Proceedings of the ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2011
August 28-31, 2011, Washington, DC, USA

DETC2011-48173

UNDERSTANDING OF EMOTIONS AND REASONING DURING CONSUMER TRADEOFF BETWEEN FUNCTION AND AESTHETICS IN PRODUCT DESIGN

Brian Sylcott
Integrated Design Innovation Group
Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, PA, 15213
Email: sylcott@cmu.edu

Jonathan Cagan
Integrated Design Innovation Group
Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, PA, 15213
Email: cagan@cmu.edu

Golnaz Tabibnia
Affective Neuroscience Lab
Department of Social & Decision Sciences
Carnegie Mellon University
Pittsburgh, PA 15213
tabibnia@andrew.cmu.edu

ABSTRACT

In this work we investigate how consumers make preference judgments when taking into account both product form and function. In prior work, where aesthetic preference is quantified using visual conjoint methods, aesthetic preference and functional preference were handled separately. Here we introduce a new methodology for testing the hypothesis that when consumers make decisions taking into account both a product's form and its function they employ a more complex decision making strategy than when basing their decision on form or function alone. We believe that this strategy will involve both cognitive and emotional processes.

We used a two stage conjoint analysis to develop a preference function that takes both form and function into account. When compared with participant ratings of form and function combinations across 14 subjects, the model is shown to have a correlation of approximately 0.56, $p < 0.001$.

Next we developed a novel paradigm using functional magnetic resonance imaging (fMRI) to determine what parts of the brain are primarily involved with any given tradeoff between form and function. While in the scanner, study participants were asked to make decisions between options where only form varied, where only function varied, and where form and function both varied.

Results from 7 participants suggest that choices based on products that vary in both form and function involve some unique and some common brain networks as choices based on form or function alone; most important, emotion-related regions are activated during these complex decisions where form and function are in conflict. These results demonstrate the feasibility of using fMRI to address questions about the mental processes underlying consumer decisions.

INTRODUCTION

The ability to capture and characterize consumer preference is an important tool for design engineers. When developing a design solution, engineers need useful information about their target users so that they can better tailor their designs. Boatwright and Cagan [1] have argued that emotion is as critical as functionality to captivate the marketplace and increase willingness to pay. As a result, an effective model of consumer preference needs to take into account both form and function and the fact that emotion can tie into how consumers trade off aesthetics and performance. This model can inform designers on how best to allocate resources during the design process and what features to include in a product.

In this work we propose a method of modeling consumer preference that combines both the aesthetic and functional aspects of a product into a single function describing overall consumer preference. This method is based on a statistical tool widely used in market research called conjoint analysis [2]. This work is an extension to the work done by Orsborn et al.

[3] that introduced a visual conjoint approach that allowed for continuously varying choice parameters. In this study, we look at preference for vehicle design and performance specifications. For each participant we first performed conjoint studies to capture form preference (using visual conjoint) and function preference (using traditional conjoint) separately. In order to derive a preference function that encompassed both form and function, we introduced a second stage to the analysis. An additional conjoint study was performed where subjects were presented with combinations that included both aesthetic and performance information. The previously acquired preference functions were used to vary the levels of form and function presented in the combinations. To confirm the validity of this method, we asked participants to rate combinations of form and function and compared how well the combined preference function correlated with the participant responses. Our hypothesis is that when consumers make decisions taking into account both a product's form and its function they employ a more complex decision making strategy than when basing their decision on form or function alone and that emotion plays a large role in the strategy. In other words, preference for the whole product is not simply the sum of preferences for its form and its function.

In trying to better understand consumer preference judgments, we anticipate that the mental processes consumers experience while making a judgment may yield useful insight. Having more information about the path consumers take to their decisions can possibly guide designers to better solutions to meet consumer needs. Unfortunately, in some instances consumers have difficulty explaining the thought processes that lead to their decisions and, further, logical explanation may counter emotional reasoning. In order to gain better insight into the mental processes consumers experience while making preference judgments involving both form and function, we look at the physiological processes occurring in the brain at the time of judgment using neuroimaging. Neuroimaging allows us to identify the brain regions that are active during the decision making process and some distinct regions that are associated with logical versus emotional processing.

There are several techniques for collecting brain activity data [4]. Some of the commonly used techniques are electroencephalography, EEG, positron emission tomography, PET, and functional magnetic resonance imagining, fMRI. Each technique gives specific physiological information about what is occurring in the brain at a point in time. Brain activity has been previously shown to provide useful information about the design process. For example, Nguyen and Zeng [5] used EEG to study brain activity in designers as they solved design problems. Additionally, Alexiou et al. [6] used fMRI to show that there is a difference in observed brain activity when solving a well bounded problem versus designing a solution for an open ended problem. Whereas both these studies focus on designers' thinking, in the current study we focus on users' decision making.

In the past, fMRI has been used to investigate how product characteristics such as price [7] and packaging attractiveness [8] affect consumer decisions. fMRI has also been shown to be able to give insight into the brain activities associated with emotion [4]. As a result, we chose to use this method in our study as a means of gaining further insight into the decision making process of consumers.

We anticipate fMRI data, in combination with self-report and behavioral data, will be able to inform the designer about the strategies consumers employ when making preference judgments. In this study we focused on how consumers use aesthetic and performance information to judge preference with the goal of better informing the product development process.

PREVIOUS WORK

Conjoint Analysis

Conjoint analysis has been used to model consumer preference since the mid 1960's [2]. In a traditional conjoint analysis study participants are asked to make choices between multiple options that represent various combinations of the product attribute levels in question. The number of questions and the levels of the attributes in each question are determined by design of experiments [9]. These quantities are chosen to span the design space and spaced evenly to prevent bias [10]. In general a full factorial design is not needed if the interaction effects between the attributes are negligible. We make that assumption here which allows use of a fractional factorial instead. This assumption was found to be reasonable in previous work with visual conjoint analysis using a design representation similar in complexity to that used in this work [3]. A utility function that describes feature preference can be derived from the participant's responses to these questions.

Although this method of analysis has often been used to characterize consumer preference for the functional attributes of products, extensions to the method have been made. Turner et al. [11] used conjoint analysis to capture color preference. In that study a survey was designed using three identical backpacks that were colored with different RGB values. Although the method did not predict the favorite colors of all of the study participants, the results suggested some validity in their approach to modeling color preference [11]. Kelly and Papalambros [12] presented a method for capturing aesthetic preference information from subjects. In that work the shape of a beverage bottle was parameterized and a conjoint study was performed. The shape preference function was then used in conjunction with the engineering performance characteristics of the shapes to create a Pareto front that illustrated the tradeoffs between aesthetic form preference and actual functional performance. Orsborn et al. [3] presented another method for extending traditional conjoint from functional specification to aesthetics. That worked showed that aesthetic preference for complex designs such as the front of vehicles could be captured through conjoint analysis. The designs were the composition of several Bezier curves whose control points were varied to create variations in the design. This technique resulted in a continuous design space.

Reid et al. [13] used a visual conjoint method to quantify the relationship between aesthetics and perceived environmental friendliness. That work had participants rate two-dimensional vehicle silhouettes on environmental friendliness. The results showed that cars with smoother curves were more likely to be thought of as being inspired by nature while boxier cars were less likely. Finally, Tseng [14] presented a method for capturing aesthetic preference and its relationship to actual performance in vehicles using neural networks. The results give insight into how designers can create designs that meet aesthetic and performance goals.

fMRI

The scanners used in an fMRI study are the same used in a traditional MRI study. The major difference is the resolution setting. MRI images are high in spatial resolution and give tremendous detail about the structures of the brain. In contrast, fMRI images are high in temporal resolution and give an indication of blood flow in the brain. Hemoglobin's magnetic properties differ when it is bound with oxygen from when it is not [15]. Because deoxygenated hemoglobin is more magnetic it distorts the magnetic field from the scanner as the field passes through the brain. By measuring the distortion we can determine how much hemoglobin has been deoxygenated and therefore how much oxygen a brain region used. The amount of oxygen used is an indirect measure of activity in that region.

fMRI data have been used to provide interesting insight into preference research. Vartanian and Goel [16] asked study participants to judge paintings based on aesthetics. The results of their study showed that increases in preference were correlated with activity in specific regions of the brain, including the striatum and anterior cingulate cortex. The striatum, particularly the ventral striatum, is important in processing reward, such as anticipation of winning money [17]. The anterior cingulate cortex, a region originally identified as part of the limbic (emotional) circuit, is important for conflict monitoring and error detection in both cognitive and emotional domains [18]. In a different study, Jacobsen et al. [19] asked participants to judge drawings based on their aesthetic and perceptual properties. They found that judgments of aesthetic designs activate multiple regions, including the insula, a part of the brain that receives visceral input from the body and plays an important role in emotional and motivational processes [20]. In another study, participants were scanned while tasting identical wine samples that they believed to be different in type and in price [21]. This work shows that neural activity can be affected by perception as the activation in regions associated with pleasantness were greater for the samples thought to be more expensive. Zysset et al. [22] explored the activation associated with multi-attribute decision-making. It was shown that activation during these types of tasks is distributed over several regions of the brain, including the anterior cingulate and lateral prefrontal cortical areas. The lateral prefrontal cortex, particularly the dorsolateral prefrontal cortex, is especially important for effortful or "executive" cognitive processes, including those involved in analytical thinking and reasoning [23]. In the current study we designed a paradigm that would reveal the brain activity that takes place as the participants make decisions between two options where form and function are in conflict (i.e., where one product has the better form and another has the better functional features).

METHODOLOGY

Participants

There were a total of 14 participants in the non-fMRI study (11 female; 10 male; mean age 25.9 years) and 7 subjects in the fMRI study (4 female; 3 male; mean age 23.7 years). Written consent from all subjects was obtained prior to the scanning session. All subjects had normal or corrected-to-normal vision. Subjects were instructed prior to the actual experimental session. The subjects were recruited by email. Subjects were compensated with their choice of either $25.00 or course credit.

Procedure

The study was divided into two parts. In part I the participants were presented with trials that assessed their aesthetic, functional, and combined preference. In part II we validated the preference models from part I using self-report data and performed the fMRI task.

Part I: Assessing Preference

Section 1: Aesthetic Preference Modeling

In Section 1 the subject's aesthetic preference is captured. The vehicle designs used in the study are line drawing silhouettes built using a scheme developed by Tseng [14]. An example of the vehicle representation is shown in Fig. 1.

Figure 1: Example vehicle design

These representations are the composition of eight Bezier curves. The control points of the curves are parameterized in a method that allows the 12 major features of the design - the belt angle, nose angle, ground clearance, body height, roof height, hood length, trunk length, front screen rake, rear screen rake, wheel size, front wheel position, and rear wheel position - to be varied between a high and low value. Each parameter can vary from a value of 0 (low) to 100 (high). In this study we held wheel size and front and rear wheel position constant, leaving only nine attributes.

For each of the nine attributes we used 3 levels: high, medium, and low. In this vehicle representation scheme those values are 100, 50, and 0. The SAS software package was used to determine a fractional factorial design for this analysis. Using Matlab, subjects were presented 36 trials where three vehicle design options were shown and asked to pick the one they preferred in each trial. A sample trial is shown in Fig. 2.

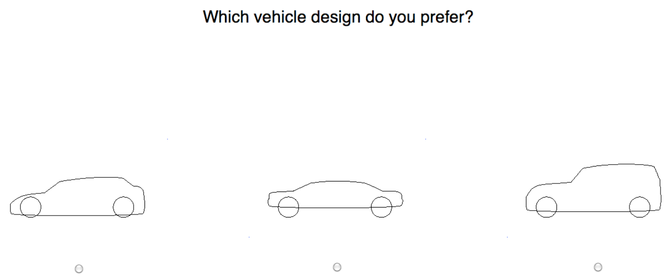

Figure 2: Screenshot of an aesthetic preference trial.

After completing the 36 trials, the subject's responses were tallied. The number of times that each level of each attribute was chosen was compared with the number of times it was presented to compute the probability that it will be chosen. The normalized probability that either low, medium, or high will be chosen for each attribute is plotted. An example shown in Fig. 3 shows that utility initially increases as hood length increases, but reaches a maximum value after which utility decreases as the hood length further increases. The plot is fit with a second order equation as done by Orsborn et al. [3].

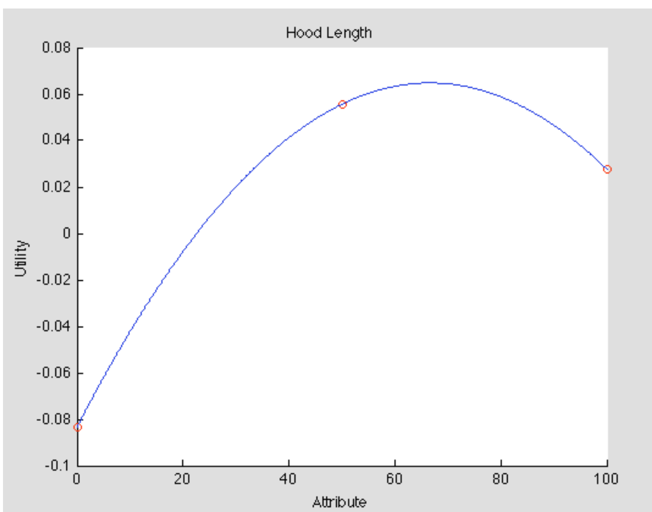

Figure 3: Sample plot of individual aesthetic attribute preference function for hood length

The fit takes on the form of Eq. 1 [3]:

$$u_i = \beta_{i1} x_i^2 + \beta_{i2} x_i + \beta_{i3}, \tag{1}$$

where

u_i = Utility from attribute i at level x_i,

β_i = Attribute i beta coefficients,

x_i = Attribute i values.

Equation 1 depicts the likelihood that the attribute will be chosen when presented at any of the levels within the range. The likelihood that the entire design will be selected is taken to be the sum of the likelihoods, or utility from each attribute and is shown in Eq. 2 [3]:

$$U(\bar{x}) = \sum_{i=0}^{n} u_i : \quad u_i = f(\beta_i, x_i), \tag{2}$$

where

U = Total utility .

The attribute betas, β_i, can be thought of as weightings as they dictate how much each attribute contributes to the total utility.

Since the utility of a design is taken as the sum of the attribute utilities, by maximizing and minimizing the utility equations from each attribute, we can determine the lower utility bound, *Umin*, and the upper utility bound, *Umax*, for the user. By altering the attribute values we can generate designs that span the range of utilities between *Umax* and *Umin*. We use this method to generate the vehicle designs that will be used in the later sections of the study.

Section 2: Function Preference Modeling

In section two of the study we model the subject's function preference. The function preference is described in terms of four performance specifications: 0-60 mph acceleration (6 – 12 seconds), fuel economy (18 – 35 MPG), horsepower (150 – 250 HP), and 60-0 mph braking distance (75 – 225 ft). These specifications were chosen based on those used by *Consumer Reports* when providing car-rating data for consumers. Here, SAS was again used to develop a fractional factorial design for the questions. Also in Matlab, subjects were presented with 18 trials containing three choices. Within each choice were the four attributes at one of three levels. A sample trial is shown in Fig. 4.

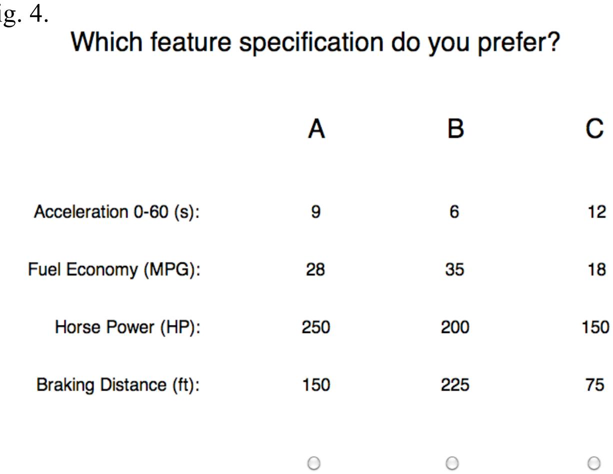

Figure 4: Screenshot of a function preference trial.

After completing the trials, the subject's function preference equations were derived in the same way as in the aesthetic section. An example plot of a function utility equation is shown in Fig. 5 where utility linearly decreases as acceleration time, measured in seconds taken to get from 0 to 60 miles per hour increases.

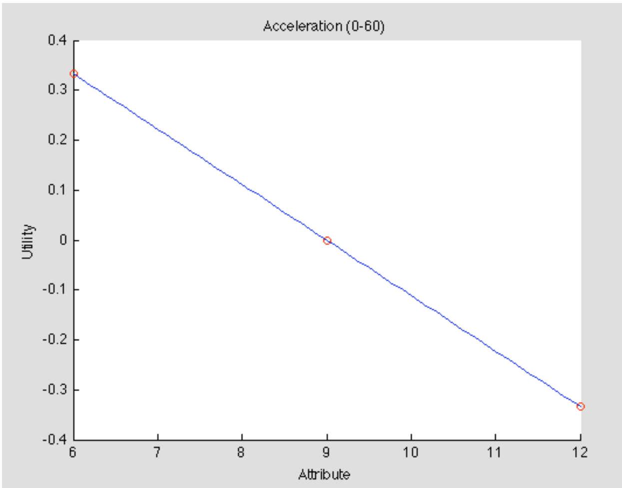

Figure 5: Sample plot of individual performance attribute preference function for acceleration.

The purpose of the first two sections was to develop preference equations describing form and function specific to each subject. In addition to quantifying the preference functions we also generated and stored example vehicle designs and specification groups that span the range from low to high utility. With these data, in the following section we investigate how the subjects trade off form and function.

Section 3: Combined Aesthetic and Functional Preference Modeling

In Section 3 we combined the aesthetic preference equation from Section 1, which we will now refer to as *Uform*, and the function preference equation from Section 2, which we now refer to as *Ufunc*. Although *Uform* and *Ufunc* were captured separately, our goal is to capture the combined preference as consumers make their decisions based on available information that includes both form and function. In order to combine *Uform* and *Ufunc* we performed a third conjoint study. In this study we treated *Uform* and *Ufunc* as attributes and used a full factorial design. The examples of high, medium, and low utility were taken from those generated in the previous sections. The design consisted of 9 trials, with 2 options and 2 attributes at 3 levels, low, medium, and high.

In each trial the subject had to make a choice between two different options each with a unique combination of form and function. A sample trial is shown in Fig. 6. Here, a high utility vehicle design is shown on the left while a low utility vehicle design is shown on the right. These vehicle designs were generated based on U*form*. Likewise the specifications, high utility on the left and low utility on the right, were generated according to U*func*.

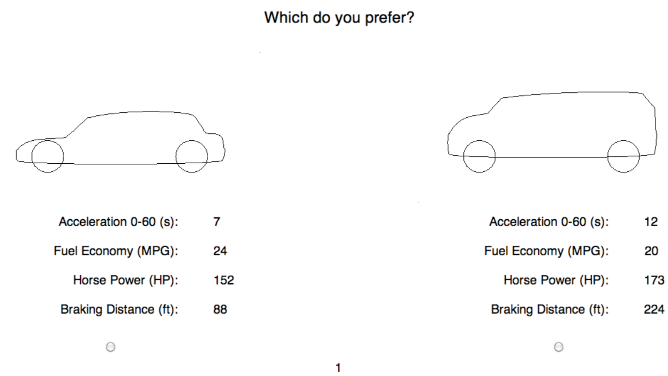

Figure 6: Screenshot of a combined preference trial.

After completing the trials, the same procedure for developing a utility function as in the previous sections was followed. As before, we were able to construct utility functions for each of the attributes in this conjoint. The key difference here was that the two attributes we tested, *Uform* and *Ufunc*, were not individual attributes but rather the composition of several different attributes we chose to describe form and function respectively. In this case the preference functions developed, *Ucform* and *Ucfunc*, describe preference for *Uform* and *Ufunc* relative to one another as shown plotted in Fig. 7 & Fig. 8.

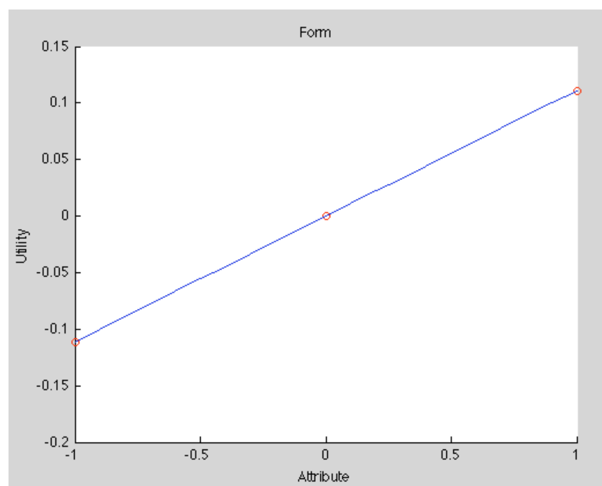

Figure 7: Sample plot of preference based on aesthetics, *Ucform*.

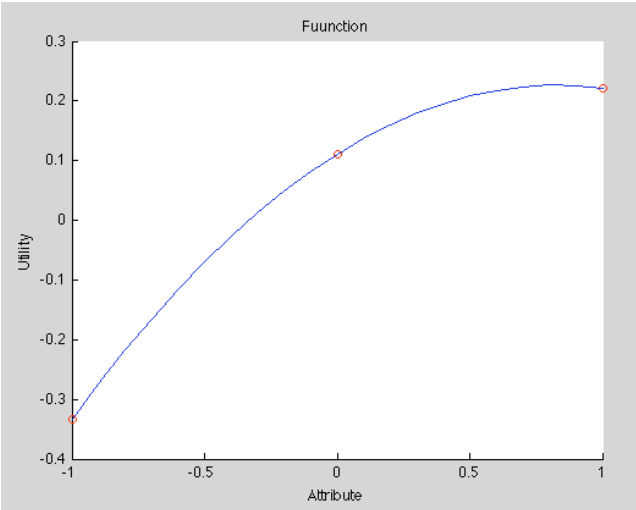

Figure 8: Sample plot of preference based on performance, *Ucfunc*

As before, the preference function derived from the conjoint is taken to be the sum of the contributing attributes. In this case the combined preference *Ucomb* is taken to be the sum of the contributing functions as shown in Eq. 3:

$$U_{comb} = U_{cform} + U_{cfunc} \,. \tag{3}$$

Note *Uform* ≠ *Ucform* and *Ufunc* ≠ *Ucfunc*. With Eq. 3 we are able to predict the utility for a given vehicle design and feature specification combination.

Forced choice conjoint analysis allows for developing preference models that characterize the tradeoffs consumers make between the attributes surveyed. As such, it would be ideal to survey both the form and function attribute simultaneously. However, this is infeasible, as the number of attributes that would need to be included would increase the decision complexity. The added cognitive load from the increased complexity has been shown to have a negative impact on choice consistency [24]. As a result, other methods for dealing with high numbers of attributes have been developed. In adaptive conjoint analysis [25] questions are asked to gauge how important attributes are to the consumer relative to one another. The survey adapts itself to the individual and weighs preference data for the most important attributes more heavily when constructing the utility model. In other work large numbers of attributes are handled by holding some of the attributes constant during some of the questions [26]. By reducing the number of attributes that actually vary from question to question an optimal design can be developed.

Here we chose to introduce the two stage conjoint analysis because we wanted the model to be able to independently assess the relative importance of the two sets of attributes (form vs. function) to the consumer. Also holding attributes constant would have made differentiating between the visual designs difficult. This method is appropriate because forcing choices between low, medium, and high form and low, medium, and high function combinations as described by the individual will capture the tradeoffs they make between form and function.

Section 4: Design Rating

In Section 4 we solicited direct information about how subjects trade off form and function. We chose examples of form and function at five different levels spanning the range from the examples generated in Sections 1 and 2. We combined them into the 25 possible combinations and presented each to the subjects and asked them to rate the combination between 0 (strongly dislike) and 100 (strongly like). A screen shot from that task is shown in Fig. 9.

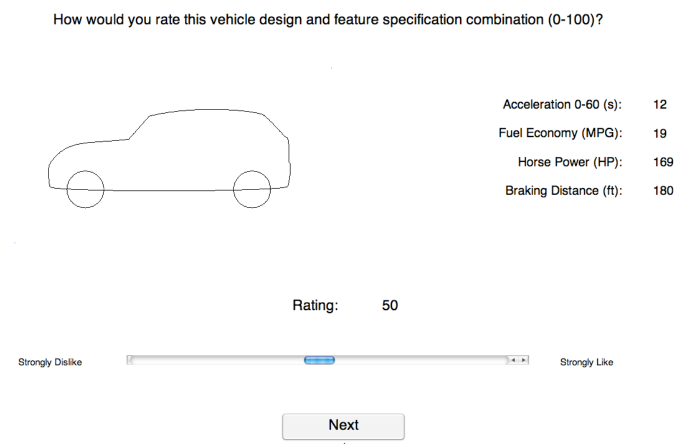

Figure 9: Screenshot of combination rating trial

We used the responses from this section to test how well Eq. 3 can model combined preference, a verification of our assumptions.

Part II: Validating Preference

The layout of Part II varied depending on whether or not the subject participated in the fMRI portion of the study.

Non-fMRI Task

After completing all of the sections in Part I, Matlab was again used to present the non-fMRI participants with several trial types that adhered to the same format as those in Section 3, a vehicle design and specification set on the left and another vehicle design and specification set on the right. Participants were asked to respond to 16 trials of each type. These trial types are summarized in Table 1.

Table 1: Summary of non-fMRI trials

Form Only (Easy & Difficult)	The form varies while function is held constant
Function Only (Easy & Difficult)	The form is held constant while the function varies
Form-Function Conflict (Easy & Difficult)	Both form and function vary

For the Form Only, Function Only, and Form-Function Conflict trials the subjects were asked to specify which option they preferred. Each trial type consisted of easy and difficult versions. In the Form and Function Only trials, the easy versions pitted high utility options against low utility options, while the difficult trials pitted high utility options against other high utility options. In the easy Form-Function Conflict trials, a high utility vehicle design is paired with a high utility specification group and pitted against a low utility vehicle design paired with a low utility specification group. In the difficult Form-Function Conflict trials, a high utility vehicle design is paired with a low utility specification group and pitted again a low utility vehicle design paired with high utility specification group. The trials we were most interested in were the difficult Form-Function Conflict trials, because these required the subject to pick either form or function, trading off one for the other. After completing the Form-Function Conflict trials, if the subject chose an option with high form utility or high function utility the subject was shown an answer they gave and asked follow up questions about how they made their decision. An example is shown in Fig. 10 and the follow up questions are listed in the results section.

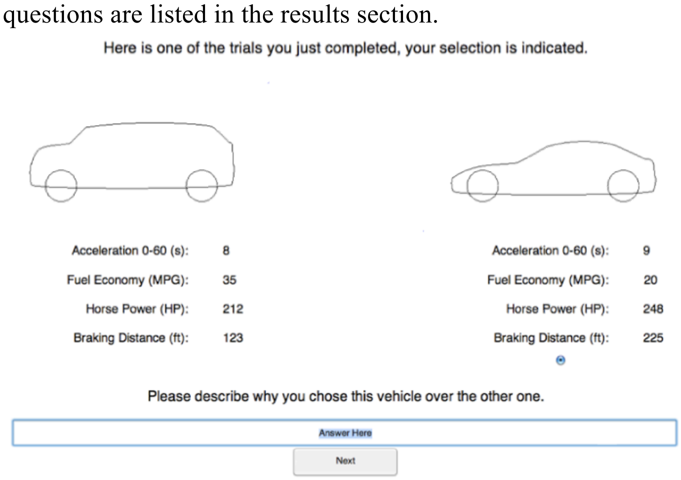

Figure 10: Screenshot of follow up question

fMRI Task

After completing part I, the subjects who participated in the fMRI portion of the study were prepped for the scanner task. Subjects were taken through a practice run of the trials they would see inside the scanner. The stimulus presentation software used for practice run and in the scanner was Macstim. In the practice run subjects used the computer keyboard to enter their responses to the trials. In the scanner the subjects had a response glove strapped to their right hand that placed buttons under each of their fingers. The subjects used their index finger to indicate the option on the left and their middle finger to indicate the option on the right.

In order to separate out the activation associated with processing the vehicle designs and specification groups from the activation associated with decision-making, the trials were presented in a staggered order. First, the vehicle designs were shown alone for 3 seconds (Design); next the specifications were added to the screen and shown for 5 seconds (Specifications); a fixation crosshair was used as a jitter for an average of 0.5 seconds; the question was then added to the screen and the subjects had 8 seconds to make a decision and enter their response (Choice); finally a fixation crosshair was used as a jitter for an average of 2.5 seconds between trials. This design is illustrated in Fig. 11.

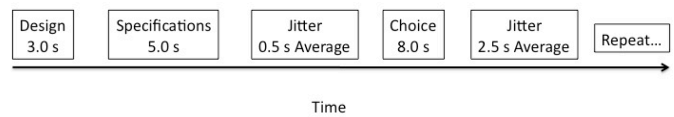

Figure 11: Experimental design of an fMRI trial

The fMRI design was structured into 4 runs of 18 trials. The runs were presented in a counterbalanced order across subjects. The trials within each run were presented in pseudorandom order. The average run duration was 362.55 seconds.

The trials the subjects were presented in the scanner were the same types as the non-fMRI participants with the following alterations. All the Form Only and Function Only trials were easy, in order to match them to the type of form and function decisions they would make in the Form-Function Conflict trials. All the Form-Function Conflict trials were difficult in the sense that one vehicle clearly had the better design and the other vehicle clearly had the better specifications. An additional trial type, the Form-Function Control trial was included. In this trial type participants were shown two vehicle design and specification groups and asked to indicate whether the two options were the same or different. An example trial is shown in Fig. 12.

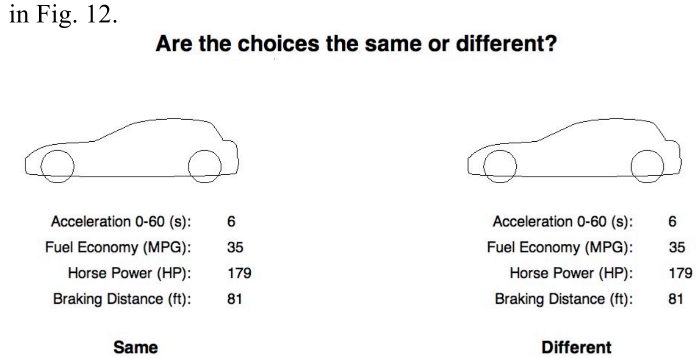

Figure 12: Screenshot of Form-Function Control trial

This trial serves as a control for the Form Only, Function Only, and Form-Function Conflict trials. By asking subjects to decide whether the two options are the same or different, we can subtract out activation associated with perceptual aspects of the decision and isolate activity specific to preference judgment. Participants were presented with a total of 16 easy Form Only trials, 16 easy Function Only trials, 16 Form-Function Control trials, and 24 difficult Form-Function Conflict trials.

fMRI Acquisition

Scans were acquired on a Siemens 3T Verio Scanner with a 32-channel head coil (Siemens AG, Erlangen, Germany). For each participant, functional scans were acquired using an echo-planar pulse sequence with TR = 2 s, TE = 28 ms, and flip angle = 79º. Each pulse recorded 35 oblique-axial slices with slice thickness 3.2 mm and no slice gap (FOV=205 mm, matrix size 64 x 64, 3.2 x 3.2 x 3.2 mm3 voxels). Four runs were acquired, each comprised of 187 volumes. Extra acquisitions were acquired at the end of the task in every run, in order to allow the hemodynamic response to the final event to return to baseline.

fMRI Data Analysis

The imaging data were analyzed using Statistical Parametric Mapping (SPM'08, Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). Data analysis steps included realignment to correct for head motion, direct normalization into a standard stereotactic space as defined by the Montreal Neurological Institute (MNI), and smoothing with an 8mm Gaussian kernel (FWHM). No participant had sudden head motion greater than 1mm.

Statistical parametric maps (SPM) were computed using the general linear model, with separate hemodynamic response functions modeled for each of the following 6 task events: Design (regardless of trial type), Specifications (regardless of trial type), Choice during Form Only trials, Choice during Function Only trials, Choice during Form-Function Conflict trials, and Choice during Control trials. Linear contrasts were computed from the four Choice events as one-way t-contrasts in first level models for each participant, as follows: Form Only vs. Control, Function Only vs. Control, and Form-Function Conflict vs. Control. To identify voxels uniquely activated during Form-Function Conflict decisions, we created a fourth contrast: 2*Form-Function Conflict vs. 1*Form Only vs. 1*Function Only.

These contrasts were then submitted to a second-level random-effects group analysis. Whole-brain analyses were conducted using significance level of $P < 0.005$ (uncorrected) for magnitude of activation, with an extent threshold of 15 voxels, which provides a reasonable balance between Type I and Type II error concerns and is consistent with the false discovery rate in typical behavioral science papers [27]. To identify the common regions associated with the Form-Function Conflict and the easy trials, we used an inclusive mask technique aimed to determine the intersection of SPM t-maps of the Form-Function Conflict vs. Control contrast with the Form Only vs. Control contrast and with the Function Only vs. Control contrast.

RESULTS

Preference Modeling (non-fMRI Participants)

We had 11 of the study participants give 16 responses to the easy versions of the Form Only, Function Only, and Form-Function Conflict trials in order to validate that the preference functions generated in Sections 1, 2, and 3 were able to predict choice. As a reminder, the high and low utility examples were generated from the preference functions of each individual participant. In over 98% of the easy Form Only trials, participants chose the high utility vehicle design option over the low utility option. In the easy Function Only trials, participants chose the high utility specification group option over the low utility option over 99% of the time. For the easy Form-Function Conflict trials, where an option with high form and function utility was pitted against an option with low form and function utility 100% of the responses were in favor of the high utility option over the low utility option.

The next statistic of interest was how well the combined utility function *Ucomb* correlated with participant ratings of vehicle design and specification group combinations. The goal here was not to predict the participant responses exactly, but rather to capture the general trend of the responses. We found a significant correlation ($r=0.56$, $p<0.001$, $n=14$) indicating a very reliable and moderately strong positive relationship between the utility values calculated using *Ucomb* and the participants' actual ratings of the vehicles.

fMRI Participant Trial Follow Up Results

Each fMRI participant was presented a total of 24 Form-Function Conflict trials. Of the 7 participants only 3 ever chose the high form utility choice over the high function utility choice. The average rate at which those three participants chose the high form utility option from all 24 options was approximately 9.5%. Their self-reported responses, summarized in Table 2, are consistent with how they chose. When they chose the high form utility option they indicated that their decision was based more on vehicle design than specification. When they chose the high function utility option they indicated their decision was based more on the specification than the vehicle design.

Table 2: Form-Function Conflict Trial Follow up Questions

Question (1-7, not at all – a great deal)	Chose Form	Chose Function
To what extent was your decision influenced by the specifications of the vehicles?	4.50	6.25
To what extent was your decision influenced by the designs of the vehicles?	6.25	3.38

fMRI Results

During decisions based on form or function alone, we found activation in both emotion-related and more executive areas. When comparing the easy Form Only trials to the Control trials, we observed increased activity in multiple areas including the dorsal anterior cingulate, a region associated with conflict monitoring. Increased activity was also observed in the dorsolateral prefrontal cortex, associated with cognitive reasoning, and the insula, associated with visceral experience. The activations in the anterior cingulate and insula are highlighted in Fig. 13

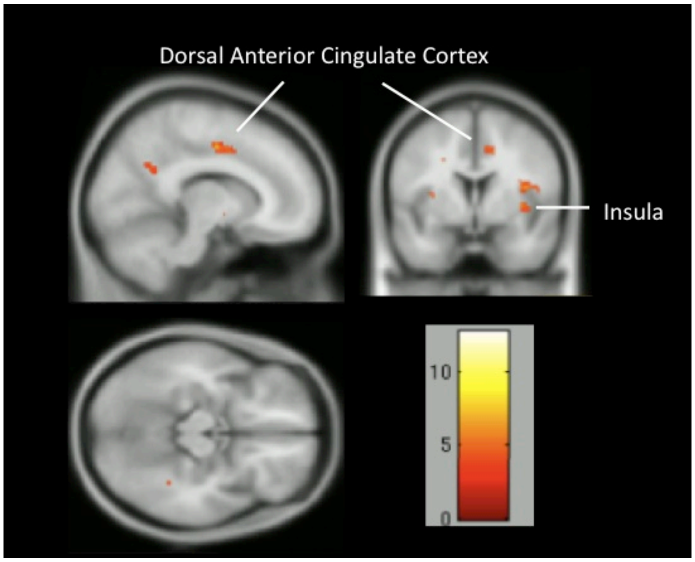

Figure 13: Neural activity during Form Only trials versus Control trials.

The easy Function Only trials compared to the Control trials again isolated activation in the dorsal anterior cingulate and the dorsolateral prefrontal cortex. Unlike the Form Only trials, however, in the Function Only trials we did not observe activation in other limbic regions, areas that are often associated with emotion. Fig. 14 shows some of the activations from these trials.

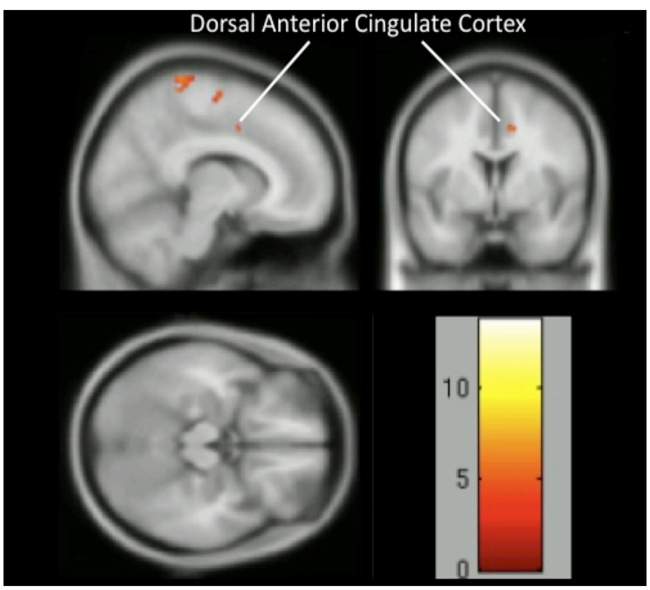

Figure 14: Neural activity during Function Only trials versus Control trials.

As shown in Fig. 15, pattern of activation in the Form-Function Conflict trials relative to the Control trials was partly unique and partly similar to the patterns observed in the Form Only and Function Only contrasts. Specifically, as in the previous two contrasts, we observed activity in the anterior cingulate. Unlike the other two contrasts, we also saw activity in the striatum and in a limbic region that included part of the ventral striatum, an area linked with emotion and in particular reward.

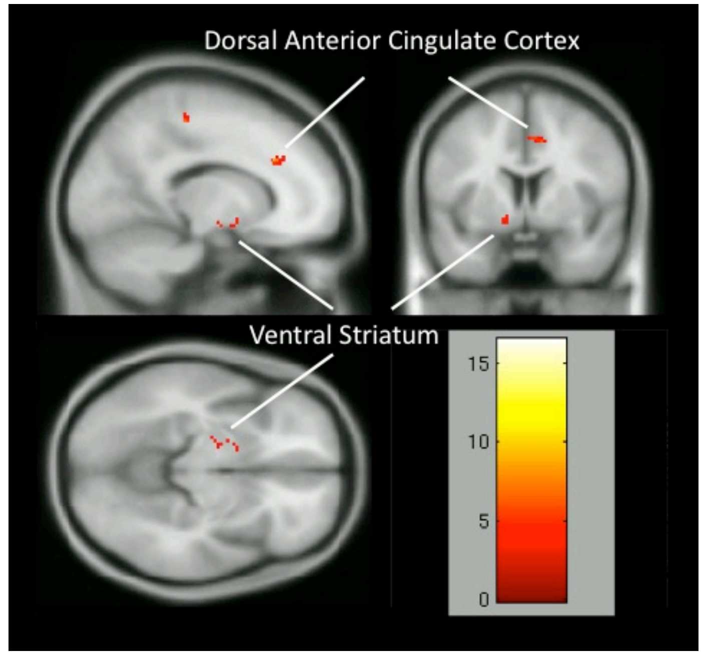

Figure 15: Neural activity during Form-Function Conflict trials versus Control trials.

The analyses critical to our hypothesis were those comparing the Form-Function Conflict trials to the Form Only and Function Only trials. As listed in Table 3, in the contrast of Form-Function Conflict vs. the Form Only and Function Only trials, we identified a number of regions that showed greater activity level during Conflict decisions. These regions, including the Midbrain, Orbitofrontal Cortex, and the Parahippocampal Gyrus / Amygdala, are associated with emotion and emotion regulation. Some activation was also observed in the Lentiform Nucleus, an area that is very close to the limbic/ventral striatum region that's activated in the conflict-control contrast. Fig. 16 highlights the activity in these regions.

Inclusive masking of Form-Function Conflict trials with the Form Only trials isolated activation in the dorsal anterior cingulate and two clusters in the superior temporal gyrus. There was no common effect of Form-Function Conflict decisions and Function Only decisions with our *a priori* thresholds.

Table 3: Activation peaks during Form-Function Conflict trials vs. Form Only and Function Only trials

	Coordinates				
Region	**x**	**y**	**z**	***t***	**Voxels**
Orbitofrontal cortex (BA47)	-26	14	-24	5.48	53
Orbitofrontal cortex (BA47)	38	24	-16	4.56	36
Medial Frontal Gyrus (BA9)	4	54	30	5.19	30
Superior Frontal Gyrus (BA8)	26	40	52	5.37	34
Visual Cortex (Cuneus and BA18)	-24	-102	-8	5.28	20
Lentiform Nucleus	-16	0	-2	4.69	16
ParaHippocampal Gyrus and Amygdala	18	6	-26	7.88	202
ParaHippocampal Gyrus and Amygdala	-18	2	-26	10.08	44
Midbrain	-6	-26	-20	7.79	211

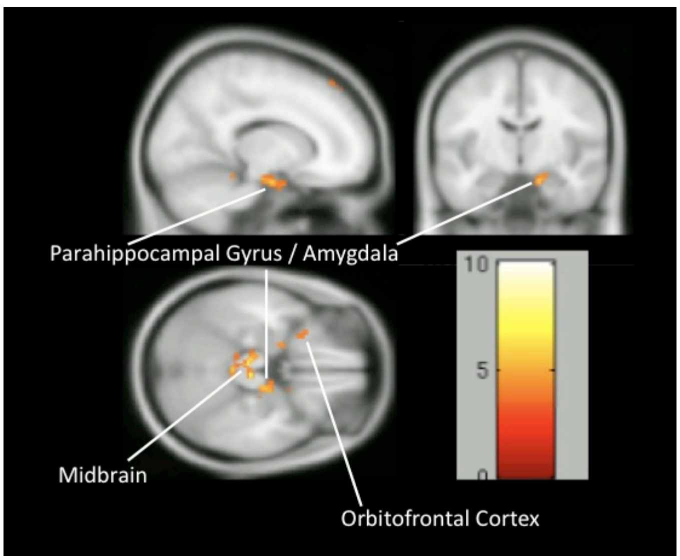

Figure 16: Difference in neural activity between Form-Function Conflict trials and Form Only and Function Only trials.

DISCUSSION

The second stage of our conjoint analysis study was able to produce a preference model that took into account both form and function. The combined preference function was shown to have a reasonably good correlation with the participant ratings, but there is room for improvement.

In the difficult Form-Function Conflict trials, subjects overwhelmingly chose the high utility specification group option over the high utility vehicle design option. Although the betas in the combined preference function indicated that subjects weighed function more heavily than form, the extent of this preference was not apparent, as most subjects never once forwent function for form. Although the low resolution of the form illustrations may have affected its preference, during debriefing several participants mentioned that during the Form-Function Conflict trials they wanted to pick the higher form option but felt they could not ignore the difference in performance specifications. This feedback from participants is consistent with our hypothesis that consumer decision-making strategy is more complex when both form and function are taken into account.

The fMRI results isolated activation during Form Only and Function Only choices in multiple brain regions, some associated with intuitive feelings and some with analytical thinking. The regions that were activated during Form-Function Conflict trials were not a direct sum of those activated during each of the Form Only and Function Only decisions. Specifically, multiple regions were uniquely activated during the Conflict trials that were not activated during the other two trial types, particularly regions associated with emotions, highlighting the importance of emotions during the conflict encountered in these decisions. Some of the regions activated in the Form Only trials, including some areas associated with emotions, were also activated in the Conflict trials, but we did not find overlap of activation in the Conflict trials with the Function Only trials. These results should be interpreted with caution, however, as they are preliminary and require further analysis.

These results are consistent with the important role of emotions in preference judgment, namely that reasoning about function alone is not the complete picture in the psychological processes surrounding products that include aesthetics as well. Although informative, the fMRI study is a pilot, providing evidence that more extensive studies may yield greater insights. Future fMRI studies should recruit a full sample of participants. These studies should also include self-report and behavioral (response time) measures to better differentiate between the emotional and analytical strategies employed by consumers when judging combined preference.

One of the major goals of this paper is to introduce the idea that fMRI can be used to study complex consumer decisions relevant to product design. One way fMRI can help is by showing whether one type of decision (e.g., choice between an option with the better design and an option with the better performance) is similar to or different from another type of decision (e.g., choice between one complete design over another). A second way that fMRI can guide our understanding of consumer decision-making is to provide insight into whether and when emotional versus rational thinking might occur, which might inform the level of confidence for conjoint-based preference modeling. fMRI can also help determine if one group of people employs a different strategy during decision-making than another group. Here we provide a preliminary illustration of the first way in which fMRI can contribute to understanding of consumer choice to inform product development.

fMRI can also be useful by providing stronger predictors of choice than behavioral measures alone. Although the combined utility function was reasonably well correlated with participants' responses, clearly more complex decisions are taking place. We believe that modeling brain activity during combined decisions might do a better job of predicting choice than a utility model alone. Previous fMRI research has shown that neural response to persuasive messages can better predict subsequent behavior change than self-reported attitudes and intentions [28].

CONCLUSION

The results of our study show that when taking both form and function into account, preference judgments are more complex than the sum of the individual judgments. A meta-conjoint approach that uses the separate conjoint analyses of form and function provides one means to account for the conflicting decisions that are made by consumers. However, this work marks the first time that fMRI was employed to assist in understanding and modeling how consumers trade off form and function in their preference judgments. The clear conflict between the two different aspects of the product resulted in activation of the emotion-oriented regions of the brain. In the future we anticipate fMRI data being a powerful tool in helping to better understand and model complex consumer behavior as a means to inform the product development process.

ACKNOWLEDGMENTS

The authors would like to thank the National Science Foundation for funding this research through the Graduate Research Fellowship program and under grant SBE0738058.

REFERENCES

[1] Boatwright, P., and Cagan, J., 2010, "Built to Love," Berrett-Koehler Publishers, San Francisco, CA.

[2] Luce, R.D. and Tukey, J.W., 1964, "Simultaneous conjoint measurement: a new scale type of fundamental measurement. Journal of Mathematical Psychology," 1, 1–27.

[3] Orsborn, S., Boatwright, P., and Cagan, J., 2009, "Quantifying Aesthetic Form Preference in a Utility Function," ASME J. Mechanical Design, 131(6), p. 061001.

[4] Phan, K.L., Wager, T., Taylor, S.F., and Liberzon, I., 2002, "Functional Neuroanatomy of Emotion: A Meta-Analysis of Emotion Activation Studies in PET and fMRI," NeuroImage, 16(2), pp. 331-348.

[5] Nguyen, T.A. and Zeng, Y., 2010, "Analysis of Design Activities Using EEG Signals," DETC2010-28477 *ASME IDETC – Design Theory and Methodology*, Montreal, Quebec, Canada, August 15-18, 2010.

[6] Alexiou, K., Zamenopoulos, T., Johnson, J.H., and Gilbert, S.J., "Exploring the Neurological Basis of Design Cognition Using Brain Imaging: Some Preliminary Results," Design Studies, Volume 30, Issue 6, November 2009, pp. 623-647

[7] Knutson, B., Rick, S., Wimmer, G.E., and Prelec, D., Loewenstein, G., 2007, "Neural Predictors of Purchases," Neuron, 53(1), pp. 147-156.

[8] Stoll, M., Baecke, S., and Kenning, P., 2008, "What They See is What They Get? An fMRI-study on Neural Correlates of Attractive Packaging," Journal of Consumer Behaviour, 7(4-5), pp. 342-359.

[9] Green, P. E., and Srinivasan, V., 1978, "Conjoint Analysis in Consumer Research: Issues and Outlook," J. Consum. Res., 5(2), pp. 103–123.

[10] Zwerina, K., Huber, J., and Kuhfeld, W., 1996, "A General Method for Constructing Efficient Choice Designs," SAS Technical Report No. TS-722E.

[11] Turner, H., Orsborn, S. and Grantham, K., 2009, "Quantifying Product Color Preference in a Utility Function," Proceedings of 2009 American Society of Engineering Management, October 14-17, Springfield, MO, USA.

[12] Kelly, J., and Papalambros, P.Y., 2007. "Use of Shape Preference Information in Product Design", Proc. ICED 2007, Paris, France, Aug. 28 – 31, 2007. Paper No. ICED07-867

[13] Reid, T.N., Gonzalez, R. D., and Papalambros, P.Y., 2010, "Quantification of Perceived Environmental Friendliness for Vehicle Silhouette Design," J. Mech. Des. 132.

[14] Tseng, I., J. Cagan and K. Kotovsky, "Learning Stylistic Desires And Generating Preferred Designs Of Consumers Using Neural Networks And Genetic Algorithms," DETC2011-48642, *ASME IDETC – Design Automation Conference*, Washington D.C., August 28-31, 2011.

[15] Huettel, S. A., Song, A. W., and Mccarthy, G., 2004, "Functional Magnetic Resonance Imaging," Sinauer Associates, Sunderland, MA.

[16] Vartanian, O., and Goel, V., 2004, "Neuroanatomical Correlates of Aesthetic Preference for Paintings," Neuroreport, 15, pp. 893–897.

[17] Knutson, B., Adams, C.M., Fong, G.W., and Hommer, D., 2001, "Anticipation of Increasing Monetary Reward Selectively Recruits Nucleus Accumbens," The Journal of Neuroscience, 21(16), RC159

[18] Bush G., Luu P., and Posner M.I., 2000, "Cognitive and Emotional Influences in Anterior Cingulate Cortex," Trends in Cognitive Sciences, 4(6), pp. 215-222.

[19] Jacobsen, T., Schubotz, R.I., Hofel, L., and Cramon D.Y.V., 2006, "Brain Correlates of Aesthetic Judgment of Beauty" NeuroImage, 29(1), pp. 276-285.

[20] Ernst, M. and Paulus, M. P., 2005, "Neurobiology of Decision Making: A Selective Review from a Neurocognitive and Clinical Perspective," Biological Psychiatry, 58(8), pp. 597-604.

[21] Plassmann, H., O'Doherty, J., Shiv, B., and Rangel, A., 2008, "Marketing Actions Can Modulate Neural Representations of Experienced Pleasantness," Proc. Natl Acad. Sci. USA 105, pp. 1050–1054.

[22] Zysset., S., Wendt, C.S., Volz, K.G., Neumann J., Huber, O., and Cramon, D.Y.V., 2006, "The Neural Implementation of Multi-Attribute Decision Making: A Parametric fMRI Study with Human Subjects," NeuroImage, 31(3), pp. 1380-1388.

[23] Goel, V. and Dolan, R.J., 2003 "Reciprocal Neural Response Within Lateral and Ventral Medial Prefrontal Cortex During Hot and Cold Reasoning," NeuroImage, 20(4), pp. 2314-2321.

[24] DeShazo, J.R., and Fermo, G., 2002, "Designing Choice Sets for Stated Preference Methods: The Effects of Complexity on Choice Consistency," Journal of Environmental Economics and Management 44, pp. 123-143.
[25] Johnson, R.D, 1987, "Adaptive Conjoint Software," in Sawtooth Software Conference on Perceptual Mapping, Conjoint Analysis, and Computer Interviewing, Ketchum, ID; Sawtooth Software, pp. 253-265.
[26] Kessels, R., Goos, P., and Vandebroek, M., 2010, "Optimal Two-Level Conjoint Designs with Constant Attributes in the Profile Sets," Journal of Statistical Planning and Inference, 140(11), pp. 3035-3046
[27] Lieberman, M. and Cunningham, W., 2009, "Type I and Type II Error Concerns in fMRI Research: Re-balancing the Scale," Social Cognitive and Affective Neuroscience 4(4) pp. 423-428.
[28] Falk, E.B., Berkman, E.T., Mann, T., Harrison, B. and Lieberman, M.D. 2010, "Predicting Persuasion-Induced Behavior Change from the Brain," The Journal of Neuroscience, 30(25), pp. 8421-8424.