Kansei Engineering, Vol. 145, 2024, 36–46
https://doi.org/10.54941/ahfe1005139

Mechanism of Multidimensional Subjective Perception of Automotive Interior Fabric Materials

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ABSTRACT

With the rise of new energy vehicles and increased consumer demand for personalization, understanding consumer behavior and emotional experience has become critical. This study analyzes the perceptual dimensions and influencing factors of automotive interior materials that affect consumers' car purchase decisions. The study analyzes consumers' preference for interior materials of new energy vehicles by examining the subjective perception differences between visual and visual-tactile dimensions. The study adopts the "material perception" theory to investigate people's perceptual evaluation of automotive interior fabric materials. Through perception experiments and multidimensional scaling analysis, we establish a space of perception dimensions and a structural model of material perception factors affecting car purchasing decisions. Regarding material roughness, there were significant differences across conditions, with visuotactile sensation rougher than visual sensation, and the interaction of material properties and sensory conditions had a substantial effect on emotionally assessed words. The study's results reveal the critical factors in consumers' car-buying choices and the advantages of automotive interior materials in the emotional perception dimension.

Keywords: Material perception, Automotive interior fabric materials, Emotional experience, Perception modeling, Multidimensional analysis

INTRODUCTION

The design differentiation of automobile interiors largely determines an automobile brand's personality and market competitiveness. In addition to design, choosing materials that express texture and sensual elements also plays a vital role in automotive interior design. The selection of high-quality interior materials can give automotive interiors a special visual effect and tactile texture. This study focuses on automotive interior seating and uses common textile materials, mainly organic, knitted, nonwoven, and fiber composites, as research objects. Functional properties of materials and manufacturing process selection of materials with objective measurability; It also depends on the production of various psychological emotions. Some studies have proposed that the description of material texture can be summarized in four dimensions: geometric, physicochemical, emotional, and associative dimensions (Zuo, 2004). Describing these dimensions allows people to convey the sensory properties of materials more comprehensively. To help people better understand the combined properties of materials and the subjective feelings associated with them.

The subjective perceptual approach to assessing materials is a complex and multidimensional area of research (Chunhong, 2018). A physiological perspective quantifies emotional perceptual needs, and an eye-tracker is used to observe whether consumers' subconscious behaviors align with consumer psychology (Jialin, 2022). Research on multisensory experience and selection of multiple packaging materials employed fuzzy theory and DEA methodology for sensory evaluation of experimental items to measure physiological signals with neural networks (Yong, 2022). There are also studies for the user's perception of automobile interiors is based on multisensory perception and feedback, and studying the user's thinking, psychological needs, and cognitive processes can reveal the intrinsic factors and laws that affect product design and innovation (Yanqing, 2019). There is a connection between consumers' physiological stimulation and psychological subjective perception induced through the physical characteristics of materials. To study such relationships, Sahli et al. (2022) focused on how humans perceive haptic characteristics of irregular, rough surfaces. The role of tactile perception in terms of roughness, texture, and friction is discussed in detail, and the effect of friction on tactile perception is explored. Kim et al. (2021) developed a structural model of affective responses elicited by tactile satisfaction with leather with tactile perception as the independent variable, the physical parameters of the material (e.g., softness, roughness, slipperiness, and elasticity) as the latent variables, and the participant's perceived satisfaction as the dependent variable. Sousa et al. (2022) discussed whether there are differences in tactile and visual characteristics, such as roughness, gloss, etc., of different plastic textures.The impact of these plastic textures on the affective dimension, i.e., how they elicit emotional responses and experiences, was also explored. Cao et al. (2020) addressed the problem of measuring subjective tactile feelings using a non-metric multidimensional scaling (NMDS) analysis to determine the dimensionality of personal perceptual feature parameters and the quantitative coordinates from the subjects' discrepancy ranking experiment. Liang et al. (2020) first conducted a sensory experience assessment experiment on an automobile sample, using quantitative theory to calculate the participant's perceptual perceptions and interior weight relationship between design elements; secondly, four dimensions of quality, emotion, price, and society were introduced, and factor analysis method was used to measure the influencing factors related to the degree of influence.

In this study, we first collect data about personal perceptions by exploring and analyzing the collected perceptual descriptive adjectives on a multidimensional scale. These data are used to build a perceptual model to examine the relationship between affective variables that affect perceived satisfaction.

Perceptual Assessment Experiments and Analytical Methods

Perceptual engineering often employs semantic difference scales to explore the relationship between perceptual keywords, design elements, and user perception assessment. Thirty participants were summoned to conduct rating experiments by rating 10 material samples made of different materials and textures and organizing, classifying, cutting, and numbering the material samples according to different textures and material categories, as shown in Figure 1. As rating indicators, we used three surface characteristics that identify the material category and texture: elasticity, softness, and roughness. Meanwhile, according to the participants' own emotional needs and preferences, the material samples were subjectively rated in terms of their impressions, with three perceptual keywords, such as "aesthetically pleasing," "comfortable," and "favorite satisfactory, "as the rating index of the emotional dimension. According to the visual and visual-tactile, two perception modes under the production of our questionnaire are shown in Table 1.

The experiment will be conducted under two conditions: Condition 1: Visual perception experiment, where participants are asked to observe the experimental material samples only through their eyes. Condition 2: In the visual-tactile perception experiment, participants can use their hands to touch the experimental material samples and observe them with their eyes, and hand movements such as pinching can be performed to recognize the sample materials according to the participant's tactile perception habits. The specific experimental steps are as follows (see Figure 2).

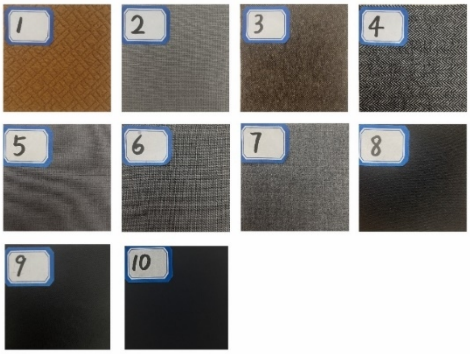

Figure 1: Sample plates for perception experiments.

Table 1. Questionnaire and semantic differential scale design.

NO.	Gender			Age			Drive Age	
				7-point SD Scale				
	7	6	5	4	3	2	1	
Rough				•				Smooth
Stiff							•	Soft
Stretchy			•					Non-stretchable
Cozy						•		Discomfort
Sleek	•							Ugly
Favorite		•						Nasty

Step 1: Arrange for the participants to experiment on a clean and tidy table and chair. Step 2: Participants were asked to truthfully fill in their personal information on paper, including age, gender, driving age, etc. This experiment was conducted for academic research only and would not disclose personal privacy. Step 3: Participants in the case ensuring a good physical and mental state, presented to the participant 10 items of material samples of the picture, according to the scoring index for the sample material 1–7 points. Step 4: Conduct a visual-tactile perception experiment where participants were provided with physical samples of the materials and given enough time to perceive the interaction and complete the scoring task. Finally, the experimental data were collected, and all used materials and equipment were cleaned up to ensure the safety and tidiness of the practical site. In addition, Experimental personnel should to set a one-day interval between the two perception experiments allowed for a more accurate assessment of participants' perceptual abilities in each experiment.

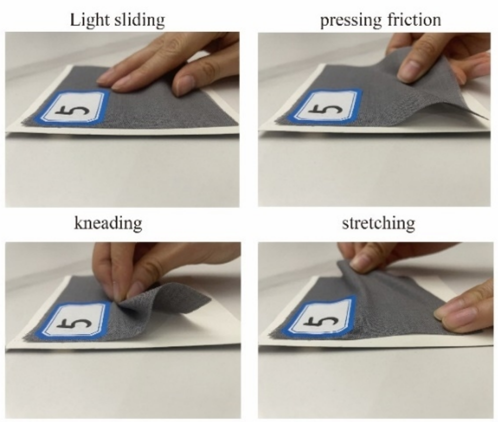

Figure 2: Experimental case demonstration procedure for perception in visual-tactile mode.

In the next step of the study, to better analyze the data affected by multidimensionality. We adopted Multidimensional Scaling (MDS) to downscale and visualize the multidimensional data and then used Structural Equation Modeling (SEM) to examine the interrelationship of the multifaceted influences and the causal relationship between the influences and consumers' satisfaction with car purchases.

In this study, SPSS/AMOS 18.0 software was used to integrate the distance between samples into a distance matrix by using Euclidean distance calculations with subjective dimensions adjectives of emotional perception of materials: comfort, aesthetics, and fondness as a triad, and then projected onto the two-dimensional space by the MDS method to recalculate the new coordinates.

To further explore and validate the potential relationships and theoretical assumptions between the variables, a theoretical model is constructed to study consumers' perceptual dimensions of fabric seating materials and the factors influencing experience satisfaction. According to the academic studies in the previous literature review, the seat material perceived by participants is affected by physical and psychological factors in multiple dimensions. The material's surface characteristics and physical properties, such as texture grain, roughness, hardness, and elasticity, affect the consumer's visual or tactile perceptions of the material and the seat's perceived comfort [15] . The theoretical modeling research framework shown in Fig. 3. The research hypotheses are as follows:

H1: Perceived roughness will have a positive effect on the perceived comfort.

H2: Perceived roughness will have a positive effect on the perceived aesthetics.

H3: Perceived roughness will have a positive effect on the perceived preference.

H4: Perceived flexibility will have a positive effect on the perceived comfort.

H5: Perceived flexibility will have a positive effect on the perceived aesthetics.

H6: Perceived flexibility will have a positive effect on the perceived preference.

H7: Perceived elasticity will have a positive effect on the perceived comfort.

H8: Perceived elasticity will have a positive effect on the perceived aesthetics.

H9: Perceived elasticity will have a positive effect on the perceived prefeernce.

H10: Perceived comfort will have a positive effect on the perceived preference.

H11: Perceived aesthetics will have a positive effect on the perceived preference.

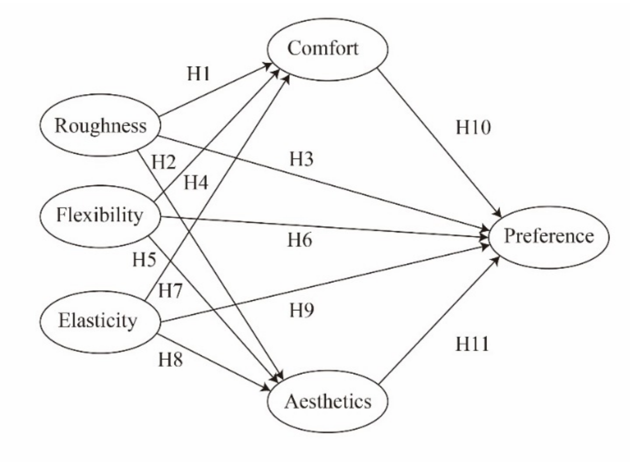

Figure 3: A research framework for perceived dimensions of fabric seating materials and factors influencing experience satisfaction.

RESULT

The descriptive statistics of the scores are shown in Table 2, and the average of the 30 models yielded Stress values and RSQ coefficients of determination of 0.259 and 0.548, respectively, which proved that the models had a reasonable degree of explanation. Fig. 4, shows the distribution of the perceptual space in the visual mode and visual-tactile mode.

The experimental assessment data were divided into two groups, visual perception assessment, and tactile perception assessment, and the structural equation modeling required that the data conform to a normal distribution as well as considering the correlation between the variables in the research model and the variables affecting the perceived fondness of the material. See Table 2 for a description of the statistical results, where the skewness coefficient, Skewness, and the kurtosis coefficient, Kurtosis, both coefficients, are less than 1, which can be considered to approximate a normal distribution. The goodness-of-fit statistics used to describe the SEM model are shown in Table 3, and GFI, CFI, NFI, and TLI are used as assessment indicators in this paper.

In this study, two structural equation models are proposed for the visual and tactile modes, as shown in Figure 5 and 6; the standardized path coefficients are analyzed, as shown in Table 4 and 5, and significant correlations between the variables are found, and in the visual perception research model, the perceived softness has a significant positive effect on comfort, with a standardized path coefficient of $r = 0.693$, and the perceived softness has a significant positive effect on the aesthetics, with a Standardized path coefficient $r = 0.591$; also perceived elasticity has a significant effect on aesthetics, but the path coefficient is negative, contrary to the hypothesis.

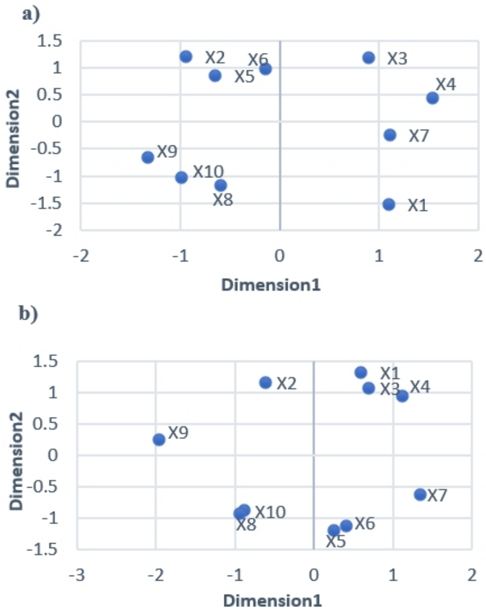

Figure 4: a) Perceptual spatial distribution in visual mode (stress = 0.25947, RSQ = 0.54775); b) perceptual spatial distribution in visual-tactile mode (stress = 0.25374, RSQ = 0.61656).

Table 2. a) Descriptive statistics of assessment data in visual mode.

	Max	Min	Mean	SD	Skewness	Kurtosis
Roughness	7.00	1.00	3.844	1.812	0.061	−0.891
Flexibility	7.00	1.00	4.144	1.847	−0.041	−1.006
Elasticity	7.00	1.00	3.844	1.788	0.127	−0.928
Comfort	7.00	1.00	3.982	1.768	0.007	−0.882
Aesthetics	7.00	1.00	4.037	1.882	−0.005	−0.980
Preference	7.00	1.00	3.889	1.817	0.015	−0.932

Table 2. b) Descriptive statistics of assessment data in visual-tactile mode.

	Max	Min	Mean	SD	Skewness	Kurtosis
Roughness	7.00	1.00	3.941	1.843	−0.047	−0.996
Flexibility	7.00	1.00	4.259	1.872	−0.164	−1.046
Elasticity	7.00	1.00	4.189	1.833	−0.082	−0.909
Comfort	7.00	1.00	4.200	1.840	−0.099	−1.009
Aesthetics	7.00	1.00	3.807	1.808	−0.030	−1.123
Preference	7.00	1.00	3.893	1.885	−0.077	−1.009

Table 3. Model fit indicator data results (GFI, CFI, NFI, TLI required to be greater than 0.9).

	GFI	CFI	NFI	TLI
Visual	0.965	0.947	0.947	0.948
Visual-Tactile	0.988	0.986	0.985	0.987

Among the variables influencing perceived liking, only softness, comfort, and aesthetics were significant, especially aesthetics, with a path coefficient of $r = 0.697$, indicating that perceived aesthetics strongly correlates with perceived liking in the visual mode. Among them, perceived softness is also related to perceived likability, and the path coefficient $r = -0.2$ shows a negative correlation with a relatively weak relationship. Therefore, we can summarize that H4, H5, H6, H7, H10, and H11 hold. Unfortunately, perceived roughness does not directly affect the subjective sensations of comfort, aesthetics, and liking in the visual mode.

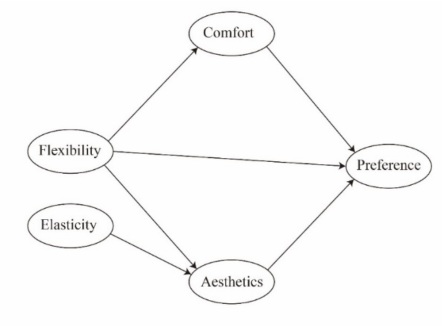

Figure 5: Research modeling in the visual mode.

In the haptic perception research model, perceived roughness and softness had significant effects on comfort, with standardized path coefficients of −0.248 and 0.585, respectively. It was found that more than the perception of roughness, perception of It was found that the perception of softness influenced the subjective dimensions of comfort and aesthetics more than the perception of roughness. Perceived elasticity also had no significant effect on aesthetics. The hypothesis is not valid. In the visuo-tactile perception research model, a strong relationship exists between perceived aesthetics and perceived liking, with a standardized path coefficient of 0.816, greater than 0.8. The path coefficients between perceived softness and perceived liking are 0.266, and the path coefficients between perceived roughness and perceived liking are −0.087, which is a relatively weak relationship. However, the variable roughness plays a role in material perception compared to the visual model. The variable has a role in material perception. Therefore, we can summarize that H1, H2, H3, H4, H5, H10, and H11 hold.

Table 4. Model fit indicator data results (GFI, CFI, NFI, TLI required to be greater than 0.9).

Causal Relationship	Estimate	S.E	C.R	P
Comfort←Roughness	0.076	0.046	1.652	0.098
Comfort←Flexibility	0.693	0.058	11.853	***
Comfort←Elasticity	−0.045	0.061	−0.737	0.461
Aesthetics←Roughness	0.068	0.058	1.171	0.242
Aesthetics←Flexibility	0.591	0.074	7.972	***
Aesthetics←Elasticity	−0.200	0.077	−2.597	0.009
Preference←Comfort	0.230	0.068	3.384	***
Preference←Elasticity	0.697	0.049	14.127	***
Preference←Roughness	−0.045	0.045	−1.007	0.314
Preference←Flexibility	−0.220	0.084	−2.632	0.008
Preference←Elasticity	0.065	0.061	1.075	0.283

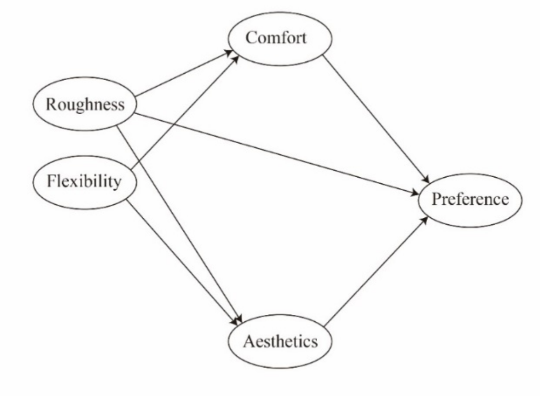

Figure 6: Research modeling in the visual-tactile mode.

Table 5. Model fit indicator data results (GFI, CFI, NFI, TLI required to be greater than 0.9).

Causal Relationship	Estimate	S.E	C.R	P
Comfort←Roughness	−0.248	0.050	−4.925	***
Comfort←Flexibility	0.585	0.056	10.404	***
Comfort←Elasticity	0.095	0.059	1.595	0.111
Aesthetics←Roughness	0.230	0.052	4.450	***
Aesthetics←Flexibility	0.530	0.058	9.184	***
Aesthetics←Elasticity	−0.042	0.061	−0.692	0.489
Preference←Comfort	0.266	0.048	5.562	***
Preference←Elasticity	0.816	0.046	17.621	***
Preference←Roughness	−0.087	0.040	−2.173	0.030
Preference←Flexibility	−0.004	0.057	−0.071	0.943
Preference←Elasticity	0.043	0.043	−0.991	0.321

DISCUSS

From the perceptual spatial distribution in the visual mode observed that X3, X4, and X7 were in one category, and X2, X5, and X6 were in another category; the plushness of the material may be an essential perceptual factor in providing participants with emotional perceptions, which may be one of the reasons for this discrepancy. The visual presentation may stimulate participants' imagination and association of emotions such as comfort, warmth, and closeness brought by the plush feeling. In addition, regarding the distribution of the second-dimensional orientation of the subjective dimensional perceptual space, one cluster consisted of samples 2, 3, 4, 5, and 6. In contrast, the other cluster included samples 1, 7, 8, 9, and 10, and it could be found that the fabric material of the first cluster was made of thicker braided threads, thus making the surface texture appear more noticeable and based on the more apparent visual information elicited emotions from the participants. Kodžoman et al. (2023) study also found that knitted texture was the most attractive visual texture, and the canvas was rated as unattractive. In the perceptual spatial distribution in the visuo-tactile mode, it is evident that sample 9 produces a significant difference from samples 8 and 10, a difference that is difficult to obtain by going into the visual senses. Sample 1's soft texture was more similar to samples 3 and 4 after touching, sample 2 caused a bumpy tactile sensation to distinguish it from samples 3 and 4, and sample 7's unique tactile sensation to distinguish it from samples 5 and 6, which were initially still more similar in the visual mode, and we can infer that those textural features, roughness, softness, and elasticity that can be sensed only by touching have a more significant impact on the participants' affective perceptions. Pan-Zagorski et al. (2022) studied that participants may prefer soft seats. The material's mechanical properties affected not only participants' perceptions of overall comfort and firmness but also their perceptions of seat size through potential differences in contact areas.

After deriving objective and subjective perception variables that may affect perceived material likeability, the proposed theoretical model was verified through structural equation modeling and combined with previous studies.

It can be found that perceived aesthetics has the most significant correlation with perceived liking in the research model, i.e., the standardized path coefficient is 0.816. aesthetics refers to the attractiveness and coordination of the appearance of an item. Min et al. (2015) found that various embossings and textures that can create a volumetric effect and reflect light can be added to the surface of fabrics. It satisfies consumers in terms of visual and psychological impact and renders a variety of interior spatial atmospheres. In this study, softness, an objective perceptual variable, directly affects perceived favoritism during visual interaction and indirectly affects favoritism through comfort and aesthetics during visuo-tactile interaction Yanqing et al. found (2019). That softness and hardness have direct and indirect effects on haptic satisfaction. Perceived slipperiness was also found to affect softness, luxury, and tactile satisfaction positively. Perceived softness also mediates elasticity, comfort, and aesthetics when touching a material surface.

CONCLUSION

The contributions of this study are as follows: (1) Plushness is an essential factor influencing the emotional perception of materials, and it can stimulate participants' emotional associations through visual presentation. (2) The material's surface characteristics and texture pattern have a more significant influence on visual perception. However, the physical quality felt by touch also plays a vital role in emotional perception.In the visual-tactile interaction, softness indirectly affects favorability through comfort and aesthetics. After touching the material surface, roughness affects the affective variables of the material. Although the effect of roughness may be overlooked when perceived only through vision, it is more easily detected in touch. (3) Finally, understanding the influencing factors of perceived material fondness is significant. It can help us provide high-quality visual presentations through online shopping platforms, adjust contrast and lighting effects, provide multiple perspectives and different distances, and work with textual descriptions and annotations, which can help consumers better perceive the material's properties in the visual mode.

ACKNOWLEDGMENT

The authors would like to express their gratitude to their fellow students in the subject group and supervisor Guo for their advice and guidance on the thesis.

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