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ORIGINAL ARTICLE

Early assessment of perceived customer value: a case study comparing a low- and high-fidelity prototype in dentistry

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ABSTRACT

Perceived customer value measures how customers perceive the total worth of a product or service. Providing a high perceived value is crucial for businesses to gain a competitive edge over their rivals and ensure long-term success. Prototyping can measure perceived customer value and effectively collect user feedback early in the process before significant investments are made. However, the effects of prototype fidelity on assessing perceived customer value are yet to be explored. Nevertheless, the fidelity levels of a prototype should be accounted for since they significantly alter the prototype's complexity, appearance, and functionality. This paper explores such effects using a low- and a high-fidelity prototype in a dentistry context. The paper used qualitative and quantitative methods to gather feedback from dental healthcare experts and patients. The results suggest that both low-and-high fidelity prototypes are suitable for assessing customer value. Furthermore, the fidelity levels complemented each other, improving the overall user feedback.

Keywords: Perceived customer value, prototyping; low-fidelity prototype; high-fidelity prototype; design thinking.

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INTRODUCTION

The low-versus-high fidelity debate in prototyping refers to the level of detail and complexity built into a prototype. Whether a prototype should be low- or high-fidelity revolves around how accurate it needs to be to test an application, model design alternatives, or demonstrate an idea. Similarly, whether prototypes must be complete, realistic, or reusable for them to be useful is a contentious issue (Rudd et al., 1996). Low-fidelity prototypes are simple and rough, often created with paper and pencil or basic digital tools. They are used to test broad concepts and gather feedback quickly and cheaply. High-fidelity prototypes, however, are much more polished and complex, sometimes even looking like the final product. They are used to test specific features and interactions and to get a more accurate representation of how the final product will look and feel. Hence, the choice between low- or high-fidelity is informed by the goals of the prototyping phase and the time and resources available.

The relationship between prototype fidelity and perceived customer value has yet to be explored. The latter is defined as a mental, subjective process of comparison where the buyer balances the costs and advantages of a product or service (Amini et al., 2016). Customers find a product or service appealing if its perceived benefits outweigh its perceived costs. This paper aims to advance the low-versus-high fidelity debate by providing exploratory research about the effects of prototype fidelity on perceived customer value for the first time. During CERN's IdeaSquare summer school 2022, we tested a new market application for H3D VISIOnAIR in dentistry, which we used as the case study of this paper.

ATTRACT is a European Union-funded research and innovation program under which H3D VISIOnAIR was developed. H3D VISIOnAIR provides vision beyond normal eyesight through augmented reality (AR) glasses. It makes use of 3D-multispectral cameras, advanced computer analytics and Near Eye Displays (NED). Dentistry is currently based on visual inspections, but these techniques are time-consuming and can lead to undetected issues. Dentists are often overbooked and overworked, reporting work-related stress, fatigue, nervousness and anxiety (Puriene et al., 2007). Unfortunately, the COVID pandemic worsened this situation. For example, the General Dental Council (2020) discovered that 68% of dental professionals surveyed felt their stress and anxiety levels had grown since the outbreak. Using H3D VISIOnAIR's headwear technology, we aim to aid dental healthcare specialists by reducing their workload with shorter check-up times and easier diagnosis thanks to insightful AR information. The glasses can scan and analyse teeth based on the RGB and infrared optical inputs, which are then combined in a computer through data processing. The result is useful AR information displayed on the glasses.

In the rest of this paper, we dive deeper into the literature about prototype fidelity and perceived customer value, describe our prototyping process, detail our data collection process, and share the findings of our exploratory research.

THEORETICAL BACKGROUND

Perceived customer value, also known as customer incentive to buy or value for customer, is the measure of how customers perceive the total worth of a product or service they are receiving (Kotler & Keller, 2012). While there are many ways of studying perceived customer value, this work focused on the ex-ante or pre-purchase customer value, as presented by Woodwall (2013). Total worth, in this context, refers to what the customer believes they are getting in return for what they are willing to pay or invest (Menon et al., 2005). In today's competitive market, where customers are confronted with many options, providing a high perceived value is crucial for businesses to gain a competitive edge over their rivals and ensure long-term success.

To increase perceived customer value, companies should focus on understanding their customers' needs and preferences and tailor their offerings accordingly. Currently, no study in the literature has directly examined the effects of low-versus-high fidelity prototyping on assessing perceived customer value. Yet, a few studies report interesting results concerning prototyping fidelity, which we briefly discuss.

Lyly-Yrjänäinen et al. (2019) proposed that perceived customer value can be assessed using a prototype, or mock-up, that combines the characteristics of a low- and high-fidelity prototype, reflecting the product's main functionality. Such a mock-up allowed them to examine the core functionalities and mechanisms of value creation of new products, investigate and quantify the product's value potential, and reduce the uncertainties related to customer preferences and perceived customer value. The study, however, did not explore the effects of varying the prototype fidelity. Nevertheless, their results show that mock-ups, in this context, a medium-fidelity prototype, can measure user-experienced costs and perceived customer value.

In comparison, Gupta (2022) did account for prototype fidelity but with a focus on product development rather than a customer-based perspective. The author studied the efforts of Spanish startups to research the US and German markets by using prototypes that ranged from low to high fidelity. The study assessed the prototype development technologies in terms of their usefulness (or usability), ease of use (for startups), ease of use (for customers), time to generate the prototype, recyclability, and investment required. Gupta (2022) reported that technologies used for developing medium-to-high fidelity ranked overall better than the ones used for developing the low-fidelity counterparts in terms of ease of use (for startups), time to generate the prototype, recyclability, and investment required. Hence, Gupta's results suggest that there is a positive linear relationship between the four previously mentioned attributes and the overall assessment of the technology.

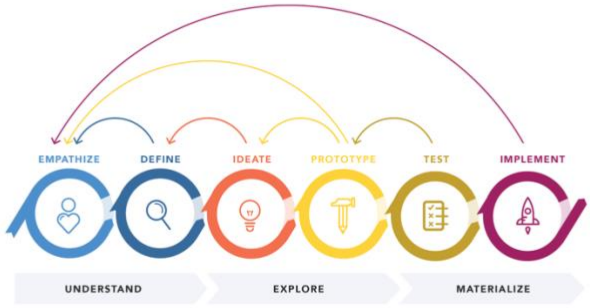

Fig. 1. The design thinking process is a human-centered strategy to innovation that is based on understanding consumer requirements, fast testing, and producing innovative ideas (Nielsen Norman Group, 2016).

The link between prototyping and customer perceived value can also be studied from the design thinking perspective. The latter is a process focused on innovative ideas while considering viability, desirability, and feasibility (Chasanidou et al., 2015). Design thinking works with quick iterations, informed by the prototyping and testing phases, in which insights into the product's functionality and appearance are gained through user feedback. Prototyping also serves to check the product assembly and highlights other issues that could arise further along in the manufacturing process. As Figure 1 shows, making a prototype is the fourth step and the first structural realisation of the design process (Razzouk & Shutte, 2012). After the prototyping follows the testing phase, which is critical in informing subsequent phases of the product development process. Design thinking touches upon prototype fidelity through the development of low-fidelity prototypes. However**,** it does not explicitly investigate customer perceived value but rather focuses on the product's desirability. As such, additional customer research and evaluation may be necessary to determine the product's actual value to the end user.

METHODS AND DATA

In under 48 hours, we produced our first low-fidelity prototype, EyeDot. As shown in Figure 2, EyeDot consisted of: 1) 3D-printed glasses; 2) a PVC pipe with a lens which served as our mock-up microscope; 3) LED lights that would light up when detecting an abnormality and 4) a holder for the thermal camera which was simulated with a mobile device. For the high-fidelity prototype, we used H3D VISIOnAIR as developed by i-Med Technology, IMEC Netherlands, and Maastricht University Medical Centre based on ATTRACT's technology. As Figure 3 shows, the prototype consists of a commercial spectral+RGB camera in a head mounted display with a specialise near infrared LED ring that periodically lights the environment for better spectral image capture (Heukelom et al., 2020).

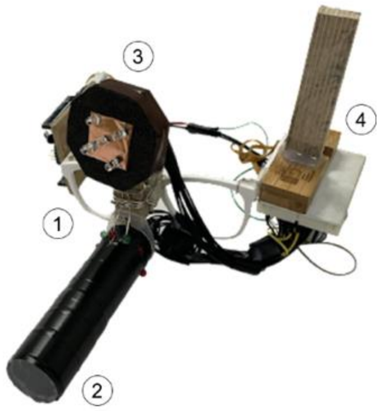

Fig. 2. The low-fidelity prototype developed at CERN's IdeaSquare summer school: EyeDot. The prototype consisted of: 1) 3D-printed glasses; 2) a PVC pipe with a lens which served as our mock-up microscope; 3) LED lights that would light up when detecting an abnormality and 4) a holder for the thermal camera which was simulated with a mobile device. Cavities and diseases could be detected easier, quicker and more precisely with EyeDot. The glasses eased the burden of using multiple tools, while also keeping the dental healthcare experts' hands free. Even more critically, EyeDot would provide all this information in real time, which is particularly important during surgical or implant processes.

Fig. 3. H3D VISIOnAIR was used as the high-fidelity prototype as developed by i-Med Technology, IMEC Netherlands, and Maastricht University Medical Centre based on ATTRACT's technology.

This paper uses a mix of qualitative and quantitative methods to investigate how the fidelity of a prototype affects perceived customer value. Our study was conducted in two rounds: round 1 consisted of interviews with four experts, and round 2 of a survey with 43 patients.

We interviewed a total of four dental healthcare experts, comprising one dentist and one orthodontist practicing in the Netherlands and one dentist and one orthodontist practicing in Romania. All the dental healthcare experts worked for the private sector. The Netherlands and Romania were selected since they both have a mix of private and public dental healthcare providers and focus on preventive dental care. Furthermore, both nations' services, technology, and relative pricing are comparable. We used an interview protocol so that every interview could be comparable (see Appendix A). The protocol had two versions: the questions remained unchanged, but the first version included an image of our low-fidelity prototype (protocol version A), while the second one included an image of our high-fidelity prototype instead (protocol version B). During the interview, we used protocol version A with the dental specialists from the Netherlands and protocol version B with the ones from Romania. Then, we performed a thematic analysis with a deductive and semantic approach to study our results, as outlined in Kiger & Varpio (2020) and summarised our results in Table 1.

Whereas the qualitative approach, the interviews, was centred around dental healthcare specialists, the quantitative approach focused on patients to understand their feelings and attitudes toward AR dentistry. The data collection was done via a cross-sectional survey (see Appendix B) combined with convenience sampling. Similar to the qualitative study, the survey had two variants: the first one included an image of our low-fidelity prototype (survey variant A), while the second one had an image of our high-fidelity prototype (survey variant B). Aside from this change, the two surveys' structure and content remained identical.

Next, we divided our initial survey sample (N_initial = 40) into groups 1 and 2, both with 20 participants each. Group 1 consisted of dental patients from the Netherlands and was only exposed to survey variant A, while group 2 comprised patients from Romania and only worked with survey variant B. Both groups had a similar age composition (i.e., half of them fell in the range of 21-29 years, followed by a third in the 18-20 years range) and were primarily males (57% for group 1 and 72% for group 2). Participants produced only one result but were asked to share the survey with acquaintances. As a result, we obtained answers from two completely independent groups of subjects.

This approach led to a final sample of N_G1 = 21 and N_G2 = 22 respondents for groups 1 and 2, respectively. The variables were measured via a five-point Likert scale derived from Sullivan & Artino (2013). Next, since we were working with ordinal data (Likert scale) we used a non-parametrical statistical test, Mann-Whitney U, to analyse the data in the SPSS Statistics software, and used an alpha level of 0.05. We summarised the survey questions into keywords to display the results more succinctly, as shown in Table 2. Lastly, we produced 4 tables and 5 graphs.

Table 1. Thematic analysis results of the dental healthcare experts' interviews. We identified eight themes and specified which group mentioned those themes. For the sake of brevity, we selected a few samples of text and not the entirety of the interviews.

Theme	Example quote in response to low-fidelity prototype	Example quote in response to high-fidelity prototype
Safety concerns	All parts of the EyeDot must be securely fastened so that nothing can fall out. Considering the safety standards I refer you to the European DIN – norms. In there is also mentioned that the device or the packaging should be very sterile.	EyeDot should not raise any concerns in regard to sterilization. Materials should be resistant; sterilization chemicals at cold temperatures are corrosive.
Usage frequency	When a bracket is glued for orthodontists, every day for endodontists and dentists.	At every consultation and for 3D scanning in regard to prosthetics work when needed.
Perceived usefulness	During surgeries, the information displayed would be useful.	Keeping in mind the fact that it is connected at the computer and the anomalies can be diagnosed easily, EyeDot should reduce working time.
Perceived disadvantages	I don't think that EyeDot will save me time during regular check-ups.	Because a lot of dentists use a little mirror to look at the back teeth or at the tooth being treated, it would be hard to look at the same areas with EyeDot and to enlarge it.
Training	Younger colleagues especially could experience benefits by using EyeDot, if it is not too expensive.	
Willingness to pay	These glasses in dentistry without any software added, I think would easily sell for €4,000 or €5,000. With the software, I would estimate they would sell for over €6,000 up to €10,000.	I would pay €10,000 euros for a functional final product.
Product potential	There are a lot of possibilities, especially concerning pathology of the mouth cavity, even though the right diagnosis often gets made after laboratory testing.	3D scanning of the models for the purpose of reconstruction would limit the interaction between the laboratory of dental technique, and the time of preparation would be shorter.
Competitor analysis		There are cameras on the market that have been developed especially to take photos of the mouth (cavity). However, these are not coupled to a pathological recognition box.

RESULTS

Round 1: Interviews with dental healthcare experts

Table 1 shows the identified themes and a few samples of coded text. Both the low- and high-fidelity groups had the same *safety concerns* regarding sterilisation, yet the low-fidelity group also mentioned the structural stability of the device while the high-fidelity group mentioned the resistance of materials. Both groups agreed on the *usage frequency* for the different branches of dentistry. Interestingly, the groups identified different benefits. In the case of the low-fidelity group, the *perceived usefulness* was delimited to more concrete situations (i.e., surgeries). In contrast, the high-fidelity group mentioned that it would reduce the general working time and facilitate diagnosis. Related to this, a *perceived disadvantage* identified by the low-fidelity group was a lack of timesaving for regular check-ups, while for the high-fidelity group, it was the difficulty of enlarging images when using mirrors. Only the low-fidelity group brought up the *training* theme. Furthermore, both groups showed a comparable *willingness to pay*, mentioning the same price ranges, although the low-fidelity group had a wider price range. Both groups agreed on the *product potential*, mentioning that the 3D technology offered many new possibilities. The *competitor analysis* theme was mentioned only by the high-fidelity prototype group. We concluded that low-fidelity and high-fidelity prototypes are suitable for assessing customer value as they brought up similar insights into the different themes. In fact, the two fidelity levels complemented each other since each prototype identified different benefits and had unique themes (i.e., *training* for low-fidelity and *competitor analysis* for high-fidelity).

Round 2: Surveys of dental patients

The Mann-Whitney U compares the differences between two independent groups with a not normally distributed ordinal or continuous variable. By visually inspecting the distributions of Figure 4, we can justify using the Mann-Whitney U test, as the distributions are asymmetrical. The test scores every sample value from low to high, assigning a rank of 1 to the smallest number and n to the biggest one. The p-value will be low if the means of the ranks in the two groups disagree. The answers were measured on a Likert scale, where a higher number translates into a more positive evaluation. Table 3 shows that the low-fidelity group had a higher mean rank score for *Satisfaction*, *Visibility*, *Surcharge Check-up*, and *Surcharge Surgery* (see panels 1-4 of Figure 2). In contrast, the high-fidelity group only had a higher mean rank score for *Comfort* (see panel 5 of Figure 2). However, despite these differences, as shown in Table 4, the two-tailed p-value of all questions exceeds our significance level of 0.05. As a result, we accepted the null hypothesis, which states that both groups have equal mean ranks. In other words, there is no statistical significance between the low-fidelity and high-fidelity groups.

Table 2. Survey questions translated into keywords.

Keywords	Corresponding question
Satisfaction	How satisfied are you with your current dental healthcare service?
Comfort	How comfortable would you feel if your dentist used EyeDot?
Visibility	How important would it be for you to see through a monitor what the dentist is seeing?
Surcharge check-up	How likely would you be willing to pay a surcharge if your dentist used EyeDot during a check-up?
Surcharge surgery	How likely would you be willing to pay extra for the service of EyeDot during surgery?

Table 3. Mann-Whitney U test of survey results. The survey had two variants: the first one included an image of our low-fidelity prototype (variant A), while the second one had an image of our high-fidelity prototype (variant B). Group 1 (N = 21) was exposed to survey variant A and Group 2 (N = 22) to survey variant B.

Ranks

	Group	N	Mean Rank	Sum of Ranks
Satisfaction	1.00	21	22.67	476.00
	2.00	22	21.36	470.00
	Total	43		
Comfort	1.00	21	20.93	439.50
	2.00	22	23.02	506.50
	Total	43		
Visibility	1.00	21	22.29	468.00
	2.00	22	21.73	478.00
	Total	43		
Surcharge checkup	1.00	21	22.57	474.00
	2.00	22	21.45	472.00
	Total	43		
Surcharge surgery	1.00	21	22.71	477.00
	2.00	22	21.32	469.00
	Total	43		

Table 4. Test statistics of the Mann-Whitney U test. The two-tailed p-value of all questions is more than our significance level of 0.05. Hence, we accepted the null hypothesis which states that both groups have equal mean ranks.

Test Statistics

	Satisfaction	Comfort	Visibility	Surcharge checkup	Surcharge surgery
Mann-Whitney U	217.000	208.500	225.000	219.000	216.000
Wilcoxon W	470.000	439.500	478.000	472.000	469.000
Z	-.366	-.575	-.153	-.301	-.374
Asymp. Sig. (2-tailed)	.715	.566	.879	.763	.708

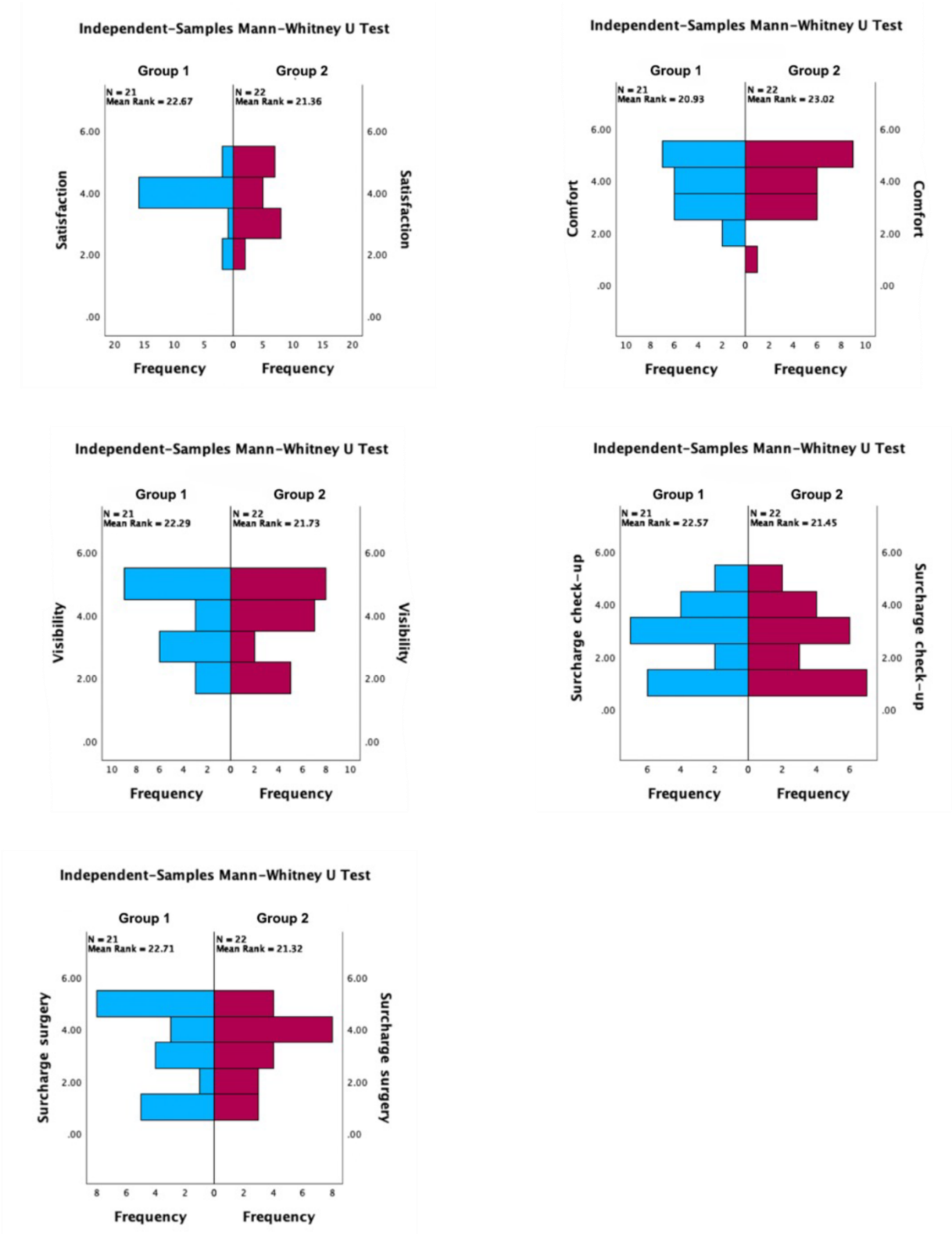

Fig. 4. In order, from top to bottom and left to right the five panels show the histograms for *Satisfaction*, *Comfort*, *Visibility*, *Surcharge Check-up* and *Surcharge Surgery* respectively. The Mann-Whitney U test compared the mean ranks of Group 1 (N = 21), which was exposed to the low-fidelity prototype, with Group 2 (N = 22), which was exposed to the high-fidelity prototype.

DISCUSSION AND CONCLUSIONS

This paper explored the effects of prototype fidelity on perceived customer value by studying the feedback obtained after exposure to one of the two types of prototypes.

Our thematic analysis found that both low-fidelity and high-fidelity prototypes can determine perceived customer value as they brought up similar insights into the different themes. Furthermore, the two fidelity levels were complementary since they identified different benefits and brought up unique themes (i.e., *training* for low-fidelity and *competitor analysis* for high-fidelity). Our Mann-Whitney U test found no statistical significance between the groups exposed to high-fidelity and low-fidelity prototypes. Because of this, we accepted the null hypothesis, which holds that both groups have equal mean ranks. Hence, considering both results, our study implies that both low-and-high fidelity prototypes are suitable for assessing customer value.

The present case study contributes to the existing literature on fidelity prototyping by expanding upon previous research primarily focused on the middle to high-end range. In particular, Karimian Pour (2015) demonstrated that a value proposition based on a fully functional mock-up of medium-fidelity was comparable in accuracy to one based on an alpha prototype of high-fidelity. Similarly, Lyly-Yrjänäinen et al. (2019) reported that perceived customer value could be effectively assessed using a mock-up of medium-fidelity. Building on these prior findings, our study suggests that they may also apply to low-fidelity design. Notably, while Karimian Pour's (2015) research was conducted at a low level of technical complexity, our study employed cutting-edge ATTRACT technology, implying that our conclusions can be generalized across a wide range of technical sophistication.

Nonetheless, the results of this research should be considered carefully due to its non-random sampling. The biggest drawback of this sampling method is its inability to estimate a sampling error. However, this is less problematic for exploratory research. Having found that perceived customer value could be weakly dependent on fidelity levels, follow-up studies should shift to probability sample design with a more robust sample size to confirm and quantify our results. Alternatively, future studies could use a single-case experimental design (SCED) if a bigger sample size is not feasible. As Smith (2012) describes, in SCEDs participants provide their own control data for comparison in a within-subject design. SCEDs then compare two study time spans, called phases, to discover causal or functional relationships.

Another limitation is the inability to test if the written description of EyeDot impacted the survey results. The prototype image would not alter the results if the description were explanatory enough. Although this effect falls outside the scope of this study, future research should take it into account and consider how to offset it (i.e., survey structure modification, use of an audio visual rather than an image accompanied by text). Lastly, sampling bias could also impact our findings. This study encompassed two types of dental healthcare specialists, dentists, and orthodontists, but it could be expanded to include endodontics, geriodontics, implantology, prosthodontics, and periodontology, to name a few examples. Similarly, dental patients could be expanded to include people younger than 17 or older than 60 years, as those groups were not part of this case study.

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SUPPLEMENTARY MATERIALS

We have included two supplementary appendices to complement this paper. The first one, Supplementary Appendix A, corresponds to the interview protocol we used, while the second one, Supplementary Appendix B, is the survey we shared with dental patients.

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