Impact of Product Design Representation on Customer Judgment

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When researchers ask customers to judge product form during the design process, they often manipulate simplified product representations, such as silhouettes and sketches, to gather information on which designs customers prefer. Using simplified forms, as opposed to detailed realistic models, make the analysis of gathered information tractable and also allows the researcher to guide customer focus. The theory of constructed preferences from psychology suggests that the product form presented will influence customer judgments. This paper presents a study in which subjects were shown computer sketches, front/side view silhouettes, simplified renderings, and realistic renderings to test the extent to which a variety of judgments including opinions, objective evaluations, and inferences are affected by form presentation. Results show a variety of phenomena including preference inconsistencies and ordering effects that differed across type of judgment. For example, while inferences were consistent across form, opinions were not. An eye tracker identified differences in viewing strategies while making decisions. Associated data, such as fixation times and fixation counts, provide additional insight into findings. [DOI: 10.1115/1.4024724]

1 Introduction

Product form affects customer product purchase and use judgments; form communicates information about product functionality, appeals to customers' aesthetic and emotional preferences, and suggests a categorization or class for a product, among other impacts [1–3]. Form also impacts engineering design decisions [4–8], and thus design researchers have leveraged experimental survey tools from psychology and marketing to learn about the relationship between product form and customer judgment [8–11]. Research on product form uses various representations of products to study customer decisions, as shown in Table 1. These representations are different in appearance from final products and also different from one another. These simplifications occur in order to make analysis and form manipulations computationally manageable, as well as to focus subjects' attention on design attributes of interest to the study.

The theory of constructed preferences from psychology has demonstrated that the context of a decision affects the decision outcome, as preferences and judgments do not pre-exist in the brain, but rather are formed in response to a decision stimulus [10,22]. MacDonald et al. [10] discusses types inconsistencies found in design research preference elicitation tasks. It is expected that the representation of product form in experimental surveys will have an effect on customer judgment, and research, to be discussed later, has demonstrated this for certain types of survey questions. The goal of this paper is to test a variety of types of judgments and evaluate the consistency of judgment across a variety of form presentations.

A review of design experiments involving customer evaluation of product form, detailed in Secs. 2.1 and 2.2, identified that these experiments employ three categories of judgments as grouped by the information that is contained in the form's image (full information versus partial information) and the information the survey respondent/customer is asked to provide (no correct answer exists versus correct answer exists), as shown in Fig. 1. These categorizations were identified to structure the experiments presented in this paper, of course, other categorizations exist. The arrows in the figure signify that objective evaluations and inferences can influence opinions. While the hierarchy of the categories is not considered to a great extent in this paper, it is difficult to imagine that a customer would have an overall opinion about a product without also having associated objective evaluations and/or inferences.

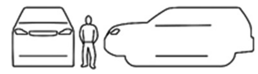
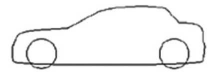
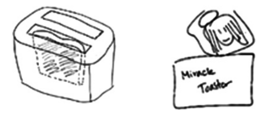
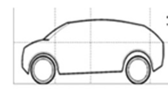
Opinion refers to product evaluations for which there is no right or wrong answer and that can vary from person to person (How creative is this design? Which design do you prefer?). Using this definition, preference evaluations are a subset of opinion evaluations. Preferences are personal, partially subjective evaluations. A person forms an opinion of each product option in the set (though this is not done for very large choice sets, where screening rules are used instead), and then forms an overall opinion of which is the best option for them. The person then makes a choice based on this opinion. *Objective evaluation* refers to product evaluations for which there is a right or wrong answer and the information to make the judgment is provided to the customer (Which product is longer? Which of the designs is symmetrical?). *Inference* refers to product evaluations for which there is a right or wrong answer and the information to make the judgment is not provided or is incompletely provided to the customer (Which design is the safest? How sustainable is this design?).

All three types of judgments are important for the study of design and are interrelated. For example, perhaps the most complex judgment that design researchers ask customers to make, "Which design do you prefer?," is an opinion that may involve the synthesis of objective evaluations, inferences, and other opinions, as shown in Table 1. Inferences, objective evaluations and sometimes verbal facts/anecdotal information have the ability to influence opinions [23,24] of visual forms [4,17]. For example, MacDonald et al. [9] presented a statistical analysis method to identify inferences between "sentinel" and "crux" attributes as presented in choice experiments, finding that when towels had quilted lines, respondents inferred that they were more absorbent. Thus, studying different questions categories, especially those that may influence opinions, is important for this research.

We conducted two experiments: one using front/side view (FSV) silhouettes and computer sketches and the other using simplified renderings and realistic renderings—both focusing on cars

Contributed by the Design Theory and Methodology Committee of ASME for publication in the Journal of Mechanical Design. Manuscript received August 4, 2012; final manuscript received May 16, 2013; published online July 15, 2013. Assoc. Editor: Jonathan Cagan.

Table 1 Examples of product representations and judgment questions in design research studies [4,6,11–21]

Authors and References	Judgment category	Question types	Sample stimuli
Kelly et al. [6]	Opinion	Indicate preference	
Dasher and Petiot [12]	Opinion	Indicate preference	
Orsborn et al. [13]	Opinion	Indicate preference	
Macomber and Yang [14]	Opinion	Indicate preference	
Sylcott et al. [11]	Opinion	Indicate preference	
Kudrowitz and Wallace [15]	Opinion	Evaluate the creativity, novelty, usefulness, and clarity of to aster designs	
Lai et al. [16]	Opinion	Rate how well car forms were suitable for family, they conveyed youthfulness and how useful they were for recreation	
Reid et al. [17]	Opinion, Inference	Indicate preference; rate how much a form conveyed environmental friendliness	
MacDonald et al. [4]	Opinion, Inference	Indicate preference; determine the flavor based on bottle shape.	
Tseng et al. [18]	Opinion, Inference	Rate how much the stimuli appeared to be rugged, fuel efficient, aerodynamic and sporty	
Sahinet al. [19]	Objective, Evaluations	Identify when stimuli looked to be the same size	
Artacho-Ramirez et al. [20]	Opinion	Rate from total agree to total disagree for the semantic descriptions of the stimuli	
Sodennan [21]	Opinion	Rate whether it is easy or difficult to evaluate different aspects of the products from the given product representation	

and coffee carafes—and found that product representation mode had an effect on opinions and objective evaluations, but did not affect inferences. One of the challenges in learning about customer judgments is that people cannot reliably explain why or how they made a decision [25]. In this study, we collect eye-gaze data to add insight to the behavioral results. The findings indicate that product representation mode matters in judgment, and that design researchers and practitioners should consider the impact of representation mode when eliciting and analyzing customer judgments. The remainder of this paper proceeds as follows: Sec. 2 discusses the relevant literature and our research hypothesis. Sections 3 and 4 present the methods and results. Sections 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. [6] used bottle silhouettes to study

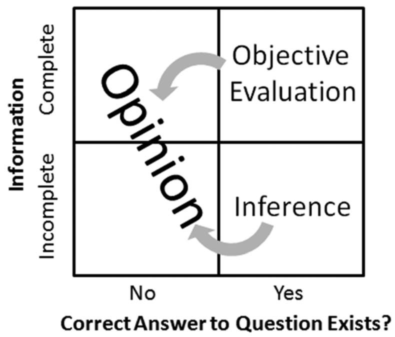


Fig. 1 Judgment categorization used in experimental design

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 [16,17] have been used to assess customers' aesthetic preferences. Lai et al. [16] 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. [17] 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. In these studies, single representation modes were used during preference elicitation tasks. None of the studies indicated or tested whether or not the selected representation mode was sufficient for garnering consistent evaluations from the subjects in their studies. In addition, these studies focused on primarily on one or two categories of evaluations (i.e., opinions or opinions/inferences), and very few examine all three, which is the topic of this paper.

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. [20] 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 [21] 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 substituted for missing visual information. Other studies investigated how customer preferences were influenced by different sketch styles and finishes [14]. 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 computer aided design (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 have been studied by Sahin et al. [19]. 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 prior studies provide some indication that different product representations influence people's evaluations of products. However, it is unknown how generalizable these results are due to the variety of methods used for altering the appearance of the stimuli and the different experimental approaches used (some controlled and others less controlled). In addition, most of these studies focused on opinions and/or objective evaluations and did not examine a variety of question categories.

2.3 Eye Tracking Research. Eye tracking data offers a new way to gather data regarding decisions about visual forms. 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 [26,27].

The mind-eye hypothesis states that people look at what they are thinking about [28]. Thus effective eye tracking studies are "goal directed" [29], 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 visual information is obtained through peripheral vision [30]. 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 [31]. Nielsen and Pernice [31] 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, but does not specify the exact thought processes.

Eye tracking studies have been conducted in numerous research areas, including web usability studies [31–33], marketing and advertising studies [34–36], and studies in psychology [29,37–39]. Gofman et al. [40] 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) [41]. Eye tracking and Mouselab have some similar abilities [41–44]. This mouse-based CPT software system "hides" information (product information) in a matrix of boxes (or cards) displayed on the computer screen. Participants move the mouse to a particular box to reveal the information in the box. Once the mouse is moved away from the box, the information will be

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%

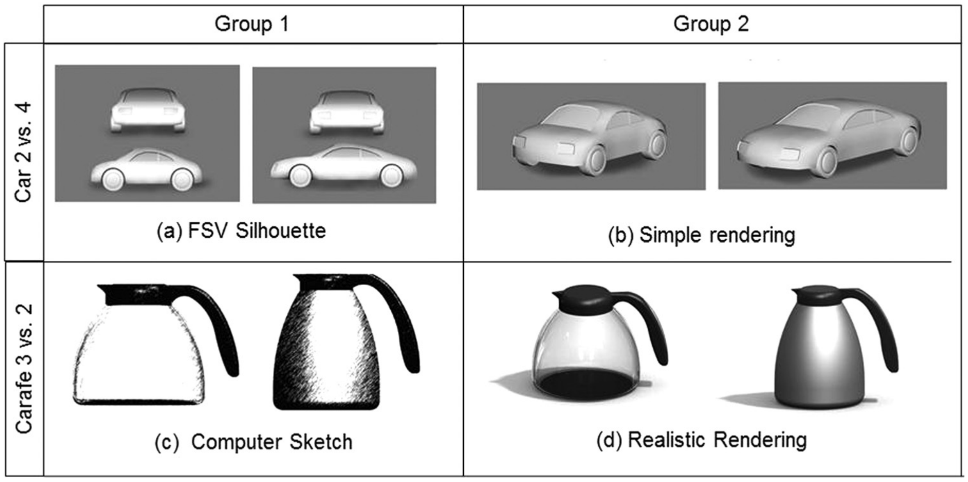


Fig. 2 Sample product pairs shown in each group

Table 3 Attributes and levels for cars

Attributes/Levels	1	2	3
Windshield/Cowl position (in.)	Original	+4 in.	+8 in
Overall width (in.)	Original	−8 in.	+8 in
Overall length (ft)	Original	−2 ft	+2 ft
Headlight height (x,y position) (see Fig. 9)	Original	0.5, 1	1, 2
Curvature of bumper (see Fig. 10)	Original	Pos 2	Pos 3

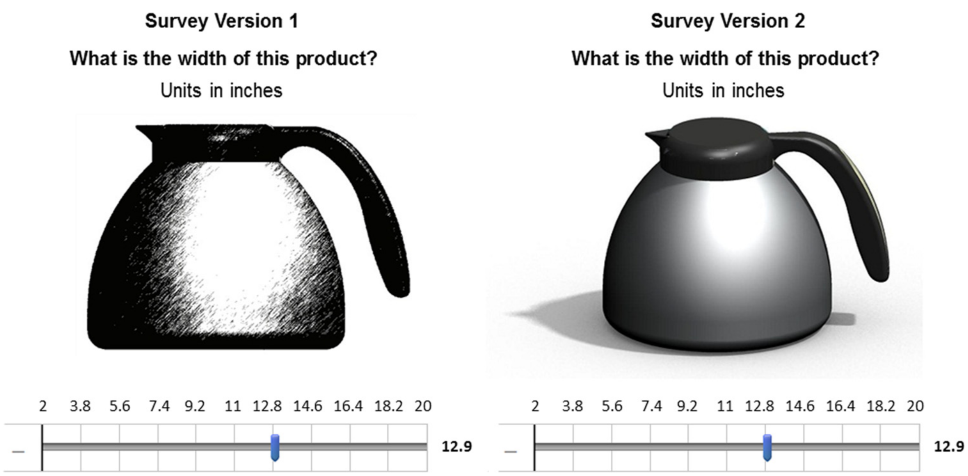


Fig. 3 Example objective evaluation questions of coffee carafe for each survey version

hidden again. The software monitors the information acquisition processes by recording several metrics [41,42,44]. Compared to Mouselab, eye tracking uses a more natural way to obtain data related to the information acquisition behavior of people [41]. Both eye tracking and Mouselab have been used in the study of decision-making processes [42–46].

A few early-stage exploratory eye tracking studies have been conducted in product design contexts. Hammer and Lengyel [47] 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. [48] 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

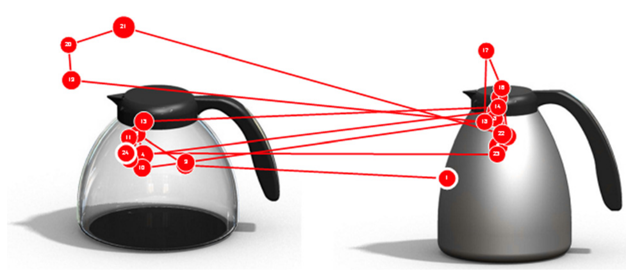


Fig. 4 Sample paired question showing scan path data

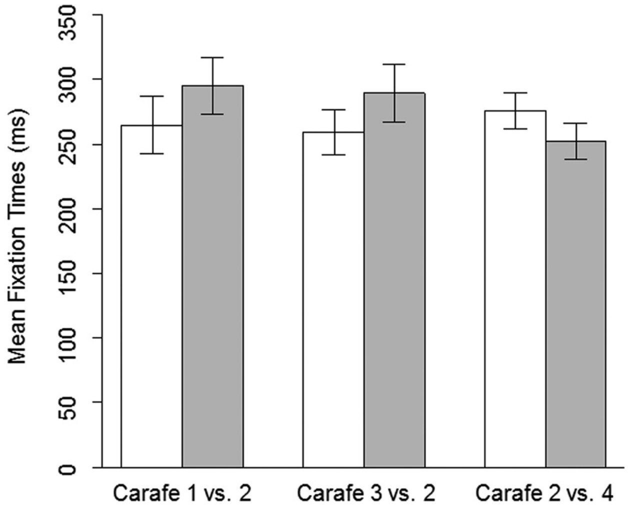


Fig. 5 Comparison of mean fixation times for preference evaluations, coffee carafe computer sketches. Carafe shown on left in Survey is Displayed left

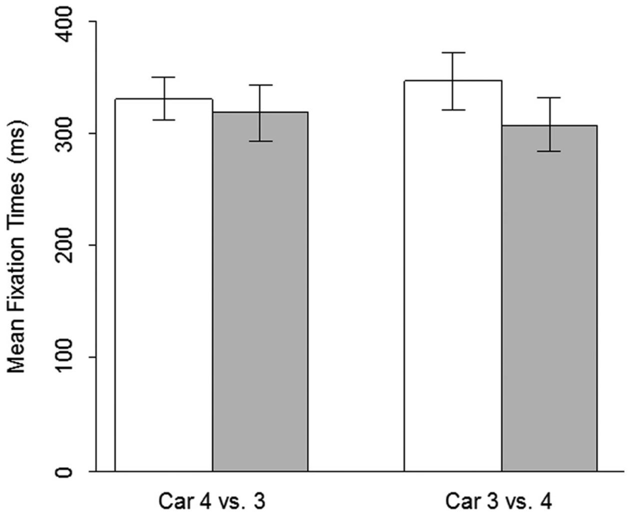


Fig. 6 Comparison of mean fixation times for preference evaluations, cars simple renderings. Car shown on Left in Survey is Displayed left

tracking data use in design research, and suggest the usefulness of more in-depth studies.

2.4 Summary and Research Hypothesis. We hypothesize that judgments of product designs will be different for different visual 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.

Testing this hypothesis can improve the design of future product design research experiments. 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). Findings on how different types of judgments are influenced by different types of simplifications will be a useful resource when evaluating the outcomes of design research customer experiments. 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 pretested 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 on the next page. 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 [49]. These criteria included the following:

- Have normal to corrected vision (contact lenses and glasses are okay except for bifocals, trifocals, layered lenses, or regression lenses).

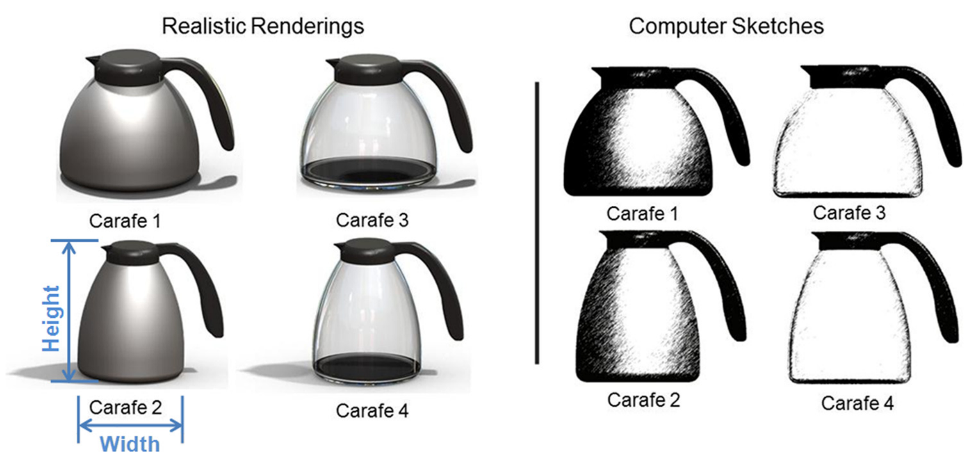


Fig. 7 Realistic renderings (left) and computer sketches (right) of coffee carafes, manipulated dimensions noted as "height" and "width"

Table 4 Attributes and levels for coffee carafes

Attributes/Levels	1	2
Height (in.)	7.3 in.	10.95 in.
Width (in.)	7.0 in.	10.00 in.
Material	Glass	Aluminum

Table 5 List of pairs shown in opinion and inference questions

Pairs of products shown	
Coffee carafes	Cars
1 versus 2	2 versus 1
1 versus 3	3 versus 1
1 versus 4	1 versus 4
3 versus 2	2 versus 3
3 versus 4	3 versus 4
2 versus 4	4 versus 3

- 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 (Group 1) or version 2 (Group 2) of the survey 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.

3.2 Materials. The car stimuli included three-quarter view renderings and front/side perspective views (FSV) of computer-sketched 2008 Audi TTs. It was chosen because it was a standard looking vehicle and it was easy for the graphic designer to model, and change the proportions on while still looking normal. Secondary impacts should be minimal because it was only car used in the experiment and no purchase or price questions were asked, and it was only compared to manipulations of itself. Three-quarter views were selected based on consultation with another researcher in the field and after conducting multiple pilot studies to select the angle 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. Figures 2(*a*) and 2(*b*) show samples of the car stimuli from each mode of representation (in this case, showing Car 2 versus Car 4).

Renderings of cars were created using Maya (Autodesk, Inc., San Rafael, CA). and a model imported from a library of pre-existing models. 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 five variables with three levels each, generating nine different variations. The three levels selected were based on values that would help to create forms with enough variation to make for engaging questions, as tested in pilot studies. Table 3 along with Figs. 3–6 provide visuals and information about the manipulations, some of which were qualitative and quantitative. 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 width or diameter of the base, and the material (aluminum or glass) (See Fig. 7 and Table 4 for details). A full factorial design of experiment was used to generate eight 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 2(*c*) and 2(*d*) show examples (in this case, carafe 3 versus 2). The complete set of stimuli is shown in Figures 7 and 8.

3.3 Experimental Design. Two surveys were developed for a between-subjects experiment using the Qualtrics survey program.[1] 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). Both surveys showed products in choice pairs. Showing only two products at a time makes it easier to collect and analyze eye tracking data, and allows for the analysis of preference reversals [50,51] and ordering effects [52]. 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 Fig. 2) and were shown one at a time for objective-evaluation questions, as shown in Fig. 3. All pairs were predetermined (e.g., Carafes 1 and 2 always a pair; Cars 2 and 9 always a pair, etc.) and remained consistent for each section of the survey (e.g., Carafes 1 and 2, Cars 2 and 9, etc. always shown for opinions and inference-based evaluations). Two pilot studies tested evaluation questions and product visuals to hone clarity of wording, and selection of product form manipulations for inclusion. For example, a pair of product-form manipulations were initially judged to be too similar, so only one form from the pair was included in the final study. Table 6 provides an overview of the study questions, how they were organized and presents the stimuli that were shown. Two cars (Cars 4 and 3) were tested for ordering effects and consistency in judgment by asking opinion and inference questions while showing the cars in the order 4 versus 3 and 3 versus 4. To manage survey length, this common effect was not also tested for carafes.

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 in. (43.18 cm) thin-film transistor (TFT) monitor with a maximum resolution of 1280×1024 pixels. At the start of the session, subjects were seated approximately 27 in. (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 6. For the objective evaluation questions, subjects were specifically told to consider the product's 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 to 200 in. (5.08 – 508 cm) and coffee carafes on a scale from 2 to 10 in. (5.08–25.4 cm). The scales started at 2 in. (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 min.

4 Results

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 [53]. The Bradley-Terry Model states that the probability that option

[1] www.qualtrics.com

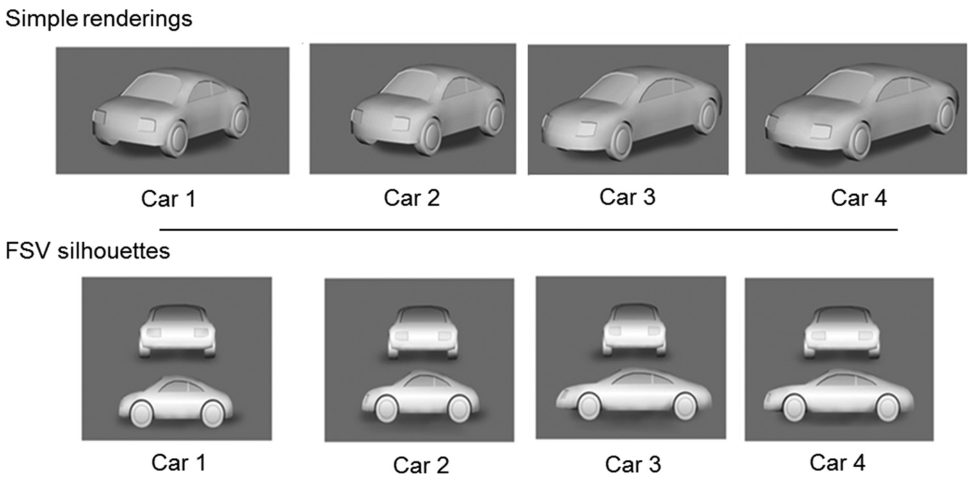


Fig. 8 Simple renderings (top) and FSV silhouettes (bottom) of cars used in the study

Table 6 Summary of survey design and structure

Decision category	Section order	Question type and sample questions		Stimuli shown	Randomization
Opinions	I	Preference	Given these two options, which one do you prefer?	Cars and coffee carafes	Predetermined pairs of stimuli randomized for each question type
	II	Stylishness	Given these two options, which one is more stylish?		
Objective Evaluations	III	Width	What is the width of this product?	Cars and coffee carafes	Each stimulus randomized for each question type
	IV	Length	What is the length of this product?	Cars	
	V	Height	What is the height of this product?	Coffee carafes	
Inferences	VI	Heat retention	Given these two options, which one retains heat better?	Coffee carafes	Questions randomized for predetermined pairs of stimuli
		Recyclability	Given these two options, which one is more recyclable?	Coffee carafes	
		Fuel efficiency	Given these two options, which one is more fuel efficient?	Cars	

Table 7 Relative strength of preference results between groups

			Group 1	Group 2
Product	Question	Stimulus Nos.	FSV silhouette	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 Nos.	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

"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". Below equation shows this relationship

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

The rationale is that if the probabilities can be estimated using a logistic model, then the strength of each item can be estimated using Eq. (1). Computing the SOP determines the relative rankings of each product. Relative rankings are used as the products were presented in pairs. This analysis was done for each product pair (see list of pairs in Table 5). Due to modeling constraints, the

Table 8 Strength of preference comparisons between products shown to Group 1 and Group 2. Pairs labeled "N/A" were not presented in the study.

Group 1						Group 2					
(a)		FSV silhouettes				(b)		Simple renderings			
Preference Evaluations		Car 1	Car 2	Car 3	Car 4	Preference Evaluations		Car 1	Car 2	Car 3	Car 4
	Car 1	x	0.09	0.07	0.23		Car 1	x	0.74	0.0007***	0.26
	Car 2	—	x	0.88	N/A		Car 2	—	x	0.009**	N/A
	Car 3	—	—	x	0.58		Car 3	—	—	x	0.02*
	Car 4	—	—	—	X		Car 4	—	—	—	x
(c)						(d)					
Stylishness Evaluations		Car 1	Car 2	Car 3	Car 4	Stylishness Evaluations		Car 1	Car 2	Car 3	Car 4
	Car 1	x	0.64	0.04*	0.002**		Car 1	x	0.14	3.80×10^{-06}***	0.01**
	Car 2	—	x	0.02*	N/A		Car 2	—	x	0.007**	N/A
	Car 3	—	—	x	0.02		Car 3	—	—	x	0.02*
	Car 4	—	—	—	x		Car 4	—	—	—	x
(e)		Computer sketches				(f)		Realistic renderings			
Preference Evaluations		Carafe 1	Carafe 2	Carafe 3	Carafe 4	Preference Evaluations		Carafe 1	Carafe 2	Carafe 3	Carafe 4
	Carafe 1	x	0.19	0.02*	0.19		Carafe 1	x	0.02*	0.7	0.25
	Carafe 2	—	x	0.0005***	0.01*		Carafe 2	—	x	0.06	0.25
	Carafe 3	—	—	x	0.3		Carafe 3	—	—	x	0.44
	Carafe 4	—	—	—	x		Carafe 4	—	—	—	x
(g)						(h)					
Stylishness Evaluations		Carafe 1	Carafe 2	Carafe 3	Carafe 4	Stylishness Evaluations		Carafe 1	Carafe 2	Carafe 3	Carafe 4
	Carafe 1	x	0.001***	0.001***	0.79		Carafe 1	x	0.14	3.80×10^{-09}***	0.01**
	Carafe 2	—	x	3.70×10^{-09}***	0.0004***		Carafe 2	—	x	0.007**	0.4
	Carafe 3	—	—	x	0.002**		Carafe 3	—	—	x	0.02*
	Carafe 4	—	—	—	x		Carafe 4	—	—	—	x

Note: Significance levels: (*) $p < 0.05$; (**) $p < 0.01$); (***) $p < 0.001$.

SOP for product #1 of the 4 products is always set to 1.0 in the analysis; all others emerge as either greater than or less than 1.

4.1 Opinion Judgments: Inconsistent. Table 7 shows a summary of the results from Groups 1 and 2. Using the Bradley-Terry model described previously, relative rankings were determined for each question type and product category for each group. The highlighted cells show the item selected most frequently for a given question and/or product representation mode with significance at $p < 0.05$ in comparison to at least one other option. For example, in Group 2, Car 3 was selected most frequently when shown as a simple rendering during preference evaluations (2.40) and stylishness evaluations (3.54) (for question phrasing see Table 6).

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 8, parts (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 selected most frequently 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 8, part b). 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 8, part a). Similar trends were observed in evaluations of coffee carafes. In Group 1, Carafe 2 was selected most frequently 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 8, parts (e) and (g)]. Carafe 2 was also most preferred when shown as a realistic rendering to Group 2 (1.81); however, Carafe 3 was selected most frequently for stylishness evaluations (3.54) within this same group. The statistical differences are highlighted in Table 8, parts (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, Cars 4 and 3 were selected as most stylish when viewed as FSV silhouettes (2.88) and simple renderings (3.54), respectively; Carafes 2 and 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 9 summarizes the products and measurements that tested at the $p < 0.001$ level for a difference in variance between groups; the group listed first (e.g., FSV silhouette > Simple rendering) in

Table 9 Measurements with greatest degree of variance

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**

Note: (**) = $p < 0.001$.

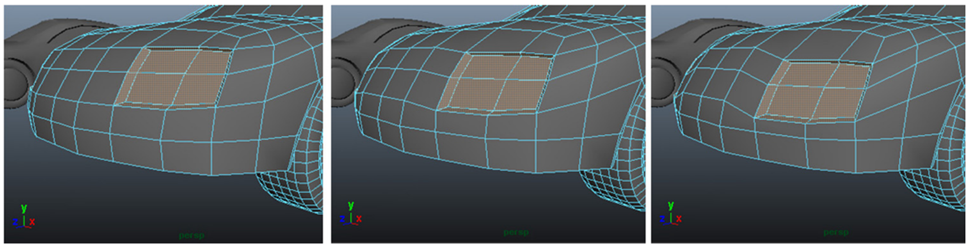


Fig. 9 Three levels for headlight vertical position

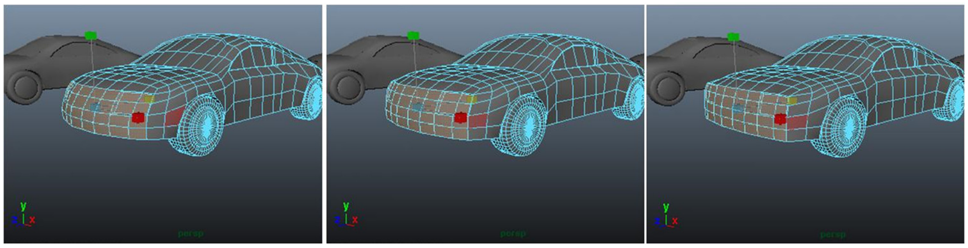


Fig. 10 Three levels for curvature of bumper

the column "Variance Relationship" is the one that showed greater variance. There were also differences in the degree of variance of measurements for the height and width of Carafes 1 and 4, and the height of Carafe 3.

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 Carafe 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 [23], 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 in Fig. 4, and the total time spent viewing each option was ascertained. The results show differences in fixation times spent on each option between groups.

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 7. A Welch two-sample t-test was conducted comparing the fixation times spent on each option (option on left, option on right) for a given product and representation mode. 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 versus 4, there was a difference in the time spent viewing Option 1 (Carafe 2) when shown as a computer sketch (Mean (M) = 276 ms; Std. Dev. (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 = 87 ms) ($p < 0.001$). 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 versus 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 Figs. 5 and 6, respectively. In Fig. 10, 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.

The data were analyzed to examine whether or not people spent more time looking at the option they selected or the one they rejected. Table 10 presents results for total fixation times for preference questions including the location of the option that was actually selected (left or right). These findings have not been statistically tested.

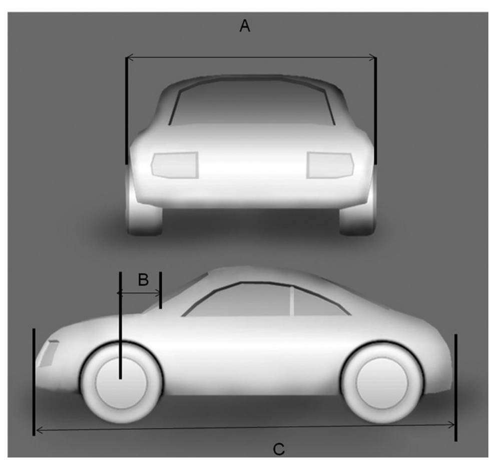


Fig. 11 Dimensions for overall width (a), distance between cowl and tire center (b), and overall length (c).

Table 10 Summary of viewing strategies for preference questions

Product pairs	Representation mode	Final selection on left		Final selection on right		N
		# Resp. Left gaze time longer	#Resp. Right gaze time longer	# Resp. Left gaze time longer	# Resp. Right gaze time longer	
Carafe 3 version 2	Computer sketch	3	5	11	12	31
Carafe 1 versus 2	Computer sketch	6	8	10	7	31
Carafe 2 versus 4	Computer sketch	12	9	6	4	31
Carafe 3 versus 2	Realistic rendering	7	5	13	5	30
Carafe 1 versus 2	Realistic rendering	5	5	12	8	30
Carafe 2 versus 4	Realistic rendering	6	10	6	8	30
Car 2 versus 3	Simple rendering	6	5	13	6	30
Car 1 versus 4	Simple rendering	6	7	10	7	30
Car 4 versus 3	Simple rendering	7	5	9	9	30
Car 3 versus 4	Simple rendering	13	7	5	4	29
Car 2 versus 3	FSV silhouette	6	8	13	4	31
Car 1 versus 4	FSV silhouette	8	5	10	8	31
Car 4 versus 3	FSV silhouette	7	9	9	6	31
Car 3 versus 4	FSV silhouette	14	4	8	5	31

Subjects' fixation patterns, displayed two predominant trends:

(A) *Subjects chose the option associated with the longer aggregate fixation time (shown in columns 3 and 6).* As shown in the first row of Table 10, 48% of respondents ($3 + 12 = 15$ people) did this when evaluating Carafe 3 versus 2 as a computer sketch.

(B) *Subjects choose the option associated with the shorter aggregate fixation time, the opposite of the above pattern (shown in columns 4 and 5).* Table 10 shows that 52% of respondents ($5 + 11 = 16$ people) did this when evaluating Carafe 3 versus 2 as a computer sketch. Of interest is the 2nd column under "final selection on left." Gaze should linger longer on the left option naturally, however, these *individuals spent more time loo*king at the option on the right, but then choosing the option that is on the left. Possible explanations are discussed in Sec. 5.

5 Discussion

The hypothesis that people form different inferences, opinions, and objective evaluations of products when viewing different product representation modes was accepted for opinions and objective evaluations. The null hypothesis could not be rejected for inferences.

The results demonstrate that people's opinions and objective 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 7 shows that Car 3 was most preferred and evaluated as most stylish when shown as a simple rendering, and Table 9 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 9 does not identify significant differences in the variance of the objective evaluations for Carafe 2. Carafe 3 was deemed as most stylish when shown as a realistic rendering, but it was not the most preferred. Carafe 2 was the most stylish and most preferred in computer sketches. This difference demonstrates inconsistency in opinions across representation and also demonstrates that the most stylish product is not always the most preferred.

These results indicate that objective evaluations, such as ability to accurately and easily discern product size, may influence the strength and consistency of people's opinions. Further studies are needed to make conclusive observations. To err on the side of caution, the authors 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. Therefore, care must be taken in how this is done. 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 9.

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. This study tested common inferences for familiar products. The results cannot be used to speculate on uncommon inferences (e.g., inferring the flavor of the coffee from the shape of the pot). If the results hold for common inferences in general, it can be concluded that inconsistency in opinion across representation mode is not caused by inconsistent inferences. It may instead be caused by inconsistency in other judgments, such as objective evaluations.

As previously mentioned, the eye-mind hypothesis states that people look at what they are thinking about. The authors found two different gaze "patterns": look more at the product selected, and look more at the product not selected. These two patterns may be linked to different decision-making strategies. Looking more at the product selected could be linked to a focus-on-the-positive, or maximizing decision strategy [54]. A consumer uses a maximizing strategy to get the most value possible out of their choice. If this strategy is used, gaze should fixate on the best product and the evaluation of its best and most important attributes. Looking more at the product selected may also be linked to confirmation bias, a bias in which people look for information to support a decision they have already made [55]. Looking more at the product not selected could be linked to an eliminate-the-negatives or satisficing decision strategy [54]. A related decision strategy is elimination-by-aspects [56], in which consumers create a set of criteria to screen products efficiently and find a product that is good enough. If this approach were taken, gaze should fixate on product attributes that do not surpass cut-off criteria. Maximizers and satisficers are known to represent different types of consumers [54], so it would follow that both of these types were represented in the survey population. Previous studies have identified differences in preference in comparative versus non-comparative questions [57], and the results here suggest this may be linked to viewing approach. More work is needed to form this discussion into testable hypotheses, but it begins to suggest that people not only look at *what* they are thinking about but also that the *what* can be linked to the *how* they are thinking about it.

6 Conclusion

Product representation matters when measuring customer opinions and objective evaluations. The results of the study showed that people were inconsistent in their evaluations of preference and styling for coffee carafes shown as realistic renderings and for cars shown as FSV silhouettes. This and other inconsistencies suggest that it is important that product design researchers use pilot studies to pretest planned experimental judgments across a variety of visual representation forms. Ideally, researchers should choose one or more forms that will improve the robustness of experimental conclusions. Future studies could create classifications to guide design researchers toward the product representation most suitable for various product categories and types of judgments. 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 customer preferences [14], but the results indicate that showing simple renderings generated more consistent customer preferences when evaluating cars (as opposed to silhouettes), 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. This finding suggests that the information people infer is not susceptible to or influenced by the form of the information that was presented/not inferred.

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 insights that could not have been obtained from a traditional survey. The fixation time data suggested the presence of at least two different decision-making strategies. It also showed some indications of ordering effects when the same pairs of products were showed in reverse order and when items with relatively high strength of preference was shown as an option on the left or right. Future studies can investigate choice protocol in more depth using eye tracking data.

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.

Acknowledgment

We thank Ted Martens and Brady Wold for developing models of the cars in Maya and Photoshop, and Kevin Kauffman for developing the models of coffee carafes in Solid Works and Photoshop. The thoughts and insights of Hannah Chua and colleagues in the ISU IRIS Design Lab are gratefully acknowledged. This research was supported by the ISU 2050 Mack Challenge Scholar Fund and the ISU Graduate College Postdoctoral Fellowship program.

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