INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

STUDY OF THE CORRELATIONS BETWEEN USER PREFERENCES AND DESIGN FACTORS: APPLICATION TO CARS FRONT-END DESIGN

Antoine DAGHER[1], Jean-François PETIOT[2]
[1]PhD student, IRCCyN (UMR CNRS 6597) – Ecole Centrale de Nantes – France.
[2]Professor, IRCCyN (UMR CNRS 6597) – Ecole Centrale de Nantes – France.

ABSTRACT
In this paper, we describe a design method for a "user-oriented" product design. The method proposes an original integration of key concepts of *kansei engineering* and of intuitive user-tests to gather perceptive data. Digital mock-ups of products are used for the definition of products. The method is illustrated by a case study concerning the design of cars' front-end. From a product space made up of various products of the market, an assessment of the products according to several semantic attributes is made by a panel of 40 subjects. Multivariate data analysis techniques are used to find the main perceptual dimensions that characterise the products, and to define and describe different groups of products (cluster analysis). After a morphological analysis of the prototype of a given group, design factors are defined to generate a second product space (full factorial design). Preferences tests and assessments tests are carried out on this controlled product space. A model of preference is computed using conjoint analysis. This model allows the definition of relations between the form of design elements and the preference. A preference mapping is finally proposed, in order to try to explain how to characterise preferred products from a semantic point of view. As a result, this method could be used in early phases of design projects, in order to get on virtual products an assessment of their acceptance by a panel of users.

Keywords: User's centred design, kansei engineering, conjoint analysis, design of experiments, pairwise comparison, preference modelling.

1 INTRODUCTION
In today's highly competitive market, especially automotive industry, developing new products that satisfy consumers' needs and preferences is a very important issue. A successful product must satisfy consumers' requirements and preferences, but emotional and aesthetics factors are also very important. Few methods address the problem of aesthetics design attributes. Thus, forms design or styling activities are often reduced to a discussion based on opinion and subjectivity, with no theoretical basis [1]. For example, the perception of a product's form is often nothing but a style of design, depending much more on the designer's taste than on real customers' trends [2].
Nevertheless, Kansei engineering, founded by M. Nagamachi at Hiroshima University about 30 years ago, is a powerful approach to product design involving user's perceptions [3]. Kansei engineering proposes to quantify people's perceptions about the product form and to translate the consumer perceptions into the design elements. The principle is to collect subjective evaluations of users on a set of product, and to analyse and interpret the ratings using multivariate statistical techniques. Various modelling methods can be used to provide useful design rules (linear or non linear model, neural networks, rough set theory) [4] [5] [6]. Kansei engineering is certainly an interesting approach for product design but a number of Kansei studies suffer from several shortcomings. The set of products considered often aggregates very different devices (telephone, cars, mp3-players,…), from a functional and from a perceptual point of view, without verifying that the product belongs to the same perceptual category. Using pictures of real products, several design elements come into play and the selection of the relevant design elements is sometimes arbitrary. At last, the design of experiments theory is not always used in order to control carefully the validity of the models.

In order to control the design elements of the products, Virtual Reality (VR) seems to offer promising functionalities for the assessment of virtual products [7]. The available Virtual reality interfaces are now mature enough for suggesting to the user relevant feelings and sensations. The main problem is now to learn how to use it and to define relevant methods for their integration into the design process.

In this paper, we propose to develop an efficient design methodology to account for users' perceptions and preferences. Our methodology integrates several key concepts of kansei engineering and is based on user-tests on virtual products. We particularly put an emphasis on the user-friendliness of the interfaces used for the tests and on the relevance of the tests.

The chosen product used to describe our approach is a particular part of a car for which the design plays a crucial role in the definition of the personality of a car: the front-end. A study of the expression of the front view of cars is proposed in [8], where the authors describe the perceptual space of a family of standardized front mask of cars using the semantic differential method. In this work, a description of the perceptual categories of cars according to the design elements is proposed, but the user-preferences are not tackled. Approaches using shape grammars have been for example successfully used to describe the essence of a brand [9], but user-perception are also not tackled.

The main objective of our paper is to propose a methodology to understand the subtle links between the design variables of the different parts of a car's front-end and the users' perception and preferences. We particularly want to study in which extent preference mapping techniques [10] and conjoint analysis [11] can be used to achieve a design and define design rules.

We present in section 2 the method we developed, based on the generation of virtual products and user tests. Section 3 and 4 are dedicated to the application to car's front-end design. The tests carried out and the data analysis tools used are described in detail. Section 5 presents an analysis of the results, particularly an explanation of users' preferences by the design factors with conjoint analysis, and an analysis of preference using a semantic description of the products (preference mapping). Conclusions and perspectives are drawn in section 6.

2 METHOD

The proposed method for the study of forms perception and preferences is described in figure 1. It is based on various approaches used in psychoacoustics (design of car horn sounds [12], design of musical instruments [13]), in sensory analysis (analysis of fabrics [14]) or in kansei engineering (user-oriented design of mobile phones [15]). The approach is based on the following stages:

Phase 1: study of user's perception and of the semantic space

- Generation of a family of virtual products (cars front-ends), which constitutes the *product space n°1* (drawings of front-end view of cars are generated using a CAD system (Catia V5))
- Definition of *semantic attributes*, relevant for an accurate description of the products' personality (parallel with human facial expressions)
- Assessment of the virtual products by a panel of subjects (40 students of an engineering school) on the semantic attributes
- Data analysis: definition of the main perceptual dimensions using principal component analysis (PCA) [16]. Classification of the products with hierarchical ascendant classification (HAC) [16].
- Definition and description of groups of products, and of the "prototype" of each group
- For a given group, analysis of the design factors of the prototype

Phase 2: study of the design factors and their relation to users' preference

- Generation of the product space n°2, using the design factors and factor levels. Generation via a CAD system of the variants of the prototype (factorial design)
- Assessment of the variants by the panel of subjects on the main perceptual dimensions and according to the preference
- Study of the relationship between preference scores and design factors using conjoint analysis
- Study of correlations between preference and perceptual dimensions with preference mapping
- Interpretation of the preference by the design factors and the perceptual dimensions. Definition of design rules, for the design of a new front-end car corresponding to preference maximization

We propose to describe each stage of the method on a particular example, a car's front end.

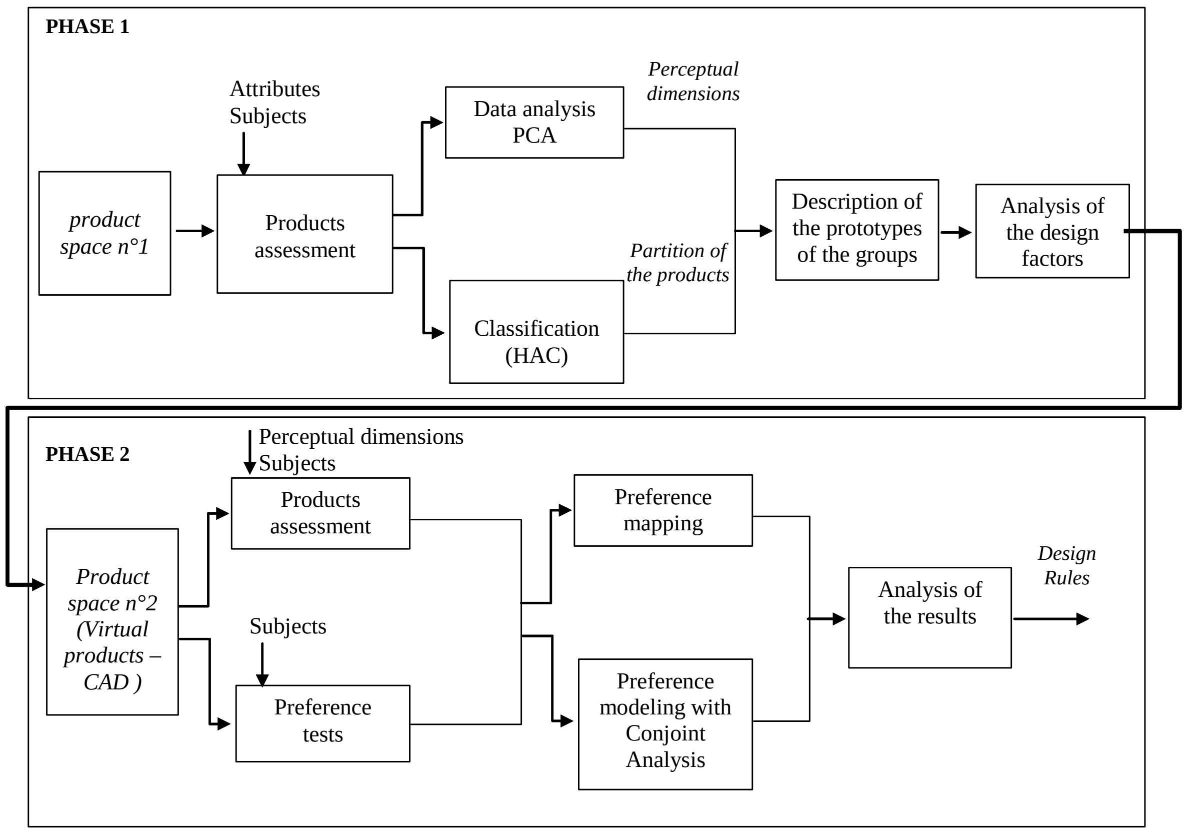


Figure 1: synoptic of the method

3 CASE STUDY: A CAR'S FRONT END – PHASE 1

3.1 Product space n°1: models generation

A set of 13 cars of the market (segment D) has been chosen to make up the product space. The choice of the products has been made in order to cover a wide range of different forms. The cars were nevertheless similar enough in order to avoid atypical cars with very particular designs. A picture of the front of the cars (taken from the same point of view) has been processed with graphical sketching software in order to select the main defining forms (figure 2). The drawings of the cars (**V01** to **V13**) were then "standardized" in order to limit the number of influential design factors on the user's perception (the colour, the brand, the type of car …, were removed on the drawings). Five main design factors were visible: the external shape, the headlights, the radiator grill, the air intake and the front bumper.

3.2 Semantic attributes definition

Product semantics for automobile design can be studied with different methods: biodesign and biomimetics are for example new interesting trends for designers [17]. In this context, we have been interested in the parallel between human facial expressions and the front-end of cars to study product semantics. We particularly focused on two previous studies [8] and [18] to generate a list of semantic attributes characteristics of car's front end. A first list of 20 semantic attributes was proposed for the evaluation of a set of cars by a panel of subjects with the semantic differential method (pilot test). Analysis of variance and factor analysis were used to select the more relevant attributes: a list of seven semantic attributes, considered as discriminating and independent, was finally proposed for the description of cars' expression (table 1) [19].

Aggressive Elegant	Intrepid Happy	Confident Severe	Laughing

Table 1: list of the semantic attributes used for the semantic differential method

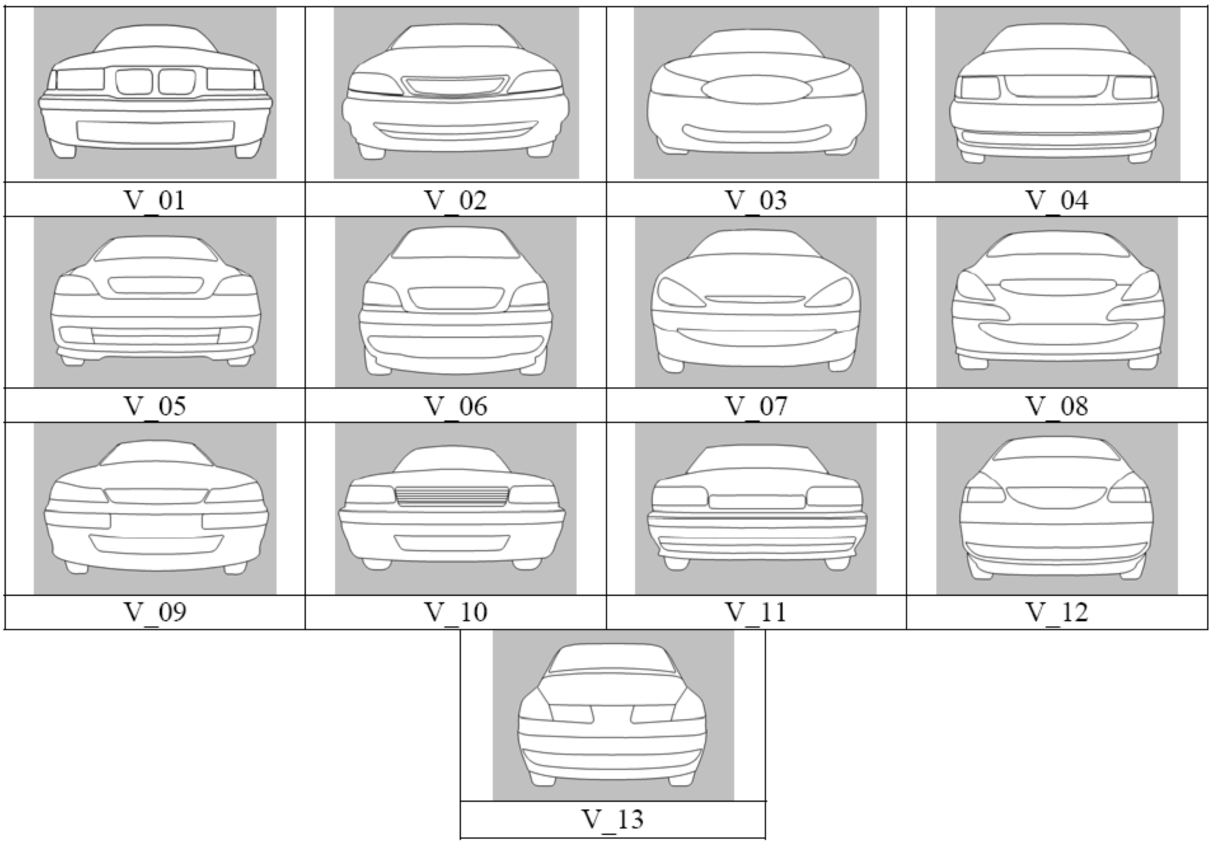


Figure 2: Product space n°1, made up of 13 different cars' models

3.3 Products assessment

A panel of 40 subjects (25 male – 15 females – students of our engineering school) was asked to look at the drawings and to assess their impressions according to each semantic attribute on a 9 points Likert scale. A user-friendly interface (programmed with MatLab) has been used to collect the data (see screen shot of the interface on figure 3). The presentation order of the cars was different for each subject to prevent order effect.

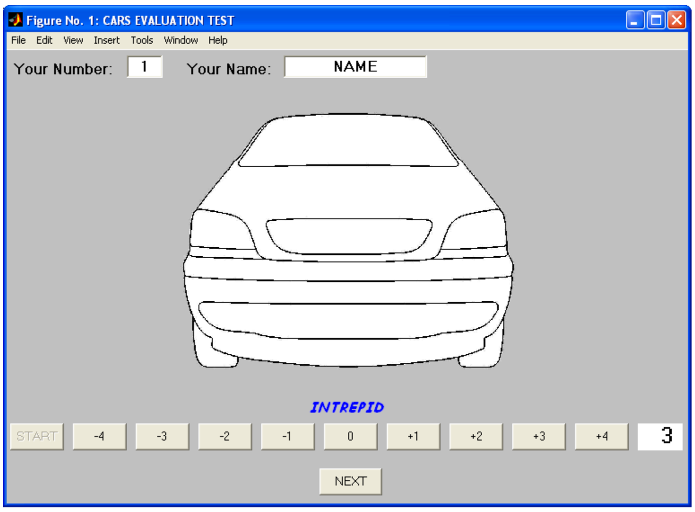


Figure 3: user-interface used for the semantic differential method (9 points Likert scale)

3.4 Analysis of the assessments

For each attribute, the agreement between the subjects has been assessed. A two-way analysis of variance (factor product and factor subject) shows that the product effect is highly significant for all the semantic attributes, the subject-effect being non-significant. For each attribute, a non-standardized Principal Component Analysis (PCA) of the matrix of the scores (products – subjects) shows a very good consensus between the subjects. These results confirm that the inter-subjects differences according to the product semantics are not so large: subjects are fairly consensual and the average value of the scores for all the semantic attributes is representative of the assessment of the panel.

3.4.1 Principal Component Analysis

To reveal the structure of the data, a standardized PCA [16] of the matrix (products – semantic attributes) of the average scores has been computed. This leads to the factorial plane plotted figure 4 (semantic attributes) and figure 5 (products). More than 95% of variance is taken into account by only two factors **F1** and **F2**: the initial data are effectively highly correlated.

Two main axes can be proposed to interpret this perceptual space: a first axis (F1) that opposes **Severe / Happy** and a second one (F2) that opposes **Peaceful / Aggressive**.

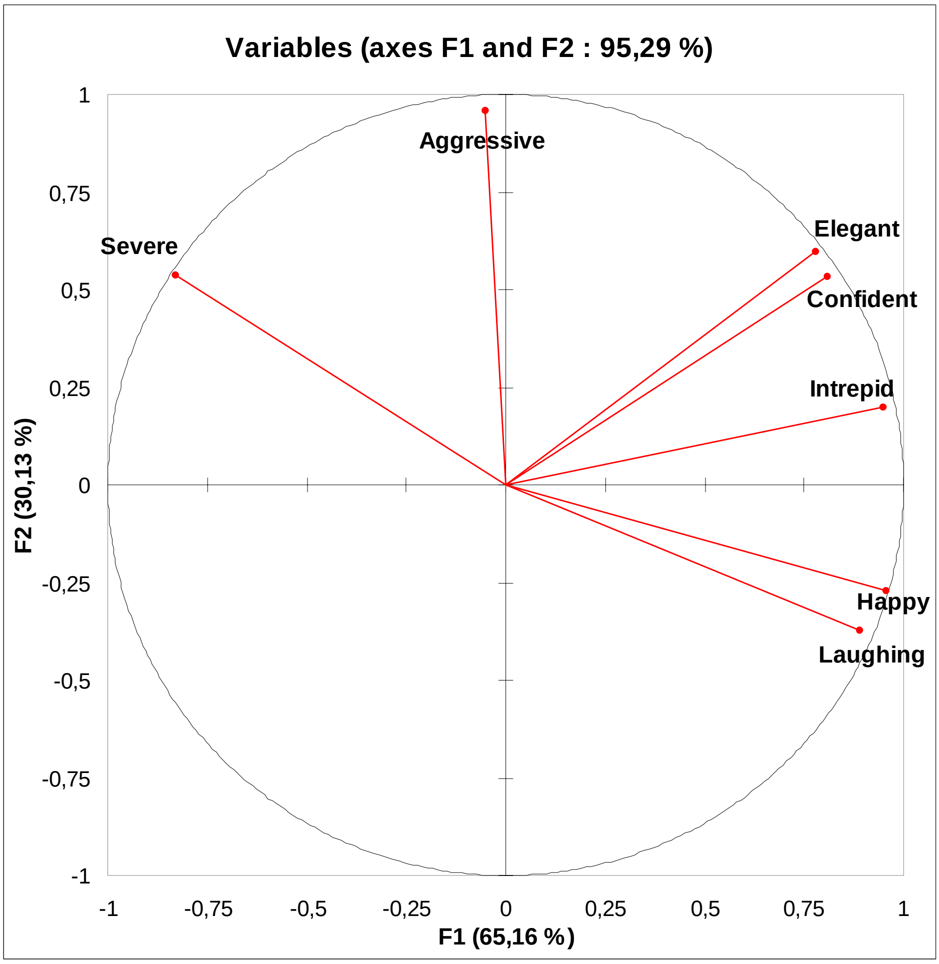


Figure 4: Position of the 7 semantic attributes in the factorial plane

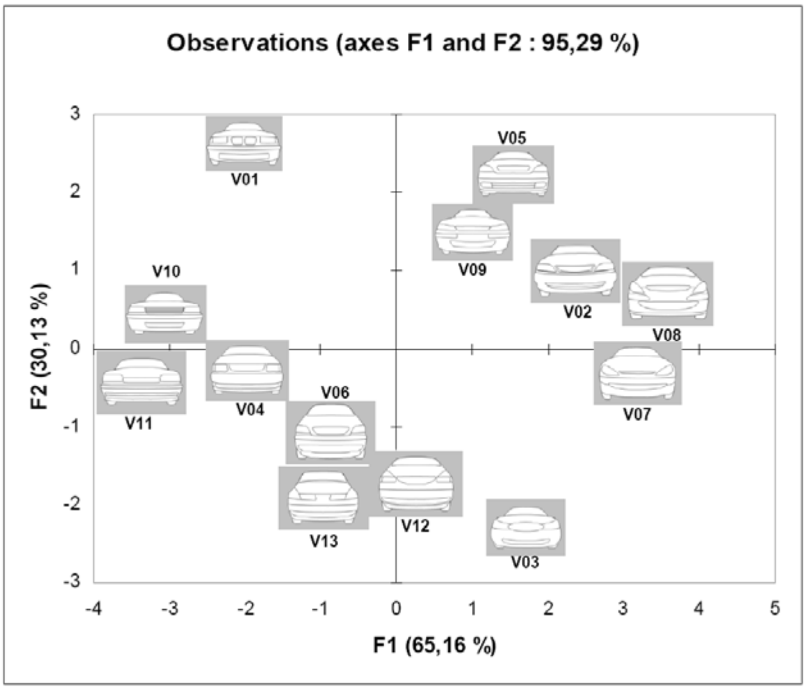


Figure 5: Position of the 13 products (cars) in the factorial plane

3.4.2 Classification of the cars

In order to provide a partition of the cars and to define groups of cars, similar from a perceptual point of view, a classification of the product space has been done. With the matrix (products – semantic attributes) of the average scores of the cars according to the semantic attributes as input, a partition of the cars has been defined with hierarchical ascendant classification (HAC) [16]. The principle of HAC is to build a hierarchical tree (dendrogram, figure 6), which shows the level of each aggregation according to the dissimilarity between the products. The method used the Euclidian distance for the computation of the dissimilarities and the Ward's method as the linkage rule (rule for the computation of dissimilarities between groups of products). A partition of three groups of cars can be defined (highest jump in the dendrogram).

Group 1 is made up of the cars V07, V8, V5, V2 and V9 (figure 7.1).

Group 2 is made up of the cars V03, V12, V6 and V13 (figure 7.2).

Group 3 is made up of the cars V01, V4, V10 and V11 (figure 7.3).

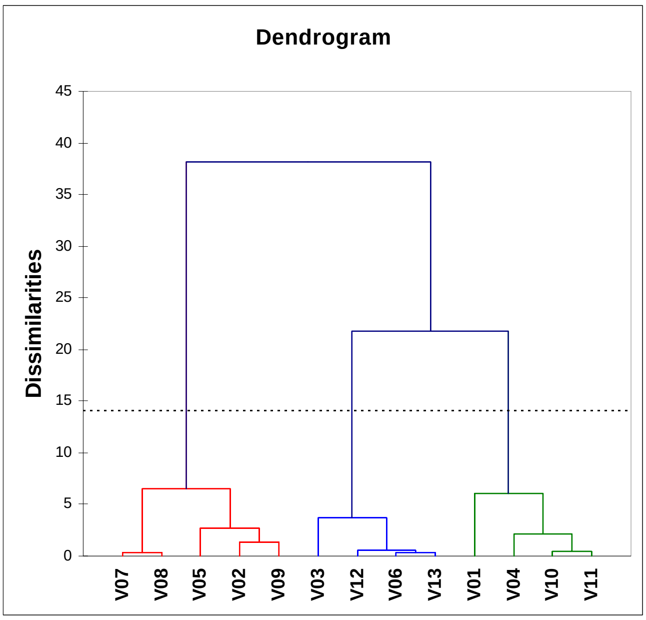


Figure 6: partition of the cars using HAC

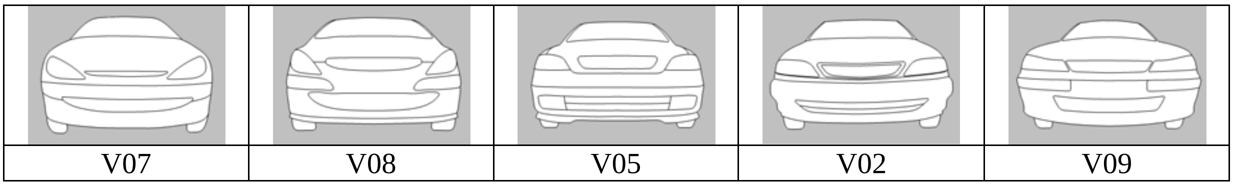


Figure 7-1: Group 1: elegant, intrepid, happy, confident and laughing

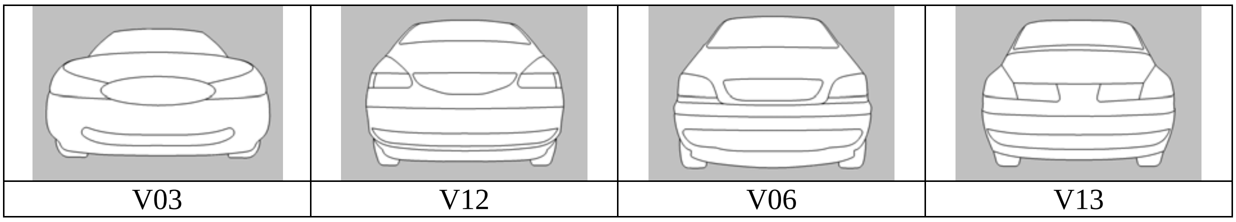


Figure 7-2: Group 2: not aggressive, not elegant and not severe

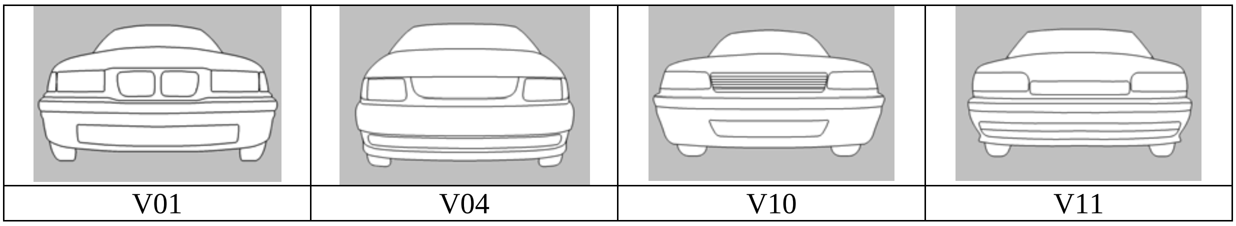


Figure 7-3: Group 3: severe, not laughing, not happy and not intrepid

With the partitions of the cars, a prototype of each group can be defined (product which is the closest to the centre of gravity of the group), and the description of the groups can be made from the average value of the group according to the semantic attributes. The description of the group is given table 2. For each group, the scores of the semantic attribute significantly different (p-value = 5%) of the average value are presented in bold.

Group	Prototype	Aggressive	Elegant	Intrepid	Happy	Confident	Severe	Laughing
1	V02	0.380	**1.210**	**1.220**	**1.230**	**1.425**	-0.735	**1.170**
2	V12	**-1.681**	**-0.869**	-0.350	0.450	0.306	**-1.044**	0.844
3	V10	0.325	-0.719	**-1.538**	**-2.175**	0.169	**1.644**	**-2.069**
Average score		-0.325	-0.126	-0.223	-0.165	0.633	-0.045	-0.018

Table 2: characterization of each group and definition of the prototype

Cars of group 1 can be qualified as elegant, intrepid, happy, confident and laughing.
Cars of group 2 are rather not aggressive, not elegant and not severe (more or less the opposite of group 1).
Cars of group 3 are severe, not laughing, not happy and not intrepid: this could be explained by the square headlights and radiator grill, specific to this group.
This description is of course coherent with the position in the factorial plane (figure 4 and 5), the input data of PCA and HAC being the same. At this level, it's quite interesting to have this description of the users' perception of products. In particular, marketing studies are often restricted to these outputs [20]. But in order to design product or provide design rules, these outputs are not sufficient. It's necessary to explain the perceptions by design factors of the products. For this, an accurate factorial design is necessary in order to control the design factors and their influence on perceptions and preferences. We propose to show how the methodology can be carried out for the car front-end design. It's first necessary for that to choose a given prototype in order to select carefully the design factors and the levels of the factors. For the rest of the study, we will focus on group 1 and especially on prototype **V02**; a set of variants of **V02** is generated with a CAD system, after an analysis of the main design factors of cars in group 1.

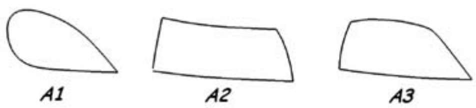
4 CASE STUDY PHASE 2: STUDY OF THE CARS OF GROUP 1

4.1 Generation of the product space n°2

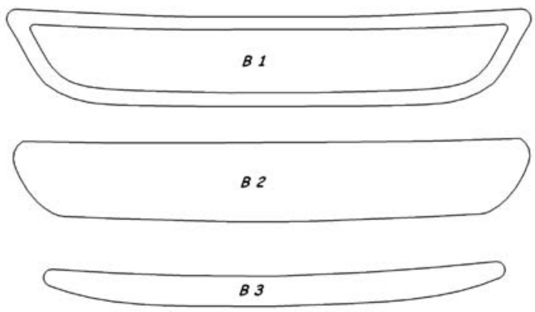
A morphological analysis of the cars of group 1 leads to the definition of 4 main design factors and their associated level:

Factor A: Headlights: 3 levels
Factor B: Radiator grill: 3 levels
Factor C: Air intake: 3 levels
Factor D: Front bumper: 2 levels

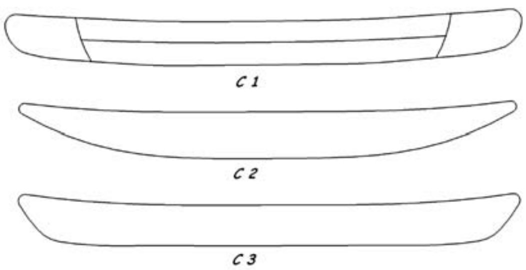
That makes a full factorial design with 3×3×3×2=54 possible products. The levels of the different factors are given in table 3. They are of course chosen inside the forms of cars of group 1 (A1 corresponds for example to the headlights of **V07**). For example, the car **A** on figure 9 is defined by the following levels of factors (A1B1C3D1), car **B** by A3B2C1D1. A CAD system was used to model the products. The external shape of the cars has been those of car **V02,** the prototype of the group.



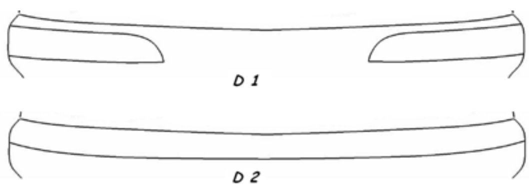
Factor A: Headlights



Factor B: Radiator grills



Factor C: Air-Intake



Factor D: Front Bumpers

Table 3: different levels of each design factor

4.2 Product assessments

Due to the large number of products of the full factorial design (54 products), an incomplete balanced factorial design was used to distribute the products to the subjects; each subject evaluated only 12 products.

Each subject was asked to look at the drawings and to assess on a 9 points scale his/her impressions according to two dimensions, the two main perceptual dimensions revealed by the PCA (**Severe / Happy** and **Peaceful / Aggressive,** see figure 4 and 5). The interface used for the evaluation is given figure 8.

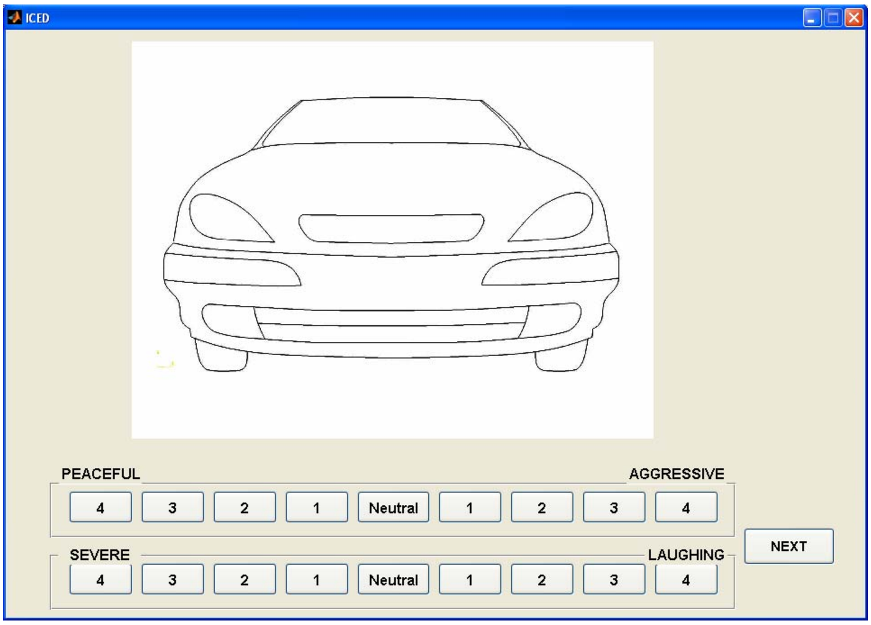


Figure 8: interface for the semantic differential method phase 2

4.3 Preference assessments

The preference assessment has been done by pairwise comparison. Each subject compared all the pairs among the 12 products of his/her incomplete balanced factorial design. A 7 levels category scale (much less, less, slightly less, equal, slightly more, more, much more) noted (<<, <, <~, =, >~, >, >>) has been used. The category scale has been next indexed on a ratio scale [1/8, 1/4, 1/2, 1, 2, 4, 8]. The interface for the test is given figure 9.

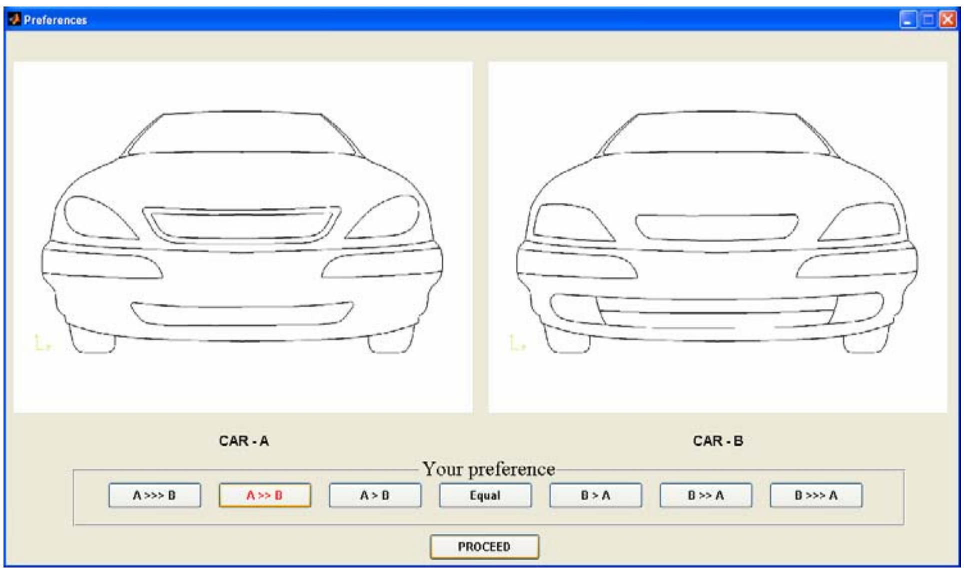


Figure 9: Interface for the pairwise comparison preference test

Many methods have been developed for the calculation of weights from pairwise comparison matrices [21]. We used the *Least Squares Logarithmic Regression* (LSLR) method proposed by [22] and [23]. Sparse pairwise comparison matrices are tolerated, which is interesting for the relative assessment of numerous products [19]. The preference scores of the whole panel of subjects have been computed from the (54×54) sparse pairwise comparison matrix.

5 RESULTS

5.1 Preference modelling using conjoint analysis

To investigate the relationship between users' preferences and design factors, a conjoint analysis was performed. Based on utility theory, conjoint analysis [11] provides a statistical procedure for identifying the relative weighting of each design factor and factor level (Part-Worth utility) in the user preference. This approach is also known in kansei engineering as the "quantification theory type I". Many algorithms may be used to estimate utility functions. We used analysis of variance (ANOVA) to determine the weight of importance of the design factors and the part-worth utility of the factors levels. The calculation of these values has been done with the preference scores of the panel as input. The results are given in table 4.

Design factor	Factor level	Utility (part-worths)	Importance
Headlights	A1	0.003	30.7%
	A2	-0.320	
	A3	0.134	
Radiator grill	B1	0.004	51.5%
	B2	0.259	
	B3	-0.505	
Air intake	C1	0.003	7%
	C2	-0.079	
	C3	-0.101	
Front bumper	D1	-0.002	10.8%
	D2	0.158	

Table 4: utility of the factor level and importance of the factor for the preference

Concerning the importance, a high percentage means that the design factor will have a great influence on the preference of the product. The results show that the radiator grill is of prime importance for the preference, the air intake playing a minor role. Concerning the utility of the factor level, a high (positive) utility score pulls the preference; a negative utility score repulses the preference. The results show that headlights type A2 are not appreciated, as radiator grill B3, and in a lesser extent air intakes C2 and C3. Headlights A3, radiator grill B2 are well-perceived by the panel of subjects. The graphs of the utility for each design factor are given figure 10.

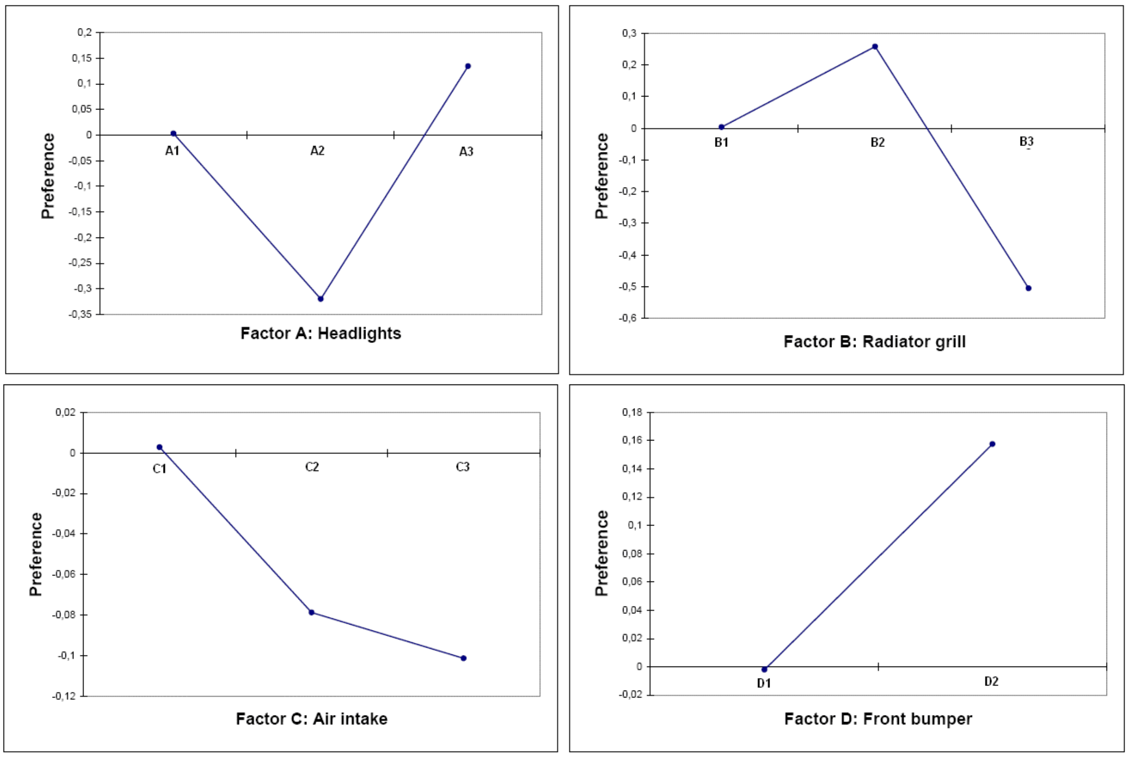


Figure 10: utilities of the design factors levels

5.2 Preference mapping

Another classical way of making sense with the preference data is to try to explain the preference scores by the semantic evaluations of the products. Preference mappings are in this way plotted to represent the correlation between the preferences data and the semantics data. The principle of external preference mapping is to fit a multiple regression model using the coordinates of the vehicles on the two perceptual dimensions (§4.2) as independent variables and the preference scores (§4.3) as the dependent variable (PREFMAP model, [10]). Vector model, circular (ideal points), elliptic or quadratic models can be used to fit a response surface on the data [7].

With the data obtained in section 4, the quality of the adjustment of the model on the data remain very poor, whatever model is used (the R^2 determination coefficient of the regression remains always under 0.1, and not-significantly different of 0 (p-value = 5%) – to be significantly different of 0 (p-value = 5%), the R^2 has to be greater than 0.2).

The main reason for this badness of fit can lie in the non-homogeneity of the panel of subject: the average value of the preference may be not representative of the panel and/or the average semantic evaluation may be not reliable enough. For a next study, the assumption according to which the panel is homogeneous according to the preference has to be verified, by studying individual preference of each subject.

6 CONCLUSIONS AND PERSPECTIVES

We presented in this paper a method for a user-centred design. The method, based on key concepts of kansei engineering, proposes several improvements. It was applied to the case of the front-end design of a car. User-friendly interfaces have been developed to collect data from user-tests. According to the subjects, the tests were very interesting if not pleasant.

The phase 1 of the method uses a set of existing cars and the semantic differential method for the definition of the perceptual space of the cars. The results show first that the inter-subjects differences according to the product semantics are not so large: subjects are fairly consensual. Secondly, the parallel with the facial expressions of human faces is an interesting way in order to define the semantic attributes and to study the design factors: again, the consensus between the subjects is rather good.

After a classification of the cars, groups and prototypes of groups were defined. The morphological analysis of the groups allows the definition of the main design factors of the groups, and the factors levels. For one group of car, the phase 2 of the method has been carried out.

The phase 2 of the method uses a full factorial design for the user's preference assessment. Virtual reality tools and digital mock-ups were used to generate various products: the main advantage is that it allows the designer to parameterize the product and to finely control the influence of a given modification of the design factors on the product semantics. To reduce the evaluation time by each subject, an incomplete factorial design has been proposed, the preference assessment being carried out by pairwise comparisons. The average preference score of the panel has been computed, and the links between the design factors and the preference has been studied with conjoint analysis. Design rules can be extracted from the utility of each design factor level.The results of preference mappings show that the inter-subjects differences according to the preference must be studied.

In perspective, fractional factorial design will be used to take into account more design factors and levels. An individual preference study will be carried out and, more importantly in design, we propose to consider a conjoint analysis model with interaction to study the interactions between the design factors. We will also try to "customize" cars designed for a specific panel of users (young, old, feminine or masculine …).

6.1.1.1 REFERENCES

[1] Warell A., 2001. Design syntactics – a contribution towards a theoretical framework for form design. *International Conference on Engineering Design ICED 01*, Glasgow.

[2] Hsu S.H., Chuang M.C., Chang C.C., 2000. A semantic differential study of designers' and users' product form perception. *International Journal of Industrial Ergonomics* 25, 375-391.

[3] Nagamachi M. (1995). Kansei engineering: a new ergonomic consumer-oriented technology for product development. *International Journal of Industrial Ergonomics*, 15, 3-11.

[4] Yoshimura M., Papalambros P.Y. Kansei Engineering in concurrent product design: a progress review. *Proceedings of the TMCE 2004*, April 13-17, Lausanne, Switzerland, Horvath &

Xirouchakis (eds).
[5] Nagamachi M. 2002. Kansei engineering as a powerful consumer-oriented technology for product development. *Applied Ergonomics* 33, 289–294.
[6] Hsiao S.W., 2002. Concurrent design method for developing a new product. International *Journal of Industrial Ergonomics* 29, 41-55.
[7] Petiot J-F., Chablat D. « Subjective evaluation of forms in an immersive environment ». International Conference *Virtual Concept 2003*, Biarritz, November 2003.
[8] Park S.H., Kamaike M., Nagao T. “A study of the expression in the front view design of a passenger car”. *Proceedings of he 6th Asian design conference*, 2003, Tsukuba, Japan.
[9] Cagan J, Mc Cormack J-P., Vogel C.M. "Capturing the essence of a product’s brand trough a shape grammar representation". *International Conference of Engineering Design*, ICED 03, Stockholm, August 19-21, 2003.
[10] Caroll J.D. “Individual differences and multidimensional scaling” in Shepard, Romney, Nerlove, *Multidimensional scaling: theory and application in the behavioral sciences*. Vol 1, pp105-155. 1972.
[11] Green, P. Carroll, J. and Goldberg, S. A general approach to product design optimization via conjoint analysis, *Journal of Marketing*, vol 43, summer 1981, pp 17-35.
[12] Lemaitre G., Susini P., Winsberg S., Mc Adams S. perceptively based design of new car horn sounds. *Proceedings of the 2003 international Conference on Auditory Display*, Boston, MA, USA, July 6-9, 2003.
[13] Petiot J.F., Poirson E., Gilbert J., 2005. User-centered design via sensory analysis techniques and optimization procedures: application to musical instrument design, *International Conference on Engineering Design*, ICED 05 Melbourne, Australia.
[14] Giboreau A., Navarro S., Faye P., Dumortier J. (2001). Sensory evaluation of automotive fabrics : the contribution of categorisation tasks and non verbal information to set-up a descriptive method of tactile properties. *Food Quality and Preference.* 12, 311-322.
[15] Lai H.H., Lin Y.C., Yeh C.H., Wei C.H. user-oriented design for the optimal combination on product design. *International Journal of production Economics*. 100 (2006) 253-267.
[16] HairJ.F., Tatham R.L., Anderson R.E., Black W. Multivariate Data Analysis (5^{th} Edition), Prentice Hall, 1998.
[17] Hacco, E., Shu, L.H., 2002, Biomimetic Concept Generation Applied to Design for Remanufacture, *Proceedings of ASME DETC/CIE*, Montreal, QC, Canada.
[18] Jindo T., Hirasago K., 1997. Application studies to car interior of Kansei engineering. *International journal of industrial ergonomics* 19, 105-114.
[19] Petiot J-F., Yannou B. « Measuring consumer perceptions for a better comprehension, specification and assessment of product semantics». *International Journal of Industrial Ergonomics*. Vol 33/6 pp 507-525, 2004.
[20] Kaul A. R., Rao V. Research for product positioning and design decision: an integrative review. *International Journal of Research in Marketing*, 12, 1995, 293-320.
[21] Yannou B., 2002. Toward a web-based collaborative weighting method in project. *Proceedings of IEEE Systems Man and Cybernetics*, Hammamet, Tunisia.
[22] Lootsma F.A., 1981. Performance evaluation of nonlinear optimization methods via multi-criteria decision analysis and via linear model analysis, *Nonlinear Optimization*, M.J.D. Powell ed., Press A. Vol. 1, London, 419-453.
[23] De Graan J.G., 1980. Extensions to the multiple criteria analysis of T. L. Saaty. Report National Institute of Water Supply.

Contact: Antoine DAGHER / Jean François PETIOT
IRCCyN – Ecole Centrale de Nantes
1, Rue de la Noë – BP 92101 44321 Nantes Cedex 3 – France
Tel: +33 2 40 37 69 55 / +33 2 40 37 69 59
Fax: +33 2 40 37 69 30
e-mail: Antoine.Dagher@irccyn.ec-nantes.fr
e-mail: Jean-Francois.Petiot@irccyn.ec-nantes.fr