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Experimental Study for Computer Aided Affective Product Styling

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ABSTRACT

In addition to a product's functionality, the emotional responses invoked by the product styling also play a role in deciding whether it appeals to the end users. This can be seen from many marketing campaigns attempting to bring out the affective values of products such as how they reflect a user's personality and enrich his/her lifestyle. A number of ergonomic studies have been carried out to explore these emotional aspects of product design. However, the results obtained often focused on individual features or only provided qualitative insights. In this paper, we utilize factorial experiment to systematically analyze how certain shape factors individually and interactively influence the user's impression of glasses frame. This approach not only allows us to identify various shape features and their combinations, but also to derive computational models for computer aided affective design. The experimental findings confirm some common perceptions of glasses frames. More information is revealed when considering the interactions between shape features.

Keywords: product design, factorial experiment, affective design, product styling.
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1. INTRODUCTION

When designing a product, one crucial aspect to consider is how the user can emotionally relate to it [1]. The systematic analysis of the user's emotional responses to the design of products began in the 90s in Japan. It was focused on understanding how the user feels about a particular design features such as shape or materials. *Kansei Engineering* [2] is a technique aiming to transform a user's affecting responses into design parameters. With the links established between the two, the final product containing the relevant design parameters or features is expected to invoke the corresponding "feelings" of users. The technique was later applied to study a wide range of products such as the design of car interiors [3], consumer electronics [4], and industrial equipment [5]. Other researchers focused on the pleasurable aspect of products in particular and studied how a product can enrich a user's mental activities [6]. McDonagha et al. [7] introduced the concept of *soft functionality* to describe the emotional responses or other less tangible aspects that influence how the user interacts with the products. A product personality profiling method has been developed to elicit the soft aspects [8]. Hsiao et al. [9] studied the relationship between product profiles and affective responses across large, medium, and small products and attempted to uncover the fundamental dimensions of affective responses to product shapes. They showed that across the three product categories the shape features like curvy lines were more likely to be perceived as soft, feminine characteristics of the products.

Those past studies have addressed the emotional effects of individual features. However, issues such as the interactive effects between each design features and how they contribute to the user's impression on the final product as a whole are difficult to study using their approaches. Moreover, most of the results obtained from those qualitative methods are difficult to be transformed to computational models. There is still a lack of support to computer aided techniques for affective 3D product styling. Therefore, this research conducts an experimental study for better understanding people's affective responses towards the product shapes. A factorial experiment is constructed to characterize how various shape factors individually or interactively affect a user's emotional responses, with 3D glasses frames as an example. The selection of the test elements and the experimental settings were suggested by industrial designers collaborating in this study. The factorial approach allows us to identify the shape features and their combinations that significantly influence five different product styles. The results obtained from multivariate analysis of variances validate some common perceptions of the glasses frame design quantitatively. They also reveal interesting insights to the interactions between shape features. These findings serve as a basis for computational models that facilitate customization of 3D product design with particular emotional responses.

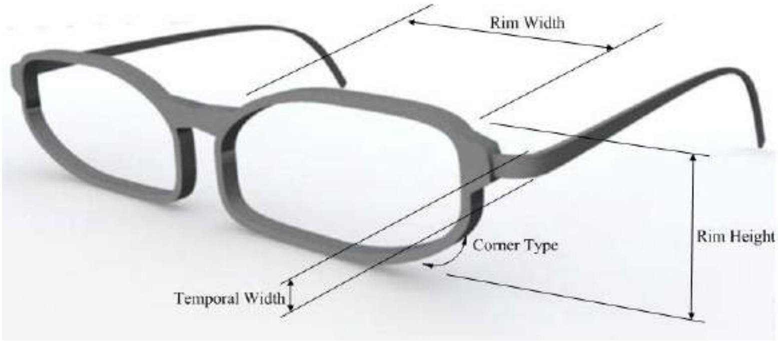

Fig. 1: Selected shape factors for glasses frames.

2. METHDOLOGY

2.1 Construction of Test Models

Factorial design [10] is an experimental technique that allows the experimenter to study the effects of multiple independent variables at the same time with a reduced number of trials. The independent variables are manipulated by the means of adjusting the predefined levels of selected factors. One can examine how those variables individually or interactively influence the experimental results with the factorial approach. This work conducted a factorial experiment to characterize how various shape factors affect a user's emotional responses towards 3D glasses frames. The DOE (Design of Experiment) techniques were first employed to choose the factors that we can vary their attributes in a systematic way. The variations of the factors were then combined to form the 3D shape of the test product. The selected elements, as illustrated in Fig. 1, and how we varied their attributes are described as follows:

- **Temporal width**: w1 (narrow, 0.125), w2(wide, 0.75)
- **Rim aspect ratio**: a1 (0.5), a2(0.75)
- **Rim corner symmetry**: s1 (full symmetry, FS), s2 (horizontal symmetry, HS), s3(vertical symmetry, VS), s4(diagonal symmetry, DS)
- **Rim corner type**: t1(circular), t2(square)

The fractions bracketed in the specifications of the temporal width and rim aspect ratio are calculated with a base width, i.e. w_1 is one-eighth, w_2 is three-fourth, and the height in a_1 is one-half of the width. The experiment was then run with a full mixed level factorial design. The combinations of the factors and levels yield a total of 32 glasses frame models. Fig. 2 shows 4 exemplary models tested in the experiment.

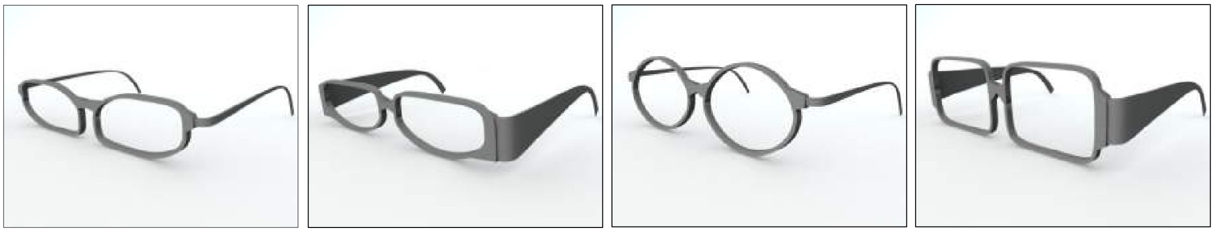

Fig. 2: Four exemplary 3D models of glasses frame.

2.2 Choosing Adjectives

We collected a total of 59 adjectives from related literatures and design magazines. The KJ method [11] was used to cluster these adjectives into five groups that describe five corresponding concepts. Three industrial designers were invited and joined with one of the authors to participate in the KJ clustering sessions. There were totally two clustering sessions. The first session was performed by the author and one industrial designer from Taiwan. The author led the session in terms of keeping the focus and flow of the discussion. He gave no explicit instructions to how the adjectives should be clustered. The clustering was completed with the following procedures:

1. Each of the 59 adjectives was printed on an individual card. These cards provide ideas of KJ clustering technique.
2. The author picked out one adjective card. He then asked the designer to pick another card with the adjective of a similar meaning.
3. The author picked out another adjective card and asked the designer if it had a similar meaning to the pair previously grouped. If it did, it was added to the pair's group; and
4. if it was of a different meaning, it formed a new group and the designer would be asked to pick another adjective card that belongs to the newly-formed group.
5. Step 3 and 4 were repeated until all adjective cards had been clustered.
6. The clustered groups were eventually reduced to five after further discussions between the author and the designer.

The second session was carried out by the author with the two designers from the US. The session was performed with internet conferencing. The adjective groups clustered in the first session were sent over to the two designers using email. With the author and the two designers all having the adjective files at hand, they discussed the necessary rearrangements of the clusterings. At the end, they identified five main concepts described by the adjective groups and their bi-polar representatives (see Fig. 3):

- **Gender connotation**: Feminine - Masculine
- **Popularity**: Common - Special
- **Design specialty**: Original - Dull
- **Reflected value**: Magnificent - Rough
- **Structural firmness**: Robust – Fragile

Fig. 3 illustrates the clustered results of the 59 adjectives. What enclosed in the central eclipse are the five conceptual measures identified in the KJ sorting process. The smaller circles radiating from each center contain the adjectives clustered in each group. The two circles shaded with the same color as the central eclipse are the bi-polar representatives. Note here that the results cannot possibly reflect or include each individual's agenda. In our case, indeed, the readers may have their own interpretations on some of the adjectives collected in this study and how they should have been clustered. Nonetheless, KJ-sorting is an efficient method to quickly reduce vast amount of information. Much of the outcome is produced through the cooperation and negotiation among domain experts. Given the complex nature of human emotions, this method helps in terms of rapidly reducing the problem space and generating the expert heuristics for our work.

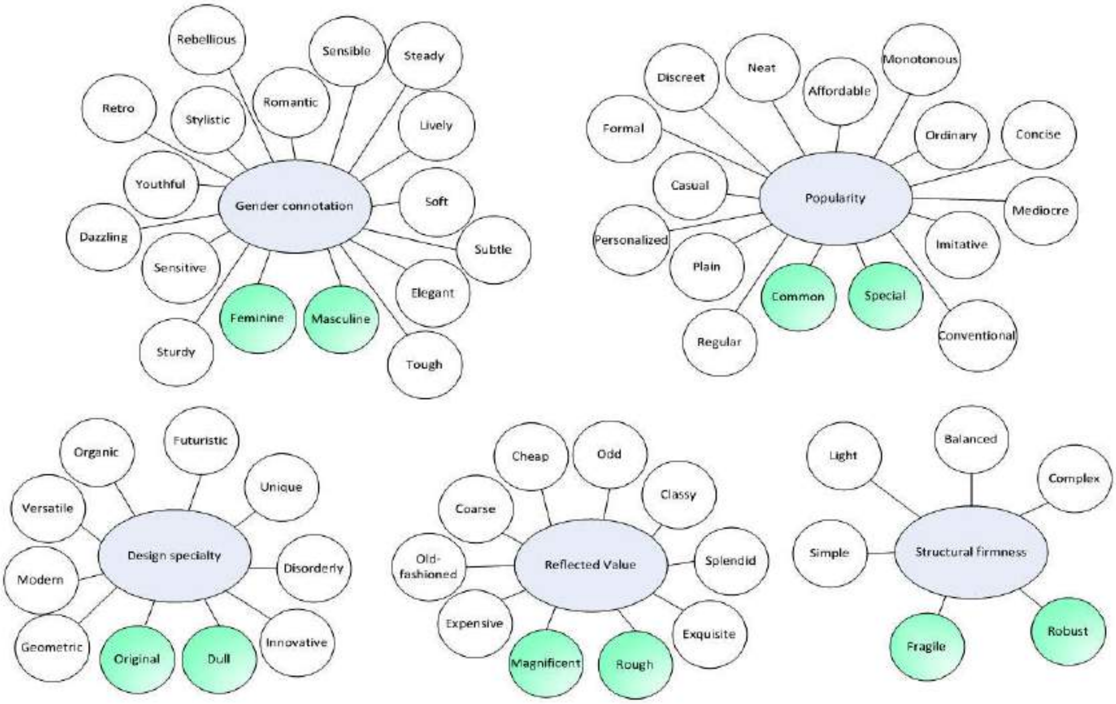

Fig. 3: KJ-sorted adjective groups.

2.3 Human Cognition Experiment

We recruited 30 subjects to participate in the experiment. They were undergraduate or graduate students at National Tsing Hua University, between the ages of 21–35. A Java-based web application was developed for presenting the models to the participants. It allows a participant to interactively move, drag, and rotate the 3D models in real time. A questionnaire was designed for the participants to fill in with their emotional responses. The questionnaire lists 32 models labels and under each model label, each of the five bi-polar adjective sets contains a 7-position Likert scale, labeled with: slightly agree, agree, strongly agree, towards each extreme, and the middle position is labeled with neutral. The experiment was conducted as follows. An experimenter firstly explained the purpose and the rules of the experiment. The participant was then presented with the Java-based application. A demonstration was given to show how to control the 360 degree viewing of the glasses frame models. Each participant was given 3 minutes to practice the viewing control. Each participant needs to mark the levels of affective response according to his/her perception about the shape of the current glasses frame. The experimenter controlled the order of presenting the 3D model. A random order of the presentation was pre-calculated for each participant. The experiment session lasted one hour.

3. RESULTS AND DISCUSSIONS

The collected data was analyzed with Multivariate Analysis of Variances (MANOVA) [12]. The aim of the MANOVA analysis is to identify the main and interactive effects of the shape factors that are statistically significant in changing the user's affective responses towards the glasses frames. A probability measure called *p*-value calculated from MANOVA determines the statistical significance. It measures how confident we can generalize the results derived from the sample in representing the whole population. For example, if the *p*-value is 0.1, it means 90% of confidence we have in the sample that can reflect the interested behavioral feature of the whole population. An acceptance level, called α level, is chosen to determine whether confident enough to claim the findings. We follow the convention in most statistical analysis, i.e. $\alpha = 0.05$ [13]. Tab. 1 shows the results of the participant's judgments on the gender connotation of glasses frame shape with respect to the changes of each factor and their possible combinations. The headings of the table are described as follows. DF stands for *Degree of Freedom*. In factorial design, the levels (values) of the independent variables are predetermined. F is a measure of the ratio between the effects caused by the systematic variations (our manipulations of the factor levels) and the unsystematic variations (any other unknown random factors). The F value should be larger than 1 to conclude that the differences in the subjects' responses are due to the systematical manipulations. If $p < 0.05$, the corresponding factor produces a statistically significant effect on the product shape. The significant factors and combinations are highlighted in the table.

Factors	*DF*	*F*	*p*
Temporal width (w)	1	13.11	0.000
Aspect Ratio (a)	1	107.17	0.000
Corner Symmetry (s)	3	1.41	0.239
Corner Type (t)	1	9.68	0.002
w x a	1	3.19	0.075
w x s	3	0.7	0.549
w x t	1	3.56	0.059
a x s	3	0.32	0.814
a x t	1	27.59	0.000
s x t	3	7.46	0.000
w x a x s	3	0.14	0.936
w x a x t	1	0.07	0.799
w x s x t	3	1.43	0.234
a x s x t	3	23.34	0.000
w x a x s x t	3	0.69	0.556

Factors: Design elements

DF: Degree of Freedom

F: Between group variance/Within group variance

p: Statistically significant level

Tab. 1: MANOVA result of gender connotation.

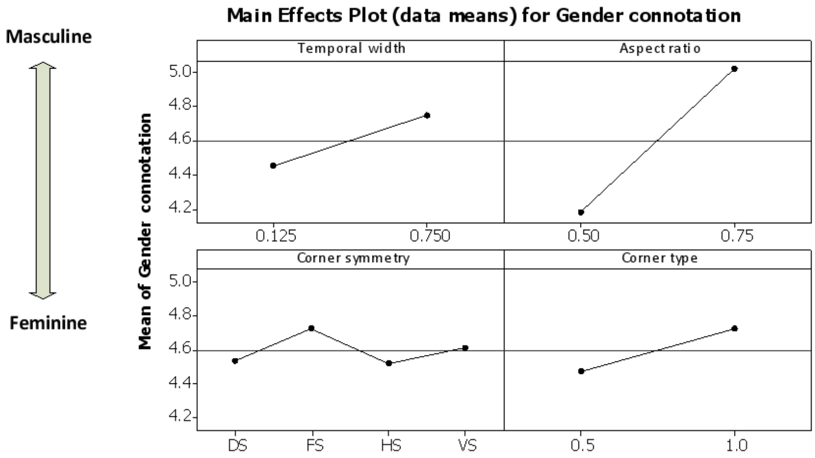

Fig. 4: Mean plots of the main effects and interactions for gender connotation.

3.1 Gender Connotation

The highlighted parts in Tab. 1 show that the changes of temporal width, aspect ratio, and corner type produce a significant impact on the participants' responses on gender connotation. In addition, the interactions between aspect ratio, corner type, and corner symmetry (i.e. *a* x *t*, *s* x *t*, and *a x s x t*) also affect the participants' judgments. We further examine the means of participants' responses plotted with respect to the changes of factor levels. As shown In Fig. 4, the levels of the factors are marked on the horizontal axis, whereas the vertical axis represents the subject's responses towards the factor levels. The black dots connected by the straight lines show the mean responses in accordance with the factor levels. For a 7-position scale, the midpoint 4 represents a neutral response. The points above and below the midpoint represent the tendencies towards the endpoints of each conceptual measure. When the temporal width becomes wider, it tends to make the glasses frame look relatively more masculine. The participants respond similarly to the frame's aspect ratio. A larger aspect ratio produces a relatively more masculine look. For the corner types, a more squared corner also makes the glasses frame look more masculine as compared to a circular one.

Factors	***DF***	***F***	***p***
Temporal width (w)	1	0.54	0.461
Aspect Ratio (a)	1	67.2	0.000
Corner Symmetry (s)	3	31.52	0.000
Corner Type (t)	1	15.24	0.000
w x a	1	2.58	0.109
w x s	3	1.95	0.120
w x t	1	0.01	0.931
a x s	3	0.42	0.736
a x t	1	1.93	0.165
s x t	3	3.27	0.021
w x a x s	3	0.03	0.992
w x a x t	1	1.47	0.225
w x s x t	3	1.22	0.302
a x s x t	3	3.72	0.011
w x a x s x t	3	0.56	0.639

Tab. 2: MANOVA results of popularity.

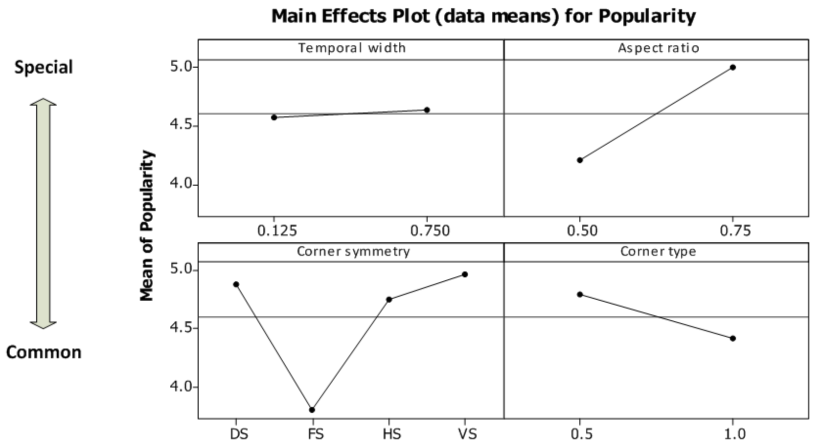

Fig. 5: Mean plots of the main effects for popularity.

3.2 Popularity

As shown in Tab. 2, the effects of the aspect ratio, corner symmetry, and corner type are significant on popularity. Compound effects can also be seen in the combinations of corner symmetry and corner type as well as aspect ratio, corner symmetry, and corner type. Fig. 5 shows that for aspect ratio the lower level is more common than the upper level. The responses caused by changing the corner symmetry are even more apparent. The fully-symmetrical rim is a lot more common than the other three types of symmetry. For corner type, the squared corner is also more commonly seen than the circular one. Regarding interaction between corner symmetry and type, the trend of the effects of corner type varies with different corner symmetry. When the rim is diagonally-symmetrical, changing the corner type does not produce much impact on the participants' impression on popularity. Changing the corner from circular to squared type makes the glasses frame more common.

Factors	*DF*	*F*	*P*
Temporal width (w)	1	8.65	0.003
Aspect Ratio (a)	1	19.37	0.000
Corner Symmetry (s)	3	21.67	0.000
Corner Type (t)	1	5.88	0.015
w x a	1	0.5	0.479
w x s	3	2.2	0.087
w x t	1	1.5	0.221
a x s	3	1.32	0.267
a x t	1	0.02	0.881
s x t	3	1.45	0.227
w x a x s	3	0.12	0.947
w x a x t	1	0.13	0.715
w x s x t	3	0.27	0.847
a x s x t	3	2.66	0.047
w x a x s x t	3	0.39	0.758

Tab. 3: MANOVA result of design specialty.

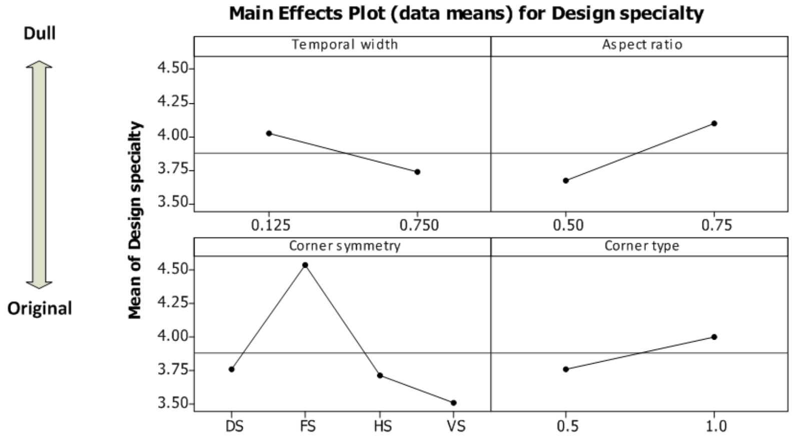

Fig. 6: Mean plots of the main effects and interactions for design specialty.

3.3 Design Specialty

Tab. 3 shows all of the four design factors that affect the participants' responses on the design specialty of the glasses frame. There is a significant interaction between the aspect ratio, corner symmetry, and corner type. Fig. 6 shows that the larger temporal width gives the impression of being more original than the narrow one. The larger aspect ratio, however, looks less original than the smaller one. In the case of corner symmetry, the fully-symmetrical rim is considered to be least original among the three. And the vertically-symmetrical rim produces the most original appearance. For the corner type, the participants judge the squared corner to be less original than the circular one.

3.4 Reflected Value

Tab. 4 shows that the participants' responses on the reflected value are affected by the temporal width and aspect ratio. Although the corner type and symmetry alone do not produce a significant effect, there is a strong interaction between the two. Fig. 7 shows the trends of the effects. The narrow temporal is deemed to be more rough and low-valued than the wide one. The smaller aspect ratio, however, looks more high-valued to the participants. While the fully-symmetrical rim reflect a value less than the other three, the vertically-symmetrical rim gives an impression of being most valuable. For the corner type, the squared corner appears to be relatively more valuable than the circular one.

Factors	***DF***	***F***	***P***
Temporal width (w)	1	60.74	0.000
Aspect Ratio (a)	1	4.56	0.033
Corner Symmetry (s)	3	1.66	0.174
Corner Type (t)	1	0.72	0.396
w x a	1	1.22	0.269
w x s	3	0.11	0.955
w x t	1	0.01	0.939
a x s	3	2.18	0.089
a x t	1	0.56	0.456
s x t	3	6.51	0.000
w x a x s	3	0.36	0.784
w x a x t	1	2	0.158
w x s x t	3	0.61	0.608
a x s x t	3	1.3	0.273
w x a x s x t	3	0.24	0.872

Tab. 4: MANOVA result of reflected value.

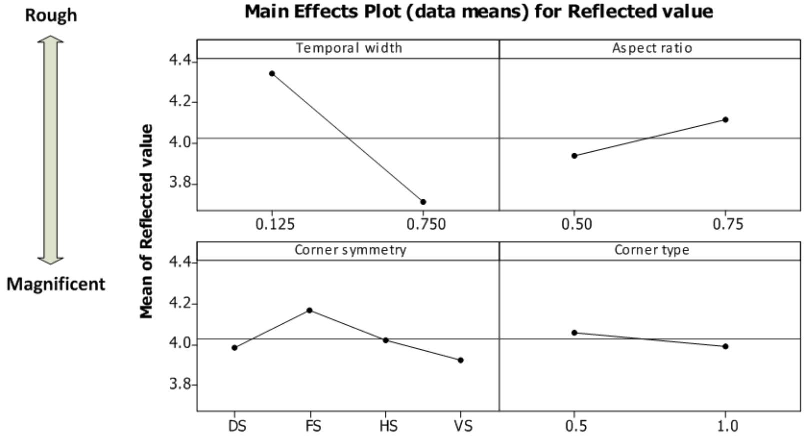

Fig. 7: Mean plots of the main effects and interactions for reflected value.

3.5 Structural Firmness

As shown in Tab. 5, the impression of the structural firmness is less influenced by the design factors. Only the main effect of varying the temporal width is found to be statistically significant. There is, however, interaction between the corner symmetry and type that produces a significant impact. The mean plots for the main effects (see Fig. 8) indicate that changing the temporal width produces a much steeper line than the other three. The glasses frames look more robust to the participants when they have wider temporal. Overall, the mean responses invoked by the other three factors are below the neutral point. However, changing their levels does not make a significant difference. When the rim is constrained to be fully or diagonally symmetrical, changing the corner from circular type to squared type reduce the impression of robustness. Conversely, when the rim is constrained to be horizontally or vertically symmetrical, a circular corner looks relatively less robust than the squared one.

4. COMPUTER-AIDED AFFECTIVE DESIGN

The experiment helps us identify the affective responses that a particular shape feature may invoke. The insights obtained from the experiment can serve as a guideline for computer-aided affective design of 3D product shape. For example, a more masculine look of the glass frame can be produced by increasing the aspect ratio of the rim or squaring the rim corner. The symmetry of rim corner can also be varied to accommodate the need of originality.

Factors	***DF***	***F***	***P***
Temporal width (w)	1	850.77	0.000
Aspect Ratio (a)	1	0.71	0.400
Corner Symmetry (s)	3	0.27	0.848
Corner Type (t)	1	0.02	0.892
w x a	1	1.12	0.289
w x s	3	1.32	0.268
w x t	1	3.12	0.078
a x s	3	0.15	0.928
a x t	1	0.06	0.807
s x t	3	2.63	0.049
w x a x s	3	1.4	0.241
w x a x t	1	0.04	0.849
w x s x t	3	0.46	0.713
a x s x t	3	2.5	0.058
w x a x s x t	3	0.38	0.770

Tab. 5: MANOVA result of structural firmness.

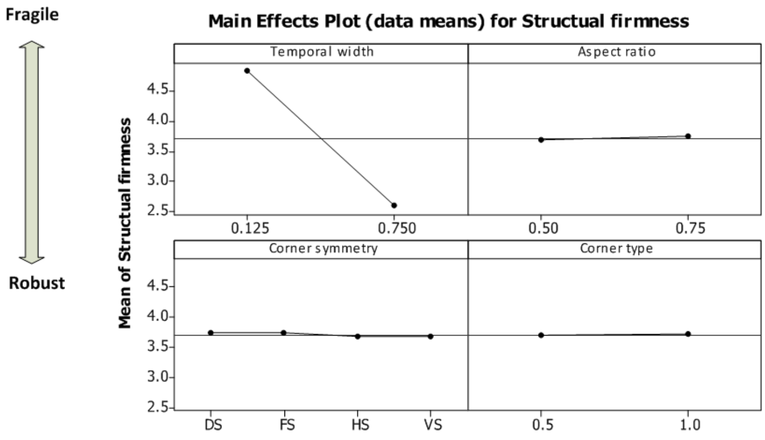

Fig. 8: Mean plots of the main effects and interactions for structural firmness.

The possible representative glasses models under the five conceptual measures are shown in Table 6. In addition to understanding the trends of the user's emotional responses towards different shape factors, we also build up computational models of their relationships with multiple regressions as follows:

Gender connotation *= 1.91 + 0.47w + 3.38a + 0.508t - 0.079DS + 0.117FS - 0.096HS*
Popularity *= 3.51 + 0.113w + 3.15a - 0.750t - 0.092DS - 1.17FS - 0.217HS*

Design specialty = $2.29 - 0.457w + 1.71a + 0.471t + 0.254DS + 1.03FS + 0.204HS$
Reflected value = $4.04 - 1.01t + 0.692a - 0.137t + 0.063DS + 0.246FS + 0.096HS$
Structural firmness = $5.07 - 3.58t + 0.258a + 0.021t + 0.067DS + 0.067FS - 0.004HS$

These five equations characterize the affective responses as the linear combinations of the shape factors studied in our experiment. When a new glasses frame is designed based on the combinations of these factors, we can compute the level of the affective responses that it may invoke with these regression equations. The result helps the designer evaluate the glasses frame design. A product prototype or template that offers a particular affective response can be thus generated for further design refinement. Another potential use of our experimental findings is customization for affective design. The end user can express his/her need of a particular emotional feature of the product, and the product shape can be constructed accordingly. We developed a Web-based prototyping system for demonstrating this idea. The system provides toolbars for continuously adjusting the temporal width and the aspect ratio. Different types of the frame symmetry and the corner can also be selected from the interface (see Fig. 9). The user is allowed to upload his/her head model for trying on the glasses frame being customized. Fig. 10 (upper left) shows a design neutral in gender connotation. Increasing the temporal width produces a more "robust" shape as shown in Fig. 10 (upper right). Changing the symmetry type creates a design shown in Fig. 10 (lower left), which should give a less common perception. An original design can be obtained with the asymmetry as shown in Fig. 10 (lower right).

Conceptual measures	**Representative Design**	
	Feminine	*Masculine*
Gender Connotation:		
	Common	*Special*
Popularity:		
	Original	*Dull*
Design Specialty:		
	Magnificent	*Rough*
Reflected Value:		
	Robust	*Fragile*
Structural Firmness:		

Tab. 6: Representative glasses frame models for the five conceptual measures.

Fig. 9: A Web-based prototyping system for computer-aided affective design.

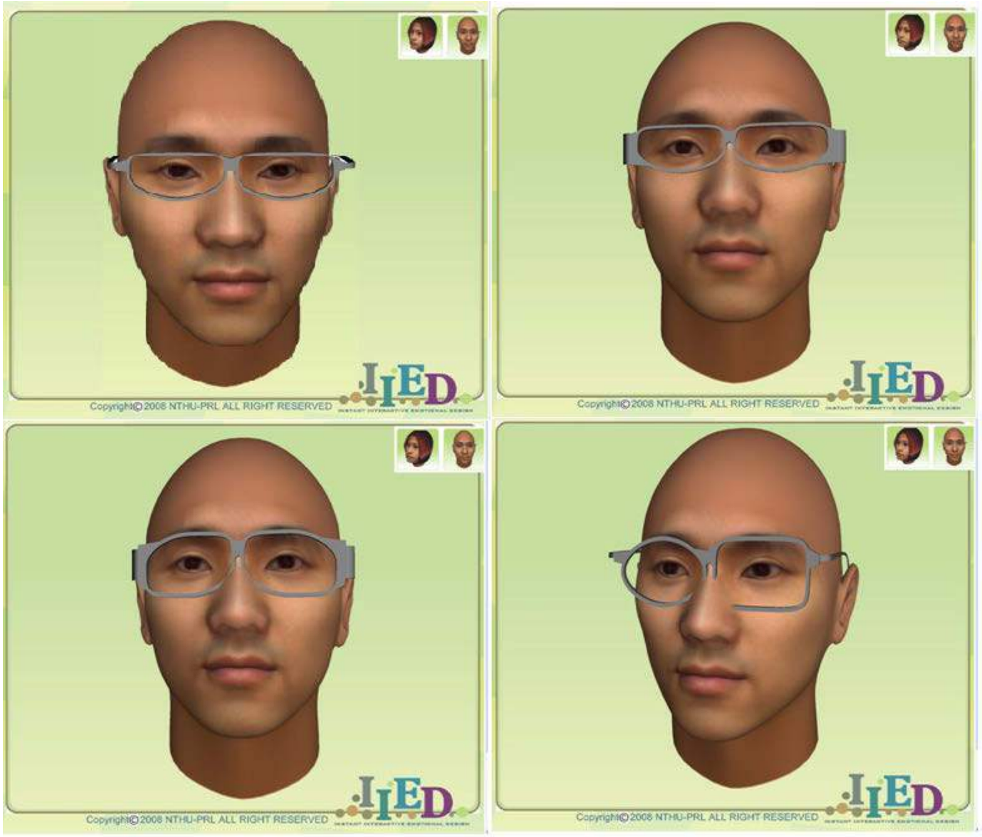

Fig. 10: Customized glasses frame with different affective responses.

5. CONCLUSION

This paper presents an experimental study conducted for affective product design. We employed factorial experiment techniques in the study that allows us to examine how various shape factors individually and interactively influence users' responses to glasses frames. The variations of temporal width, rim aspect ratio, rim corner symmetry, and corner type were combined to produce 32 test product models. Five adjective groups and their bi-polar representatives (gender connotation, popularity, design specialty, reflected values, and structural firmness) were identified by industrial designers using the KJ sorting method. The experiment data was analyzed with Multivariate Analysis of Variances (MANOVA). The results show the main and interactive effects of the shape factors statistically significant in changing the affective responses. They validate some common perceptions of the glasses frame design, e.g. increasing the temporal width or the aspect ratio makes it look more masculine; asymmetry produces better design specialty; a larger temporal width offers a more robust appearance. Interesting insights to the interactions between shape features were also obtained. These findings give a support to computational models that facilitate customizations of product design with particular emotional responses A Web-based prototyping system was implemented for demonstrating this idea. The target product in this paper is evaluated on its own. One possible extension of our work is to incorporate contextual information, i.e. when the product is in use. One can present the glasses frames while they are worn by people with various facial shapes or under different occasions such as doing sports or having business meetings. In addition to personal preferences, one can also study how the design of product relates to interpersonal interactions since most likely it will invoke certain affective responses of others. The methodology proposed in this paper can also be applied to investigate other design features such as the materials and colors of products, provided that the relevant parameters are carefully defined or provided by domain experts. The aim of this work is not to replace, but to complement the role of designers. The proposed system can generate design templates to stimulate the creativity of designers and improve communications with the end users. In terms of application development, we will look into the possibility of integrating FFD (Free-Form Deformation) techniques with this work for automatic affective product design.

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