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IMPACT OF PRODUCT DESIGN REPRESENTATION ON CUSTOMER JUDGMENT WITH ASSOCIATED EYE GAZE PATTERNS

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ABSTRACT

Researchers often use simplified product form representations, such as silhouettes, sketches, and other two-dimensional representations of products, to examine customer preferences. While these simplified representations make the analysis procedure tractable, for example linking certain design manipulations to certain preferences, the reality is that people evaluate more sophisticated product representations during purchase decisions. This paper presents the results of a study where two groups of people were shown either computer sketches and front/side view (FSV) silhouettes or simplified renderings and realistic renderings of cars and coffee carafes. Human judgments measured included opinions, objective evaluations, and inferences. Results show a variety of phenomena including preference inconsistences and ordering effects. Data collected from an eye-tracker help to elucidate these findings.

1 INTRODUCTION

It has been well established that product form has an important role in supporting customer decisions [1-3]. Research on product form has often used very simple representations of products to study customer decisions and preferences [4-6]. Simple product representations make modeling and analysis a more tractable process for the researcher. Others have considered simple three-dimensional representations [7, 8]. Figure 1 shows some examples.

Researchers have studied the impact of different renderings on designers. Wong [11] compared rough and ready prototypes. He introduced rough prototypes to interface designers; working rough at the early stage enables designers to focus on high-level

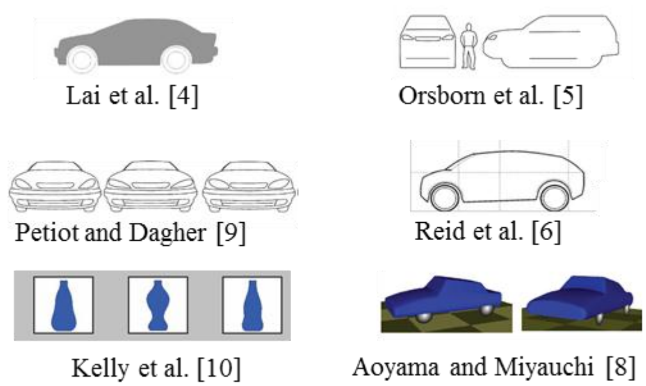

FIGURE 1. EXAMPLES OF SIMPLE REPRESENTATIONS USED IN DESIGN RESEARCH STUDIES

issues: "by leaving out a mediocre solution, the team was free to brainstorm on new ideas and not focus the critique on visual placeholders that were obviously weak [11]." Once the idea became precious, the designer would be less willing to give feedback or change it. Schumann et al. [12] obtained results similar to Wong's. They assessed the effect of non-photorealistic rendered images in CAD, which looked hand-made. The sketches proved to be more successful, compared with exact CAD plots, at triggering viewers to further discuss the design. Citrin [13] and Meyer & Bederson [14], among others, have examined user behavior during sketching; we want to expand this work by examining how different product representations may influence customer decisions.

We examine three types of customer decisions or human judgments: opinions, objective evaluations, and inferences. *Opinion* refers to product evaluations for which there is no right or wrong answer: an evaluation of a design's creativity, or how

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much one likes a product. This type of judgment has attracted considerable attention in prior studies on design evaluations. For instance, Horn and Salvendy [15] reviewed consumer-based assessment of product creativity and showed the importance of developing a more detailed model of product creativity. Kudrowitz and Wallace [16] used aspects of creativity as important criteria to assess the quality of product idea sketches. Further on we will address the wealth of study done on customer preferences [6, 17-20]. The opinion categorization of product evaluations includes product preferences. *Objective evaluation* refers to a product evaluation of a measureable quantity that can be ascertained from given product information (such as an image), for example length or relative length. *Inference* refers to an evaluation that cannot be correctly made based on the information (visual or textual) presented. For example, it is nearly impossible to evaluate the weight of a car given only an image of the car, but one can infer the weight based on the information in the image combined with other judgment criteria. Most design studies consider customer opinions and the inferences they might draw from certain design elements. All three types of judgments are important for the study of design. Preferences are subjective but draw information from both inference and objective evaluations of products.

Understanding customer judgments in the product design process is an important area of study in the design research community [2, 9]. Methods from psychology and marketing provide useful tools in eliciting customer preferences that have been leveraged for design research [6, 17-20]. One of the challenges with stated-choice preference elicitation methods is that one must rely solely on customers' self-reports, and if customers are asked to explain their choice, as research shows, they are not always able to articulate why or how they made a decision [21]. This research employs the use of an eye-tracker to corroborate self-report data. The mind-eye hypothesis states that people look at what they are thinking about [22], and effective eye-tracking studies are "goal directed" [23], meaning that eye movement will correspond to a given task.

We conducted two experiments: one using FSV silhouettes and computer sketches (see Fig. 2a, c) and the other using simplified renderings and realistic renderings—both focusing on cars and coffee carafes (see Fig. 2b, d)—and studied whether or not changes in product representation mode would influence human judgments. The study was conducted using an eye-tracking system so that gaze data could help to corroborate the evaluations reported.

The remainder of this paper proceeds as follows: Section 2 discusses the relevant literature and our research hypothesis. Section 3 and 4 present the methods and results. Section 5 and 6 discuss the results and conclusions.

2 BACKGROUND LITERATURE

Methods for eliciting customer preferences in the context of design research are extensive. This section discusses some of the representation modes often used in design research studies and provides background on the eye-tracking literature. Gaps in the literature are discussed and a hypothesis that drives this research is proposed.

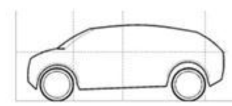
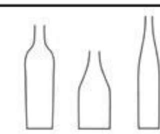
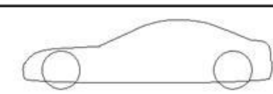
2.1 Elicitation of Preferences Using Single Product Representation Modes

Studies in design research commonly use one product representation mode during preference elicitation tasks. For example, Kelly et al. [10] used bottle silhouettes to study customer shape preferences for a cola bottle. The methodology consisted of using conjoint analysis to assess preferences for bottle shapes. Although a variety of new designs were presented, the result was a shape very similar to a Coca-Cola bottle, which suggests that people may gravitate to familiar shapes. Vehicle silhouettes [4, 6] have been used to assess customers' aesthetic preferences. Lai et al. [4] used a robust design technique to assess the "feeling" quality of a product and used vehicle profiles as a case study. The objective was to design a passenger car that evoked feelings of youthfulness, conveyed family and was useful for outdoors. Reid et al. [6] created a method for quantifying a perception-based attribute called perceived environmental friendliness (PEF). They define perception-based attributes as design characteristics that can influence people's evaluations of the objective qualities of a product, such as safety and weight. The methodology used psychology-based experiment design and methods to measure PEF, as well as to measure preference, familiarity, and the degree to which individuals thought forms were inspired by nature. Table 1 presents a summary of these studies and others that used only one product representation mode. The literature discussed in the next section examines the effects of different representation modes on human judgments.

2.2 Elicitation of Preferences Using Multiple Product Representation Modes

Researchers have studied and compared multiple representation modes in customer or designer perceptions. Artacho-Ramirez et al. [28] studied the effectiveness of different product representations to convey the aesthetics, symbolic value, and semantic information of a pair of speakers. This study showed that as the mode of representation became more sophisticated, there were decreased differences in how people perceived the products. They showed that photographs and 2D virtual images were interpreted differently than a real product. However, when a navigable 3D model was used, perceptions were similar to the real product (in the context of the experiment). Soderman [29] examined how different representations influenced customer understanding of a 1999 Volvo S80. Three product representations were used: black and white hand sketches; virtual reality views of the exterior and interior using a heading mounted display; and an actual model in an illuminated hallway. Soderman found that the degree of realism of the representation influenced certainty about specific attributes of the vehicle and that prior knowledge was

TABLE 1. SUMMARY OF PREVIOUS PREFERENCE ELICITATION WORK AND THE TYPES OF JUDGMENTS STUDIED

Authors and References	Category of Human Judgment	Specifically, subjects were asked to:	Sample stimuli shown (see author's papers for full set)
Kelly et al. [10], Dagher and Petiot [9], Orsborn et al. [5]	Opinion	Indicate their preference	See samples in Figure 1
Macomber and Yang [24]	Opinion	Indicate their preference	
Sylcott et al [20]	Opinion	Indicate their preference	
Lai et al. [4]	Opinion	Rate how well car forms were suitable for family, it conveyed youthfulness and how useful it was for recreation	
Reid et al. [6]	Opinion, Inference	Indicate preference; rate how much a form conveyed environmental friendliness	
MacDonald et al. [25]	Opinion, Inference	Indicate preference; determine the flavor based on bottle shape.	
Tseng et al. [26]	Inferences	Rate how much the stimuli appeared to be rugged, fuel efficient, aerodynamic and sporty	
Sahin et al. [27]	Objective Evaluations	Identify when stimuli looked to be the same size	

substituted for missing visual information. Other studies investigated how customer preferences were influenced by different sketch styles and finishes [24]. The product forms included a cube, phone, and chair. The sketch styles included line drawings and shaded drawings, and the levels of finish included: unfinished, in-progress, finished, and stylized or CAD models. They found that finished sketches of shaded drawings received the highest rankings and were seen as more realistic than the line drawings. Subjects in the study generally saw CAD drawings as "boring," "bland," and "predictable."

Apart from customer preferences, designers' perceptions of different product representations were studied [27]. This work compared how engineering designers and industrial designers (experts and novices for both groups) perceived three product representations: industrial design sketches, CAD models, and physical prototypes. Within these types of representations, the authors also tested two illusions: architrave and irradiation. The product forms examined were simple models of cars. The authors found differences between each group and attributed some of those differences to experience level and certain skills that each discipline provides.

These studies demonstrate that different representation modes can elicit different human judgments, but most of these studies focused primarily on one or two types of human judgments. The next section discusses the types of human judgments typically studied.

2.3 Human Judgments Studied in Design Research

Previous preference elicitation studies have mainly focused on customers' opinions; very few have examined the role of opinions, inferences, and objective evaluations on choice in a given study. Table 1 summarizes the human judgments often examined in the extant literature. Most of the studies provided subjects with visual stimuli.

Previous work by MacDonald et al. [19] discusses three types of inconsistencies in preference elicitation tasks, two of which are relevant for the present study. Comparative inconsistencies occur when two or more groups of individuals respond differently to very similar preference elicitation procedures. Internal inconsistencies occur when individuals' choices in one part of a study contradict or fail to explain their choices in another part of the same study.

In the studies in Table 1, there are models that indicate what visual information people used or did not use to make their decisions, but there is no further exploring of how people make those decisions. Other researchers in engineering [30-33] have used think aloud protocol [34], which requires participants to speak out whatever thoughts come to mind while they are completing a task [34], in order to understand participants' cognitive processes during problem solving. Yet, the resulting verbalized thoughts are always incomplete [34] and could be difficult to analyze. In addition, there are also concerns about using think aloud methods [34] or other methods which ask subjects how they made their decisions: previous work has shown that people's own reasoning about their behavior and choices is not always aligned with what actually determines their behavior and choice [19, 21].

2.4 Eye-Tracking Research

An alternative approach to understanding decisions about products is to use "hard" eye tracker data such as fixation count and fixation duration. An eye-tracker is a device that monitors eye movements, in this case while evaluating images on a computer monitor. Typical measures taken with an eye-tracker are: (1) fixations, eye movements that stabilize the retina over a stationary object of interest; (2) fixation time, a measure of the duration of the fixation; and (3) scan paths, connections between consecutive fixations [35, 36].

The mind-eye hypothesis states that people look at what they are thinking about [22]. Thus effective eye-tracking studies are "goal directed" [23], meaning that eye movement will correspond to a given task. Some limitations of the eye-mind hypothesis do exist in the context of eye-tracking studies for airline instrument panels, in which instance visual information is obtained through peripheral vision [37]. However, though it is possible to be looking at one thing and thinking about something else, the mind-eye hypothesis holds true often enough to indicate what individuals are paying attention to when viewing a given stimuli, such as a web page [38]. Nielsen and Pernice [38] suggest that people fix their gaze on design elements they are concerned about and that the duration of their gaze is a measure of the amount of thought processing.

Eye-tracking studies have been conducted in numerous research areas, including web usability studies [38-40], marketing and advertising studies [41-43], and studies in psychology [23, 44-46]. Gofman et al. [47] found a relationship between the first glance and purchase intentions: a first glance on a font label resulted in a 23% increase in subsequent purchase, as opposed to 8% if the first glance landed elsewhere in the picture area. Eye tracking has also been used as a third type of process tracing method for information acquisition research, in addition to information display boards and computerized process tracing (CPT) [48]. It has similar abilities as Mouselab [49-51], a mouse-based CPT (computerized process tracing, to provide gaze time, sequence, and frequency of users' information acquisition behavior. But eye tracking provides more complete data of what and how subjects acquire information during a task without altering the information processing behavior, compared to Mouselab [48]. Both eye tracking and Mouselab have been used in the study of decision-making processes [49-53]. In addition, a few early stage exploratory eye-tracking studies have been conducted in product design contexts. Hammer and Lengyel [54] examined eye-movement data to identify the product characteristics influential to customers' evaluations. They only present one example of each product that was studied and do not discuss the specific variables that were manipulated. Koivunen et al. [55] sought to understand the visual approaches that people use to develop a first impression of a product by examining scan path data. These limited-scope studies provide documented examples of eye-tracking data use in design research, and suggest the usefulness of more in-depth studies.

2.5 Summary and Research Hypothesis

In all of the discrete choice studies with visual presentations discussed in the previous sections, simplified two-dimensional drawings and renderings were used to represent the products, without investigating whether or not different representations would have produced the same results. The study presented here hypothesizes that judgments, including preferences, will be different for different representation modes of products.

Hypothesis: People form different inferences, opinions, and objective evaluations of products when viewing computer sketches, simplified renderings, realistic renderings, and FSV silhouettes as product representation modes.

Visual representations are often highly simplified in order to constrain the experimental design variables represented in the images to a number that can be tested for statistical significance, with a reasonable number of customer evaluations (as in any statistical study, the more independent variables in the model, the more complex the study design). If eye-tracking data can bolster model findings, it is possible that models could be created with fewer customer evaluation measurements and more finely-detailed product representations.

3 METHOD

In order to test our hypothesis, two surveys were designed using questions that served to elicit opinions, objective evaluations and inferences. The questions used were pre-tested in a pilot study and through informal peer review. The product categories tested included cars and coffee carafes that were each created using a design of experiments discussed below. Each survey used 2 representation modes: Version 1 showed the products as computer sketches and FSV silhouettes; Version 2 showed products as simple and realistic renderings.

3.1 Participants

A total of 62 adults (30 females, 32 males) from Iowa State University (ISU) and the surrounding area participated in the study. Participants were recruited using flyers, Craigslist postings, and email messages to campus list-servers. All participants met the inclusion criteria for participation in studies with an eye-tracker, based on guidelines listed by Pernice and Nielsen [56]. These criteria included the following:

- Have normal to corrected vision (contact lenses and glasses are okay except for bi-focals, tri-focals, layered lenses or regression lenses)
- Do not have glaucoma, cataracts, eye implants, or permanently dilated pupils
- Can read a computer screen and the Web without difficulty
- Do not need a screen reader, screen magnifier or other assistive technology to use the computer and the Web

Participants were randomly assigned to version 1 or version 2 of the survey, to be called “Group 1” and “Group 2,” and compensated with five dollars in cash at the conclusion of the study. A majority of the participants were middle-aged ISU staff. Table 2 summarizes demographic information of the participants in each group.

TABLE 2. SUMMARY OF DEMOGRAPHIC INFORMATION OF PARTICIPANTS IN EACH GROUP (N=31 PER GROUP).

	M	F	18-24	25-35	36-45	46-55	56-65
Group 1	52%	48%	23%	42%	13%	13%	10%
Group 2	52%	48%	29%	32%	23.5%	13%	3%

3.2 Materials

The car stimuli included three-quarter view renderings and front/side perspective views (FSV) of computer-sketched Audi TTs. Three-quarter views were selected based on consultation with another researcher in the field and after conducting multiple pilot studies to select the angle view shown. Future studies could be done to investigate different angles. FSV silhouettes were done this way to ensure that both participants saw near-equivalent visual information. Figure 2a and 2b show samples of the car stimuli from each mode of representation (in this case, showing Car 2 vs. Car 4).

Renderings of cars were created using Maya (Autodesk, Inc., San Rafael, CA), and the FSVs of these renderings were then transported to Adobe Photoshop (Adobe Systems, Inc., San Jose, CA). The variables that were manipulated were the overall vehicle length, vehicle width, distance between the cowl and center of the front tire, height of the headlight, and curvature of the front bumper. A Taguchi design of experiment was used to manipulate the 5 variables with 3 levels each, generating 9 different variations. Four of the nine vehicles were selected and used in the study discussed here, based on results from pilot studies which showed these four produced strong effects. Figure 2 shows examples.

The carafe stimuli included renderings and simulated sketches. The renderings were created using Solid Works (Dassault Systèmes S.A., Concord, MA). The variables that were manipulated were the overall height, the diameter of the base, and the material (aluminum or glass). A full factorial design of experiment was used to generate 8 different variations. Four samples were selected from the set and were used in the experiment. Computer sketches of the four samples were created using Adobe Photoshop. Figures 2c and 2d show examples (in this case, carafe 3 vs. 2). The complete sets of stimuli are shown in the Appendix.

3.3 Experimental Design

Two surveys were developed for a between-subjects experiment using the Qualtrics survey program (www.qualtrics.com). One survey tested judgments on products shown as realistic and simplified renderings (version 2), and the other tested judgments on products shown as computer sketches and FSV silhouettes (version 1). Product pairs were always the same representation mode within each version of the survey and subjects were randomly assigned to each group. The stimuli were presented in choice pairs for all opinion and inference-based questions (see Figure 2) and were shown one at a time for objective-evaluation questions, as shown in Figure 3.All pairs were predetermined (e.g., Carafe 1 and 2 always a pair; Car 2 and 9 always a pair, etc.) and remained consistent for each section of the survey (e.g., Carafe 1 and 2, Car 2 and 9, etc. always shown for opinions and inference-based evaluations). Table 3 provides an overview of how the study questions were organized and presents the stimuli that were shown. Two cars were tested for ordering effects and consistency in preference. Cars 4 and 3, by asking opinion and inference questions while showing the cars in the order 4 vs. 3 and 3 vs. 4.

3.4 Procedure

Subjects completed the survey on a T120 Tobii Eye-tracker (Tobii Technology AB, Danderyd, Sweden) with a sampling rate of 120 Hz and a 17 inch (43.18 cm) TFT monitor with a maximum resolution of 1280 x 1024 pixels. At the start of the session, subjects were seated approximately 27 inches (68.6 cm) away from the eye-tracker and were led through a calibration task. Once the calibration was acceptable, the web-based survey began. The study provided subjects with introductory information, and then followed the survey flow shown in Table 3. For the objective evaluation questions, subjects were specifically told to consider the products’ size based on real-life dimensions. A sliding scale based on units of inches was provided on each screen. Car dimensions were evaluated on a scale from 2 – 200 inches (5.08 – 508 cm) and coffee carafes on a scale from 2 – 10 inches (5.08 – 25.4 cm). The scales for cars and coffee carafes started at 2 inches (5.08 cm) to prevent participants from using the scale itself as a reference. The study concluded with a number of demographic questions and provided subjects an opportunity to give feedback. Each session lasted for approximately 20 minutes.

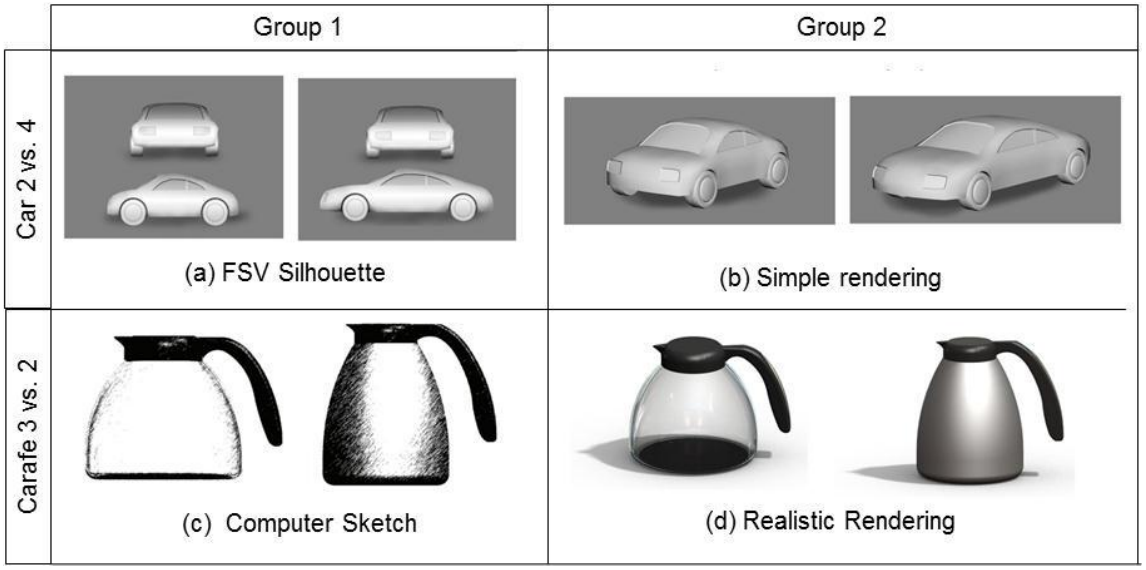


FIGURE 2. SAMPLE PRODUCT PAIRS SHOWN IN EACH GROUP.

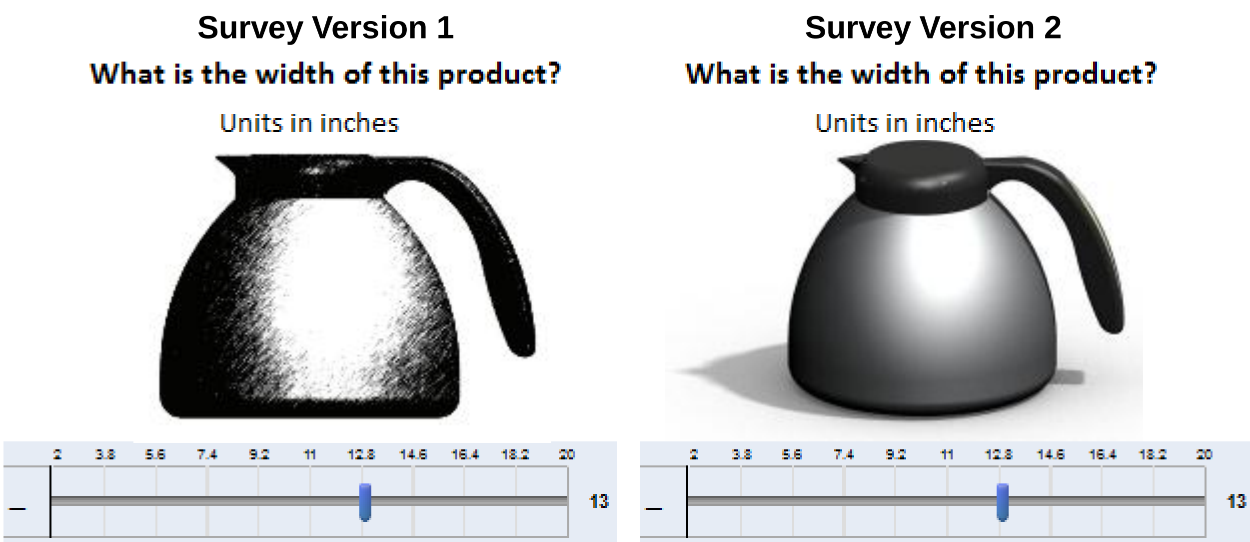


FIGURE 3. EXAMPLE OBJECTIVE EVALUATION QUESTIONS OF COFFEE CARAFE FOR EACH SURVEY VERSION.

TABLE 3. SUMMARY OF SURVEY DESIGN AND STRUCTURE.

Decision Category	**Section order and question type**		**Stimuli Shown**	**Randomization**
Opinions	I	Preference	Cars and coffee carafes	Predetermined pairs of stimuli randomized for each question type
	II	Stylishness		
Objective Evaluations	III	Width	Cars and coffee carafes	Each stimulus randomized for each question type
	IV	Length	Cars	
	V	Height	Coffee carafes	
Inferences	VI	Heat Retention	Coffee carafes	Questions randomized for predetermined pairs of stimuli
		Recyclability	Coffee carafes	
		Fuel Efficiency	Cars	

4 RESULTS

The results of the study showed preference inconsistencies and ordering effects on a behavioral (i.e. self-report) and physiological (i.e. eye-gaze data) level, respectively. In order to examine our hypothesis, the Bradley-Terry logit model for paired evaluations was used to determine the relative strength of preference (SOP) for the paired choice questions [57]. The Bradley-Terry Model states that the probability that option 'A' is chosen over option 'B' can be indicated by the SOP for option 'A' divided by the sum total of preferences for option 'A' or 'B.' Equation (1) shows this relationship:

$$P_{A|B} = \frac{S_A}{(S_A + S_B)} \qquad (1)$$

The rationale is that if the probabilities can be estimated using a logistic model, then the strength of each item can be estimated using Equation 1. Computing the SOP helps to determine the relative rankings of each product since they were shown as pairs but in up to 6 different combinations. This analysis was done for each product pair (see list of pairs in Appendix). Due to modeling constraints, the SOP for product #1 of the 4 products is always set to 1.0 in the analysis. This does not affect the results because the results are based on relative rankings.

4.1 Opinion and Preference Judgments: Inconsistent

A summary of the results from Groups 1 (shaded orange) and 2 (shaded gray) are shown in Table 4. The cells highlighted showed the item most preferred for a given question and/or product representation mode with significance in comparison to at least one other option at $p < 0.05$. For example, in Group 2, Car 3 was most preferred when shown as a simple rendering during preference evaluations (2.40) and stylishness evaluations (3.54). For preference evaluations, the difference was significant when Car 3 was paired with Car 1 (p=0.0007), Car 2 (p=0.009), and Car 4 (p=0.02). A similar trend is also observed for stylishness evaluations within this group. See Table A.1 (b) and (d) for the p-values for preference and stylishness evaluations, respectively. When cars were shown as FSV silhouettes in Group 1, Car 4 was most preferred for stylishness evaluations (2.88) and was statistically significant when paired with Car 1 (p=0.0002) and Car 3 (p=0.02) (see Table A.1b). For preference evaluations, though Car 2 appears to be the most preferred on a numerical basis (1.62), the differences were not significant (see Table A.1a). Similar trends were observed in evaluations of coffee carafes. In Group 1, Carafe 2 was most preferred when shown as a computer sketch during preference (1.41) and stylishness (2.57) evaluations. For preference evaluations, the difference was significant when Carafe 2 was paired with Carafe 3 (p=0.0005) and Carafe 4 (p=0.01), and for stylishness evaluations there was a significant difference for all options it was paired with [see Table A.1 (e) and (g)]. Carafe 2 was also most preferred when shown as a realistic rendering to

TABLE 4. RELATIVE STRENGTH OF PREFERENCE RESULTS BETWEEN GROUPS.

Product	Question	Stimulus No.	Group 1 FSV silhouette	Group 2 Simple renderings
Cars	Preference	1	1	1
		2	1.62	1.10
		3	1.56	2.40
		4	1.37	1.36
	Stylishness	1	1	1
		2	0.88	1.55
		3	1.7	3.54
		4	2.88	2.09
Product	**Question**	**Stimulus No.**	**Computer sketch**	**Realistic renderings**
Coffee Carafes	Preference	1	1	1
		2	1.41	1.81
		3	0.55	1.10
		4	0.72	1.34
	Stylishness	1	1	1
		2	2.57	1.55
		3	0.39	3.54
		4	0.93	2.09

Group 2 (1.81); however, Carafe 3 was most preferred for stylishness evaluations (3.54) within this same group. The statistical differences are highlighted in Table A.1 (f) and (h).

These results show that representation can lead to inconsistency in evaluation across subjects. For cars, more preference and style rating variance is seen for FSV silhouettes than simple renderings, and for carafes, more variance is seen for realistic renderings than computerized sketches. The results also indicate there are comparative preference inconsistencies in the stylishness evaluations of both cars and carafes between groups. For example, Car 4 and Car 3 were selected as most stylish when viewed as FSV silhouettes (2.88) and simple renderings (3.54), respectively; Carafe 2 and Carafe 3 were selected as most stylish when viewed as computer sketches (2.57) and realistic renderings (3.54), respectively.

4.2 Objective Evaluations: Inconsistent

The objective evaluation data showed significant differences between the variances in each group's judgment of size measurements. The classical Levene test was used to compare the variance between the groups. This test helps to identify group differences but does not indicate the exact group contributing to the difference. Comparison of the standard deviations for each product category and dimension measured helped to identify which group had the higher variance. Table 5 summarizes the products and measurements that tested at the $p<0.001$ level for a difference in variance between groups; the group listed in the second column is the one that showed greater variance. There were also differences in the degree of variance of measurements for the height and width of Carafe 1 and 4, and the height of Carafe 3.

TABLE 5. Measurements with greatest degree of variance (p<0.001 = **).

Product	Dimension	Variance Relationship
Car 1	Width	FSV silhouette > Simple renderings**
Car 4	Length	FSV silhouette> Simple renderings**
Car 3	Length	FSV silhouette>Simple renderings**
Carafe 1	Width	Computer sketch > Realistic renderings**
Carafe 1	Height	Computer sketch> Realistic renderings**
Carafe 4	Width	Realistic renderings > Computer sketch**
Carafe 4	Height	Realistic renderings> Computer sketch**
Carafe 3	Height	Realistic renderings> Computer sketch**

4.3 Inference Judgments: Consistent

Evaluations of inference-based questions were the same between groups for every question and product category regardless of product representation mode. People perceived that glass carafes are more recyclable and that metal carafes retain heat better. When carafes of the same material were presented together (i.e. both glass or metal), approximately 68% chose the carafe that appeared to be short and stout (Carafe 1 or Carafe 3) as being able to retain heat better, and 60% perceived the carafe that was tall and narrow (Carafe 2 or 4) to be more recyclable. Results for the inference-based questions about cars were not surprising: the smaller the car, the more fuel efficient it was perceived to be. Previous work shows that people often use heuristics in making choices [58], and this appears to be consistent between product representations.

4.4 Eye-Tracking Results – Opinion Judgments

Eye-tracking data were analyzed to examine any correlations that could help explain the trends observed in the behavioral data and to see if there were differences between groups. We focus the analysis on fixation time because it can be objectively quantified. Participants simply scanned back and forth to make a choice as shown, and the total time spent viewing each option was ascertained. Scan path data are not analyzed because the nature of paired choice questions did not show unique patterns (See Figure 4). However, scan path can simply be analyzed by looking at the sequence of fixations (e.g., fixation 1, fixation 2, etc.) if that is important to researchers and if the experimental design included a manipulation that could influence the scan path [35]. The results show differences in fixation times spent on each option between groups.

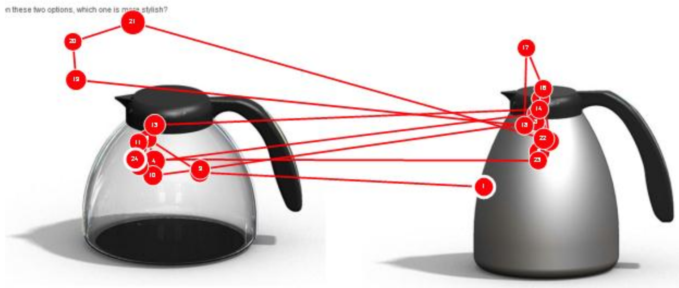


FIGURE 4. SAMPLE PAIRED QUESTION SHOWING SCAN PATH DATA.

The eye-tracking data selected for analysis were those associated with questions and products that showed the greatest strength of preference as shown in Table 4 (shaded items). A Welch two-sample t-test was conducted comparing the fixation times spent on each option for a given product and representation mode. In other words, the results answer the question: is there a difference between the amount of time spent viewing I vs. J when the question is shown in representation mode 1 vs. 2? In the case of coffee carafes, people generally spent more time viewing the pairs of options for preference evaluations when the carafes were shown as realistic renderings. For example, when evaluating Carafes 2 vs. 4, there was a difference in the time spent viewing Option 1 (Carafe 2) when shown as a computer sketch (M=276 ms; SD=71 ms) versus a realistic rendering (M=325 ms; SD=90 ms) (p<0.05). Similarly, when viewing Option 2 (Carafe 4), people in the computer sketch group spent less time (M=252 ms; SD=72 ms) than those viewing it as a realistic rendering (M=347 ms; SD=87ms) (p<0.001). This trend can be seen for a majority of the questions involving coffee carafes. For cars, this difference was only significant for stylishness evaluations of Cars 4 vs. 3, particularly option B (Car 3); people spent more time viewing option B when shown as a simple rendering (M=307 ms; SD=187 ms) versus a FSV silhouette (M=247; SD=167 ms) (p<0.001).

Mean fixation times are consistent with the strength of preference as shown in Figure 5 and 6, respectively (next page). In Figure 5, it can be seen that people spent more time looking at Carafe 2, for which subjects had strong preference, than alternatives it was paired with. Figure 6 shows that people spent more time looking at Car 3, for which subjects had strong preference, than the alternative. In both cases, the differences were not significant.

5 DISCUSSION

The results demonstrate that people's preferences and object evaluations, analyzed as groups, have varying degrees of consistency across visual representation style. In some cases, the products that subjects consistently showed the strongest favorable opinions for are the same ones that showed less variance in people's objective evaluations. For example, Table 4

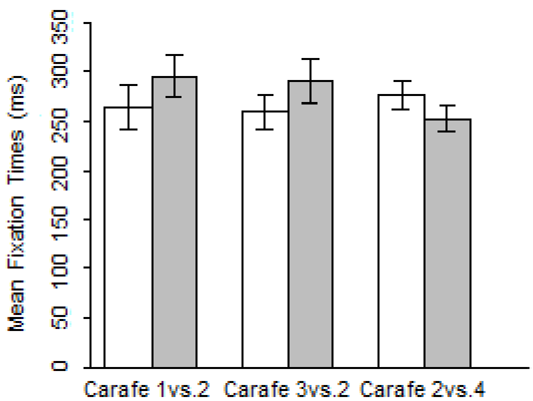


FIGURE 5. COMPARISON OF THE MEAN FIXATION TIMES FOR PREFERENCE EVALUATIONS OF COFFEE CARAFES SHOWN AS COMPUTER SKETCHES. IN EACH PAIR, CARAFE LISTED ON THE LEFT WAS SHOWN ON THE LEFT.

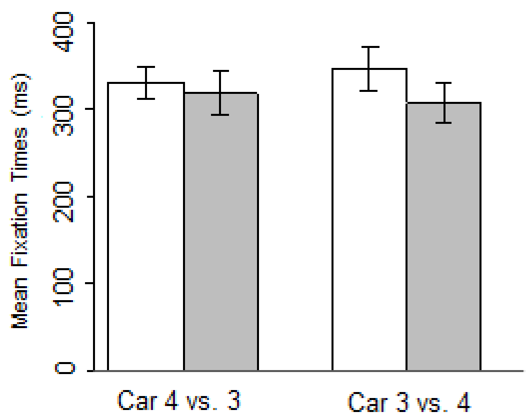


FIGURE 6. COMPARISON OF THE MEAN FIXATION TIMES FOR PREFERENCE EVALUATIONS OF CARS SHOWN AS SIMPLE RENDERINGS. IN EACH PAIR, CAR LISTED ON THE LEFT WAS SHOWN ON THE LEFT.

shows that Car 3 was most preferred and evaluated as most stylish when shown as a simple rendering, and Table 5 shows that when Car 3 is shown as a simple rendering, there was less variance compared to FSV silhouettes. Similarly, Carafe 2 was the most preferred when shown as a realistic rendering and computer sketch; however, Table 5 does not identify significant differences in the variance of the objective evaluations for Carafe 2. These results indicate that objective evaluations, such as ability to accurately and easily discern product size, can implicitly influence the strength and consistency of people's opinions and preferences. Therefore, the authors tentatively recommend that when collecting opinion information, such as preference or aesthetic evaluation, design researchers first clarify with subjects the basic physical dimensions and characteristics of the products in pre-experiment activities or discussion. An alternative approach would be to give such information in the visual stimuli directly. However, in the authors' pretests for this study, subjects had difficulty interpreting such information. Further, complications can arise—highlighting dimensions of products may cause subjects to fixate on this information and/or inflate the importance of it in their choices. One solution is to calibrate subjects by exposing them to real-world forms before testing evaluations of 2D computer screen representations. This approach will cause subjects to anchor judgments to these forms, but this can be accounted for in results analysis.

We suspect that some product features are easier to detect in certain visual representations. This presents an alternate explanation for the variance in the objective evaluations questions discussed in Table 5.

Inference-based questions, such as inferring fuel efficiency or heat retention, showed the most consistent trends of all the decision tasks and across product representations shown in the experiment. Inference questions require taking information from visual representations and analyzing it using evaluation criteria and rules to draw conclusions; the findings suggest that these criteria are durable across visualization form. This is useful for researchers who work to identify, for example, car forms that look "sustainable" or "safe." According to the results of this research, it is not necessary to have detailed visual representations in order to perform such studies. In engineering design, it appears that various product representations may be suitable for inference-based questions. Additional product categories and question types should be tested to verify this conclusion.

Analyzing fixation times from the eye-tracking data confirmed the results of the aggregated preference data shown in Table 4. The authors further examined gaze data for individual subjects to provide insights into heterogeneous aspects of individual, as recommended in [59]. Subjects' decision patterns, as interpreted from fixation time data, can be classified as:

1) *Subjects choose the option associated with the longer aggregate fixation time*. This can be interpreted as a verification process, in which subjects carefully analyze their preferred option before making a choice. It may be related to confirmation bias, a bias in which people look for rationale to support a decision they have already made [60].

2) *Subjects choose the option associated with the shorter aggregate fixation time, the opposite of the above pattern*. This can be interpreted as a process-of-elimination. It may be related to difficult decisions that presented very similar options. For example, in preference decisions between cars 4 and 3, both cars are of the same length, but of a different width. In the simple renderings group, this may have required greater levels of discrimination. Approximately 40-60% of participants use this viewing strategy, depending on the question being asked and representation mode.

A general trend observed was that viewing strategy 1 was more prominent when the most preferred product was shown as at left on the screen (for example 60% used this strategy for FSV silhouettes of Car 4 vs. 3), and strategy 2 when the preferred product was shown as at right on the screen (63%

used this strategy for FSV silhouettes of Cars 3 vs. 4). This was true for preference evaluations of coffee carafes shown as computer sketches and realistic renderings (for 2 pairs only) and stylishness evaluations of cars shown as both FSV silhouettes and simple renderings. Note these are observational findings only and have not been statistically tested.

6 CONCLUSION

Product representation matters when measuring consumer preferences, opinions, and objective evaluations. The results of the study showed that people were consistent in their evaluations of preference and styling for coffee carafes shown as computer sketches and for cars shown as renderings. Future studies could create classifications to guide design researchers toward the product representation most suitable for various product categories. This experiment found that computer sketches of carafes provide enough information for subjects to respond consistently, a result consistent with previous findings that sketches are suitable for eliciting consumer preferences [24]., but the results show that showing renderings generated more consistent consumer preferences, suggesting that researchers should consider product representation carefully. The results of the inference-based questions showed that product representation did not matter, as people were consistent in their choices on all questions between groups.

Future studies could test other representation modes, including hand sketches and 3D animations. A suggestion that requires further experimentation is to calibrate subjects by exposing them to real-world forms before testing evaluations of 2D computer screen representations. This approach will cause subjects to anchor judgments to these forms, but this can be accounted for in the results analysis.

An eye-tracker provided valuable insights that otherwise could not have been obtained from a traditional survey. In addition to providing information on the fixation patterns people use during decision making, it helped to identify the heterogeneity that exists between individuals and the importance of it in their choices. The fixation data revealed the impact of ordering effects in the case with cars previously discussed.

Ordering effects (the impact of word order in survey questions) have been studied extensively in psychology literature, but very few studies focus on ordering effects in the visual domain. Future work could involve how ordering effects might inform design researchers regarding consumer judgments: product representation and the order of alternatives may have an effect on judgments. Future studies can also investigate the choice protocol using eye-tracking data, as previous studies have indentified differences in preference in comparative vs. non-comparative questions [61].

Limitations of this work are that factors such as prior knowledge and the use of peripheral vision may play a role in a person's decision-making process that cannot be detected using an eye-tracker. It is suggested that eye-trackers be used to identify trends and/or correlations with behavioral data using fixation times or fixation counts and to design experiments and stimuli carefully if scan path data are to be analyzed.

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http://www.useit.com/eyetracking/methodology/eyetracking-methodology.pdf (Last Accessed 02/20/12).
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APPENDIX

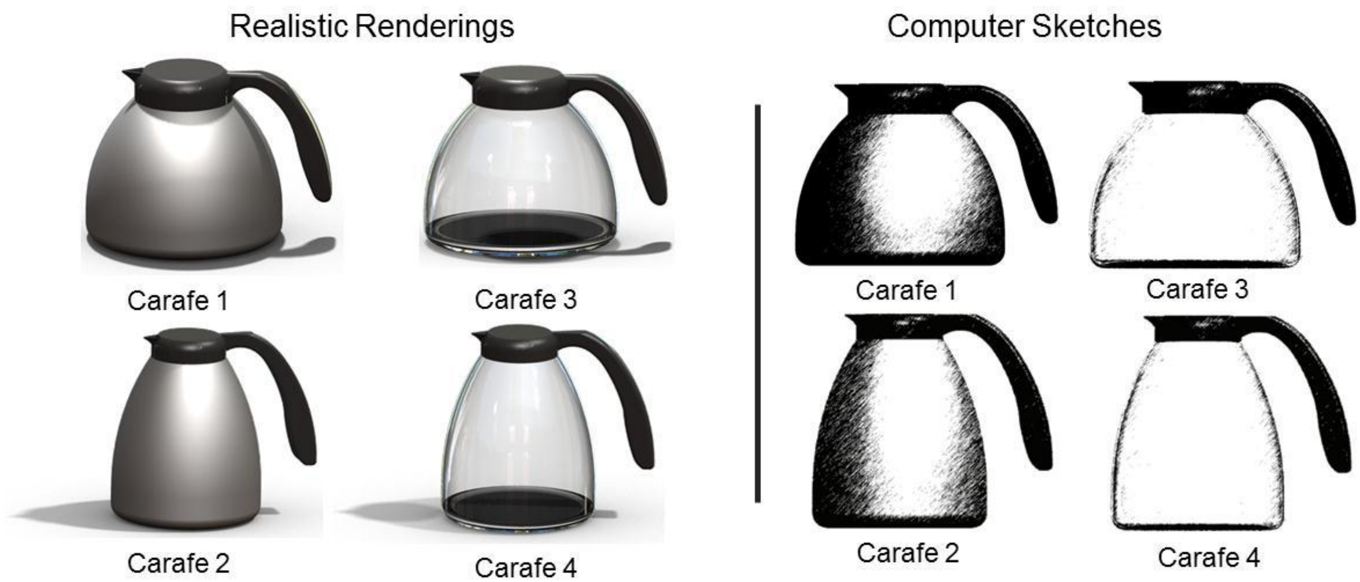

FIGURE A.1. REALISTIC RENDERINGS (LEFT) AND COMPUTER SKETCHES (RIGHT) OF COFFEE CARAFES USED IN THE STUDY.

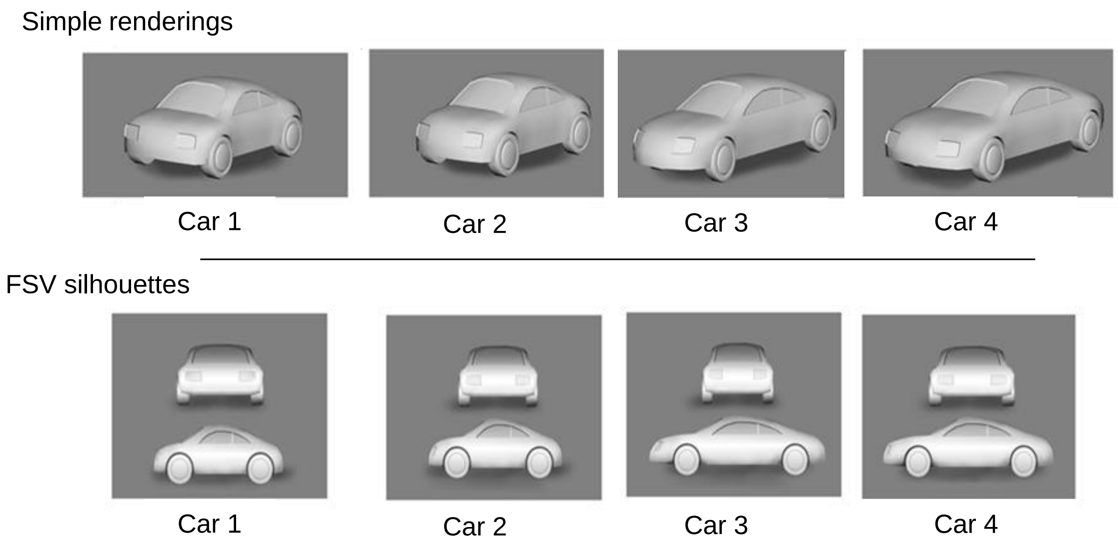

FIGURE A.2. SIMPLE RENDERINGS (TOP) AND FSV SILHOUETTES (BOTTOM) OF CARS USED IN THE STUDY.

TABLE A.1. DATA TABLE LISTING P-VALUES ASSOCIATED WITH STRENGTH OF PREFERENCE COMPARISONS BETWEEN PRODUCTS SHOWN TO GROUP 1 AND GROUP 2. PAIRS LABELED "N/A" WERE NOT PRESENTED IN THE STUDY. SIGNIFICANCE LEVELS: (*) p<0.05; (**) p<0.01); (***) p<0.001.

Group 1 — (a) FSV silhouettes — Preference Evaluations

	Car 1	Car 2	Car 3	Car 4
Car 1	x	0.09	0.07	0.23
Car 2		x	0.88	N/A
Car 3			x	0.58
Car 4				x

Group 2 — (b) Simple Renderings — Preference Evaluations

	Car 1	Car 2	Car 3	Car 4
Car 1	x	0.74	0.0007***	0.26
Car 2		x	0.009**	N/A
Car 3			x	0.02*
Car 4				x

Group 1 — (c) Stylishness Evaluations

	Car 1	Car 2	Car 3	Car 4
Car 1	x	0.64	0.04*	0.002**
Car 2		x	0.02*	N/A
Car 3			x	0.02
Car 4				x

Group 2 — (d) Stylishness Evaluations

	Car 1	Car 2	Car 3	Car 4
Car 1	x	0.14	3.80E-06 ***	0.01**
Car 2		x	0.007**	N/A
Car 3			x	0.02*
Car 4				x

Group 1 — (e) Computer Sketches — Preference Evaluations

	Carafe 1	Carafe 2	Carafe 3	Carafe 4
Carafe 1	x	0.19	0.02*	0.19
Carafe 2		x	0.0005***	0.01*
Carafe 3			x	0.3
Carafe 4				x

Group 2 — (f) Realistic Renderings — Preference Evaluations

	Carafe 1	Carafe 2	Carafe 3	Carafe 4
Carafe 1	x	0.02*	0.7	0.25
Carafe 2		x	0.06	0.25
Carafe 3			x	0.44
Carafe 4				x

Group 1 — (g) Stylishness Evaluations

	Carafe 1	Carafe 2	Carafe 3	Carafe 4
Carafe 1	x	0.001***	0.001***	0.79
Carafe 2		x	3.70E-09 ***	0.0004***
Carafe 3			x	0.002**
Carafe 4				x

Group 2 — (h) Stylishness Evaluations

	Carafe 1	Carafe 2	Carafe 3	Carafe 4
Carafe 1	x	0.14	3.80E-06 ***	0.01**
Carafe 2		x	0.007**	0.4
Carafe 3			x	0.02*
Carafe 4				x

TABLE A.2. LIST OF PAIRS SHOWN IN OPINIONS AND INFERENCE BASED QUESTIONS.

Pairs of Products Shown	
Coffee Carafes	Cars
1 vs. 2	2 vs. 1
1 vs. 3	3 vs. 1
1 vs. 4	1 vs. 4
3 vs. 2	2 vs. 3
3 vs. 4	3 vs. 4
2 vs. 4	4 vs. 3