Layered Modeling of Sensory and Affective Responses: Modification by Considering Unique Factors of Affective Responses

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Abstract. Layered modeling is used to understand the semantic structure of sensory and affective responses acquired through the sensory evaluation of products. In this paper, we propose a method for establishing layered models, which considers unique factors, that is, unpredictable components independent of other variables. When creating a layered model, the subjective rate to each verbal criterion of sensory evaluation is treated as a variable, and the variables with the lowest estimation accuracy are remodeled. Conventionally, the determination coefficient of each variable has been used as a criterion for estimation accuracy. However, this value is influenced by unique factors, including random repetition errors. This influence should be removed because the estimation of unique factors is not improved by modifying the model structure. We consider the influence of unique factors of a certain variable by using the determination coefficient of linear regression by using the other variables. We applied the modified modeling method to the sensory evaluation of miso, or fermented soybean paste.

Keywords: Structural equation modeling · Sensory evaluation · Miso

1 Introduction

In understanding and designing the affective responses experienced from products, it is useful to mathematically model the relationship between the sensory and affective responses. Layered modeling is one of the methods used to establish such models [1–6]. Figure 1 illustrates an example of a layered model for tasting experiences. Each node corresponds to the score assigned to a verbal criterion, which is typically an adjective. For example, the score for *mild* is expressed as follows:

$$y_{mild} = -0.31x_{bitter} + 0.25x_{umami} + e \quad (1)$$

where x is the score for sensory word, y is the score for affective and evaluative words, and e is a random error. This formula indicates that food with little bitterness and more umami is considered milder. The layered model expresses the semantic structure of sensory and affective responses in an easy-to-understand manner.

H. Shoji et al. (Eds.): KEER 2020, AISC 1256, pp. 168–173, 2020.
https://doi.org/10.1007/978-981-15-7801-4_17

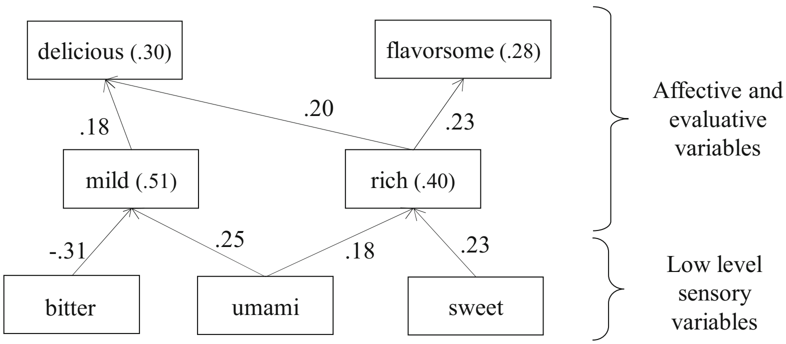

Fig. 1. Layered model of sensory and affective responses to foods.

Figure 1 shows an example of a layered model of sensory and affective responses to foods. The value beside the edge is the strength of the relationship between two variables. The value following the adjective is the R^2 value, which is the estimation accuracy of the variables for the affective and evaluative words. The variables in the bottom layers are correlated to each other.

There are several methods for establishing a layered model. The method in [1] automatically determines the structure of the model, including the number of layers, and validates the model by structural equation modeling, whereas layered models are designed or hypothesized by experienced assessors in other methods. However, there is a concern with the method in [1]. In the process of creating a layered model, variables with the lowest estimation accuracy are remodeled. Conventionally, the determination coefficient of each variable has been used as a criterion for estimation accuracy. However, this value is influenced by unique factors (i.e., unpredictable components that are independent of other variables). Unique factors include random repetition errors. This component should be considered when modeling (see Sect. 2.2), which the method used in [1] did not. In case that the variables include large unique factors, the previous approach may establish incorrect models. In this paper, we propose a method for establishing layered models that consider unique factors, and we apply the method to the sensory evaluation of miso, or fermented soybean paste.

2 Method: Layered Modeling

2.1 Conventional Modeling Method

First, structural equation modeling (SEM) is applied to a two-layered model in which the low-level sensory items are explanatory variables, and the upper-level affective and evaluative items are objective variables, as shown on the left in Fig. 2. The explanatory variable with the lowest estimation accuracy, R^2, is placed in a higher layer to be explained by other affective and evaluative variables, as shown on the right in Fig. 2. By repeating this operation until the statistical criteria of SEM are satisfied, a multi-layer model can be obtained.

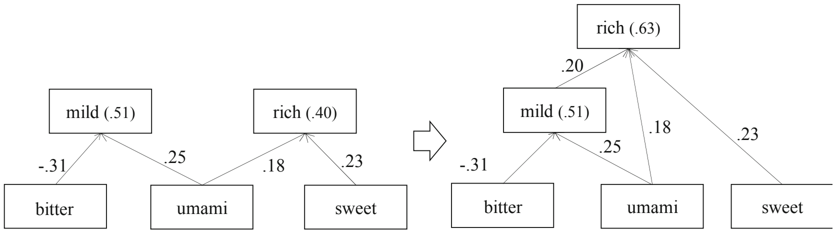

Fig. 2. Stepwise development of the layered model [1]. The variable with the lowest value in the parentheses (i.e., *rich*) is relocated into a higher layer.

2.2 Modification by Considering Unique Factors

As mentioned in the Introduction, the method using R^2, as shown in Sect. 2.1, does not consider the presence of unique factors that are independent of other components. Unique factors are unpredictable by modifying the model structure, so when creating a model, their effects should be removed. Therefore, the objective variable is predicted by linear regression of all other variables as shown in (2), and the coefficient of determination, $\hat{R}^2$, is introduced. This value is the maximum estimation accuracy of linear predictive models in principle.

$$\hat{y}_i = \sum_{i \neq j} a_{ji} y_j + \sum b_{ji} x_j \tag{2}$$

$$\hat{R}_i^2 = \frac{\sum_{k=1}^{n} (\hat{y}_{ik} - \bar{y}_i)^2}{\sum_{k=1}^{n} (y_{ik} - \bar{y}_{\mathrm{i}})^2} \tag{3}$$

where x is the low-level sensory variable, y is the upper-level affective and evaluative variable, $\hat{y}$ is the estimated y value, $\bar{y}$ is the mean of y, a_{ji} and b_{ji} are the coefficients that show the strength of the connection between variable i and variable j, and n is the number of samples.

The variable with the smallest ratio of R^2 to $\hat{R}^2$ is the one with poor estimation accuracy. Therefore, in the model considering the unique factors, a model is established using $R^2/\hat{R}^2$ instead of R^2.

3 Example Using the Sensory Evaluation of Miso (Fermented Soybean Paste)

3.1 The Sensory Evaluation of Miso

Participants tasted twelve kinds of miso and scored eleven low-level sensory items, and nine affective and evaluative items in seven levels. These items were selected among approximately 200 potential words used for expressing foods by voting tasks involving several assessors. The low-level sensory items are represented by uni-sensory organs and they represent gustatory, osmatic, and textural aspects, including *salty, sour, bitter, melty, sticky, rough, fermented, umami, moist, astringent,* and *soy sauce-flavored.* The affective and evaluative items are composed of the integration of multiple sensory channels, feelings, and overall significance or importance, which includes *delicious, simple, mild, sharp, rich, flavorsome, mellow, refined,* and *light.* The meanings or definitions of these words were well explained to the participants before the rating task. They rinsed their mouth with tea before each evaluation so that the evaluation would not be influenced by the miso that had been eaten before.

3.2 Participants

The participants were nine people from Nagoya University. None of them studied or worked in the food industry.

3.3 Established Layered Models

The obtained evaluations were standardized for each individual and item, and modeled using the method described above. Figure 3 shows the layered model created by the conventional method, and Fig. 4 shows the layered model considering the unique factors. The values next to the word are R^2 and $R^2/\hat{R}^2$. We present only statistically significant links. The bottom variables are correlated.

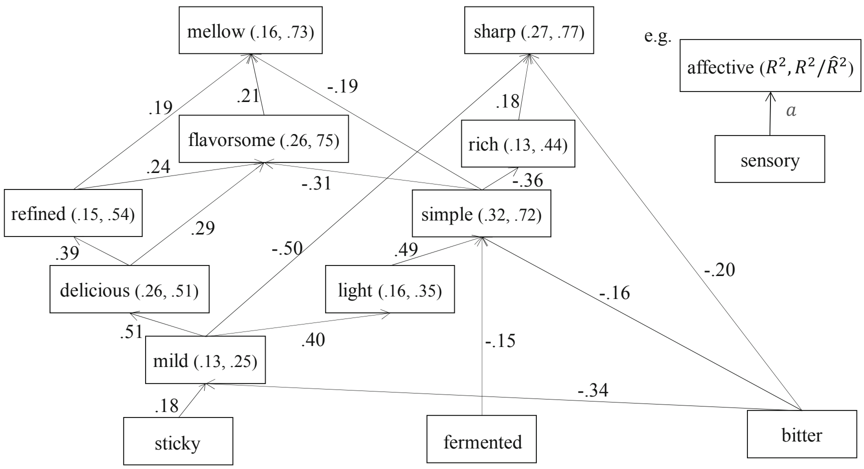

Fig. 3. Layered model established by the conventional method GFI = 0.95, CFI = 1.00, and χ^2 = 43.7 $df = 45$ ($p < 0.53$).

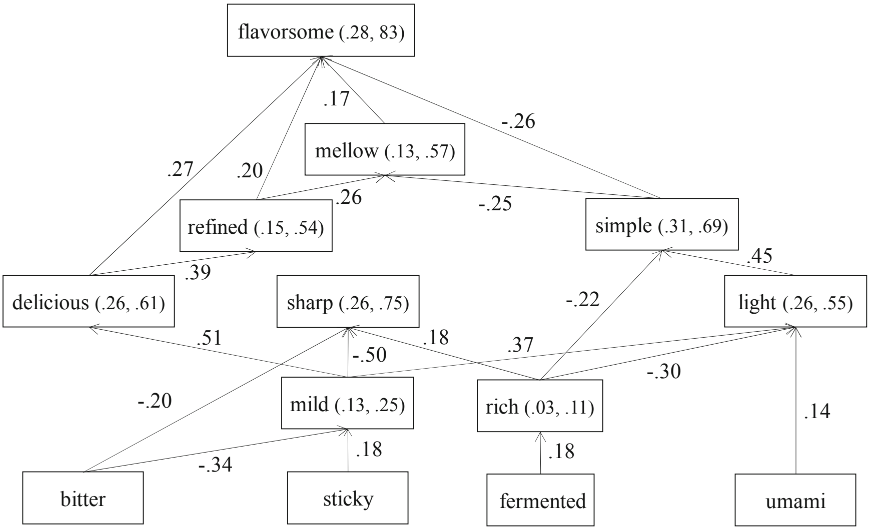

Fig. 4. Layered model established by the new method GFI = 0.95, CFI = 1.00, and χ^2 = 50.3 df = 53 (p < 0.58).

3.4 Elementary Screening for the Semantic Validity of Models

As shown in Figs. 3 and 4, in both types of models, the stickier and less bitter *miso* were judged to be mild. *Mild* positively affected *delicious*, and delicious miso was judged as refined and flavorsome. Mild miso was judged as light, and *light* positively affected *simplicity*. A simple miso was not judged as flavorsome or mellow. These results are semantically reasonable.

Some words were placed on different layers between the two models. For example, *simple* was placed on a lower layer than *rich* (the taste which is composed of a greater number of gustatory factors) in the model established by the conventional method, whereas *rich* is placed in a lower layer than *simple* in the model established by the new method. As a result, the end of the edge from *fermented* is *simple* in Fig. 3, whereas it is *rich* in Fig. 4. Although their semantic relationships were similar, *fermented* directly affected *simple* negatively in Fig. 3, but indirectly in Fig. 4. Similarly, *fermented* indirectly affected *rich* positively in Fig. 3, but directly in Fig. 4. However, *simple* and *rich* had a negative relationship.

The two types of models largely agree with each other, except for *umami*. In the model established by the conventional method, as shown in Fig. 3, *umami* was not significantly linked with the other variables; however, *umami* positively influenced *light* in the model established by the new method, as shown in Fig. 4. Nonetheless, this influence was not potent in terms of the coefficient value (.14) between *umami* and *light*. To systematically compare the semantic validity of these two types of models, a method used in [7] can be used, but remains to be studied in the future. In [7], several assessors compared a few layered models regarding their semantic validity.

4 Conclusion

We modified a method of layered modeling for sensory and affective responses, which was originally developed in [1]. The modified method establishes a layered model based on net R^2, excluding the effects of unique factors that cannot be predicted by the combination of variables in the model. We used food samples as an example, but this method is expected to be applied to other types of stimuli.

Acknowledgment. This study was supported in part by MEXT KAKENHI (17H04697).

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