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SENSORY CHANNEL EFFECTS WITH VR STIMULI ON PERCEIVED EMOTIONS OF MATERIALS

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Abstract. *The products' functionality and appearance are indispensable factors to satisfy customers' needs. Especially, an outstanding design goes beyond functionality and gives satisfaction to customers, and thus, leads customers to buy the products. Actually design affects people's emotional perception through sensory channels, including visual, tactile and auditory channels. Therefore, sensory channels of delivering good emotions to customers are crucial. In this study, we examine whether there are significant differences among 'tactile channel only', 'tactile plus visual channel' and 'tactile plus visual channel with virtual reality (VR) stimuli' for delivering emotions when we touch surfaces of materials. A total of 33 participants took part in the experiments, in which each of participants was provided 15 experimental conditions (5 material types × 3 sensory channel types) and agreeability of 12 emotional expressions, namely, 'Warm', 'Cold', 'Slippery', 'Sticky', 'Smooth', 'Rough', 'Hard', 'Soft', 'Bumpy', 'Flat', 'Wet', and 'Dry', was measured. From the results of experiments, we found the significant interaction effects between sensory channel type and material type on 'Warm' and 'Hard' emotions. Specifically, two materials such as 'Rubber' and 'Glass', showed significant differences between 'tactile plus visual based on VR' and other two sensory channel types. Therefore, from the experimental results, we suggest guidelines for using visual sensory channels with VR stimuli to deliver tactile emotions of material surfaces.*
Keywords: Perceived emotions, Touch sensation, Virtual reality, Visual stimuli

1. **Introduction.** One of the key questions in product design may be 'what kind attributes of products will be delivered to the customer?' This question can be answered in various aspects, such as functionality, utility, and convenience. In addition, another question of 'what kind of feelings do the products deliver to the customers?' is also valuable because the feelings of products that are mostly decided by the appearance or surface design of products can affect the customers' familiarity, favorability and motivation to buy. Among human's sensory channels based on the five senses, namely, sight, sound, touch, smell and taste, influential sensory channels related to the product design are currently visual, tactile and auditory channels. Primary information of the product is gathered through visual channel, and secondary information is obtained through tactile or auditory channels. Moreover, nowadays tactile senses from products are getting more and more important to satisfy customers' needs [1]. In this context, there are studies which investigated the effects of tactile sensation with visual senses on delivering emotions from material surfaces [2-10]. For example, the experiments of evaluating the capabilities of visual and tactile senses for perceiving the roughness of the wool were conducted by Lederman et al. [3]. In their study, they reported that there was no significant difference of performance between visual and tactile senses on perceiving the roughness of materials. One of materials used most in the related studies was sandpaper, but the experimental results were not consistent. In the result of Bjorkman's experiment [4], he asserted that

visual sense showed a little more variance than tactile sense. Other studies, however, had different results, in which it was concluded that no significant difference in variance was found between visual and tactile senses [5-7]. In the meantime, there was another experiment, in which wood and fabric were used as materials and the experimental results showed that no significant difference existed between visual and tactile senses on their performance of perceiving roughness [8]. Despite inconsistent experimental results, it was agreed by all the studies that the capabilities of both visual and tactile senses to perceive the roughness of materials were good.

Besides perceived roughness, a variety of emotions, which were expressed by emotional adjectives such as warm, cold, slippery, sticky, smooth, rough, hard, soft, bumpy, flat, wet, and dry, were employed to find out the relationship between physical features and tactile perceptions of material surfaces [2]. Using these emotional adjectives, Kim et al. conducted experiments to investigate which emotions the customers wanted to feel when touching the surfaces of the products [1]. In the meanwhile, the study on the texture perception with sighted and blind people was conducted to see if visual imageries were useful for texture detection [11]. The results in this study showed that rough surfaces were well perceived through both visual and tactile senses. However, as surfaces got smoother, the better perceptual performance on surface roughness was found through tactile sense than visual sense. It meant that it was not easy to define the visual imagery on surface roughness for the texture perception. In addition, many studies have been conducted on visual and tactile perceptions in virtual reality as well. In the aspects of perceiving objects and delivering emotions, the studies in virtual reality (VR) mainly examined how to make humans feel like real world in the virtual space [12-15], but there were few studies that investigated the effects of visual sensation through virtual reality on delivering tactile emotions from material surfaces.

In most cases, the delivery of emotions from products is rarely done with only a tactile sense, but the visual sense acts together with the tactile sense. However, prior studies fail to give clear conclusions about the effects of visual senses on delivering tactile emotions from material surfaces, in that they reported inconsistent experimental results about the perceptual performance between visual and tactile senses, and also it is hard to get the information about the effects of VR-based visual sensation on delivering tactile emotions from material surfaces due to lack of empirical studies. Thus, this study sought to examine the effect of a visual channel on delivering tactile emotions from material surfaces. It is also necessary to examine the effects of visual stimuli from virtual reality (VR) as well as from real world during delivering tactile emotions from material surfaces, since the case where visual stimuli from virtual reality are transmitted through the visual channel to perceive information of products will become common in the near future. The purpose of this study is to investigate the effects of sensory channels on delivering tactile emotions from material surfaces by examining difference between visual senses with real images and visual senses with virtual images while perceiving tactile emotions. We applied the following three sensory channel types to three experimental conditions: i) perceiving tactile emotions by using only tactile sensory channel without visual stimuli, ii) perceiving tactile emotions by using both tactile and visual sensory channels with viewing real images, and iii) perceiving tactile emotions by using both tactile and visual channels with viewing 360° images through VR Head-Mounted Device. In this regard, we employed five materials to perceive tactile emotions and measured twelve tactile emotions in the experiments.

This paper is organized as follows. Method section gives a description of experiment participants, experimental settings, such as preparation of materials and measurement of tactile emotions, and procedures of experiment. Sections 3 and 4 present the results of experiment, and conclusion and discussion with recommendations for future work, respectively.

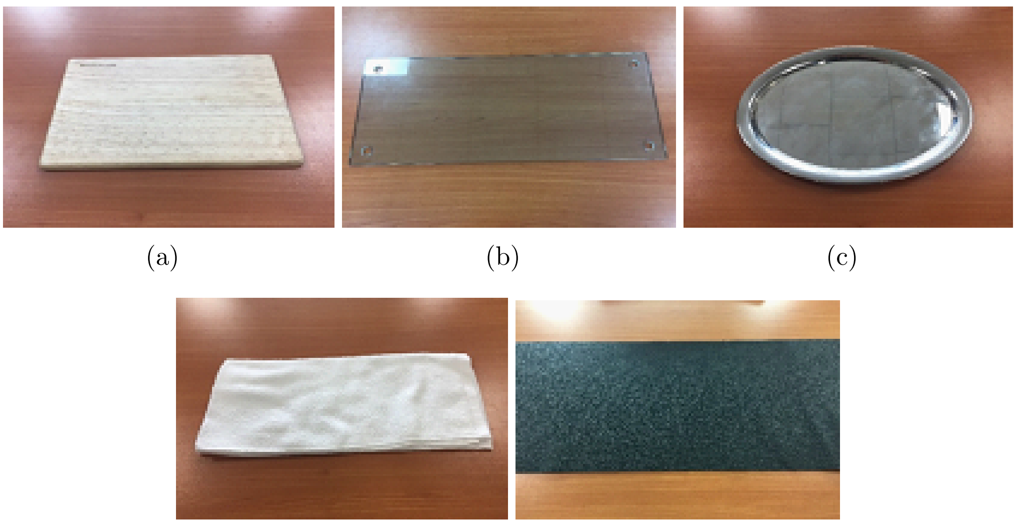
2. **Methods.** In this study, by the within-subject experimental design, each participant of the experiments was asked to touch 5 different materials' surfaces accompanied with 3 different sensory channels and to respond to the questions that asked the agreeability of 12 tactile emotions in 7-point interval scale.

2.1. **Participants.** A total of 33 participants (25 males and 8 females), who were university students and were in their twenties (mean = 24.76 years old, SD = 1.62), participated in the experiments. All of the participants do not have any difficulty in visual and tactile sensation including color blindness and tactile disorder.

2.2. **Experimental settings.** In order to understand the effects of the tactile sense without visual stimuli and with visual stimuli, which were by naked eyes or by 360° VR images, on tactile emotions of material surfaces, 3 sensory channel types were employed. In this regard, experimental settings of sensor channels were as follows: i) participants were asked to touch the surfaces of materials while blocking the sight with an eye bandage, ii) participants were asked to touch the surfaces of materials while the sight was free to see with naked eyes, and iii) participants were asked to touch the surfaces of materials while they saw the 360° images of material surfaces through VR Head-Mounted Device (HMD).

Preparation of materials. In order to perceive a variety of emotions through the tactile sense, five kinds of materials whose surfaces had different physical features were prepared as follows: wood, glass, metal, fabric and rubber. As seen in Figure 1, a wood board (a), a flat glass board (b), a metal plate (c), a cotton towel (d) and a rubber mattress (e) were employed for the experiments. To eliminate possible nuisance factors from the surfaces of materials, including shape of materials, surface temperature and humidity around materials, the flat areas of material surfaces were used in the environments of normal temperature and humidity.

Measurement of tactile emotions. To measure the tactile emotions of the material surfaces, 12 emotional adjectives, that is, warm, cold, slippery, sticky, smooth, rough, hard, soft, bumpy, flat, wet, and dry, were selected from the previous studies [1,2]. 7-point interval scale (1: strongly disagree, ..., 4: neutral, ..., 7: strongly agree) was employed for measuring the agreeability of those 12 emotional expressions as dependent variables.



(a) (b) (c) (d) (e)

Figure 1. Materials for experiments: (a) wood board, (b) glass board, (c) metal plate, (d) cotton towel, and (e) rubber mattress

2.3. Procedure. 15 experimental conditions (5 material types × 3 sensory channel types) were provided to each participant with the following steps. First, a participant was asked to experience one of 15 experimental conditions. Second, the participant was asked to respond to the questions about the agreeability of 12 emotional adjectives each. Finally, the above two steps were repeated 15 times to each participant until the participant experienced all of 15 experimental conditions in a random order.

3. Results. Analysis of variance (ANOVA) was conducted to identify the significant factors for tactile emotions, and then Fisher's least significant difference (LSD) method as the post-hoc analysis was applied to the significant factors to find where the significant difference existed among their multiple levels. In the ANOVA analysis, 12 tactile emotions were considered as the dependent variables, and sensory channel type (tactile without visual stimuli, tactile with visual stimuli (naked eye) and tactile with virtual reality), material type (wood, metal, rubber, glass and fabric) and participant (subject effect) were used as the independent variables. And two-way interactions between main factors were also included in the ANOVA model.

As expected, the results of ANOVA showed that both of material type and participant were significant main factors for all 12 tactile emotions, but sensory channel type as a main effect was not significant. We employed five different types of materials that were supposed to provide various tactile emotions; however, the research focus of this study was to investigate sensory channel effects in each material by analyzing the interaction effects between sensory channel type and material type. The ANOVA results for interaction effects showed that there were significant interaction effects between sensory channel type and material type for 'warm' and 'hard' emotions, but not for the other emotions. Thus, the ANOVA and LSD results for 'warm' and 'hard' emotions are shown in detail in the following subsections, separately.

3.1. Warm. Among 12 tactile emotions, 'warm' emotion was employed as a dependent variable, and three main factors and three two-way interactions were included as independent variables in the ANOVA model, as seen in Table 1. Besides significant main effects of material and participant, the interaction effect between sensory channel and material was significant ($F_{(8,256)} = 2.11$, $p = 0.035$). It means that the sensory channel effects are different among five material types, and thus it is necessary to examine where the significant difference exists in the combination of material types and sensory channel types.

The LSD method was used to find where the significant difference exists in the combination of material types and sensory channel types for 'warm' emotion. In Table 2, the LSD results showed that in the material of 'rubber' 'tactile without visual' channel (mean = 4.85) had significantly higher score than 'tactile with VR' channel (mean = 4.33) in terms of 'warm' emotion ($t_{(256)} = 2.297$, $p = 0.022$). It means that the surface of rubber is perceived to be warmer when we touch the surface of rubber with closed eyes than when

Table 1. ANOVA results for 'warm'

Variable	Results	
Sensory Channel	$F_{(2,256)} = 1.56$	$p = 0.219$
Material	$F_{(4,256)} = 66.21$	$p = 0.000$**
Participant	$F_{(32,256)} = 6.85$	$p = 0.000$**
Sensory Channel × Material	$F_{(8,256)} = 2.11$	$p = 0.035$**
Sensory Channel × Participant	$F_{(64,256)} = 1.07$	$p = 0.344$
Material × Participant	$F_{(128,256)} = 2.91$	$p = 0.000$**

Note. **: $p < 0.05$

Table 2. LSD results for 'warm'

Material	**Comparison between Sensory Channels**	***t*-value (d.f. = 256)**	***p*-value**
Wood	Tactile without Visual – Tactile with Visual	−1.486	0.138
	Tactile without Visual – Tactile with Virtual Reality	−0.946	0.345
	Tactile with Visual – Tactile with Virtual Reality	0.540	0.589
Metal	Tactile without Visual – Tactile with Visual	0.405	0.686
	Tactile without Visual – Tactile with Virtual Reality	−0.270	0.787
	Tactile with Visual – Tactile with Virtual Reality	−0.676	0.500
Rubber	Tactile without Visual – Tactile with Visual	1.621	0.106
	Tactile without Visual – Tactile with Virtual Reality	2.297	0.022**
	Tactile with Visual – Tactile with Virtual Reality	0.676	0.500
Glass	Tactile without Visual – Tactile with Visual	1.486	0.138
	Tactile without Visual – Tactile with Virtual Reality	−0.540	0.589
	Tactile with Visual – Tactile with Virtual Reality	−2.027	0.044**
Fabric	Tactile without Visual – Tactile with Visual	−0.676	0.500
	Tactile without Visual – Tactile with Virtual Reality	−1.081	0.281
	Tactile with Visual – Tactile with Virtual Reality	−0.405	0.686

Note. **: $p < 0.05$

Table 3. ANOVA results for 'hard'

Variable	**Results**	
Sensory Channel	$F_{(2,256)} = 0.99$	$p = 0.378$
Material	$F_{(4,256)} = 71.41$	$p = 0.000$**
Participant	$F_{(32,256)} = 5.83$	$p = 0.000$**
Sensory Channel × Material	$F_{(8,256)} = 0.67$	$p = 0.009$**
Sensory Channel × Participant	$F_{(64,256)} = 0.56$	$p = 0.988$
Material × Participant	$F_{(128,256)} = 4.65$	$p = 0.000$**

Note. **: $p < 0.05$

we touch it with seeing VR images of it. It can be understood that seeing VR images of the rubber plays a role to some extent in mitigating 'warm' emotion when we touch the rubber surfaces.

In the material of 'glass', 'tactile with VR' channel (mean = 2.36) had significantly higher score than 'tactile with visual' channel (mean = 1.91) in terms of 'warm' emotion ($t_{(256)} = -2.027$, $p = 0.044$). It means that the surface of glass is perceived to be less warm when we touch the surface of glass with seeing it than when we touch it with seeing VR images of it. It can be understood that seeing VR images of the glass plays a role to some extent in enhancing 'warm' emotion when we touch the glass surfaces.

3.2. **Hard.** Among 12 tactile emotions, 'hard' emotion was employed as a dependent variable, and three main factors and three two-way interactions were included as independent variables in the ANOVA model, as seen in Table 3. Besides significant main effects of material and participant, the interaction effect between sensory channel and material was significant ($F_{(8,256)} = 0.67$, $p = 0.009$). It means that the sensory channel effects are different among five material types, and thus it is necessary to examine where the significant difference exists in the combination of material types and sensory channel types.

The LSD method was used to find where the significant difference exists in the combination of material types and sensory channel types for 'hard' emotion. In Table 4, the LSD results showed that in the material of 'rubber' 'tactile with VR' channel (mean = 2.39) had significantly higher score than 'tactile without visual' (mean = 1.85) channel

Table 4. LSD results for 'hard'

Material	**Comparison between Sensory Channels**	***t*-value (d.f. = 256)**	***p*-value**
Wood	Tactile without Visual – Tactile with Visual	−1.173	0.242
	Tactile without Visual – Tactile with Virtual Reality	0.000	1.000
	Tactile with Visual – Tactile with Virtual Reality	1.173	0.242
Metal	Tactile without Visual – Tactile with Visual	0.000	1.000
	Tactile without Visual – Tactile with Virtual Reality	−0.335	0.738
	Tactile with Visual – Tactile with Virtual Reality	−0.335	0.738
Rubber	Tactile without Visual – Tactile with Visual	−0.335	0.738
	Tactile without Visual – Tactile with Virtual Reality	−3.015	0.003**
	Tactile with Visual – Tactile with Virtual Reality	−2.680	0.008**
Glass	Tactile without Visual – Tactile with Visual	−0.335	0.738
	Tactile without Visual – Tactile with Virtual Reality	1.508	0.133
	Tactile with Visual – Tactile with Virtual Reality	1.843	0.067*
Fabric	Tactile without Visual – Tactile with Visual	1.340	0.181
	Tactile without Visual – Tactile with Virtual Reality	−0.168	0.867
	Tactile with Visual – Tactile with Virtual Reality	−1.508	0.133

Note. **: $p < 0.05$, *: $p < 0.1$

($t_{(256)} = -3.015$, $p = 0.003$) and also than 'tactile with visual' (mean = 1.91) channel ($t_{(256)} = -2.680$, $p = 0.008$) in terms of 'hard' emotion. It means that the surface of rubber is perceived to be harder when we touch the surface of rubber with seeing VR images of it than when we touch it with seeing it or with closed eyes. It can be understood that seeing VR images of the rubber plays a role to some extent in enhancing 'hard' emotion when we touch the rubber surfaces.

In the material of 'glass', 'tactile with visual' channel (mean = 6.67) had suggestively higher score than 'tactile with VR' channel (mean = 6.33) in terms of 'hard' emotion ($t_{(256)} = 1.843$, $p = 0.067$). It means that the surface of glass is perceived to be harder when we touch the surface of glass with seeing it than when we touch it with seeing VR images of it. It can be understood that seeing VR images of the glass plays a role to some extent in mitigating 'hard' emotion when we touch the glass surfaces.

4. **Conclusion and Discussion.** This study investigated the effects of sensory channels on delivering tactile emotions according to the surfaces of materials. Based on the experimental results, the conclusions of this study can be summarized as follows. First, among 5 materials, that is, wood, metal, rubber, glass and fabric, only 'rubber' and 'glass' provided significant sensory channel effects. Second, among 12 tactile emotions, 'warm' and 'hard' were only two tactile emotions that showed significant interaction effects between sensory channel type and material type. Third, 'tactile with VR' channel delivered relatively mild or neutral-oriented tactile emotions rather than the 'tactile without visual' and 'tactile with visual' channels. For example, when 'rubber' basically provided high level of 'warm' emotions (i.e., more than 4 point out of 7 point) 'tactile with VR' channel delivered lower level of 'warm' emotion (4.33) than 'tactile without visual' channel (4.85), whereas 'tactile with VR' channel delivered higher level of 'warm' emotion (2.36) than 'tactile with visual' channel (1.91) when 'glass' basically provided low level of 'warm' emotions (i.e., less than 4 point out of 7 point). Likewise, when 'rubber' basically provided low level of 'hard' emotions 'tactile with VR' channel delivered higher level of 'hard' emotion (2.39) than 'tactile without visual' channel (1.85) and 'tactile with visual' channel (1.91), whereas 'tactile with VR' channel delivered lower level of 'hard' emotion (6.33) than 'tactile with visual' channel (6.67) when 'glass' basically provided high level of 'hard' emotions.

Thus, it can be concluded that the visual channel with conveying VR images may inhibit delivering strong levels of some tactile emotions, such as 'warm' and 'hard' emotions, specifically. However, for delivering the other tactile emotions, there was no significant difference among sensory channels, which means the visual channel with naked eyes or with VR images does not give additional significant effects on delivering tactile emotions except 'warm' and 'hard' emotions. There have been some studies that examined 'multisensory perception' [16-18], some of which dealt with the role of visual channel in the perception of touch location [16]. Except for this study, however, it is hard to find any study that investigates the role of visual channel in delivering various tactile emotions and also the roles of visual channels with real image and VR image, respectively. There were also limitations to draw more general conclusions for the effects of 'tactile with VR' channel, because 360° images through VR HMD were employed in this study. It would be possible that VR with 360° images could not be sufficient enough to deliver exact visual information about surface texture of materials in actual reality. Therefore, the further study may need to employ immersive VR environments to deliver more accurate information in the surface texture of material instead of VR with 360° images.

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