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Exploring Cross-Sensory Perception: The Correlation of Visual and Tactile Sensations in Home Product Materials

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ABSTRACT

This research investigates the interconnection between visual and tactile perceptions through the lens of household product materials. By focusing on common materials used in these products, the study aims to investigate the correlation between the tactile and visual perceptions of materials. An experiment was conducted to explore the cross-sensory correlation between vision and touch. Using a controlled variable method, the material samples were divided into three categories based on differences in roughness, hardness and type. Twenty-one participants engaged with these materials through blind tactile sensation and subsequently described their concurrent visual experience via a questionnaire. The questionnaire evaluated visual perceptions in terms of style features, physical properties, and functional characteristics. Findings indicate that the tactile properties of materials influence visual perceptions among users. Specifically, materials with higher levels of roughness are perceived as visually complex, darker, and heavier, suggesting reliability, while smoother materials are associated with a more transparent and clean visual impression. Harder materials are typically viewed as brighter, heavier and cleaner. Regarding material type, both acrylic and mirror-finished metal are more likely to evoke "bright" visual experiences, with mirror-finished metals also perceived as "heavier" compared to acrylic and frosted metals. These insights provide valuable guidance for product designers, suggesting that material selection can enhance user experiences by aligning tactile feedback with visual expectations.

Keywords: Cross-sensory perception, Visual-tactile sensation, Home product materials, User experience

INTRODUCTION

In daily life, we interact with many different materials that evoke diverse sensations, with over 70% of these sensations being obtained through vision (Ludden et al., 2009). In home settings, touch serves as another important means of acquiring sensory information during product interaction. This study focuses on typical materials used in home products such as TPU, PVC, leather, acrylic, and metal, aiming to explore the connection between the visual and tactile sensations these materials evoke in users, that is, cross-sensory perception (Li et al., 2017). The goal is to offer insights to product designers on material selection to create products that provide a more enriching sensory experience.

Researchers have extensively organized and defined the concepts surrounding sensory perception. Multi-sensory perception is described as any neural or behavioral process that involves multiple senses (Lloyd et al., 2020), and another definition highlights it as the internal neural and behavioral responses triggered by stimulating multiple senses (Stein et al., 2010). Essentially, cross-sensory perception involves using one sense to comprehend and identify information acquired through another sense. This paper explores the types of visual information that can be perceived through various tactile sensations.

There has been significant experimental research on cross-sensory perception. Steer et al. (2023) investigated the cross-modal correspondences of deformable interfaces, enabling participants to perceive colors and shapes by touching materials of varying hardness. Zuo et al. (2016) explored users' perception of different materials and textures on hair dryer handles to suggest product improvements. Tang et al. (2017) developed a method for industrial design material testing and evaluation based on users' visual and tactile experiences, creating a system for testing user visual and tactile experiences. Gui et al. (2021) studied the application of cross-sensory elements in children's toy packaging.

Therefore, the aim of this paper is to investigate the correlation between visual and tactile perceptions of different materials in a home setting. Two research questions are raised in response to the research goals:

i) What visual experiences do people have when using touch to perceive materials with varying physical properties?
ii) Why do certain tactile experiences evoke specific visual associations?

METHODS

As shown in Figure 1, the research was divided into three steps: i) Preparation; ii) Experiment, and iii) Analysis. During the Preparation phase, a variety of typical home products were collected to analyze and summarize their perceptual experiences. From this analysis, we selected materials for the experiment and identified appropriate vocabulary for evaluating visual perception. The Experiment phase involved conducting experiments to explore the correlation between visual and tactile perceptions. Finally, the Analysis phase consisted of both data and qualitative analysis of the experimental results.

Sections 3, 4, and 5 of this paper will detail these research methods.

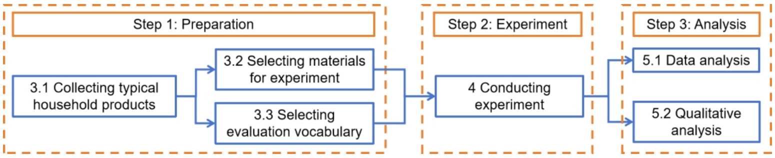

Figure 1: Study design.

STEP 1: PREPARATION

Collecting Typical Household Products

Procedure

To better understand the types and characteristics of materials in common home products, we collected a wide range of these products. We then summarized their main interaction points, prevalent materials, and aspects of perceptual experience research.

Results

We selected six common household products for analysis, including sweeping robots, washing machines, refrigerators, smart toilet seats, smartwatches and telephones, as shown in Table 1. We sorted out the materials used in these products, noting the colors and textures of each part, and summarized keywords for perceptual experience research. This informed the subsequent selection of vocabulary for visual evaluation.

Table 1. Common household products.

The types of home product	Brand	Product interaction points	Picture indication	The types of material	Common colors	Common textures	Perceptual experience
Sweeping and mopping robot	Kovos	Switch, shell, dust box, brush...		Screen: tempered glass Shell: plastic, aluminum alloy, stainless steel Dust box: translucent plastic Brush handle: plastic	White, black, dark gray	Shell: polished, brushed metal, matte Dust box: translucent matte	Cold-warm, dry-wet clean-unclean, relaxed-tense, comfortable-uncomfortable
Washing machine	Samsung	Front door, drawer, button, knob...		Inner barrel: stainless steel, plastic Shell: metal, plastic Doors and door seals: rubber, silicone.	White, dark gray	Anti-mildew coating, glass door texture	Light-heavy, soft-hard, dry-moist, safe-dangerous, clean-dirty, traditional-modern, sanitary
Refrigerator	LG	Sliding door, drawer, electronic screen...		Internal storage space: glass, plastic, stainless steel shells: stainless steel, plastic Refrigerator and freezer doors: glass, plastic	White, stainless steel color	Stainless steel panel surface, Easy-to- clean interior surface	Cold-warm, hard- soft, dry-moist, depressed-pleasure, fear, clean-dirty, natural-industrial, nostalgia, health
Smart toilet seat	Panasonic	Operation panel, toilet lid, toilet seat...		Cover: acrylic Panel: plastic material, with film on the outside	White, light gray	Glossy, frosted	Dry-wet, flat- concave, comfortable-uncomfortable, clean-unclean, convenient, clear
Smart watch	Xiao Mi	Watch strap, screen, charge		Watch strap: silica gel, TPE, artificial leather Screen: alloy, tempered glass	Black, dark gray, white	Matte, leather and silicone texture	Cold-warm, light-heavy, soft-hard, relaxed-tense, comfortable-uncomfortable
Telephone	Panasonic	Handle, button		Shell: plastic, metal Handle: plastic, rubber Button: plastic, metal, rubber	Black, gray, white	Matte, frosted	Cold-warm, light-heavy, clean- unclean, traditional- modern

Selecting Materials for Experiment

Procedure

Based on the materials in Table 1, we created samples and measured their roughness and hardness (Figure 2). Each material underwent three measurements, with the average value taken after excluding significantly deviant data. The results are shown in Tables 2 and 3. We classified roughness and hardness into three categories - low, medium, and high - based on these measurement results (see Table 4), ensuring minimal tactile differences within each category. The hardness units were standardized to Ha.

Figure 2: Measuring roughness and hardness.

Table 2. Roughness measurement results (unit: Ra in um).

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13
first measurement	0.079	1.434	4.617	1.897	0.113	1.84	0.182	5.394	12.52	0.173	0.056	0.224	0.528
second measurement	0.058	1.274	4.64	1.908	0.12	1.931	0.16	5.326	12.07	0.115	0.057	0.284	0.548
third measurement	0.063	1.395	4.8	1.737	0.118	1.851	0.158	5.394	11.79	0.115	0.054	0.254	0.602
average value	0.07	1.37	4.69	1.85	0.12	1.87	0.17	5.37	12.13	0.13	0.06	0.25	0.56

Table 3. Hardness measurement results (unit: Ha).

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13
first measurement	41.5	42	42	40.2	58.5	60.8	25.6	18.1	17	86	94.5	99.2	25
second measurement	42.5	41.2	41	41.1	60	55	26	18	16.6	86.8	94.5	99	26
third measurement	42.5	41	41.1	45.8	58.5	60	26.8	19	17.4	87.5	94.6	99.2	25
average value	42.17	41.40	41.37	42.37	59.00	58.60	26.13	18.07	17.10	86.77	94.53	99.13	25.33

Table 4. Interval division.

Roughness (Ra/um)			Hardness (Ha)		
Low	Moderate	High	Low	Moderate	High
< 1.00	$1.00 \sim 3.00$	> 3.00	< 30.00	$30.00 \sim 60.00$	> 60.00

Results

Using the measured data and the established intervals, we further selected experimental materials and divided them into three groups. The first group examined the relationship between different roughness levels and visual perception, using three types of TPU with low hardness but varying roughness (low, medium and high). The second group explored the connection between different hardnesses levels and visual perception, with materials in the low roughness range but varying in hardness (low, medium and high). Due to the strong correlation between material hardness and type, this group did not control for material uniformity. The third group investigated the relationship between different material types and visual experience, using materials with low roughness and high hardness, specifically acrylic, mirror-finished metal and frosted metal (see Figure 3).

Number	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3
Sample									
Material	TPU	TPU	TPU	Silica gel	PVC	Acrylic	Acrylic	Mirror-finished metal	Frosted metal
Roughness(Ra/um)	Low(0.07)	Moderate(1.37)	High(4.69)	Low(0.17)	Low(0.12)	Low(0.13)	Low(0.13)	Low(0.06)	Low(0.25)
Hardness(Ha)	Low(42. 37)	Low(41. 37)	Low(41. 40)	Low(26.13)	Moderate(58.6)	High(86.77)	High(86.77)	High(94.53)	High(99.13)

Figure 3: Three groups of material samples.

Selecting Evaluation Vocabulary

Procedure

Based on the perceptual experience research points outlined in Figure 1, we further discussed the visual experiences associated with tactile experience in home environments and proceeded with the selection and classification.

Results

We identified three evaluation dimensions: style features, physical properties, and functional characteristics. For each dimension, we selected three visual evaluation words relevant to the home environment, as shown in Figure 4. In addition, we gathered feedback on visual experience related to touching material samples through questionnaires. The questionnaire utilized a Likert scale, a psychological response scale on which subjects indicate their level of agreement with a statement (Yang et al., 2010).

Figure 4: Visual evaluation vocabulary.

STEP 2: EXPERIMENT

Participants

We recruited 21 students from various majors (including both undergraduates and graduate students) as participants. The group comprised 11 males and 10 females, with an average age of about 22 years old. Each participant completed the experiment in approximately 30 minutes.

Tasks

The experiment involved an apparatus called a "touching box", which allowed participants to feel the material samples with their fingers without seeing them. Participants were instructed to place their one hand inside the touching box and use their other hand to complete a questionnaire on a computer, based on their tactile impressions (Figure 5). Concurrently, researchers conducted further interviews based on participants' responses to understand their immediate thoughts.

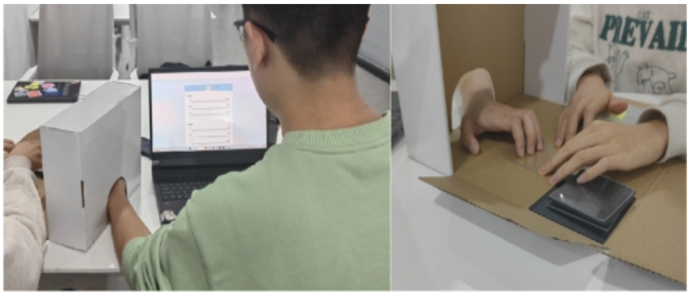

Figure 5: Experiment task.

Procedure

Before starting the experiment, we introduced the content and tasks of the experiment to each participant. This included instructions on how to interact with the material samples, how to complete the questionnaire, and a brief explanation of the vocabulary used in the questionnaire.

During the experiment, participants placed their left hand in the touching box and filled out the questionnaire with their other hand. This setup ensured that they could not see the material while completing the questionnaire. The experimenter changed the material in the touching box and randomized the presentation order of the three groups of materials to mitigate any potential bias from the order of touch. Throughout the experiment, the experimenter engaged with participants, asking questions to express their associations and feelings. This approach served dual purposes: facilitating subsequent analytical studies and preventing participants from experiencing numbness due to prolonged repetitive touching of the materials.

STEP 3: ANALYSIS

Data Analysis

We applied one-way ANOVA to evaluate the significance of visual perception vocabulary across different material groups (significant at $\lambda = 0.05$, as shown in Table 5). In Group 1, roughness significantly influenced the dimensions of *simple-complex, light-dark, transparent-opaque,* and *clean-unclean*. In Group 2, hardness had a significant impact on *light-dark, light-heavy* and *clean-dirty* dimensions. In Group 3, material type significantly impacted the *light-dark, transparent-opaque* and *clean-dirty* dimensions.

Table 5. Results of data analysis.

	Group 1(Average value ± Standard deviation)			F	p
	$1-1(n=21)$	$1-2(n=21)$	$1-3(n=21)$		
Nature-Industrial	0.33 ± 1.32	0.33 ± 1.11	0.43 ± 1.21	0.043	0.958
Simple-Complex	**−1.43 ± 0.60**	**−0.81 ± 1.33**	**0.29 ± 1.31**	**12.385**	**0.000 ∗ ∗**
Modern-Traditional	−1.29 ± 0.96	−0.67 ± 1.35	−0.52 ± 1.54	2.022	0.141
Bright-Dark	**−0.81 ± 1.17**	**0.24 ± 1.26**	**0.48 ± 1.33**	**6.253**	**0.003 ∗ ∗**
Lightweight-Heavy	−1.14 ± 1.20	−0.86 ± 1.31	−0.19 ± 1.57	2.678	0.077
Transparent-Opaque	**−0.71 ± 1.55**	**0.29 ± 1.68**	**1.05 ± 1.24**	**7.259**	**0.002 ∗ ∗**
Reliable-Unreliable	−0.24 ± 1.26	−0.67 ± 1.32	−0.71 ± 1.38	0.827	0.442
Clean-Dirty	**−1.48 ± 0.68**	**−0.90 ± 1.04**	**−0.29 ± 1.10**	**8.072**	**0.001 ∗ ∗**
Durable-Fragile	−0.52 ± 1.21	−0.86 ± 1.20	−0.86 ± 1.31	0.505	0.606
	Group 2(Average value ± Standard deviation)			F	p
	$2-1(n=21)$	$2-2(n=21)$	$2-3(n=21)$		
Nature-Industrial	0.43 ± 1.29	0.33 ± 1.35	0.86 ± 1.39	0.905	0.410
Simple-Complex	−0.86 ± 1.15	−1.14 ± 1.01	−1.14 ± 0.96	0.522	0.596
Modern-Traditional	−1.00 ± 1.26	−1.38 ± 0.74	−1.29 ± 1.10	0.737	0.483
Bright-Dark	**−0.19 ± 1.40**	**−1.05 ± 1.16**	**−1.14 ± 1.20**	**3.658**	**0.032∗**
Lightweight-Heavy	**−1.33 ± 1.06**	**−0.48 ± 1.12**	**0.00 ± 1.41**	**6.544**	**0.003 ∗ ∗**
Transparent-Opaque	−0.14 ± 1.53	−0.19 ± 1.60	0.29 ± 1.68	0.562	0.573
Reliable-Unreliable	−0.19 ± 1.21	−0.76 ± 1.14	−0.57 ± 1.36	1.157	0.321
Clean-Dirty	**−0.62 ± 1.24**	**−1.00 ± 0.95**	**−1.38 ± 0.67**	**3.158**	**0.050∗**
Durable-Fragile	−0.48 ± 1.33	−0.95 ± 1.16	**−0.48 ± 1.40**	0.939	0.397
	Group 3(Average value ± Standard deviation)			F	p
	$3-1(n=21)$	$3-2(n=21)$	$3-3(n=21)$		
Nature-Industrial	0.67 ± 1.28	1.14 ± 1.39	0.90 ± 1.22	0.707	0.497
Simple-Complex	−1.19 ± 1.08	−0.90 ± 1.48	−0.43 ± 1.47	1.694	0.192
Modern-Traditional	−1.33 ± 0.97	−1.19 ± 1.21	−0.90 ± 1.30	0.734	0.484
Bright-Dark	−1.00 ± 1.22	−1.14 ± 1.39	0.62 ± 1.24	12.124	0.000**
Lightweight-Heavy	−0.57 ± 1.21	0.24 ± 1.37	−0.24 ± 1.14	2.248	0.114
Transparent-Opaque	0.19 ± 1.47	−0.19 ± 1.75	1.33 ± 1.11	6.136	0.004 ÷ ⋆
Reliable-Unreliable	−0.33 ± 1.28	−0.57 ± 1.21	−0.62 ± 1.16	0.333	0.718
Clean-Dirty	−1.29 ± 0.96	−1.52 ± 0.60	−0.48 ± 1.25	6.695	0.002 ∗ ∗
Durable-Fragile	−0.71 ± 1.15	−0.67 ± 1.24	−0.43 ± 1.25	0.335	0.717

Group 1: Different Roughness Levels

Figure 6 illustrates that materials with higher roughness correlate with more complex visual styles, and darker, more opaque features. Additionally, in the clean-dirty dimension, all materials in Group 1 scored negatively, indicating a tendency towards cleanliness, with lower roughness enhancing the visual perception of cleanliness. (Vertical axis: Score; Horizontal axis: Sample number).

Group 2: Different Hardness Levels

As shown in Figure 7, materials in Group 2 consistently showed negative values across three salient dimensions, indicating a tendency towards bright, light, and clean visual experience. Higher hardness correlated with brighter and cleaner appearances, while lower hardness was associated with lighter perceptions. (Vertical axis: Score; Horizontal axis: Sample number).

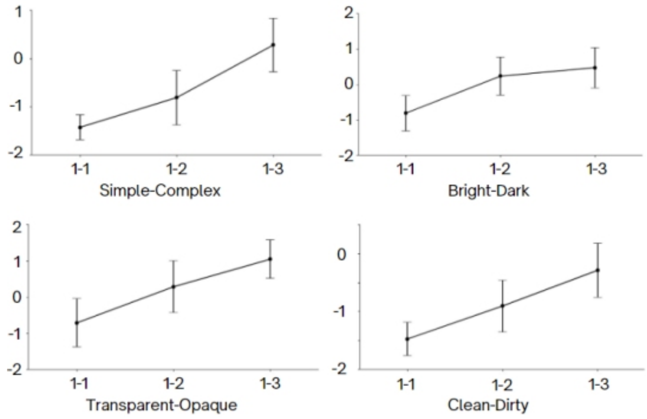

Figure 6: Error bar plot of group 1.

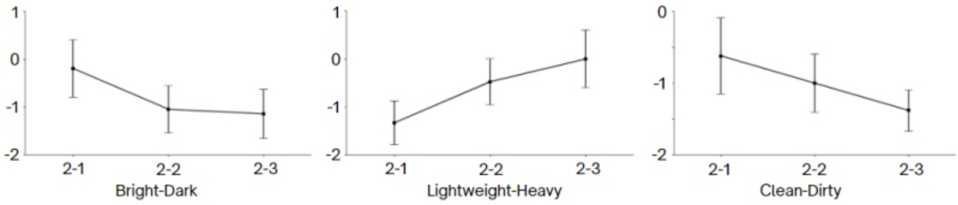

Figure 7: Error bar plot of group 2.

Group 3: Different Material Types

As depicted in Figure 8, among the significant dimensions, the differences between acrylic and mirror-finished metal were not significant, and the differences with frosted metal were more pronounced. Frosted metal was perceived as darker and more opaque. All three materials were associated with cleanliness, but acrylic and mirror-finished metal appeared visually cleaner than frosted metal. (Vertical axis: Score; Horizontal axis: Sample number).

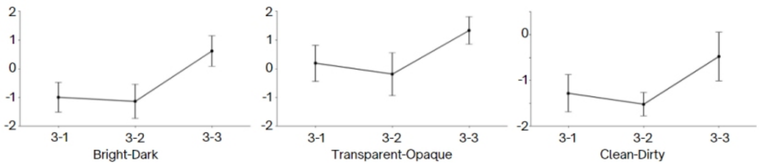

Figure 8: Error bar plot of group 3.

Qualitative Analysis

Throughout the experiment, we actively engaged with participants to understand their immediate experience and to prevent numbness. Consent was obtained to record the entire experiment. These recordings were then transcribed, anonymized, and subjected to qualitative analysis using MAXQDA software. The specific coding process unfolded as follows: Firstly, researchers organized the raw data, filtered out irrelevant information, and retained valuable text paragraphs as units for coding. Subsequently, they categorized and labeled each unit according to a pre-defined classification system. As the coding process progressed, the researchers continuously revised and improved the category system to accommodate new data attributes. Upon completing the coding, we identified and summarized the inherent patterns and characteristics within the data. The purpose of this analysis was to explain the reasons behind participants' specific visual sensations experienced through tactile interaction, as detailed in Table 6.

Table 6. Analysis of cross-sensory perception reasons.

Secondary Coding (Frequency)	First Coding (Frequency)	Typical Statement (Subject Number)
Inferring Material Type (29)	Associating the objective properties of materials (19)	Both of these two are like glass, so I think they will be transparent.(P21)
	Associating the subjective feelings of materials (10)	Wood reminds me of nature.(P5)
Imagining Application (27)	Associating the specific products (16)	The material is very rough and reminds me of leather on cars or leather sofas.(P9)
	Associating the using scenes (11)	I feel like this material is very similar to the kind of transparent table mats used in roadside restaurants.(P6)
Direct Visual Sensations from Touch (19)	Physical properties association (2)	High hardness is associated with high density, and high density is associated with high weight.(P16)
	tactile perception association (6)	This material feels so cool, like a cold industrial style product. (P17)
	Hard to explain (11)	This material doesn't feel that slippery, and I feel like it may not be as bright as the previous two materials. There's no reason why. (P7)

DISCUSSION

The data and qualitative analysis revealed that most subjects fell into three categories when performing cross-sensory perception:

(1) Inferring Material Type: Participants often guessed the type of material by touch and then based their visual assessment on this inference. This aligns with Knut et al. (2017), who examined the correlation between various materials and perceptual dimensions. For example, in the context of roughness and the dimensions of *simplicity-complexity, clean-unclean*, some participants directly linked their visual impressions

with tactile sensations: '*This material is rougher than the last one, and it may look densely packed. So it's more complicated and unclean, and it feels like it will harbor dirt*,' said participant 6 (P6)."

(2) Imagining Application: Some participants imagined real-life applications,influencing their visual assessment. This reflects findings that cross-sensory perception variations relate to individual environmental backgrounds (Zuo, 2010). For example, regarding roughness and *transparent-opaque dimension*, a participant related: '*I feel that this material is very similar to the transparent table mat in my home, and it is* very *smooth*,' stated participant 9 (P9).

(3) Direct Visual Sensations from Touch: Certain participants directly translated tactile sensations into visual impressions. For example, in evaluating material type and the light-dark dimension, a participant commented, 'This material, frosted metal) feels slippery, so it might not be as bright as the others, though there's no specific reason why,' observed participant 7 (P7).

Based on these findings, we propose five design recommendations for material selection in home product design:

i) Smooth materials help create simpler styles, while rough materials can achieve more complex styles.
ii) Smoother and softer materials can offer individuals a brighter visual experience, whereas rougher and harder materials tend to evoke a sense of darkness. Frosted textures can also contribute to a darker aesthetic.
iii) Softer materials leave a visually lightweight impression; in contrast, harder materials can evoke a sense of weight and security, as seen in electronic door locks.
iv) Smooth materials can suggest transparency; in contrast, rough or frosted textures imply less transparency, which is an important consideration for products that require internal visibility.
v) Smooth and hard materials, such as acrylic or metal, contribute to a clean appearance, this is beneficial, for instance, in the dust box of a sweeping robot to improve user experience.

CONCLUSION

In this study, we investigated the correlation between tactile and visual perceptions of materials used in home products. Our findings indicate that material roughness significantly influences visual perception; higher roughness correlates with a more visually complex style and darker characteristics, while lower the roughness is associated with a more transparent and cleaner visual experience. Materials hardness impacts visual perception as well: materials with higher hardness are perceived as brighter, heavier, and cleaner. Material type affects visual associations: compared to frosted metal, acrylic and mirror-finished metal are more likely to evoke "clean" and "transparent" visual experiences, whereas frosted metal tends to be associated with "dark" characteristics more than the other two.

From these insights, we proposed five design recommendations for selecting materials in home product design, outlined in the discussion section. These suggestions can guide designers in making informed material choices to enhance the visual experience of home products. Future research will expand to include a broader range of materials and delve into the interaction between tactile and visual experiences across different product categories and components.

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