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Study on the effect of shape and material on user tactile experience: A case study of mobile phone

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Abstract: *To solve the problems in the tactile experience such as strong ambiguity of cognitive, heavy burden in sensory experiment, the difficulty in describing the relationships between the emotional and the product physical attribution, we propose a layer based tactile approach in this paper. Specifically, the approach includes the following steps. Firstly, we obtain a collection of adjectives which can describe the tactile perception by the focus group, and by condulting the similarity estimation experiment and the multidimensional scaling analysis, several emotional factors which can explain the tactile comprehensive emotions are obtained. Then, sensible data of tactile comprehensive emotions and various emotional factors are retrieved through the tactile evaluation experiment, and the multiple linear regression equations for tactile comprehensive emotions and various emotional factors are obtained. Next, we perform the principal component analysis on each physical property, as well as the correlation between each principal component and haptic sensation factor. Combined the layered thought with the sensory experiment and mathematical statistics method, the evaluation model of "tactile comprehensive emotion-emotional factor-physical attribute" is established. The order of the influence of each physical attribute on tactile sensation can be calculated. With the in-depth analysis of the cognitive process of strong ambiguity of touch, the fuzzy touch experience was clarified, which provided a reference for product tactile experience evaluation and design.*

Keywords: *Tactile perception; hierarchical; emotional factors; experience design*

1. Introduction

It has long been recognised that as consumer products become mature in their market their functionality and usability become taken for granted. The user experience is an important indicator of the evaluation of usability. An excellent user experience could make users develop a positive emotion such as joy, surprise, satisfactory, and easily make them indulge in it. Recently, it is proposed some suitable strategies for developing the user experience which meet human's needs in the five senses (sight, hearing, touch, taste, and smell). Specially, in some handheld products (e.g. mobile phones, hair dryers, mouse, toothbrushes, game controllers, etc.), the tactile experience plays more important role than other senses[1-3].

Most of the current studies of tactile experience focus on the influence of materials. Fenko[4]mentioned that materials affect the tactile perception (warmth) of the product, what's more, the figurative meaning(warmth) is associated with social interaction, intimacy and friendly atmosphere. And several authors reported that it is suitable for designers to manipulate the intended warmth for a product or building through its materials [5-6].

In the tactile experience, material, the material is only one aspect, and the shape factor associated with the product is also part of it. The macro-spatial aspects involving in shape, length, width, size, weight, etc., as cannot be ignored in study of tactile experience. Similarly, Rahman[7] mentioned texture, hardness, shape, size all need to be take account in. Thus, how the combination of shape and material affects the user tactile experience still demand further exploration.

Its methods are those of affective engineering, a westernized approach to the Japanese-introduced Kansei engineering. Products, characterised by values of their properties (independent variables) about materials and shapes, are evaluated in terms of words (dependent variables) that represent the affective and sensorial responses of interest. Statistical analysis establishes relationships between the words (a semantic space) and places the materials and shapes in that space. Understanding the relationships between the affective and sensorial responses and what are the materials and shapes properties that determine how a material or a shape is placed then may lead to improved materials selection or shape design for affect.

In the tactile experience, Users' affection, such as "comfortability", "warmth", "Pleasant" etc., However, in product design, designer needs to user affection demand. Most relevant literature describe the relationship between a certain user's affection and the product they experience. For example, scarf and comfortability, furniture stone and warmth. As can be seen from these aspects of products themselves, one affection of these are particularly Significant. What's more, the emotional factors required by different people for mobile phones are also different. For example, young people hope mobile phones to be simple, trendy and comfortable, while middle-aged people want mobile phones to be stable, decent, and heavy. Thus, there is necessary to further refine the affection level to match the diverse needs of people for products.

However, grip experience is a kind of comprehensive evaluation of experience, featured by strong fuzzy. What's more, the semantic description of the touch of product is generally emotional. Some fuzzy words can be used to express these emotional feelings, such as "feeling satisfied", "too incredible" and "intolerable". In terms of evaluation, satisfaction[8], surprise [9] are often used as a term to evaluate comprehensive emotions. For example, for a comprehensive emotion evaluation index for the children's grip experience, the expression such as "a sense of wonder" may be a better alternative. Therefore, in the product grip experience design, a comprehensive emotion evaluation index should be clearly decided based on the emotional needs of the product target users in the grip experience of mobile phone, satisfaction is suitable as a comprehensive emotion.

As it is difficult to describe the complex and vague grip experience, comprehensive emotions need to be pointed out first. In addition, some sensible words used to explain this comprehensive emotion also need to be pointed out. Chen[10] state that Indulgent, Sensual, Relaxing, Natural, Simple, Delicate can describe the affective when touch the paper-boards and oriented polypropylene (OPP) flexible films. In present study, the sensible words can be obtained by focus group.

When analysing the emotional factors, it is common to obtain the main components through the SD method and principal component analysis of the evaluation data in the kansei engineering[11]. however, on one hand, it needs the participants to conduct sensory evaluation experiments on all adjectives in a specified number of samples, which lead to thinking pressure of the participants as well as inaccurate evaluation, meanwhile, when the semantics between vocabularies were close, it is difficult for users to make a decision; On the other hand, there is no checking mechanism to determine whether these descriptors cover all the dimensions of the tactile emotion[12]. Therefore, to cope with the aforementioned problems, such as thinking pressure reduction and judge covery and so on, Similarity estimation method and multidimensional scale analysis is adopted in this paper to conduct a cluster study on multiple adjectives containing the interpretation of tactile sense[13-14]. The multidimensional scale analysis is characterized by visualization to present the similarity degree of a series of concepts, which was first produced in psychological analysis and later used in product market positioning research. Through the similarity evaluation experiment and data fitting[12][14], these products were positioned in the "concept space", and the distance between the data points was determined by the calculated differences. In this way, the product relations in the "concept space" can be described product similarities. For example, Hughes[15] studied the effect of roughness on tactile sensitivity by using texture gradient to carry out multidimensional scaling analysis.

Because different age groups have different needs of emotional factors. the emotional factors weights for comprehensive emotions were also different. In order to analyze the intrinsic influence mechanism of emotional factors on comprehensive emotions, regression analysis is needed.

Psycho- physical, also called perceptual dimension. The existing literature rarely states the reasons for using a perceptual dimension, and there is no clear indication that the perceptual dimension is related to the research object. Okamoto[12] generalizes that tactile textures have three fundamental perceptual dimensions, roughness (rough/smooth), hardness (hard/soft), and warmness (cold/warm) dimensions were very frequently observed.

Data acquisition for tactile physical attributes can be divided into two categories. One is the physical attributes that can be directly obtained through instrument measurement. For example, JIN[16] obtained seven kinds of physical evaluation attributes (shape, color, material, screen, keyboard, details and volume) about the touch of mobile phone through collection. Another is which can't be measured easily by the instrument, through the participants subjective judgment, and indirectly get the data of physical properties, such as: Tang[17] classified the visual and tactile physical characteristics of industrial design materials into three evaluation dimensions: texture, smoothness and softness. Yanagisawa[18] determined the physical feature dimensions of surface texture of materials as roughness, softness and slippage, and all of them were evaluated subjectively by the participants, and physical attribute data was obtained indirectly.

Firstly, through focus group discussion, the set of adjectives describing the product's touch is obtained. Secondly, the similarity evaluation experiment is carried out for the semantic differences of adjectives, and the multi-dimensional scale analysis of the evaluation data is carried out to obtain the spatial distance relationship in the semantic space, and a number of emotional factors are obtained by clustering. Thirdly, the product samples are collected, the participants are gathered, and the tactile evaluation experiment is carried out for the comprehensive emotion and a number of emotional factors. Fourthly, multiple linear regression was used to carry out data analysis to establish the relationship model of comprehensive emotion and emotion factors. Fifthly, according to the physical attribute data of the product sample, principal component analysis is conducted, and the correlation between each principal component and tactile emotion factors is calculated, and the relationship between emotional factors and physical attributes is described. Finally, based on the hierarchical relationship between "physical attributes - emotional factors - comprehensive emotions", the discussion is carried out to provide reference for the improvement of product tactile experience.

2. Method

2.1 Experiment1

As far as the smartphone market is concerned, the difference with regarding to performance, quality and shape of mainstream brands is shrinking, which results in a homogenization phenomenon. The design of the physical attributes which affect the tactile experience such as material, chamfering and weight, has become the focus of smartphone manufacturers. For smart phones, this part takes "satisfaction" as the comprehensive emotion evaluation index, and applies the hierarchical evaluation method of product grip stratification.

2.1.1 Experimental purpose

For the group discussion, we have obtained 12 adjectives which can serve as "satisfaction" interpretation. These adjectives are volume sense, metal feeling, temperature sense, conciseness sense, sense of congenial texture, comfort sense, security sense, tenderness sense, fit sense, full sense, smooth feeling, sense of concavo-convex, respectively. Based on similarity assessment, a multidimensional scaling analysis and clustering, we can obtain touch emotional factors.

2.1.2 Participants

There are 55 undergraduate and graduate students majoring in industrial design with professional judgment ability for the difference of 12 adjectives' semantics.

2.1.3 Procedure

55 participants are required to rate the semantic differences between 12 adjectives. The smaller the semantic difference, the lower the score, and vice verse. Specifically, the score represent that two words have identical semantics, and 9 represents two words have very weak similarity degree.

In the experiment, we assume that the ambient temperature is comfortable. The participants hold and touch the smartphone while experiencing the adjective meanings in a quiet environment [21].

2.2 Experiment2

2.2.1 Experimental purpose

By conducting sensory evaluation experiment, multiple linear regression analysis is performed to analyze the relationship between sensory satisfaction and 4 emotional factors.

2.2.2 Participants

Sixty participants with using experience of smartphone.

2.2.3 Materials

It takes 29 types of smartphones with no wear on the surface as experimental samples. They are belonged to 8 main steam brands, such as: iPhone (7 types), HUAWEI (8 types), MI (5 types), VIVO (3 types), OPPO (3 types), SAMSUNG (1 type), MEIZU (1 type), LENOVO (1 type).

2.2.4 Procedure

Firstly, the participants read the experimental process instruction to understand the text interpretation of four emotional factors; Then, the participants touched the phone to form tactile cognition of emotional factors; Next, the participants' eyes are covered, different samples are touched, and the score of comprehensive satisfaction and 4 emotional factors are recorded at the same time. The score is between -3 and 3, with -3 being the most dissatisfied and 3 the most satisfied.

2.3 Data analysis

2.3.1 Comprehensive emotional layer- Emotional factor layer

To explore the relationships between the emotional layer and the emotional factor layer, the most popular method is the multiple linear regression analysis[16][19].

Let comprehensive emotion (Y) be the dependent variable, p emotional factors (X_1、X_2、……、X_p) independent variables, and n samples which can be meatured. The value of the l sample is (Y_l , X_{l1} , X_{l2} ,…… X_{lp}). The expression can be expressed as follows:

$$Y_l = \hat{Y}_l + e_l = B_0 + B_1 X_{l1} + \ldots\ldots + B_p X_{lp} + e_l \tag{1}$$

The dependent variable (Y_l) consists of two parts: the estimated value ($\hat{Y}_l$), which represents the part determined by the independent variables; the residual value(e_l), is the difference between the dependent variable (Y_l) and its estimated value ($\hat{Y}_l$); B_0 is the constant of the normalized regression equation, and B_1 ,……, B_p are the partial regression coefficients of the normalized regression equation.

2.3.2 Emotional factor layer - physical attribute layer

There is a correlation between subjective tactile emotion factors and multiple physical attributes [16]. In order to describe the relationships between physical attributes and emotional factors, the principal component analysis is firstly carried out by combining the sensory evaluation experimental data of emotional factors and physical attributes data [20]. Then, the main components and tactile perception factors are analyzed. Finally, the corresponding physical attributes of each emotional factor are obtained. The specific steps are listed as follows:

(a)By principal component analysis of product physical attribute data, U principal components are obtained ($F_1, F_2, \ldots, F_u$). According to the accumulated contribution rate, the first V principal components are selected.

(b)The correlation analysis of V principal components ($F_1, F_2, \ldots, F_v$) and p tactile emotion factors in 1.3.1 was conducted, and the relationship of "emotion factor - physical attribute" is described according to the correlation coefficient.

3. Result

3.1 Experimental data processing and analysis

In SPSS 17, multidimensional scale analysis is conducted on the data, and the results are as follows. The weighted average model decision coefficient is 0.416, and the pressure value is 0.295. Fig.1 shows the individual difference by Euclidean distance model of 12 adjectives. According to the spatial distance and corresponding adjective interpretation, 4 key tactile emotional factors can be concluded through clustering. Laminating sense, tenderness sense, comfort sense, security sense are of one kind, which is called "comfort factors". Concave-convex feeling and smooth feeling are the same type called "slippery factor". Sense of congenial texture and conciseness is one kind, which is called "concise factor". Metal sense, temperature sense, volume sense are one kind, called "volume factor". In order to understand the

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internal relations of each word [22], combined the spatial relations and adjective semantics, the two dimensions in fig.1 can be described as: rational - perceptual (dimension 1), shallow - deep feeling (dimension 2).

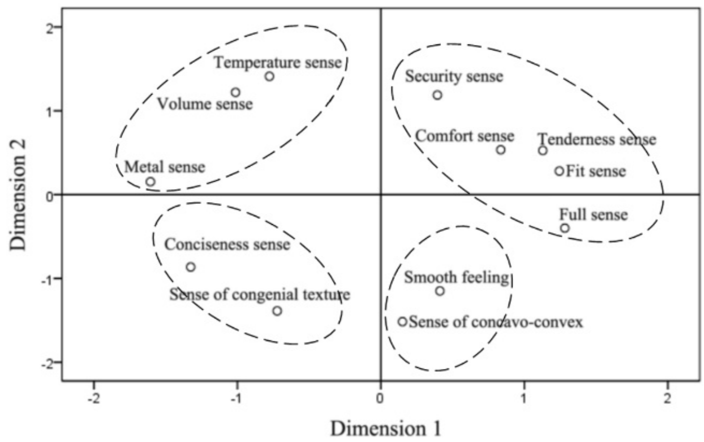

Figure 1: Euclidean distance model

3.2 Experimental data processing

The factors of concise, comfort, volume and slippery are respectively recorded as X_1、X_2、X_3、X_4, and the touch satisfaction of the dependent variable is recorded as Y .The scatter diagram (as shown in Fig. 2) between the independent variables and the dependent variable is observed, and all the four emotional factors are in positive relation to satisfaction.

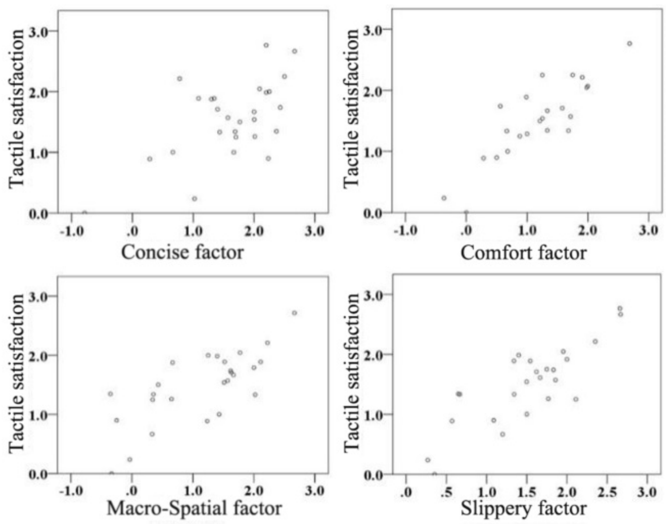

Figure 2: Scatter plot of tactile satisfaction and emotional factors

After performing multiple linear regression analysis in SPSS 17, the model's determination coefficient is 0.900 and adjusted to 0.883, indicating that all emotional factors could explain the comprehensive satisfaction of touch. After regression equation significance test, the probability of F test statistic (53.880) is less than 0.05. It indicates that there is a linear relationship between independent variables and dependent variable. As shown in table 1 below, the probability P of t test statistics in the significance of regression coefficients of the independent variables is <0.05, indicating that there is a significant linear relationship between the dependent variable and the four independent variables. In addition, the tolerance of each emotion factor is not as low as close to zero. In terms of volume factor with the lowest tolerance, the value was 0.386, indicating the influence of volume factor on tactile satisfaction is independent with other influencing factors in degree of 38.6%.

Table 1: Table of regression coefficient analysis

	Standardized coefficients	T-test statistics	P	tolerance
Constance		1.208	0.239	
Concise factor	0.178	2.223	0.036	0.648
Comfort factor	0.381	3.981	0.001	0.456
Macro-Spatial factor	0.401	5.110	0.000	0.386
Slippery factor	0.222	2.134	0.043	0.679

Thus, the linear regression equation is:

$$Y = 0.178X_1 + 0.381X_2 + 0.401X_3 + 0.222X_4 \tag{2}$$

According to the data, the weight value of emotional factors indicates that the smartphone with a good sense of volume and comfortable touch is more favored by consumers.

3.3 Correlation analysis of emotional factors and physical attributes

This part combines sensory evaluation experiment and physical attribute parameters of smartphone samples, adopts the principal component analysis method to obtain the principal components of physical attributes. Moreover, it conducts the correlation analysis between the principal components of physical attributes and the score data of emotional factors to describe their correlation. The specific process is as follows:

3.3.1 Extraction and measurement of physical attributes affecting tactile perception

Through focus group discussion and related literature study, 9 physical attributes of smartphones are extracted, namely: length, width, size, thickness, weight, chamfer size, temperature, hardness, smoothness. Among them, temperature, hardness and smoothness are obtained indirectly through sensory evaluation experiment. The rest of the physical property data comes from the phone's inherent parameters or is directly measured.

3.3.2 Principal component analysis of physical properties

Table 2: Principal component analysis of physical properties-Total Variance Explained

Principal component	Characteristic root	Contribution rate	Cumulative contribution rate
1	3.729	41.430%	41.430%
2	1.556	17.293%	58.724%
3	1.144	12.707%	71.430%
4	1.108	12.309%	83.740%

* This table only retains the principal components whose characteristic root is greater than 1, i. e. the first 4 principal components.

Table 3: Principal component analysis of physical properties-Component Matrix

Physical properties	Principal component			
	1	2	3	4
Width	**0.975**	0.021	0.039	0.019
Length	**0.972**	0.121	0.077	-0.074
Size	**0.962**	0.078	0.087	0.045
Weight	**0.856**	0.208	0.067	0.106
Smoothness	0.032	**0.809**	-0.061	-0.146
Chamfer	0.333	**0.677**	-0.040	0.022
Warmness	0.224	-0.200	**0.848**	-0.234
Hardness	-0.089	0.575	**0.625**	0.333
Thickness	0.075	-0.090	-0.095	**0.949**

* Bold indicates more information about the original physical attributes.

Through the principal component analysis of 9 physical attributes corresponding to 29 phones in the sensory evaluation experiment, the total variance of the original variables is explained as shown in table 2. The principal components whose feature root is greater than 1 (the first 4) are extracted, and the cumulative contribution rate is up to 83.7%, indicating that the first 4 main components cover most of

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the original information. In the factor loading matrix (as shown in table 3), the principal component 1 is length, width, size and weight. The principal component 2 is smoothness and chamfer size. The principal component 3 is temperature and hardness. The principal component 4 is the thickness.

3.3.3 The relationship between emotional factors and physical attributes

Correlation analysis is conducted by combining 4 emotional factors and 4 principal components of physical properties, and the results are shown in table 4. The principal component 1 is only negatively correlated with the volume factor, that is, in the sample range, the smaller size and lighter weight of the smartphone, the volume perception is better, but the correlation is not obvious. The principal component 2 is moderately positively correlated with the concision factor, while it is positively correlated with the comfortable factor and the slippery factor. In other words, the more smooth surface, and the larger chamfer, the user's perception of concision, comfortable and slippery are better. The principal component 3 is in a weak positive correlation with the degree of concision. That is, the warmer and harder of the surface material, the concision is perceived better, but the correlation is not obvious. The principal component 4 is moderately negatively correlated with volume factor. That is the thinner the phone, the better its volume perception.

Table 4: Correlation coefficient of emotional factors-physical properties($p<0.05$)

Emotional factors	Physical properties			
	PC1	PC2	PC3	PC4
Concise factor	-	0.415	0.359	-
Comfort factor	-	0.626	-	-
Macro-Spatial factor	-0.320	-	-	-0.460
Slippery factor	-	0.742	-	-

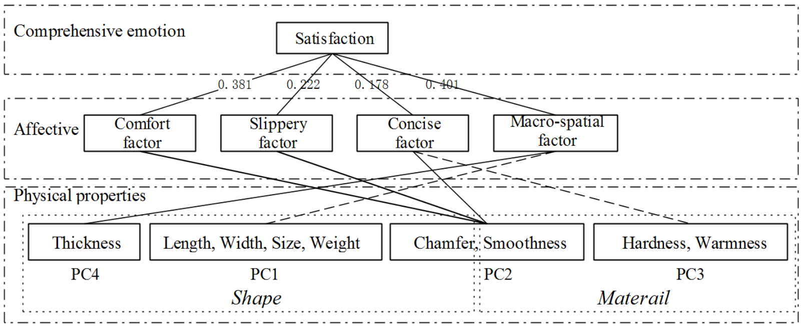

Figure 3: Evaluation hierarchy model of cell phone

4. Discussion

To sum up, the hierarchical tactile evaluation model of smartphone can be described as shown in figure 3, which describes the specific content of the comprehensive satisfaction layer, emotional factors layer, and physical properties layer, weight coefficients of emotional factors and their correlations between physical attributes principal components, aims to provide a reference for tactile experience design.

Statistical analysis of the combined results has shown that a layered structure (Fig. 3) exists, from physical properties, to affective evaluation, to comprehensive emotion evaluation, in which to consider relationships between physical properties and their comprehensive emotion. The detail of Fig. 3's structure is provisional. From the results of principal component analysis, the principal component 3(*hardness* and *warmness*) , might indicate that a surface perceived as *hard* might also be more likely to be perceived as being cold, (Chen et al. also found a correlation between hard-soft and warm-cold). Surprisingly, Smoothness have a relationship with chamfer, while the smoothness represents the surface of a product, the chamfer represents the shape of product, indicate that there is a intangible connection between surface and shape: the more rounder, the more smoother, which have a correspond with our cognition that the ball is smoother than the square.

In combination with table 1, table 3, table 4 and figure 3, the following description is obtained for the tactile evaluation of mobile phones: For principal component 2 (smoothness, chamfer size), it has a strong correlation with emotional factors except for volume factor. The principal component 3 (cold and warm, soft and hard) is only weakly related to the concise factor, and the concise factor in table 1 has the lowest contribution to the degree of tactility satisfaction. The principal component 1 (length, width, size, weight) and principal component 4 (thickness) are only correlated with volume factors, and the correlation between principal component 4 and volume factors is greater than that of principal component 1, as shown in table 4, indicating that the influence of principal component 4 on tactility is greater than that of principal component 1. To sum up, the importance of each physical attribute on the sense of touch can be sorted as: principal component 2 (smoothness, chamfer) > principal component 4 (thickness) > principal component 1 (length, width, size, weight) > principal component 3 (temperature, hardness).

5. Conclusion

In the eyes of the research content, combined with the hierarchical concept, the paper puts forward the "tactile comprehensive emotion-affective factors-physical attributes" of the user's perception of the product under the tactile channel, which can clarify the fuzzy tactile experience. In the eyes of research method, the relationship between each layer is analyzed through sensory evaluation experiment and mathematical statistics principle, and the technical route of product tactile evaluation is constructed, which is applied in smart phones. In addition, combining similarity evaluation and multi-dimensional scale analysis, this paper adopts the method of "cluster before evaluation" to reduce the thinking pressure of evaluation.

In the real product experience, the consistency of visual and tactile experience may affect the tactile experience. In the subsequent research, it will be further expanded from the perspective of vision- tactile consistency.

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Author’s contributions

Conceptualization, Zhuan Zhou. Investigation and methodology, Zhuan Zhou, Liangyuan Wang. Writing of the original draft, Zhuan Zhou. Writing of the review and editing, Zhouke Kang Wenqin Zeng. Data analysis, Liangyuan Wang.

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