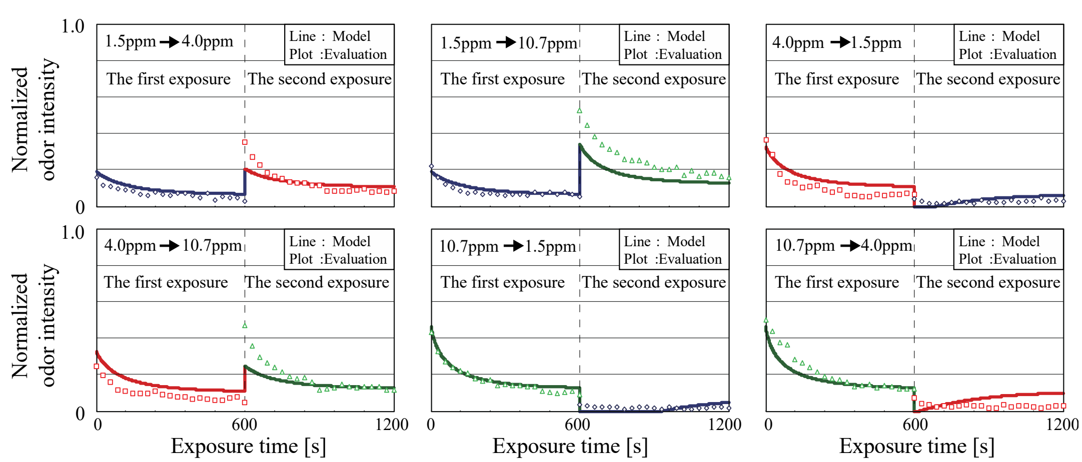

Figure 8: Relationship between ethyl acetate concentration and odor intensity (Model calculation and Experimental Value)

From Figure 8, odor intensity obtained by model calculation is almost following the measured odor intensity change, and especially the error in the first exposure is less than that in the second exposure. The reason of this tendency seems that the all the parameters were identified using the data in the first exposure.

3 EXPERIMENT FOR OLFACTORY ADAPTATION AND RECOVERY OF INDIVIDUAL PANEL

Another experiment was conducted to investigate the applicability of the olfactory model presented in the last chapter. As time schedule was shown in Figure 9, not only the adaptation process but also recovery process was examined. In the last 12 minutes, each panel was exposed to intermittent 10 second exposure of 7.5 ppm of ethyl acetate every 1 minute during odorless exposure for 12 minutes. This change of concentration was controlled by mass flow controller. In the first part of the test, shot time exposures of three concentrations were given to panels to know the relationship between concentration and odor intensity. In this experiment, the olfactory model was applied to individual odor intensity of each panel, in addition to the average value of all panels. The number of panels was five (two males and three female students whose age are from 19 to 21 years old).

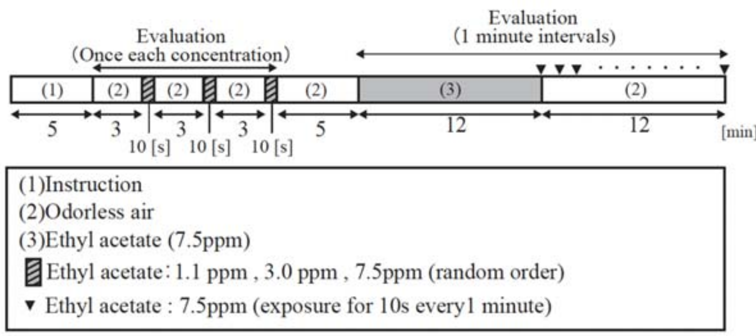

Figure 9: Time schedule of experiment

Figure 10 shows the relationship between the concentration of ethyl acetate and normalized odor intensity from the votes at the intermittent exposures of 10 seconds during odorless air exposure shown in Figure 9. As is seen in Figure 10 and 11, the values of model parameters, k_c, C_{th0}, α and β are not the same as previous experiment introduced in the last chapter. It means that enough number of panels will be needed to identify the valid value of parameters. It is not certain that the 13 panels in the last chapter were enough or not to apply the model to wide usage of the prediction of changing odor intensity. Generally speaking, more than tens of panels might be necessary to determine the model parameters. It can be said that the further research to get data from many panels will be needed.

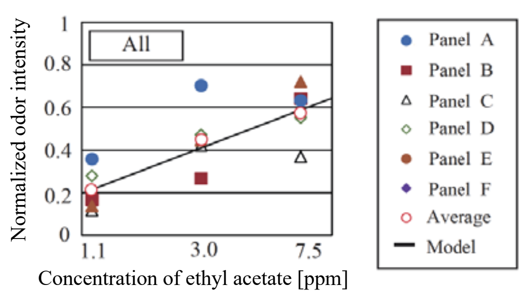

Figure 10: Relationship between concentration of ethyl acetate and normalized odor intensity

In Figure 11, the calculated odor intensity using identified values of model parameters were drawn in each graph. The calculated odor intensity is in good agreement with the measured data, but it seems that it is difficult to apply this model to recovery process. One reason is the difference of the time needed for the odor sense to recover under odorless air exposure. Recover process seems to be faster than adaptation process. The number of data is not enough to reach a conclusion, but the further research will be needed to examine the applicability of the olfactory model based on the impulse response function to the recovery process of olfactory adaptation.

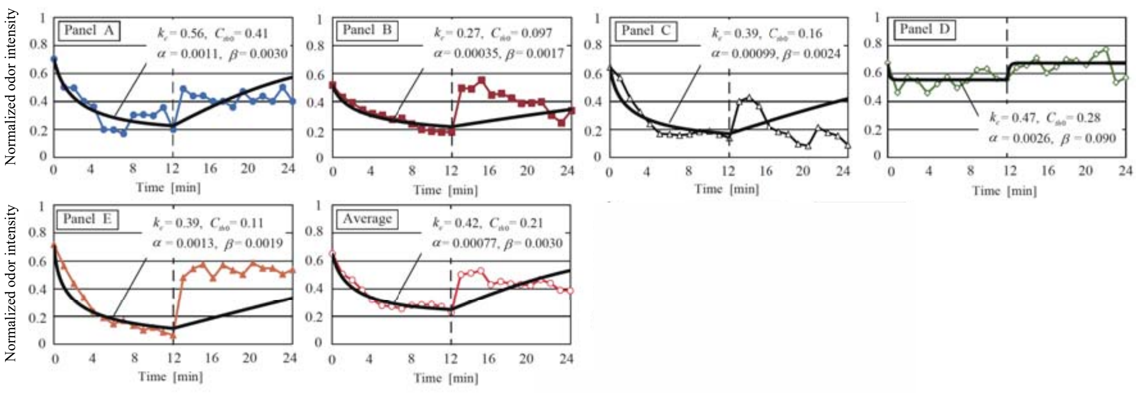

Figure 11: Relationship between ethyl acetate concentration and odor intensity

It is, additionally, turned out that the concentrations of ethyl acetate in this experiment (Chapter 3) were doubtful, because the sampled test airs were analysed in some company and the concentration value of about half of intended concentration. The model parameters in this chapter might be wrong, but the concluding remarks are not affected by these concentration errors.

4 CONCLUSIONS

From the experiments and investigation on the characteristics of olfactory adaptation and recovery process, the following remarks were concluded:

1) The decay process of odor intensity under adaptation depends on the individual, but the average value of odor intensity decays exponentially.
2) The olfactory model based on Weber-Fechner`s law and impulse response function is valid to predict changing odor intensity under adaptation process using identified model parameters derived from the experimental data.
3) In the recovery process of olfactory adaptation, there is large discrepancy between odor intensity calculated by the olfactory model and measured value by the experiment with 6 panels. The necessity of further research with a large number of panels is confirmed.

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