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Interaction of Visual and Haptic Impressions in Visuo-haptic Texture Cognition

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***Abstract*—The interaction among modalities is useful in the field of virtual reality and augmented reality. However, the effects of sensory interaction have yet to be fully elucidated. In this research study, we investigated the interaction between visual and haptic impressions in visuo-haptic texture cognition. We discovered that the influence of the interaction between visual and haptic impression occurs when the impression have differences with regard to stimulus in the haptic modality.**

I. Introduction

Recently, multisensory studies have become more common [1]. Especially, in the field of virtual reality and augmented reality, these research studies are in great demand in studies that use multimodal interaction [2]. However, almost all of them focus on one or certain specific physical properties [3] and differences in materials [4], so the mechanisms of the interaction are still not completely understood.

In this research study, we focused on impressions felt from texture, and we investigated the interaction between visual and haptic impressions based on the data of our previous study [5]. The consideration of differences in interaction among evaluation words will enable us to use effective and efficient sensory interaction.

II. Subjective Evaluation Experiments

We conducted subjective evaluation experiments to quantify impressions felt from texture. We performed experiments for three conditions: visual, haptic, and visuo-haptic (Fig. 1). Prior to these experiments, we collected as evaluation words 19 words for the visual and haptic conditions, ensuring representativeness and completeness for the impression space of the texture. In the visuo-haptic condition, we used the same words as those in the visual condition. They were actually Japanese words. We used 20 synthetic resin samples (Fig. 2) with various textures as stimuli.

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

Fig. 1: The three conditions used in the experiments.

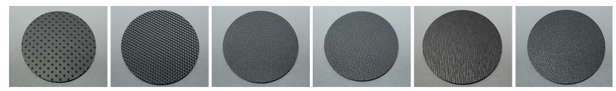

Fig. 2: Examples of stimuli.

A. 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); and 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.

B. Results and Discussion

1) Factor Analysis: 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 factor analysis with the data using the maximum likelihood method and the Promax rotation. We interpreted extracted factors as displayed in TABLE I. The similarities and differences between the visual and visuo-haptic factor structure suggest the superiority of the visual modality and the influence of the haptic modality on visuo-haptic condition.

TABLE I: Interpretation of factors.

	visual condition	haptic condition	visuo-haptic condition
factor 1	Activity	Smoothly	Activity
factor 2	Roughness	Regularity	Discomfort
factor 3	Comfort		Roghness

2) Two-Way Analysis of Variance (ANOVA): We performed two-way ANOVA to investigate the difference of impressions, with stimuli and three conditions used in the experiments, for five evaluation words that all of the conditions shared: “regular,” “sporty,” “uneven,” “progressive,” and “youthful.” The results are displayed in TABLE II.

For “regular” and “uneven,” the interaction between the stimulus and condition was significant. Therefore we tested the simple main effects of the condition as part of a post-hoc analysis.

According to the result of the post-hoc test (TABLE III), “regular” has no difference with regard to the stimulus in the

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TABLE II: Results of two-way ANOVA.

	Stimulus		Condition		Stimulus×Condition	
	F value	sig	F value	sig	F value	sig
regular	24.992	.000*	0.577	.577	8.276	.000*
sporty	6.173	.000*	0.265	.770	2.023	.056
uneven	33.251	.000*	1.046	.345	3.141	.003*
progressive	8.372	.000*	0.073	.930	1.336	.225
youthful	5.839	.000*	1.663	.209	1.463	.184

* highlights statistical significance.

TABLE III: Results of simple main effect test.

	Visual condition		Haptic condition		Visuo-haptic condition	
	F value	sig	F value	sig	F value	sig
regular	23.194	.000*	1.518	.185	42.320	.000*
uneven	33.251	.000*	13.047	.000*	13.141	.003*

* highlights statistical significance.

haptic condition, in contrast to "uneven." This suggests that, for participants did not feel difference of "regular" with regard to stimulus in haptic condition.

III. Multiple Regression Analysis

We performed multiple regression analysis to investigate the effect of the interaction between visual and haptic impressions.

A. Method

We calculated and compared two models (with or without interaction) that predict the visuo-haptic rating based on the visual and haptic rating. 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 common to all conditions.

1) Model without Interaction: The model without interaction is depicted in Equation 1:

$$VH = \alpha_1 V + \beta_1 H \tag{1}$$

In this equation, V, H, and VH are the scored visual, haptic, and visuo-haptic ratings, respectively; and α_1 and β_1 are the regression weights for V and H, respectively.

2) Model with Interaction: The model with interaction is depicted in Equation 2:

$$VH = \alpha_2 V + \beta_2 H + \gamma(V \times H) \tag{2}$$

Here, we added the $V \times H$ (the scored visual rating multiplied by the scored haptic rating) to Equation 1 as an independent variable (γ indicates the regression weight for $V \times H$).

B. Results and Discussion

1) Influence of Interaction: We obtained 100 regression equations (20 stimuli × 5 evaluation words) for each model. In 28 equations, we confirmed that the model with interaction was more suitable by comparing it with the Akaike information criterion (AIC). In these situation, it can be assumed that the interaction between visual and haptic impressions have influence on visuo-haptic texture cognition.

2) Difference among Evaluation Words: We compared the median values of AIC for each evaluation word to investigate that whether the interaction between visual and haptic impressions varies depending on evaluation word.

TABLE IV: Comparison of median value of AIC.

	regular	sporty	uneven	progressive	youthful
Equation 1	121.6	129	133.7	135.4	132
Equation 2	122.2	130.2	132.2	134.8	141.7

According to TABLE IV, contrary to the three evaluation words of "uneven," "progressive," and "youthful," for the two evaluation words of "regular" and "sporty," Equation 1 was more suitable. Concerning "regular" and "uneven," which yielded different results for the simple main effect test, the suitable model was also different. Both the results of simple main effect test and the comparison of AIC suggest the same thing: For evaluation words, like "uneven," which have differences with regard to the stimulus in the haptic condition, interaction occur in the visou-haptic texture cognition.

IV. Conclusion

We investigated the interaction between visual and haptic impressions felt from texture. We conducted subjective evaluation experiment, and using factor analysis, we confirmed that both visual and haptic modality have influence on visuo-haptic texture cognition. In addition, we performed two-way ANOVA and multiple regression analysis to investigate differences of interaction between visual and haptic impressions among evaluation words. As the result, the influence of the interaction varies depending on whether feel the differences of the impression with regard to stimulus in haptic modality. Specifically, when the impression have differences with regard to stimulus in the haptic modality, the interaction has influence on visuo-haptic texture cognition. Detailed research on more diverse evaluation words is necessary to reproduce the interaction of the visual and haptic impressions in the field of virtual reality and augmented reality.

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