Semantically Layered Structure of Tactile Textures

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Abstract. This study constructed a multi-layered semantic structure of adjective pairs that are used to express the tactile properties of materials. We analyzed the causalities between adjectives using the DEMATEL method, involving twenty-nine adjective pairs and forty-six materials, and thus constructed a multi-layered structure. The constructed structure contained psychophysical, affective, and preferential layers. The psychophysical layer consisted of words related to the physical properties of materials, which were rough/smooth, uneven/flat, hard/soft, cold/warm, sticky/slippery, and wet/dry. The affective layer included affective sensations such as comfortable/uncomfortable and friendly/unfriendly. The words related to individual preferences, which include rich/poor, good/bad, like/dislike, and happy/sad, were located on the highest layer of the structure. The constructed structure helps us understand affective and preferential perceptions of materials through psychophysical perceptions.

Keywords: Psychophysical perception, Affective perception, Preferential perception, Multi layer, Texture

1 Introduction

Tactile textures are expressed using a multi-layered and dimensional perceptual space. For example, the psychophysical perception of materials, such as roughness, softness, and warmness, and the affective perception of materials, such as comfortableness and richness, constitute tactile textures. Understanding the structure of tactile textures is helpful in various fields such as in the design of tactile texture displays [1, 2] and commercial products with textural affinity [3].

To express the tactile textures of materials, adjective pairs such as "rough-smooth" were commonly used in early studies [4–6]. These studies analyzed the structures of tactile textures by using adjective pairs. Okamoto et al. [7] analyzed studies on the dimensional structures of tactile textures in order to find a common understanding of such structures. They suggested that psychophysical perceptions of material are composed of the five dimensions that are "rough-smooth," "uneven-flat," "hard-soft," "warm-cold," and "sticky-slippery." Guest et

⋆ This work was in part supported by MEXT KAKNEHI (13J02247 and 24700192) and Shitsukan 25135717.

Table 1. List of twenty-nine adjective pairs used in the experiment

Beautiful-ugly	Friendly-unfriendly	Modern-classic	Sticky-slippery
Clean-dirty	General-Specific	Natural-artificial	Strange-usual
Clear-vague	Good-bad	Regular-irregular	Uneven-flat
Comfortable-uncomfortable	Happy-sad	Rich-poor	Warm-cold
Concrete-abstract	Hard-soft	Rough-smooth	Wet-dry
Dangerous-safe	Interesting-uninteresting	Sharp-dull	
Delicate-bold	Itchy-not itchy	Significant-insignificant	
Exciting-boring	Like-dislike	Simple-complex	

al. [8] identified the perceptual or semantic dimensions of psychophysical and affective words describing textural experiences.

Although psychophysical perceptions can be easily connected to the physical properties of materials–for example, Young's moduli are pertinent to softness percepts–it is difficult to predict the relationship between affective perceptions and the physical properties of materials. Many studies on the design of affective perceptions such as richness and comfortableness have implicitly defined and used the multi-layered structure of affective and psychophysical perceptions of materials. Meanwhile, thus far, the semantically layered structure of tactile textures has yet to be systematically established. A layered structure of affective and psychophysical perceptions of textures was once proposed by Chen et al. [9], in which the structure was based on the correlation coefficients between adjective words. However, a systematic approach with a validation was not developed because the topic was beyond the main scope of their study.

We established a semantically layered structure of tactile textures based on the causal relationships between affective and psychophysical words. Such a structure will enhance understanding of the perceptual relationships between the psychophysical and affective percepts of materials.

2 Experiment to construct a semantically layered structure

We analyzed the causalities between adjective pairs using the DEMATEL (decision making trial and evaluation laboratory) method [10] that has been mostly used to analyze, for example, the structure of social problems involving multiple factors. As far as we know, the DEMATEL method has not been used to analyze the perceptual structures of material surfaces. In the experiments, the participants touched materials and evaluated the causalities between adjective pairs that are potentially related to textural perceptions. The results were integrated across the participants and used to determine a semantic structure of tactile textures. All the experimental procedures, including the recruitment of participants, were approved by the Ethics Committee of the Graduate School of Engineering at Nagoya University.

Table 2. List of forty-six materials

Aluminum foil cloth	Fake suede	Iridescent sheet	Sponge
Artificial grass	Fake woven leather	Long hair fake fur	Stainless steel scrubber
Coarse woven straw	Felt	Magnolia wood	Steel wool
Cork board	Fine Japanese paper	Mirror plate	Tile
Corrugated paper	Fine woven straw	Mosaic tile	Towel
Cotton	Glass beads (1.5mm)	Oak wood	Urethane resin
Cotton cloth	Glass beads (3.5mm)	Perforated aluminum	Wall paper
Crumpled paper	Glass beads (5mm)	Pyramid rubber matting	Woven linen
Denim	Glass beads (7mm)	Sapelli wood	Woven rush grass
Fake alligator hide	Glossless vinyl sheet	Satin	Woven wire mesh
Fake boa	Glossy vinyl sheet	Short hair fake fur	
Fake cowhide	Goose feathers	Soft fake fur	

2.1 Adjectives representing tactile perception of materials

The twenty-nine adjective pairs shown in Table 1 were used to express tactile perceptions of materials. These pairs were selected based on the studies on tactile textures [4–6, 8] and included the five common adjectives representing the psychophysical percepts of tactile textures [7]. In addition, the list includes affective words such as "comfortable-uncomfortable" and "rich-poor" that are potentially helpful in the manufacturing of commercial products.

2.2 Method to specify the causalities between adjective pairs

The eleven volunteers ($n = 11$) actively touched the forty-six types of materials shown in Table 2 that were singly-presented to each participant in a randomized order. The participants were instructed to freely touch them in a box, therefore they did not see the materials and their touch motions. Then, they evaluated the causalities for all permutations of adjective pairs: ${}_mP_2 = 812$, where m is the number of adjective pairs ($m = 29$). They scored the causality ${x_{ij}}^{(k)} (k = 1, 2, \ldots, n)$ in terms of the extent to which a subjective evaluation for materials using adjective pair i influenced another one using adjective pair j using a six-point scale (5: very influential, 0: no influence).

3 Result: Semantically layered network of adjective pairs

3.1 Data analysis: Calculation of total influence matrix

For each participant, the initial direct-relation matrix $\boldsymbol{X}^{(k)} \in \boldsymbol{N}^{m \times m}$ of the degrees of causality ${x_{ij}}^{(k)}$, was normalized to $\boldsymbol{Z}^{(k)}$ as follows:

$$\boldsymbol{Z}^{(k)} = \frac{1}{s^{(k)}} \boldsymbol{X}^{(k)} \tag{1}$$

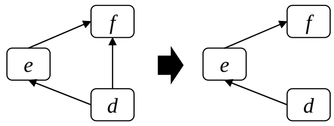

Fig. 1. Rule of omitting arc while maintaining reachability

where $s^{(k)}$ was the maximal summation of the rows or columns and was determined by

$$s^{(k)} = \max\left(\sum_{i=1}^{m} {x_{ij}}^{(k)}, \sum_{j=1}^{m} {x_{ij}}^{(k)}\right) \quad (i, j = 1, 2, \ldots, m). \tag{2}$$

Next, the average direct-relation matrix $\boldsymbol{A}$ was computed across the participants as follows:

$$a_{ij} = \frac{1}{n}\sum_{k=1}^{n} {z_{ij}}^{(k)} \tag{3}$$

where a_{ij} and ${z_{ij}}^{(k)}$ were the elements of $\boldsymbol{A}$ and $\boldsymbol{Z}^{(k)}$, respectively. Finally, we computed the total-relation matrix $\boldsymbol{F}$ as follows:

$$\boldsymbol{F} = \boldsymbol{A} + \boldsymbol{A}^2 + \boldsymbol{A}^3 + \cdots = \sum_{b=1}^{\infty} \boldsymbol{A}^b = \boldsymbol{A}(\boldsymbol{I} - \boldsymbol{A})^{-1}. \tag{4}$$

$\boldsymbol{A}^l$ is the indirect-relation matrix and indicates the effect from adjective pair i to j after mediating other $(l-1)$ pairs.

3.2 Construction of multi-layered structure

On the basis of the total-relation matrix $\boldsymbol{F}$, we determined the multi-layered structure that expressed the causal relationships between adjective pairs. The nodes and arcs in the structure represented the adjectives and the presence of causal relationships between adjectives, respectively. When the elements f_{ij} of $\boldsymbol{F}$ was larger than a threshold, a directional arc was set from adjective pairs i to j. In addition, we minimized the number of arcs while maintaining the reachability between nodes. For example, as shown in Fig. 1, the arc between the two nodes d and f was omitted when three arcs existed across the three nodes d, e, and f.

We established the two types of structures, as shown in Figs. 2 and 3 using two threshold levels: 0.050 and 0.035. The structure in Fig. 2 included twenty-one nodes and forty-eight arcs while twenty-five nodes and seventy-six arcs existed in Fig. 3. The black nodes were related to none of the other nodes. In other words, few participants regarded that they had any causal relationships with the others. The white nodes were leaf nodes that did not affect the other nodes. The root nodes that are not influenced by the others are shown in dark gray.

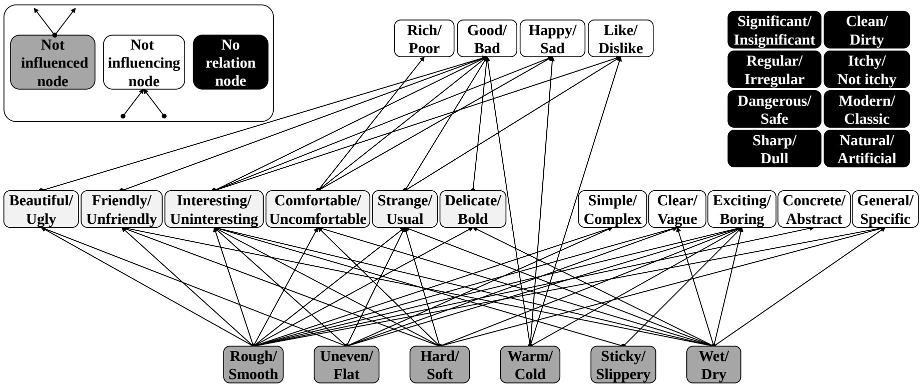

Fig. 2. Example 1: Constructed semantic layered structure (threshold is 0.05)

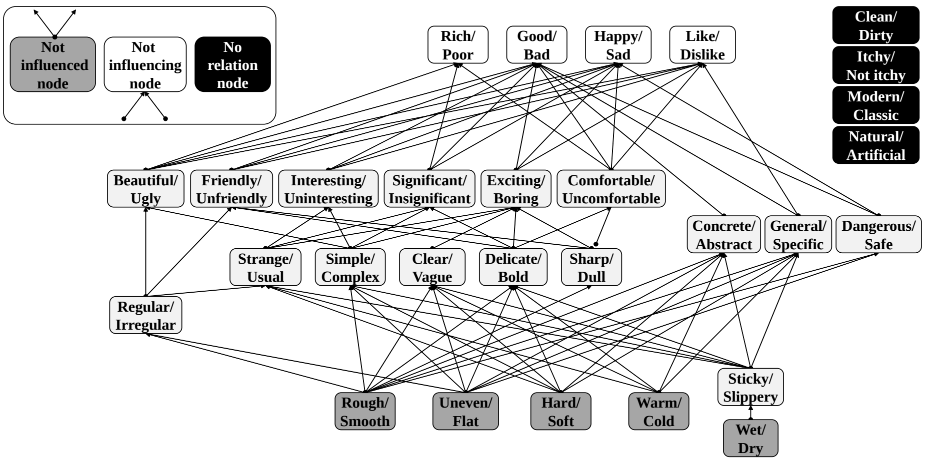

Fig. 3. Example 2: Constructed semantic layered structure (threshold is 0.035)

The lowest layer of the constructed structures contained the six types of adjective pairs: rough/smooth, uneven/flat, hard/soft, cold/warm, sticky/slippery, and wet/dry. While these pairs are related to the psychophysical perceptions of materials, many of the adjectives in the higher layers expressed affective perceptions. At the highest layer of the structures, the four types of adjective pairs including rich/poor, like/dislike, happy/sad, and good/bad were located. These four adjective pairs are highly linked to individual preferences. The structures corresponded to be semantic relationships between adjective words.

In this article, we showed only two examples of structures; however, we also established other types of structures with different threshold values. As well as the above two examples, most of the other structures share the same nodes at the lowest (psychophysical) and highest (preferential) layers. Their differences were observed in the intermediate (affective) layers. Such differences were also found in the two sample structures of Figs. 2 and 3. The structure in Fig. 2 included one middle layer, whereas the one in Fig. 3 had two middle layers. In general, smaller threshold values led to the production of more complex middle layers.

Although we should carefully validate the constructed structures and the application of the DEMATEL method to our purpose, we found some similarities between the results in this study and those in an earlier study. The constructed structures included the psychophysical, affective, and preferential words in the lowest, middle, and highest layers, respectively. This arrangement of layers is consistent with the study of Chen et al. [9], in which the psychophysical percepts also influenced affective percepts. In addition, the locations of some affective words that were commonly used in [9] and in our study are similar. In both studies, “exciting” and “rich” (precious and premium in [9]) are placed in the higher layers whereas “simple” and “delicate” are in the lower layers. These similarities between [9] and our study apparently support the validity of our method and results.

4 Conclusion

We constructed the semantically multi-layered structures of adjectives expressing tactile textures of materials by applying the DEMATEL method that was not originally designed for the analysis of adjective words. The constructed structures were composed of psychophysical, affective, and preferential layers, and such layered structures of adjectives will help in understanding the affective perspectives of materials.

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