The Integration of Visual and Haptic Impressions Felt from Synthetic Resin Texture

Taishi Fujiwara* Atsushi Takemoto† Yusuke Tani Kensuke Tobitani Noriko Nagata‡

Kwansei Gakuin University

ABSTRACT

The ability of texture perception is important to estimate the materials and properties of objects. However, the ways how multimodal information can be applied to texture recognition has yet to be fully elucidated. In this research study, we modeled the relationship among visual, haptic, and visuo-haptic impressions using multiple-regressions analysis. Some of the models demonstrated that the product of scored visual and haptic impressions plays an important role in multimodal texture perception. This result suggests that a multimodal texture perception can greatly change the impressions of texture more than we imagined.

Index Terms: Human-centered computing—Interaction design—Interaction design theory, concepts and paradigms

1 INTRODUCTION

Various studies have been conducted on texture perception related to a single modality [1]. However, in our lives, we often use multimodal information. Recently, multisensory studies have become more common, but quantitative analyses of the integration of multimodal information are few in number. Additionally, almost all of them focus on one or certain specific physical properties [2, 4] and differences in materials [3], so the mechanisms of the integration of multimodal impressions are still not completely understood.

In this research study, we focused on impressions regarding the visual and haptic texture perceptions of synthetic resins, and we modeled impression structures for the visual, haptic, and visuo-haptic modalities. This will enable us to estimate impressions felt from a texture, and will be helpful for adjusting the texture that have desire impressions in the field of product design and virtual reality.

2 SUBJECTIVE EVALUATION EXPERIMENTS

We conducted subjective evaluation experiments to investigate differences in texture recognition for various sensory systems. We performed the experiments for three conditions: visual, haptic, and visuo-haptic (Fig. 1). We used 20 synthetic resin samples (Fig. 2) with various textures as stimuli. Prior to these experiments, we collected words to evaluate, via a free-description experiment, the impressions felt from the stimuli (visual condition only and haptic condition only). Then, we excluded any unfit words based on the result of goodness-of-fit experiment. Moreover, we conducted a word-similarity rating procedure and used the multidimensional scaling method and hierarchical cluster analysis to select words that ensured representativeness and completeness. Finally, we selected 19 words as evaluation words for each of two of the conditions: the visual condition and the haptic condition. In the visuo-haptic condition, we used the same words as those in the visual condition. They were actually Japanese words.

*e-mail:t.fujiwara@kwansei.ac.jp
†e-mail:a.takemoto@kwansei.ac.jp
‡e-mail:nagata@kwansei.ac.jp

(a) visual condition; (b) haptic condition; (c) visuo-haptic condition.

Figure 1: The three conditions used in the experiments.

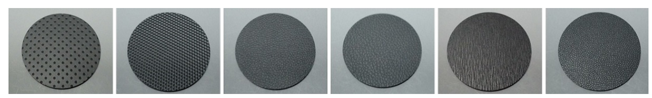

Figure 2: Examples of stimuli.

2.1 Method

The visual condition had 19 participants (17 men and two women) with an average age of 21.45 (SD = 0.75); the haptic condition had 20 participants (19 men and one woman) with an average age of 21.5 (SD = 0.74); the visuo-haptic condition had 20 participants (18 men and two women) with an average age of 21.55 (SD = 0.75). They evaluated the strength of the impression felt from the stimulus on a five-point scale.

2.2 Results and Discussion

We scored the rating data from 0 to 100, and we contracted three-dimensional data (stimuli$\times$evaluation words$\times$participants) to two-dimensional data (stimuli$\times$evaluation words) by taking the average of each participant. Then, we performed a factor analysis with the data using the maximum likelihood method and the Promax rotation. Based on the Kaiser-Guttman criterion, three factors each for the visual and visuo-haptic conditions were extracted. At the same time, for haptic condition, two factors were extracted (see the lists in Table 1). We interpreted these factors as shown in Table 2. According to the these interpretation, the similarities and differences in the visual and visuo-haptic conditions demonstrate the superiority of the visual modality and the influence of the haptic modality on visuo-haptic condition.

3 MODELING

We performed a linear multiple-regression analysis to model the relationships among visual, haptic, and visuo-haptic impressions.

3.1 Method

We calculated a multiple linear regression to predict the visuo-haptic rating of a model based on its components' visual and haptic rating. The regression model is depicted in Equation 1 (wherein V, H, and VH are the scored visual, haptic, and visuo-haptic ratings; and α and β are the regression weights for V and H). We used data extracted from the same stimulus for 14 participants (all men) with an average age of 21.57 (SD = 0.72) who participated in all of the conditions. We analyzed five evaluation words that all of the

Table 1: Results of factor analysis.

(a) visual condition;

	foctor1	factor2	factor3
dry	-1.001	-.054	.116
aged	-.997	-.157	.000
regular	.926	.560	-.054
youthful	.919	-.048	.084
futuristic	.888	.113	.204
sporty	.855	-.141	.032
progressive	.830	-.031	.233
uneven	.807	-.038	.316
rough	-.701	.600	.122
beautiful	.530	-.345	.434
heavy	-.439	.143	.107
slick	.037	-1.026	-.117
smooth	-.015	-.969	-.007
sophisticated	.113	.948	-.062
jagged	-.230	.901	.475
warty	.292	.700	-.309
uncool	-.057	.401	-.611
dislikable	-.038	.445	-.583
firm	.180	.216	.417

(b) haptic condition;

	foctor1	factor2
tough	-1.031	.358
uneven	-1.013	.145
uncouth	-1.008	.162
flat	.986	-.033
grippy	-.981	.143
coarse	-.969	.070
light	.914	.025
rugged	-.863	-.193
youthful	.855	.031
sporty	.852	.099
fine	.824	-.122
comfortable	.773	.178
good-to-touch	.759	.235
good	.720	.317
progressive	.563	.271
aligned	.003	.931
regular	-.362	.880
inhomogeneous	-.541	-.646
stable	.019	.502

(c) visuo-haptic condition.

	foctor1	factor2	factor3
regular	1.055	.568	-.040
aged	-1.032	-.136	.022
futuristic	.985	-.086	.134
sporty	.952	-.001	-.002
progressive	.936	-.139	.170
youthful	.861	-.136	-.110
dry	-.826	-.223	.358
sophisticated	.739	-.454	.123
rough	-.720	.075	.381
heavy	-.620	.217	.045
uncool	-.168	1.002	-.235
warty	.240	.945	.015
uneven	.118	.925	.176
beautiful	.469	-.758	.168
dislikable	-.293	.756	.031
firm	.496	.580	.326
jagged	-.026	-.118	.957
slick	.140	-.362	-.685
smooth	.120	-.484	-.588

Table 2: Interpretation of factors.

	Visual	Haptic	Visuo-Haptic
factor 1	Activity	Smoothly	Activity
factor 2	Roughness	Regularity	Discomfort
factor 3	Comfort		Roghness

conditions shared: "regular," "sporty," "uneven," "progressive," and "youthful."

$$VH = \alpha V + \beta H \tag{1}$$

3.2 Results and Discussion

As a result of the analysis, we obtained 100 models (20 stimuli$\times$5 evaluation words). The average absolute value of standardized partial regression coefficient for the visual terms was 0.35, and the average for the haptic terms was 0.25. Therefore, we confirmed that haptic information is essentially as important as visual information. However, only seven of the 100 models had high coefficients of determination (over 0.6), and 27 had very low coefficients (less than 0.1). This suggests that the relationships among the visual, haptic, and visuo-haptic modalities cannot be simulated completely with a simple linear regression model.

4 Modified Model

In the previous section, it was revealed that a simple linear regression model cannot fully express the integration of visual and haptic

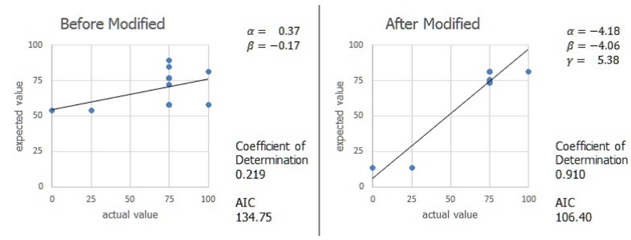

Figure 3: The most improved model.

impressions. Therefore, we modified the regression equation.

4.1 Method

The modified equation is depicted in Equation 2.

$$VH = \alpha V + \beta H + \gamma(V \times H) \tag{2}$$

Here, we added the product of $V \times H$ (the scored visual rating multiplied by the scored haptic rating) to Equation 1 as an independent variable (γ indicate the regression weight for $V \times H$). The product divided by 100 was used for matching the scale with each variable. We compared this model with the unmodified model using the Akaike information criterion.

4.2 Results and Discussion

In 28 models (out of 100), a decrease in the Akaike information criterion were confirmed. The most improved model is revealed in Fig. 3, which depicts a large increase in the coefficient of determination. Moreover, the average absolute value of standardized partial regression coefficient is 0.71 for the visual terms, 0.73 for the haptic terms, and 0.94 for their interaction. This result suggests that the impression felt from texture changes is mainly based on visual and haptic interaction.

5 Conclusion

We have modeled the relationships among the visual, haptic, and visuo-haptic impressions. The results indicated that the integration of visual and haptic impressions cannot be expressed with a simple linear regression model; in addition, the influence of the interaction between the visual and haptic modalities was stronger than we imagined. Hence, we can control the visual impression felt from texture by using haptic information. Further consideration will be needed to reproduce the interaction of the visual and haptic modalities in the field of product design and virtual reality.

Acknowledgments

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