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CROSS-MODAL EFFECT BETWEEN TASTE AND SHAPE CONTROLLED BY CURVATURE ENTROPY

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ABSTRACT

In recent years, cross-modal effects in which perceptions interact with each other have been drawing attention. In the case of the cross-modal effect between vision and taste, the effect of the angularity of shapes on taste has been widely studied while there has been little research on the other features of shapes. Previous studies have shown that the emotional valence arisen from visual perception causes the cross-modal effect between vision and taste. Therefore, this study focuses on the complexity of shapes, which is said to influence emotional valence, as a visual stimulus and aims to confirm the cross-modal effect induced by its sensation. First, based on previous research, the hypotheses about the effects of the complexity of shapes on taste were made. Second, by using particle swarm optimization algorithm, closed curve shapes were generated based on curvature entropy, a quantitative index of the complexity of shapes, which indicates the randomness of curvature transition. Third, cup holders, which had these closed curve shapes on their sides, were created by using a 3D printer. Finally, by comparing the tastes of orange juice in these cup holders, the effect of the complexity of shapes on the perception of sweetness, sourness and intensity was confirmed. The results suggest that the complexity of shapes controlled by curvature entropy weakens the perception of sweetness whereas it enhances that of sourness and intensity. This finding can be used for reducing sugar intake in bottle packaging.

Keywords: *cross-modal, shape, complexity, taste, curvature entropy*

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1. INTRODUCTION

In recent years, cross-modal effects in which perceptions interact with each other have been drawing attention (Yanagisawa, 2018; Lin et al., 2021). In the case of the cross-modal effect between vision and taste, the effect of the angularity of shapes on taste has been widely studied (Blazhenkova & Kumar, 2018; Velasco et al., 2015; Velasco et al.,2016; Ngo et al., 2011; Becker et al., 2011; Van Rompay et al., 2017) while there has been little research on the other features of shapes (Turoman, 2018; Salgado-Montejo et al., 2015). Previous studies have shown that the emotional valence arisen from visual perception causes the cross-modal effect between vision and taste (Turoman, 2018; Salgado-Montejo et al., 2015). Therefore, this study focuses on the complexity of shapes, which is said to influence emotional valence (Palmer, Schloss, & Sammartino, 2013), as a visual stimulus and aims to confirm the cross-modal effect induced by its sensation. From the previous studies, it is estimated that the complexity of shapes controlled by curvature entropy weakens the perception of sweetness whereas it enhances that of sourness and intensity.

This paper is organized as follows. Section 2 illustrates the method to generate shapes using index of the complexity of shapes. Section 3 presents the method of the experiment. Then, Section 4 shows results and discussion of the experiment. Lastly, Section 5 provides conclusions.

2. SHAPE GENARATION

2.1. Quantification of complexity

Curvature entropy H was proposed as a quantitative index of the complexity of shapes (Ujiie et al., 2012; Matsumoto et al., 2019; Okano et al., 2020; Kato & Matsumoto, 2020). On calculation of H, firstly, the closed curve shape is divided into equal portions and the curvature κ on each portion is calculated. Next, using the maximum diameter D of the shape, the dimensionless curvature κ^* is calculated by Equation (1). Here, κ^* is used to obtain the dimensionless curvature function $\kappa(l)$, which is a function of the curve length l and κ^*, as shown in Fig. 1.

$$\kappa^* = \kappa D \tag{1}$$

Then, κ^* on each portion is quantized into each state s_i ranging from -E to E (the total number of states is V) as shown Fig.1.

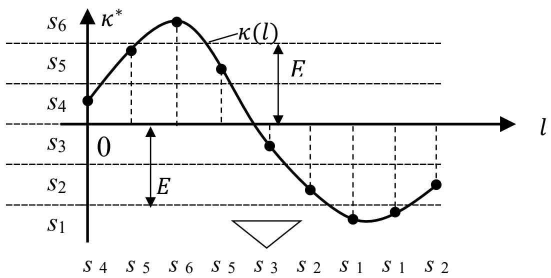


Figure 1. Plotting curvature of each curve unit and classifying curvatures into some groups (quantization)

Lastly, H is defined as Equation (2) based on q_i (the occurrence probability of state s_i) and $q_{i,j}$ (the transition probability from state s_i to state s_j).

$$H = -\frac{1}{\log_2 V}\sum_{i=1}^{V}\sum_{j=1}^{V} q_i q_{i,j} \log_2 q_{i,j} \tag{2}$$

2.2. Generation of closed curve shapes

In this study, closed curve shapes are drawn by cubic Bézier curves with 14 connection points. Cubic Bézier curves are the curves defined by connection points and control points (Yamaguchi, 1988). Next, this study used particle swarm optimization algorithm for generation of closed curve shapes. This is an algorithm to search for a global solution by considering the parameters for the optimization as particles (Kennedy, 1995). Each particle has four pieces of information: current position, private best position, global best position, and velocity. Based on this information, an optimal solution candidate is obtained by updating the current position and velocity of each particle until the degree of adaptation f satisfies the allowable range $f_{\max}$. In generation, the distance moved from each connection point of the basic shape was used as the current position in the particle swarm optimization. Additionally, the symmetry of the shape, the flatness of the upper and bottom parts, and the maximum distance moved from each connection point were set as the constraints for the generation of closed curve shapes.

3. METHOD

This section illustrates the conditions for the experiment.

1. Participant：

In order to verify the effects of the complexity of shapes against other shape features, samples were divided into 3 groups, showing other shape with the same level of complexity for each group. Additionally, the previous research pointed out that age can modulate the degree of cross-modal effects (Forde & Delahunty, 2004). Therefore, subjects were divided with minimum age differences within and between groups.

- 1st group: 10 participants (7 males, 3 females), ranging in age from 20 to 22 years (M = 21.4, SD = 0.8).
- 2nd group: 10 participants (7 males, 3 females), ranging in age from 20 to 23 years (M = 21.6, SD = 1.0).
- 3rd group: 10 participants (7 males, 3 females), ranging in age from 19 to 22 years (M = 21.0, SD = 1.1).

2. Sample shapes：

The parameters of H on cupholder shapes were optimized for human cognition, and a coefficient of determination R^2 of logarithmic approximation was 0.634 when $\{E, V\}$ were {0.4, 15}. Under these parameter settings, 12 closed curve shapes (three shapes for each level of H) were generated in total, using the four levels of H as the objective function to generate shapes other than the basic shape, as shown in Fig.2. Cup holders with the generated closed curve shape on its silhouette was created by using a 3D printer. Then paper cups in these cupholders were filled with 100% orange juice and presented to the participants. Besides, the cup holders were painted black to make it easier to recognize the silhouette of cupholders referring to the past research (Van Rompay et al., 2017).

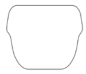
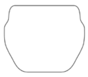
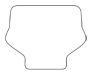
	Sample 1 (Basic Shape)	Sample 2	Sample 3	Sample 4	Sample 5
Curvature entropy	0.047	0.071	0.095	0.118	0.142
Group 1					
Group 2					
Group 3					

Figure 2. Closed curve shapes generated by PSO

3. Environment：

To minimize the effects of sound (Guetta & Loui, 2017), temperature (Maehashi, 2011), and lighting (Van der Heijden et al., 2021), experiment was conducted in a quiet room where the temperature was kept at about 20 degrees Celsius, and the illumination was kept at about 520 Lx. As shown in Fig.3, two samples placed at eye level were tasted with a straw, without being touched by hands since the surface roughness of cupholders can affect taste (Van Rompay et al., 2021).

Figure 3. Experimental environment

4. Evaluation：

From the two samples out of five samples allocated for each group, the participants were asked to select the sample with the greater sweetness, sourness, and intensity. Evaluations were conducted 21 times per one participant, with the first evaluation being a practice session.

To eliminate the effect of the presentation order, which has been pointed out in previous studies (Pich et al., 2020), the participants were asked to evaluate the samples both in the order of sample A to sample B and sample B to sample A.

4. RESULTS AND DISCUSSION

Based on Thurston's pairwise comparison method, evaluated values on Thurston's scale of taste were calculated (Indo, 1962). Using the evaluation value of the basic shape (Sample1) as the reference value, these evaluation values were corrected by calculating the difference from the reference value in order to make comparisons between groups. Figures.4-6 illustrate the relationship between curvature entropy and corrected Thurstone's scale of sweetness, sourness and intensity.

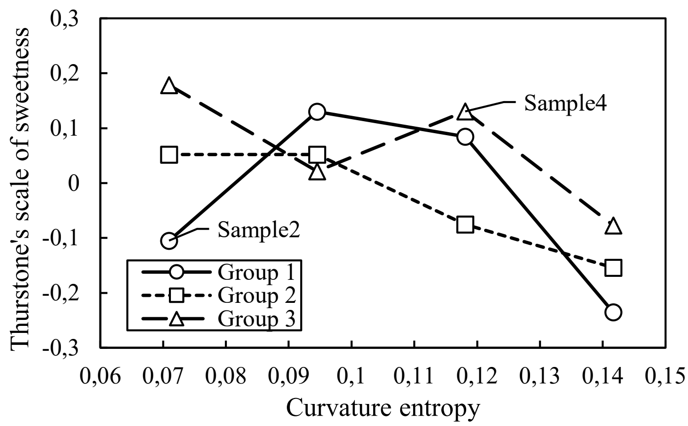


Figure 4. Relationship between curvature entropy and Thurstone's scale of sweetness

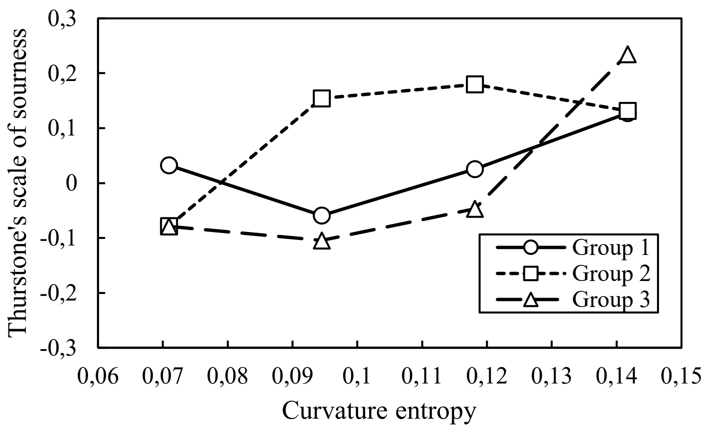


Figure 5. Relationship between curvature entropy and Thurstone's scale of sourness

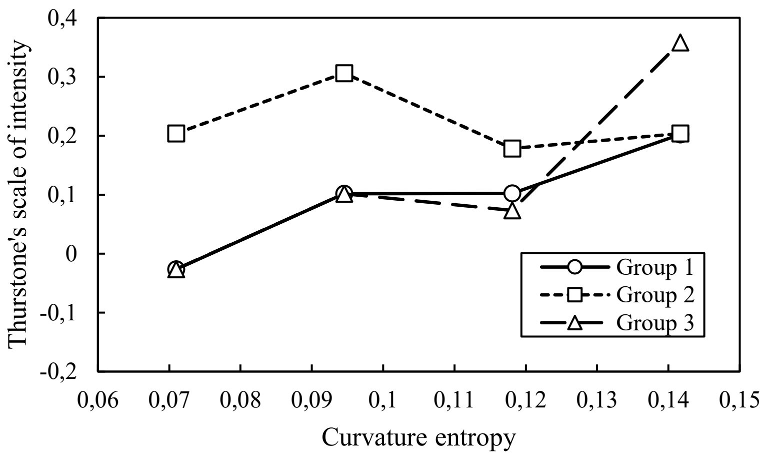


Figure 6. Relationship between curvature entropy and Thurstone's scale of intensity

For these corrected values, a one-way analysis of variance was conducted to examine the significance of the variability between groups relative to the variability within each group. The results were significant at the 5% level for sweetness, sourness and intensity. In other words, H was found to be a factor that modulates sweetness, sourness, and intensity. Then, the correlation coefficients were calculated in order to examine what kind of trends existed in the sweetness, sourness, and intensity according to change in H. The result illustrates that sweetness had a negative correlation with H, while sourness and intensity had a positive correlation. (Sweetness: -0.559, Sourness: 0.667, Intensity: 0.557)

Here, we discuss the shapes that deviated from the trend shown in Figs.4-6. Due to space limitation, we mainly discuss the result of sweetness which shows characteristic trend. Firstly, the evaluated value of sweetness for sample 2 in the first group was low compared to the trend. Since the impression of sweetness is high when the center of gravity is low (Arboleda & Arce-Lopera, 2020), we can estimate that the evaluated value of sweetness was low because the center of gravity position was higher for sample 2 in the first group than for the other shapes. As for sample 4 in the third group, the evaluated value of sweetness was high compared to the trend. Since rounded shapes tend to give the impression of sweetness (Van Rompay et al., 2017), we can estimate that the evaluated value of sweetness was high because the gentle curve near the mouth of the cup easily illuminated when output in 3D, and it may have been emphasized and gave the impression of roundness.

5. CONCLUSION

This study focused on the complexity of shapes controlled by curvature entropy as a visual stimulus and aimed to confirm the cross-modal effect induced by its sensation. The results suggest that the complexity of shapes controlled by curvature entropy weakens the perception of sweetness whereas it enhances that of sourness and intensity. This finding can be used for reducing sugar intake in bottle packaging.

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