Eye Tracking Data Understanding for Product Representation Studies

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ABSTRACT

Within the mechanical engineering discipline, product representation studies have been used to inform engineers on the suitability of their product designs for prospective customers. However, these studies are mainly based in customers' oral responses leading engineers to modify the product design accordingly. In contrast, we consider the eye tracking data associated with customer judgments of 2D and 3D product representation studies. Eye tracking data contains unforeseen facts and patterns not captured through customers' oral responses. In this research, we conduct data analysis and present a set of features for analyzing similar eye tracking studies. These features include (1) question-based analysis, (2) question and category dependencies, (3) product and category dependencies, (4) gender impact and (5) experiment repeatability situations. In addition, a brief comparison of the 2D and 3D product representation experiments is described for each feature.

Categories and Subject Descriptors

H.1.2 [**User/Machine Systems**]: Human information processing; H.3.3 [**Information Search and Retrieval**]: Information filtering; H.2.1 [**Logical Design**]: Data models

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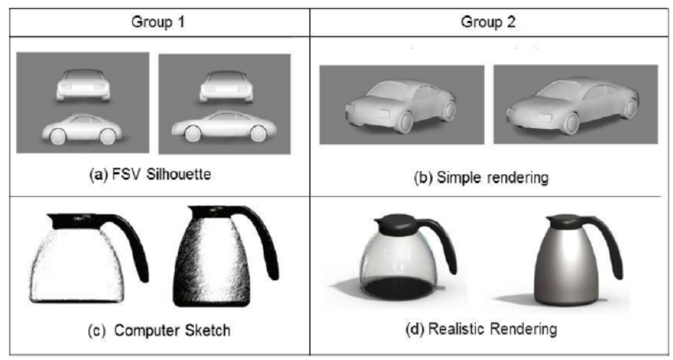


Figure 1: 2D and 3D Product Representation Examples

Keywords

product representations; mind-eye hypothesis; knowledge management

1. INTRODUCTION

This study used eye-tracking data to examine question, category, product and gender differences in subjects' interactions with two and three dimensional product drawings. [2]. These product observations reveal opinions, emotions and preferences through studying an individual's thought process related to what is viewed, which is also called the mind-eye hypothesis [5]. The eye tracking data has the potential to uncover previously hidden commonalities amongst the participants and/or products. It becomes relevant in predicting subjects' understanding and preferences in order to better inform the product design process. The mechanical engineering field is an example discipline that could benefit from this study. As mechanical drawings become complex, it is crucial to not only understand the design but also the design's intended processes. This research's significance lies in laying the groundwork in providing product designers scientific evidence as to how to better interpret participant feedback about products in the designing process.

In this research, we perform preliminary data analysis on two eye tracking product representation studies conducted by Reid et al. [9]. One experiment viewed the FSV silhouettes and computer sketches (2D renderings) and the second experiment viewed the realistic and simplified renderings (3D renderings) as depicted in Figure 1. These studies divided the participants into two randomly-selected groups of 31 subjects each. The participants' demographic information was also collected including their age ranges, educational backgrounds and professions. The product categories are cars, coffee carafes, golf tees and miscellaneous products. Each experiment recorded the participants' product design evaluation through responding to three question categories: (1) opinion, e.g., preference and stylishness, (2) objective evaluation, e.g., width, length and height and (3) inferences, e.g., recyclability, heat retention and fuel efficiency. The resulting eye tracking data consists of scenes with x-y coordinates based on participant, question and product category.

The contributions of this study is to:

- present initial common characteristics for product design that are affiliated with question, product and category elements, and
- showcase a working example of eye tracking data analysis, e.g., data cleaning, data modeling, database design and implementation and finding relevant data patterns.

Section 2 discusses the related work of product representation studies and eye tracking research. Section 3 describes the eye tracking factors of interest to product design evaluations. Section 4 demonstrates the usefulness of these factors through query analysis and results. We conclude and summarize the paper in Section 5.

2. RELATED LITERATURE

2.1 Product Representation Studies

Product representations and its impact on design has been studied not only to capture consumer's choices, opinions, judgments and buying preferences but also to receive design recommendations. HCI researchers often conduct such studies as a part of usability testing. Products presented digitally and their observation leads to uncovering patterns of usability and interest, for both the product and the subject. Lai, Chang and Chang [6] analyze the human affection to a product by using a car and its different representations. Their work will help product designers improve their product design and achieve proximity to target feelings and target specific markets. The consumer's response to the visual domain in product design has been studied in literature [3].

Creusen and Schoormans [2] used product representation to elicit consumer choices, this would help the people manufacturing these products to increase profits as they would be able to design and manufacture products conforming to user's choice. They determined six different roles of product appearance for consumers and then suggested how appearance of a product plays a role in consumer product evaluation and choice and hence this is an example of how product representations are used to determine choices of people that can impact the business of these products. Similar studies [8]. Maeng, Lim and Lee (2012) have also been done to see what captures subject's attention. In Pieters and Wede [8], advertising had benefitted greatly by using these techniques to increase a product's sale. Maeng et al. [7] proposed user-product interaction concepts to reveal user's needs and functions rather than leveraging technology needs or use cases. The subject better understands her needs as a result of building and using the methods while informing product designers of how to improve the quality of their products.

2.2 Eye Tracking and Eye Fixation Research

Eye fixation research in cognitive psychology dates to the mid 1970's [5], which proposed that "the rapid mental operations of the central processor (active memory) can be revealed by analysis of eye fixation during a task involving visual input and hence it is possible to understand various memory tasks by studying this model" (p.1). This area of research definitely proves that a person's thought processes to a great extent are defined by what they are viewing at that point in time. This piece of research showed possibilities of analysis of eye fixation data in interpreting interesting facts not only about the product being viewed but also the subject viewing it. Just and Carpenter [5] explains that eye fixations can depict thought process and hence prove useful in making many recommendations about the subject. When a subject's verbal responses and eye movements are tracked simultaneously, product designers can better determine what she is looking at exactly. Researchers have also used eye tracking as a tool to determine what the person actually perceives and thinks, which helps make stronger recommendations about the product, its design and usability.

Eye tracking studies draw interesting perspectives to various phenomena. The impact eye movement monitoring [4] has been studied as a process tracing methodology in decision making research. The authors directly relate eye movements to producing a process tracing mathematical model and in turn infer how humans make decisions. The study signifies the new direction of using the eye tracking data for analyzing human thought process along with high end techniques like neuroimaging. Strandvall [11] combines HCI and eye tracking research by devising a system that records the eye movements while a subject is completing a task for example on a web site. By analyzing these eye movements, researchers can record the subject's behavior. The behavioral reactions have been studied and applied to understand usability preferences of people. In contrast to prior eye tracking research, Sahin et al. [10] center on the designers' perspective. It focusses on changes in designer's evaluation with changing media unlike other studies that focus on gathering customer preferences to improve designs rather than understanding the designer's perception.

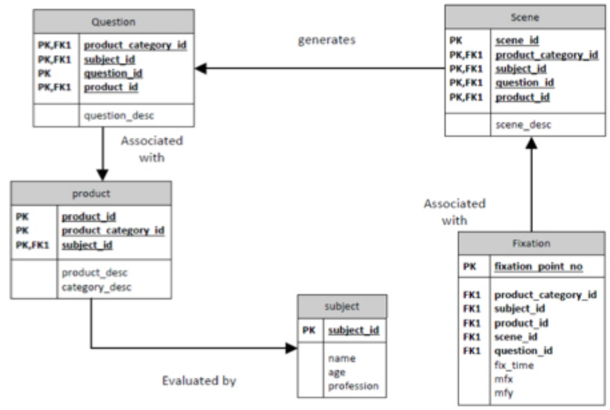
We use Reid et al.'s work [9] as the testbed of our experimentation since it addresses multiple dimensions of eye tracking research such as opinions (refers to product evaluations for which there is no right or wrong), objective evaluations (product evaluations of a measurable quantity) and inferences (conclusions that cannot be made by observation alone). These dimensions' impact differ based on the products' representation modes. By presenting some factors to consider when analyzing eye tracking data, we can use these findings to better inform similar eye tracking studies. In particular, we are working toward formulating interdependen-

FixIn	Time	FixT	MF_X	MF_Y	Stim	ProdNo	SubjectNo
367	123625	658	439	397	S14	10055.12	SU01

(a) *2D unprocessed data sample*

FixT	X	Y	Scene	Question	Category	Product	SubjectNo
658	439	397	S14	100	55	12	SU01

(b) *2D processed data sample*



(c) *Entity-Relationship Diagram*

Figure 2: Eye tracking data

cies and correlations amongst subjects, products, questions and designs.

3. DATA FEATURES OF INTEREST

The Tobii eye tracker captures the subject's eye movements while they were taking the 2D and 3D product representation surveys. In Figure 2a, we display a sample of the pre-processed Tobii raw data structure. The first three columns were redundant and not required. The fourth column FixT gives the total fixation time of the subject for the current (x,y) coordinate on the screen in milliseconds. The MF_X and MF_Y features are the (x,y) coordinates of the screen where the subject is fixated for that FixT time. Stim is the scene number. The ProdNo is an number string appending the question, category and product ID(s) to a particular fixation instance. As such, the first three digits are the question ID, the next two digits are the category ID and the digits after the point are product/products identifier depending on if there are one or two digits after the dot. The two digits after the dot depict two separate product identifiers in the scene. The last column is the subject identifier. We proceeded to clean the data (Figure 2b) and structured it for more effective data management. Based on conversations with those who conducted the 2D and 3D product representation studies, we present the database design in Figure 2c. We propagate the subject identifier to each database table subject understanding will be analyzed throughout this study. As such, we identify several data features and feature combinations that are of interest to these studies and would most likely be used in similar eye tracking studies.

3.1 Question Analysis

Question analysis is identifying how subjects' respond to different types of questions over the duration of the experiment. These questions assist product designers in pinpointing the necessary element to the final product design. As a result, the questions impact the product as well as the subject. By collectively analyzing the opinion, objective evaluation and inference questions, researchers can infer impact of certain questions (or group of questions) and/or influence on subjects. Within each question type, a subject's judgement and her behavior may have unexpected interdependence. A particular question type could indicate her increased interest (or the corollary, difficulty) in answering a question.

3.2 Question and Category analysis

The question and category analysis evaluates the correlation between the seven question types and the specific product category. We consider which product category takes more time for each question and then infer a subject's acquaintance with the selected products. For example, between opinion, inferences and objective evaluation, subjects may find it easier to give an opinion about a familiar category like a car but for the same familiar category, they may take more time to objectively evaluate.

3.3 Product and Category Analysis

For the opinion and inference categories, products are viewed in pairs while for the objective evaluation category, single products are displayed. The product and category analysis aims to assess which product/product-pair is more interesting to the subject, product/product pair or its features are difficult to interpret for the subject or which question associated with the product/product-pair was more difficult for the subject to respond. Studies comparing certain day to day products, which belong to separate categories, could use these observations to inform how fixation times vary across categories and whether it depicts patterns of interest. Inferences like which category is familiar and which design makes the category look simpler could be very informative in the design process.

3.4 Gender Analysis

To the best of our knowledge, eye tracking studies have not specifically addressed the role of a subject's gender in contributing to product, category and question evaluations. The familiarity with products and interpretation of questions can vary for subjects and gender can be an important factor in isolating commonalities and differences. By concentrating on a subject's gender, we inquire if eye tracking data is a suitable information source of determining the influence of gender in subjects' judgements. In addition, our initial gender analysis acknowledges the impact of gender on product design selection.

3.5 Repeated Exposure Analysis

Repeated exposure experiments have one unknown variable: the subjects. In our case, the products, category and questions are the control variables so the experiment scenes remain consistent across both 2D and 3D product representation studies. In a prior repeated exposure study and its impacts on choice, "the results suggest that preferences for visually complex product designs tend to increase with repeated exposure, while preferences for visually simple product designs tend to decrease with repeated exposure." [1]. We aim to analyze the changes in opinion of different subjects when they are made to view the same scene. The difference in time and choice patterns may be an indication of changing the the participation population or the product design for the same exact scene.

4. EXPERIMENTAL STUDY

In this section, we describe the experimental evaluation of two product representation studies in which subjects were observed and data was collected using the Tobii Technology. We conducted an initial eye tracking data analysis for product representation studies focussing on the five data features presented in the previous section. We discuss the experimental setup in more depth and the corresponding results.

4.1 Experimental setup

The original experiment [9] surveyed two groups of 31 participants, 15 women and 16 men each. One group viewed 73 scenes and answered questions concerning 2D product representations while the other group viewed 78 scenes and responded to questions about 3D product representations. The 2D and 3D study participant demographics were similar with varying age ranges (18-65) and nearly evenly split between those who were college-educated and those who had degrees beyond college. The opinion (preference and stylishness), objective evaluation (width, length and height) and inference (recyclability, heat retention and fuel efficiency) question types are asked in the same order; however, the actual questions are randomly shown. The cars, coffee carafes, golf tees and miscellaneous product categories are not used for each question type in both studies. Also note that the Tobii eye tracking data collected only included the (x,y) coordinates from the selected area that included the product/product pairs. Single product was shown for objective evaluation and products were shown in pairs for inference and opinion category questions.

4.2 Results

We conducted a series of experiments to showcase the applicability of the five relevant eye tracking data features. We use the average time (per scene) as our performance metric. Due to insignificant representation of participants in each demographic, in particular, educational background, we are unable to conduct an in-depth data analysis e.g., hypothesis testing using a t-test. With more studies, we could perform a comprehensive statistical analysis and provide appropriate supporting evidence. These results are meant to share initial observations. Due to space restrictions, we present a subset of our outcomes from the experimental evaluation.

Question Analysis.

In Figure 3, we display the average time spent per scene per question type for all subjects in the 2D and 3D product representation studies. As expected, the 3D average times of preference questions are slightly elevated due to it being the first question type viewed by all subjects. The width questions are observed as having the highest average time. We hypothesize that the depth perception needed to respond to all objective evaluation questions, and in particular, width, is difficult. Hence, the subjects required more time to render a response. Also, the average time did not vary significantly between the 2D and 3D product representation. Most 3D average times are slightly lower than the 2D average times. Further verification and validation experiments are required to support our claim.

Question ID	2D Avg (sec)	3D Avg (sec)
Preference	7.980	8.240
Stylishness	6.250	5.907
Width	15.764	14.289
Length	14.663	12.651
Height	12.258	11.889
Inference set one	6.997	6.321
Inference set two	6.304	6.578

Figure 3: Average time spent per question for 2D and 3D studies

Question and Category Analysis.

We examine how category selection impact question type and display the results in Figure 4(a)-(c). Building on our observation that objective evaluations have higher average times, we notice that the miscellaneous category takes more time than the other three categories. In subsequent eye tracking studies, we suggest removing this category. Subjects may be too unfamiliar with products and/or product variation implying experimental design bias.

Product and Category Analysis.

We examine how actual 2D and 3D product representations may attribute to the average viewing time of the subjects. There were 33 unique product combinations viewed by the subjects in both the experiments. We show the 2D single product and product pair results in Figure 4(d) and (e). The 3D outcomes were very similar. Single products were viewed for objective evaluation questions to better assess the width, length and heights of the product representations, and thus, the average times are higher than for 2D product pairs. Car image 3, 4 and 9 have higher average times than the other single products using in the study. For 2D product pairs, car images (4, 9) and (2, 5) report higher average times relative to the other combinations. Interestingly, car images (9, 4) did not report a similar average time. To better understand the source and/or cause of this difference, further investigation is warranted. We hypothesize that golf tee image 5 has special characteristics since the average time of golf tee images (2, 4) is nearly 50% of golf tee images (2, 5).

Gender Role Analysis.

The initial evaluation of gender in product representation studies starts with calculated the overall total average time men and women dedicated to completing the surveys. In

	Preference Questions		Stylishness Questions	
Category	2D Avg (sec)	3D Avg (sec)	2D Avg (sec)	3D Avg (sec)
Cars	8.906	8.270	6.980	6.522
Coffee Carafes	6.559	7.496	5.608	5.290
Golf Tees	8.555	7.772	5.724	N/A
Miscellaneous	9.193	11.083	N/A	N/A

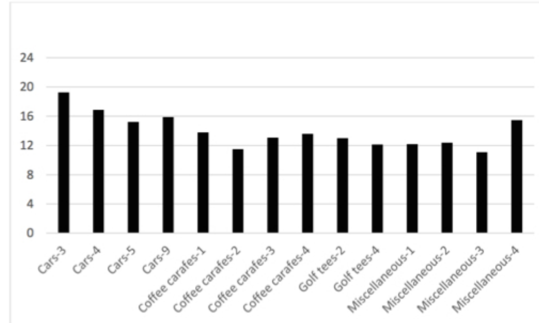
(a) 2D and 3D Opinion Questions and Category Results

	Width Questions		Length Questions		Height Questions	
Category	2D Avg (sec)	3D Avg (sec)	2D Avg (sec)	3D Avg (sec)	2D Avg (sec)	3D Avg (sec)
Cars	18.835	14.940	14.663	14.663	11.624	10.680
Coffee Carafes	14.224	12.644	N/A	N/A	12.494	11.944
Golf Tees	12.625	N/A	N/A	N/A	12.773	13.072
Miscellaneous	N/A	14.462	N/A	N/A	N/A	N/A

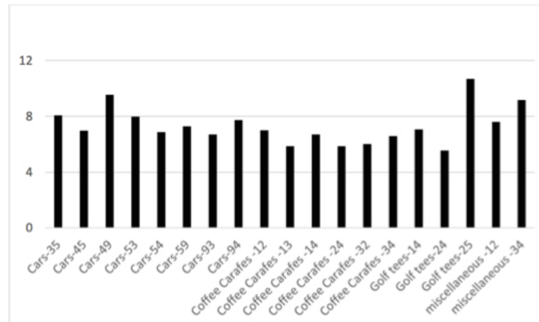
(b) 2D and 3D Objective Evaluation Questions and Category Results

	Inference Set 1 Questions		Inference Set 2 Questions	
Category	2D Avg (sec)	3D Avg (sec)	2D Avg (sec)	3D Avg (sec)
Cars	6.940	6.065	N/A	N/A
Coffee Carafes	6.878	5.984	6.348	6.459
Golf Tees	7.816	6.500	6.047	6.820
Miscellaneous	7.245	9.354	N/A	N/A

(c) 2D and 3D Inference Questions and Category Results



(d) 2D Single Product and Category Results



(e) 2D Product Pairs and Category Results

Figure 4: Category Analysis by Question and by Product

our 2D product representation study, men took an average of 613.365 seconds while for women, it was 648.280 seconds. Our 3D product representation study produced the same observation that women took slightly longer with average times of 645.376 and 691.697 seconds, respectively.

We then investigated the role of gender on three product categories as an initial indication of product preference. We are interested in capturing if men or women gravitate to particular categories and if so, whether this tendency (positivity or negatively) motivates their survey responses. More varying and traditionally gender-specific product categories are needed to fully execute this future work. For these two studies, the product categories were not selected with gender analysis as a consideration so the researchers assumed that these categories were equally familiar to men and women.

Figure 5 and 6 denote the average time spent by men and women on product categories for both studies. We observe that men fixate more on the 2D product categories while women fixate more on the 3D product categories. Also, the average times reported between the two studies varied minimally. We are motivated to see if this trend can be generalized as it would have a greater societal impact on business marketing, e.g., women may provide greater yield on 2D marketing campaigns, and curriculum material development, e.g., women may comprehend a product design concept at a different rate than their male counterparts.

Repeated Exposure Analysis.

Within the opinion question type, the same car and coffee carafes were shown for 2D and 3D experiments. Hence, the whole scene remained same (the product, category, question remains the same) and only the design changes. We explore the repeated scene exposure in an effort to see if only the design change impacts the opinions (preference and stylishness) of the subjects who view them.

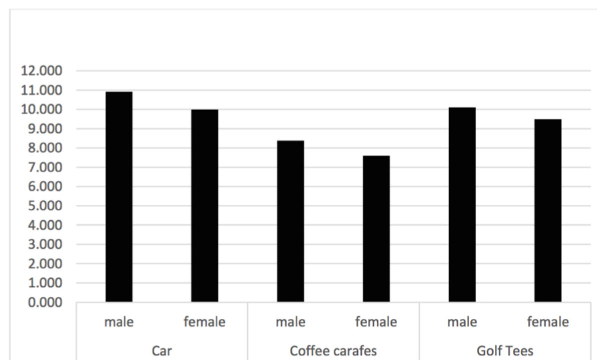


Figure 5: Average time spent on 2D product representation study by gender and category

In Figure 7 and 8, we show the preference questions results for both cars and coffee carafes. Even though Figure 7's average times are similar for most repeated 2D and 3D scenes, car images (3, 5) and (5, 3) are the exception, in which there is a nearly 2 second differential for the 3D product representation study. Figure 8 shows that consistently subjects took less time 2D repeated scenes in choosing products than for the 3D repeated scenes.

5. CONCLUSIONS

In this research, we make strives to identify general eye tracking data characteristics and test our characteristics on prior product representation studies [9]. The 2D and 3D

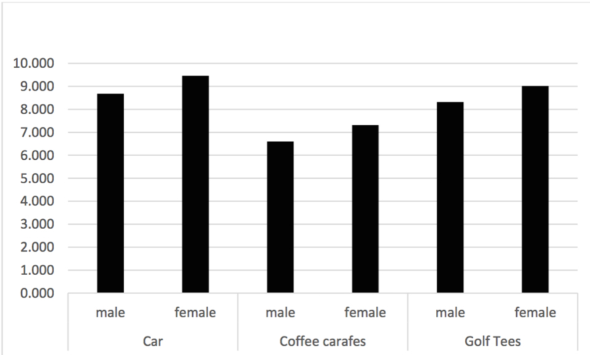


Figure 6: Average time spent on 3D product representation study by gender and category

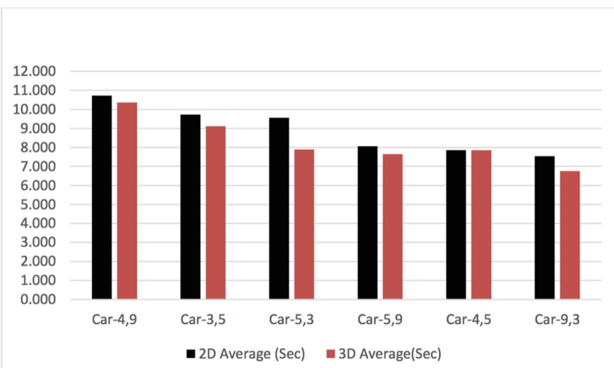


Figure 7: Car scenes with preference questions in 2D and 3D

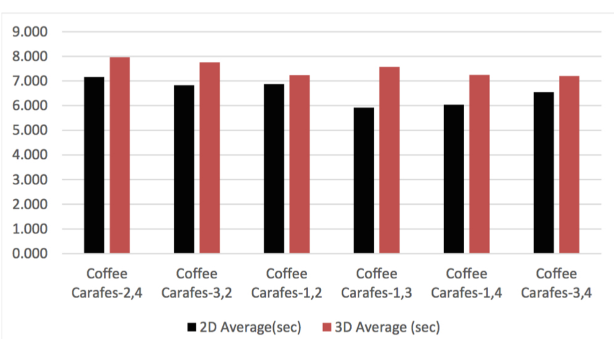


Figure 8: Coffee carafes scenes with preference questions in 2D and 3D

product representation studies consists of a total of 62 male and female participants who varied in age range and educational backgrounds. Each study focused on seven question types across the three question categories and four product categories. This research explored the impact of question, question and category interdependencies, product and category correlations, product judgement differences based on gender and repeated scene exposure for different study participant groups.

By using the average time spent viewing each scene, we observe that objective evaluations (width, length and height question types) are indeed the most time consuming questions while evaluating products. Both 2D and 3D subject groups found it more challenging to gauge width, length and height regardless of product category. As expected, the miscellaneous product category reported the highest average times spent per scene since product familiarity varied amongst the subjects. The role of gender produced a surprising observation: women spent slightly less time (on average) for cars, coffee carafes and golf tees in the 2D study, but slightly more time (on average for the same product categories in the 3D study. For the repeated exposure scenes, we observe some average time consistencies across both experiments. This data evaluation provides a potential template for handling similarly designed eye tracking studies.

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