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Why 3D Cameras are Not Popular: A Qualitative User Study on Stereoscopic Photography Acceptance

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Abstract Digital stereoscopic 3D cameras have entered the consumer market in recent years, but the acceptance of this novel technology has not yet been studied. The aim of this study was to identify the benefits and problems that novice users encounter in 3D photography by equipping five users with 3D cameras for a 4-week trial. We gathered data using a weekly questionnaire, an exit interview, and a stereoscopic disparity analysis of the 699 photographs taken during the trial. The results indicate that the participants took photographs at too-close distances, which caused excessive disparities. They learned to avoid the problem to some extent; the number of failed photographs due to excessive stereoscopic disparity decreased 70 % in 4 weeks. The participants also developed a preference for subjects that included clear depth differences and started to avoid photographing people because they looked unnatural in 3D photographs. They also regarded flash-induced shadows and edge violations problematic because of the unnatural effects in the photographs. We propose in-camera assistance tools for 3D cameras to make 3D photography easier.

Keywords Stereoscopic · 3D · Cameras · Usability · Acceptance · Disparity · Motivation · Experience · Learning · Photographing

1 Introduction

Stereoscopic 3D cameras are not popular. At the time of writing this article, the two largest [42] U.S. consumer technology retailers Best Buy (Richfield, Minnesota, U.S.) and Wal-Mart (Bentonville, Arkansas, U.S.) did not have a single 3D product among their 100 best-selling cameras or mobile phones. The reasons for the prevalence of 2D over 3D are most likely numerous. For example, only few 3D camera models are readily available, and viewing the photographs requires a 3D display, which raises the price of the investment. The 3D television market, however, has been growing steadily for the past few years, and almost 30 % of the TVs sold today are 3D capable [30]. With new developments in display technologies, such as a new glasses-free technology suitable for mobile devices [5], 3D displays might also achieve wider acceptance in other product areas. In this article, we approach the problem from the camera users' perspective and focus on discovering such HCI issues in 3D photography and the cameras, which camera manufacturers can improve.

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Before the time of automatic cameras, capturing 2D photographs required particular skill. The photographer had to manually set the aperture and shutter speed based on available light or rely on fixed aperture and shutter speed cameras that could only be used in daylight. The first simple fixed setting camera produced was the Kodak camera in 1888, which together with the Kodak process made domestic photography popular [32]. The photographers only needed to press a button to take photographs and then send the camera, or later the film, to the photo finishing service and wait for their printed photographs to arrive by mail. The shift to color photography did not take place immediately when color film was made available but occurred more than two decades later, in 1963, when Kodak introduced the Instamatic camera that made film loading effortless. In the 1970s, Japanese manufacturers made photography even easier by introducing a microprocessor in the camera to automate some tasks, such as focusing and exposure measurement, and by doing so, they challenged Kodak's market dominance. These historical events show that the camera has evolved primarily with changes that simplify the photography process. While digitalization and the camera phone have since changed the ways we take, use, and share photographs, the basic principle of 2D photography is still the same.

Three-dimensional cameras differ from 2D cameras in that they have two horizontally separated lenses that create two photographs from slightly different perspectives. A 3D display shows a separate image to each of the viewer's eyes and thus makes three-dimensional perception possible. The geometry of the camera and the display sets limits for the photographed scene, and exceeding the limits can render the 3D photograph unusable. A skilled 3D photographer can avoid these problems, but a novice is likely unaware of the limitations. Instead of simplifying photography, 3D has made it more complicated. We hypothesize this is one of the reasons 3D photography continues to be unpopular.

We conducted a four-week field study to discover the reasons why users have not embraced 3D photography and how the camera can be improved. We equipped five participants with 3D cameras and 3D displays and collected data about their experiences using a weekly questionnaire and a thorough exit interview. The participants uploaded their photographs to a web service, and we characterized the photographs after the experiment. The characterization consisted of semantic categorization, global property ranking, and computational stereoscopic disparity measurement.

In the Related Work chapter, we introduce the principles of 3D photography and the problems and benefits found in other studies. We also consider recent changes to, motivations for, and adoption of 2D photography and technology acceptance in general. The findings of the study are presented within a framework based on the UTAUT2 [47] technology acceptance model.

2 Related Work

2.1 Three-Dimensional Photography

We perceive 3D images as three-dimensional because our left and right eyes see a slightly different image. The difference in the images is called stereoscopic disparity, the distance between corresponding points in the left and right images. In a 3D camera, this disparity is achieved by projecting the scene through two separate lenses. The resulting photographs can be viewed on a 3D display, which directs each photograph to the corresponding eye of the viewer. Figure 1a and b illustrates the basics of stereoscopic 3D viewing. The larger the disparity, the further behind the display plane the object appears to be. If the disparity of an image point is negative, the point appears in front of the display, closer to the viewer. If the eyes of the viewer accommodate on the display plane to bring the image to focus, but converge at a different distance, an accommodation and convergence mismatch occurs, which causes visual discomfort [21]. If the disparity exceeds a certain limit, the human visual system can no longer fuse the images into a single percept. The image is then perceived as diplopic, a double image.

While the limits of disparity depend on several factors, such as object size, sharpness, and eccentricity, a common rule of thumb in 3D production is to limit the disparity to one degree of viewing angle [49]. The disparities in the photograph depend on the focal length used, the physical distance between the left and right lenses of the camera, and inversely on the distance from the camera lenses to the points in the scene. In current 3D cameras, the distance between the

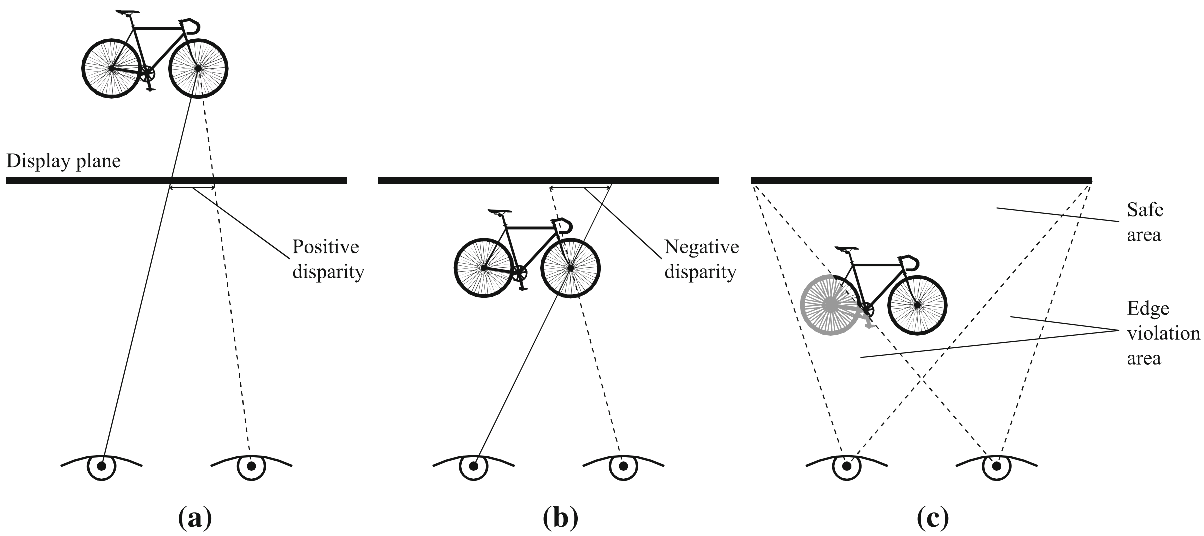

Fig. 1 Stereoscopic disparities, accommodation–convergence mismatch, and edge violation. Depending on whether the disparity between the corresponding points in the *left and right eye images* is positive or negative, the point is seen behind (**a**) or in front of (**b**) the display plane, respectively. The eyes focus on the display plane, but the convergence point is behind (**a**) or in front of (**b**) the display; thus, accommodation and convergence provide conflicting depth cues. **c** illustrates edge violation. The bicycle is only partially visible to the right eye, as the left edge of the display frame cuts out the rear wheel, marked in *gray*

lenses is fixed and focal length is limited. Thus, the photographer must make sure that the distance to the scene is not too short. Photographs with too large, or too small, disparities are considered unnatural [16]. Common 3D artifacts include the puppet theatre effect and the cardboard effect [24]. The puppet theatre effect is visible when the perceived angular size of the background does not match the perceived depth. Usually the space appears to be smaller than it actually is, hence the name 'puppet theatre effect'. The cardboard effect, where the perceived depth is not continuous but consists of discrete planes, can be caused by several factors, such as too small disparities, capture resolution, display resolution, or image coding. Edge violation, illustrated by Fig. 1c, is caused by objects in front of the display plane that are entirely or partially cropped by the sides of the display frame [41].

The three-dimensional viewing experience has been studied in different domains, such as still images [36], video [6, 15] and gaming [33, 40]. The results indicate that users prefer 3D content for its added naturalness and immersion, but the perceived benefit of 3D is content dependent. Shin and Baek [39] studied the acceptance of a 3DTV learning system. They found that immersion, flow, and presence had a positive effect on attitudes in their study. Consumer stereo cameras have received less attention, and only few studies have addressed the design of 3D consumer cameras. Montgomery et al. [26] suggested that there should be an LED in the camera to indicate whether 3D conditions have been breached. To the authors' knowledge, no studies have examined the effects of stereoscopy on domestic photography or the acceptance of 3D photography.

2.2 Technology Acceptance

Scholars have developed several models for acceptance of information and communications technology during the past decades. The basic principle of most of these models is that an individual's reactions towards a technology affect the intention to use the technology. The intention, sometimes together with the reactions, affects the actual use of the technology, which in turn creates new reactions. Based on eight technology acceptance models, Venkatesh et al. [46] developed the Unified Theory of Acceptance and Use of Technology, UTAUT. The model consists of four principal constructs that affect the behavioral intention, which in turn affects the use behavior. Drawing from other models, the authors identified performance expectancy, effort expectancy, social influence, and facilitating conditions as the most significant constructs in their studies. The four constructs' effects are moderated by four internal variables: age, experience, gender, and voluntariness.

As UTAUT was developed for acceptance of information technology in an organizational context, the model cannot be directly applied in the consumer space. The nature of consumer products is often more hedonic than utilitarian when compared with information systems in organizations. In hedonic information systems, the importance of usefulness has been shown to diminish, and instead, ease of use and enjoyment are more dominant [44]. UTAUT was further developed into UTAUT2 [47] to also be valid in the consumer space and for a wider range of technologies. The development included the addition of hedonic motivation, price value, and habit as new constructs affecting behavioral intention and the exclusion of voluntariness from the moderating factors.

Technology acceptance models have been criticized for being too simple and overlooking some psychological aspects of use intention and use behavior [1]. Bagozzi suggests that in behavior modeling, one should not focus so much on use, but instead on goals. Zhang et al. [50] studied the roles of attitude in technology acceptance and found that the use of the term "attitude" is not consistent in literature. The authors attribute the exclusion of attitude from technology acceptance models to this inconsistency. They call for a clear distinction between attitude towards behavior and attitude towards objects and the accurate conceptualization and operationalization of the two.

In this study, we chose to use UTAUT2 as a framework because the model's constructs have explained variance in behavioral intention and technology use quite well: 74 and 52 %, respectively, in a mobile Internet study [47]. We address the concerns about use intention and attitude by replacing hedonic motivation with the more clearly defined intrinsic motivation as defined by Vallerand and Ratelle [43]. They have developed a useful taxonomy of intrinsic motivation, IM: IM to know, IM to accomplish, and IM to experience stimulation. IM to know stems from "learning, exploring, and understanding new things," IM to accomplish stems from "trying to surpass oneself, creating, or accomplishing something," and IM to experience stimulation stems from "the stimulating sensations associated with [the activity]."

2.3 Camera Adoption and Motivations for Photography

The intentions behind domestic photography have been categorized in two dimensions: affective-functional and individual-social [18]. Affective individual intentions include photographs taken for personal reminiscing and affective social intentions, for example, photographs taken from a party to share with absent friends. Functional photography supports another task. Functional individual reasons include, for example, taking photographs of gift ideas while shopping, and functional social reasons such as taking a photograph of a new product and sending it to a friend as a recommendation. Compared with film photography, digital photography has become less about recording special moments of domestic life, such as holidays or gatherings, and more about recording fleeting, small and mundane events [27]. Memory, communication, and identity construction are still the main motivations for digital photography, but the balance is shifting towards more formative and communicative uses [45]. The shift towards social motivations and the importance of sharing is evident particularly in the use of Internet-enabled camera phones [34]. By sharing photographs from camera phones, people can actively shape their identity and share their experiences with postcard-like photographs. In addition, the practice and experience of domestic photography have potentially become more important than the pictures themselves [3].

2.4 Assisted Photography

Digital consumer cameras include several assistive features to help photographers capture better photographs. These features include automatically setting the camera parameters, such as aperture size and shutter speed, depending on the scene luminance as well as more sophisticated features, such as face and smile detection. Face detection is used with autofocus to ensure that faces are in focus and exposed properly, and smile detection is used in the "smile shutter" [48] to capture a photograph when the subjects are smiling. Researchers have proposed several new features to help photographers take photographs that are more aesthetic by preventing common compositional mistakes and helping them follow photography composition rules. Since the development of an autonomous photographer robot [4], algorithms have also been developed for cameras operated by people. Most proposals include the rule of thirds, but background blurring [2], detecting dissection lines [38] and capturing a dominant diagonal in the photograph [23] have also been proposed. Some algorithms have aimed at maximizing the overall aesthetic value of the photograph by finding the optimal view rectangle [29]. Current 3D cameras do not specifically assist the photographer in taking good 3D photographs; at best, they only include the assistive features inherited from 2D cameras.

3 Aim of This Study

Our research question is the following: what are the current issues with 3D photography that contribute to the acceptance of the novel technology? We expect users to encounter several 3D-related problems with photography because of the geometry of 3D photography. The stereoscopic disparities of the photograph depend on the shooting distance and the distance between the camera lenses. The human visual system limits the size of the disparities we can fuse into a single percept, and disparities that are close to the limit cause eyestrain. As the camera does not include any assistive technology that could prevent too-large disparities, we expect the users to take photographs with large disparities, especially in the beginning of the trial. When the users gain experience, they might learn the limitations of 3D photography. Another likely problem is edge violation, which occurs regularly when photographing natural scenes and which the camera does not prevent. We also expect that users will attribute the failures to 3D photography, and thus, it will have a negative influence on their intention to use the technology, which the UTAUT2 model formulates as the effort and performance expectancies' influence on behavioral intention.

4 Methods

To investigate stereo camera use, we conducted a four-week user study. We interviewed the participants afterwards and used photo elicitation [12] with the participants' own photographs. In addition to analyzing the photographs, we also analyzed the participants' perceptions of their camera use during the trial. Figure 2 illustrates the trial process. Our exploratory approach combines quantitative and qualitative analyses of the issues that beginners have with 3D photography. We selected methods that minimized the exposure of the participants to presuppositions and thus did not use predefined technology acceptance questionnaires.

Based on the findings of Guest et al. [9] who suggest that even a small number of interviews is enough to find the main themes on a subject, we decided to use a small sample in conjunction with a long trial duration. Before the trial, we conducted thorough vision testing and a pre-questionnaire. The pre-questionnaire consisted of questions about demographics, photography and 3D experience, and a six question set to determine the innovativeness score [7], which was adapted to the consumer technology domain. We equipped five female participants, pseudonyms Alice, Betty, Carol, Donna, and Emily, or A, B, C, D, and E, with 3D cameras, 3D displays and the required viewing software for 4 weeks. Table 1 shows their pre-questionnaire data. The participants were 18–26 years old and were either studying for or held an academic degree. They were not advanced photographers and had no experience with stereo photography. All but one participant had seen some 3D content prior to the trial. Carol's innovativeness score was slightly below average, and the others' scores were slightly above. All participants had normal or corrected to normal visual acuity, 20/20 or better, and normal stereo acuity, 60 arcsec or better. Each participant received 16 lunch vouchers for their participation.

The camera used in this study was a Fujifilm Real 3D W3 (Fujifilm Corporation, Tokyo, Japan). It records left and right photographs in separate image files, each 3,648 by 2,736 pixels. The camera features a built-in 3D display, but we also gave the participants separate 3D displays for the duration of the trial so that they could view their photographs. Betty used a Hyundai P240W (Hyundai IT, Icheon, South Korea) display, Carol used a Zalman Trimon M220W (Zalman Tech Co., Ltd., Seoul, South Korea), and the others used a Fujifilm Real 3D V1 photo frame.

We instructed the participants to use the camera freely but to take photographs on at least 3 days during each week and a minimum of 20 photographs per week. The participants uploaded the photographs to

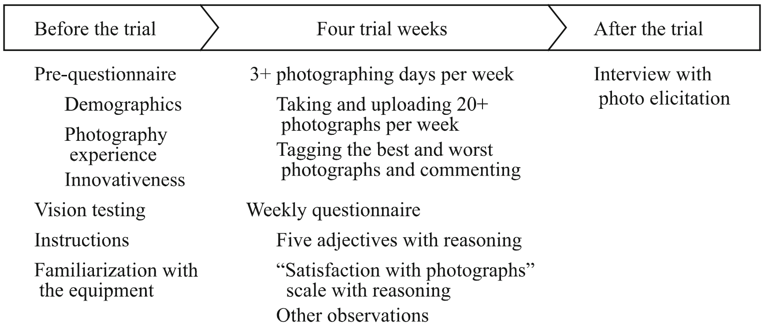

Fig. 2 Trial procedure. Prior to the trial, we screened the participants based on their vision test and pre-questionnaire results. We instructed the participants to take photos on at least 3 days each week and take at least 20 photographs each week. They filled in a weekly questionnaire on which they described their photography with five adjectives and explained why they chose those adjectives. After the trial, we interviewed each participant

Table 1 Pre-questionnaire data including demographics, photography and 3D experience, and innovativeness score [7]

	Alice	Betty	Carol	Donna	Emily
Age	21	23	26	20	18
Education	MSc student	MSc student	MSc	BSc student	BSc student
How much do you know about 3D?	Nothing	Nothing	Basics	Basics	Nothing
How much do you know about 3D photography?	Nothing	Nothing	Nothing	Nothing	Nothing
Have you ever taken 3D photographs or video?	No	No	No	No	No
Have you ever seen a 3D movie? How many?	Three	One	One	Four	None
Have you seen other 3D content? What?	Some 3D toys and in a science center	3D pictures with red-green glasses	No	A 3D game and some pictures	No
How interested would you be in using a 3D camera in the future? (1–5)	Moderately (4)	Moderately (4)	Moderately (4)	Moderately (4)	Very (5)
How would you evaluate your photographic skills? (none, basics, average, skillful, expert)	Average	Average	Average	Basics	Basics
How often do you take photographs? (daily, weekly, monthly, yearly, never)	Monthly	Weekly	Monthly	Weekly	Weekly
Innovativeness score (6–30)	20	21	14	19	20

the Picasa web service (Google Inc., Mountain View, CA, USA). We asked them not to delete any photographs and instructed them to select the best and worst shots each day by tagging them in Picasa and adding a short comment about their reasons for the selection. The number of best and worst photographs selected by a participant varied from 10 to 16. The selected photographs were used in the photo elicitation process as a starting point for the discussion. The participants filled in a weekly questionnaire about their experience with 3D photography. In the weekly surveys, the participants described their camera use with five adjectives and an explanation for each adjective. They also rated how satisfied they were overall with the photographs on a discrete scale from 1 to 10 and gave reasons for their rating.

After the trial, we used a laddering structure in the exit interviews, where we asked the participants to

Table 2 The semantic categories [25] of photographs by subject (A–E)

Category	A	B	C	D	E	Sum
People	13	**61**	30	17	28	149
C1 Portraits	2	1	2	1	0	6
C2a People outdoors	0	10	10	0	7	27
C2b People indoors	5	22	1	11	12	51
C3 Outdoor scenes with people	0	0	13	0	4	17
C4 Crowds of people	6	28	4	5	5	48
Urban environments	**33**	**28**	11	**51**	**37**	160
C5 Cityscapes	14	1	3	16	25	59
C6 Outdoor architecture	7	18	4	11	8	48
C7 Techno-scenes	12	9	4	24	4	53
Objects	19	12	**61**	**47**	**43**	182
C8a Objects indoors	5	6	27	2	18	58
C8b Indoor scenes with objects	10	3	29	30	18	90
C9 Objects outdoors	4	3	5	15	7	34
Scenery	13	9	10	12	13	57
C10 Waterscapes with human influence	0	0	0	4	0	4
C11 Landscapes with human influence	3	7	8	8	8	34
C12 Waterscapes	0	2	0	0	2	4
C14 Sky/Clouds	0	0	0	0	1	1
C17 Landscapes with fields and foliage	10	0	2	0	2	14
Plants	**44**	13	7	5	21	90
C18b Plants outdoors	42	7	2	3	12	66
C18c Plants indoors	2	6	5	2	9	24
Other	3	0	**53**	1	4	61
C19 Animals and wildlife	0	0	53	0	0	53
C20 Textures, patterns and close-ups	3	0	0	1	4	8
Sum	125	123	172	133	146	699

The two largest category groups for each participant are marked in bold, and categories with no photographs are omitted

reflect on their photography during the trial. The interview themes were the photography in general, the photographic subjects and situations, the camera design and usability, and the photographs taken. Within our interviews, we used photo elicitation to enhance the participants' recollection and to help them describe their experiences. The interview and photo elicitation data were transcribed and coded in Atlas.ti (Atlas.ti GmbH, Berlin, Germany) using a grounded theory approach. Two researchers participated in the code specification and coding work, which resulted in 744 quotations and 84 codes. We also coded the participants' reasons for selecting a photograph as the best or the worst. From the codes, we formed themes, which we assigned to the constructs of the framework: performance expectancy, effort expectancy, facilitating conditions, intrinsic motivation, experience, and habit.

The subjects of the photographs were typified by categorizing the images using a scheme of 20 semantic image categories [25]. Two researchers categorized each image through a consensus process [31], in which they decided the final category by discussion if there was a disagreement about the category in their individual coding. We also evaluated the scene's mean depth [8] for each photograph on a discrete scale from 1 to 5. The stereoscopic disparities were measured using local feature matching to find the corresponding points from the left and right photographs. We then categorized the photographs into two

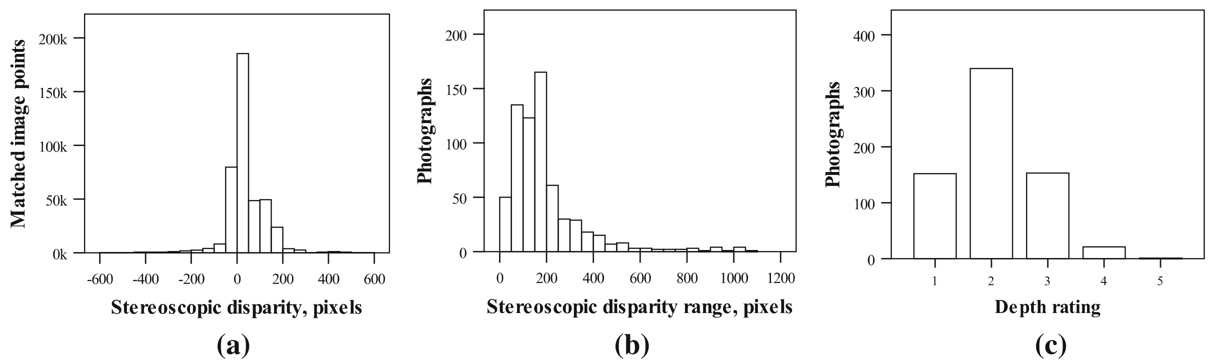

Fig. 3 **a** Stereoscopic disparity distribution of all the matched image points. **b** Stereoscopic disparity range distribution of all the photographs, i.e., the difference between the minimum and maximum disparity within a photograph. **c** Mean depth ratings of the depicted scenes in all photographs

categories based on whether the maximum disparities violated the 1° rule of angular disparity [49].

5 Results

5.1 Scenes and Subjects

The participants took 699 photographs during the trial, 123–146 photographs each. Table 2 shows the result of the semantic categorization. The three largest subject category groups were objects (26 %), urban environments (23 %), and people (21 %). All participants took several photographs in these groups, with some individual differences. Betty took more photographs of people than the others did, due to her group-dancing hobby. In addition, they all photographed plants often, particularly Alice, who took several photographs of foliage outdoors. Carol photographed her dog on many occasions, while others did not take any photographs of animals. A third of the images depicted a complex man-made structure, such as a staircase or a bicycle.

Figure 3a illustrates that the stereoscopic disparities in the images were mainly positive. Of the matched disparity points, 57 % were positive, 36 % negative, and 7 % near zero disparity, meaning that the majority of the points were perceived as located behind the display plane. Figure 3b shows that the disparity range in each image, i.e., the difference between the nearest and farthest objects' disparities, ranged from a few pixels to over 1,000 pixels, with a median of 156 pixels. The photographs typically portrayed enclosed scenes, bound by surfaces and objects, as opposed to open views showing the horizon. The mean depth of the scenes as defined by Greene and Oliva [8] was 2.1 on scale of 1–5, with nearly half of the scenes with a mean depth rating of 2, as shown in Fig. 3c.

5.2 Performance Expectancy

The interviews and weekly questionnaires contained several themes that contribute to the acceptance of 3D photography, and they are summarized in Table 3. All participants considered three-dimensionality to be a requirement for a successful 3D photograph. Everyone except Carol said that they did not want to take two-dimensional photographs with a 3D camera. Donna said that she wanted to use the full potential of the camera, and if the photograph did not look three-dimensional, then all the potential was not used. Table 4 shows the codes of the participants' reasons for selecting a photograph as the best or the worst of the session. Three-dimensionality was also the most common feature used to describe the best photographs, while the lack of 3D was often the reason for selecting a photograph as the worst. Photographs that looked like they could have been taken with a regular camera were considered failures. All the participants commented that at long distances three-dimensionality was lost. Some photographs were partially three-dimensional; for example, the foreground looked three-dimensional but the background looked two-dimensional. Betty commented that the photograph should be fully 3D or not at all. Another problem

Table 3 The main themes of stereoscopic photography acceptance in this trial, drawn from the interviews and weekly questionnaires

Performance expectancy	Effort expectancy	Facilitating conditions	Intrinsic motivation	Experience and habit
Three-dimensionality (5)	Ease of operating (5)	Integrated 3D display (3)	Testing the 3D (5)	Learning suitable distance (5)
Naturalness and realness (5)	Difficulty finding viewing position (5)	Automatic camera settings (2)	Immersion (5)	Learning suitable subjects (5)
Double images (5)	Cumbersome file transfer (5)		Interestingness of extra information (5)	Camera orientation (2)
Cardboard effect (5)	Finger in front of lens (5)		Capturing a moment or atmosphere (5)	
2D degradations (5)	Difficulty sharing (3)		Novelty (5)	
Unnatural flash shadows (3)	Difficulty succeeding in 3D (3)		Memory (4)	
Edge violations (2)			Fun (3)	
Unnatural depth of field (2)			Sharing and receiving comments (2)	

The number of participants out of five participants who reported the issue is in parentheses. Issues mentioned by a single participant are not included

Table 4 Codes of the participants' responses about why they selected a photo as the best or worst of the day

Worst photographs	*N*	Best photographs	*N*
Boring	10	Three-dimensional	13
Too close	9	Structures and shapes	8
Blur	8	Natural, real	8
Double image	7	Feel	5
Strained viewing	6	Color	5
No 3D	5	Fun	4
Bad composition	5	Depth variance	4
Unnatural	4	Angle	4
Flash	4	Interesting	3
Cardboard effect	4	Lighting	3
		Sharp	3
Zoom, orientation, foreground, shadows, flashing, dark, angle	1–2	Transparency, immersion, wow, reflections, moment, informative, detail	1–2

reported by all was that in some photographs, the 3D effect was not continuous; the photograph consisted of discrete depth layers. This made people look like cardboard cutouts. "People are not good subjects because they look flat like cardboard, somehow not real at all" (Alice).

The preference for three-dimensionality led the participants to attempt to maximize the 3D effect in their photographs. All participants said that, in their experience, the best scenes included some depth variance. The depth variance could arise from objects at different distances, continuous depth change, or depth within a single object. Alice, Carol, and Donna said that transparent and reflective surfaces looked compelling in 3D, as they conveyed the depth seen behind the surfaces. Alice, Carol, and Emily had included 2D depth cues, such as a clear vanishing point of a road or corridor, in their photographs to enhance the 3D effect. "This picture had kind of a continuous depth and different objects. Somehow the perspective and 3D act together really nicely" (Alice).

Betty noticed that in some photographs, the perceived scale was different from reality. In one instance, she mentioned that a tree in the photograph looked like a flower, and in another instance, a spacious room looked cramped in the photograph. Alice and Carol noted that the depth of field was unnatural in 3D photographs. When viewing the photograph, they could focus their eyes on objects at all depths at the same time, which was not possible when viewing the real scene, as the eyes are always focused on a certain distance. Alice and Carol also noticed that often the objects on the edges of the photograph had a somehow degraded 3D effect, indicating a stereoscopic edge violation. "In reality one could not focus on that rock and the background at the same time; the photograph is sharp in too many places" (Carol).

All participants described seeing double images when viewing their photographs. They described the effect as seeing double, images not converging, or the image breaking. Often, some part of the image was perceived as a double image, while other parts of the image were considered normal. Betty, Carol, and Donna mentioned that the double image was particularly annoying if the photograph was otherwise good. All participants had noticed that objects in the foreground at close distances usually cause double images. They described the photographs with double images as annoying, ruined, unpleasant, disturbing, unstable, unclear, garbled, flickering, or difficult to look at. Double images and too-close distances were also common reasons to choose a photograph as the worst of the session (Table 4). The evident consequence of the double image was that the 3D effect was lost or degraded. “It is difficult to look at… or I can see it as double image. It is very difficult to see it as 3D” (Betty).

Conventional image quality was also discussed. Donna and Emily talked about the composition and framing of the photograph. They considered the photograph unpleasant if the subject was partially cropped, unless the framing followed the rule of thirds or was symmetrical. Unintentional tilt also disturbed them in some photographs. All participants mentioned blurriness in their photographs. Insufficient lighting was the main cause of blurring for Donna, while the others mentioned movement as the main cause. Alice and Betty said that blurring occurred at close distances. Alice also said that the cardboard effect was not as obvious in blurry photographs. Betty, Donna, and Emily mentioned colors in the photographs. They generally preferred clear and bright colors to dark and gray colors and thought that some colors were more interesting than others. Betty and Emily also mentioned the fidelity of the colors. Some colors did not look natural in the photographs and made the photographs look less real. “The colors are quite distorted; it would be much nicer if the pictures were more natural” (Emily).

The participants discussed the camera’s zoom, macro, and flash. Alice and Emily mentioned that using the camera zoom made the photograph blurry and grainy. Alice said that using the zoom degraded the 3D effect. Emily wanted to capture macro photographs but did not succeed because even though the macro mode enabled her to focus to a close distance, the 3D did not work at close range. Betty, Carol, and Emily discussed the camera flash. The participants thought that the photographs they took using the flash were boring and unnatural. The sharp shadows created a second outline of the subject and disrupted the 3D effect according to Carol. Betty described the highlights created by the camera flash as disturbing. The photographs taken with the flash were disappointing for Emily because they did not convey the atmosphere of the moment that she attempted to capture. “I could take better photographs without the flash. Often the shadows somehow interfered with the 3D” (Carol).

Three-dimensionality, when it worked well, made the scene look more natural and real than in conventional photographs. All participants had succeeded in capturing some such photographs, and they valued the naturalness and fidelity of the best photographs. They also mentioned that in some photographs, the three-dimensionality aided in capturing the atmosphere of the moment. In contrast, Emily said that in most photographs the visible discrete layering reminded her of cartoons, which made the photographs unnatural, particularly if there were people in the scene. Alice and Betty were also disappointed by photographs of people. Betty said that people in the photographs looked out of place, almost like wax figures. She thought that the lack of movement was the reason why people looked strange in the photographs; she was half-expecting them to move. Alice mentioned that the proportions in depth looked strange in photographs with people. In one photograph, the distance of the subject’s chin from the neck appeared so long that it looked to her like the head was not attached to the body.” When I took photographs of people, they did not look real; there was kind of a stagnant feeling to them” (Betty).

5.3 Effort Expectancy

Everyone said that the camera was like a regular point and shoot camera and that it was easy to operate because of the familiar physical design and user interface. All participants also mentioned that it was easy to accidentally put one’s finger in front of a lens because they were not used to having two lenses in a camera. For Carol, the lens on the left side caused more trouble, while Betty had more trouble with the lens on the right. Betty, Donna, and Emily said that while it was easy to take photographs, it was difficult to know what would look good in 3D. “The design was slightly impractical. I took many photographs where you can see reflections from my fingers on the edges" (Carol).

Viewing the photographs was challenging. All participants had trouble seeing some of the photographs in 3D. In some cases, the problem was a failed photograph, which caused diplopia, but sometimes, effort was required to see even successful photographs in 3D. They all had experienced visual discomfort when viewing some photographs. Alice, Carol, and Donna sometimes found it difficult to know whether the photograph caused the viewing trouble or whether they were not in the correct viewing position. Carol and Donna also disliked the glossy display surface, which caused reflections and made viewing the 3D photographs even more difficult. Everyone was dissatisfied with the process of transferring the photographs and the requirement of a separate 3D display. "I can view ordinary photographs just by looking. Of course, I want this to be as effortless" (Betty).

Alice, Carol, and Donna would have wanted to share their photographs with their friends, but they felt that sharing was too difficult. Because their friends did not have 3D displays, they could not view the photographs online. The participants felt that viewing the photographs at home with friends was impractical because their friends had to physically visit them, and the displays did not allow multiple people to view the photographs at the same time. Alice and Donna also mentioned that the difficulty in finding the best viewing position made sharing even more awkward. "It would have been fun to talk about the photographs with friends, but it was difficult because only one person at a time could view the photograph" (Alice).

5.4 Social Influence and Facilitating Conditions

Only Carol's interview revealed some indication of social influence. Carol's husband had expressed interest in the 3D camera and the technology in general, and they had explored 3D content together. He was moderately skeptical about the technology, and Carol shared his view. She also considered it beneficial that other people did not notice that her device was not an ordinary camera because she did not want to explain it to others.

The participants mentioned facilitating conditions for photography in the interviews. Betty, Carol, and Donna mentioned that the integrated 3D display on the camera helped them because they could view the photograph immediately in 3D and verify whether it was successful. All participants had only used the automatic settings throughout the trial, i.e., the camera controlled the aperture, shutter speed, ISO speed, and white balance, but Betty and Emily were the only ones who mentioned this. They said that it made photography easy, but Betty added that even though taking photographs was easy with the automatic settings, it was difficult to capture successful 3D photographs. None of the participants mentioned the warning feature of the camera, which is designed to prevent the user from accidentally putting their finger in front of the lens. The warning signal was a red symbol in the bottom right corner of the LCD viewfinder. "It was easy to take photos; I used the automatic camera setting, so that was fine. But to get everything just right in the picture, that was not always so easy" (Betty).

5.5 Intrinsic Motivation

5.5.1 To Know

The participants described multiple motivations for their photography in the interviews. All five participants were interested in testing the 3D camera's capabilities and curious about what different photographic scenes look like in 3D. They attempted to identify photographic scenes for which the 3D effect was most impressive. Donna mentioned several times that she wanted to find scenes where the entire potential of the 3D camera was used. Betty, Donna, and Emily said that they took pictures of things that they would not normally photograph, just to see what they look like in 3D. "Actually, no matter what the subject was, I could then study what it looks like in 3D" (Betty).

All the participants said that the 3D photographs contained more information than conventional photographs. The participants described the extra information as scene details, object relations and distances, object form, or just as "something extra". They said that finding additional information in the photographs was interesting and exciting. Carol and Donna mentioned that the interestingness made them view the photographs for a longer time, as they visually explored the details of the scene. All the participants also thought that the three-dimensionality itself made the images more interesting. "You cannot take that kind of an image with an ordinary camera; it is the effect that makes it interesting" (Emily).

5.5.2 *To Accomplish*

All the participants mentioned capturing the atmosphere of a moment as important. Betty, Carol, Donna, and Emily considered a photograph to be a memory of a specific situation. Often, this was mentioned in the context of photographs of people, where capturing the emotions of the subjects was perceived as important. Therefore, Betty and Donna wanted to capture the facial expressions and gestures of people. Donna and Emily mentioned that looking at a photograph later made them feel good if the atmosphere of the situation was conveyed by the photograph. Emily said that she wanted to remember how she felt in the situation. The photograph could also function as a memory of a broader timeframe. Betty and Donna discussed the idea of returning to look at the photographs in the future to see how people have changed and to remember the people in their life at that time. "I want to save some important moments in my life anyway so that later I can recall what that moment felt like" (Emily).

Carol and Donna mentioned that they wanted to take photographs so that they could share them with other people on a social networking website or at their home. Carol talked about sharing the photographs with other dog owners and the people who had attended the same events. Donna mentioned sharing holiday photographs with groups of friends as an example. The motivation to share the images was related to the desire to receive comments in both cases. Carol felt that sharing and receiving comments increased the feeling of togetherness. "Generally, it's really nice to be able to share your experiences and also to get other people's comments on them" (Donna).

5.5.3 *To Experience Stimulation*

All participants reported experiencing some level of immersion while viewing the photographs. They said that they felt some objects coming towards them, as if they could touch the objects or step inside the photograph. Donna said that sometimes she felt almost like being part of the scene, and Alice described looking at a 3D photograph as almost like looking out a window. Often, the immersive photographs were also the most impressive and considered the most successful. Everyone also discussed the novelty of the experience. They said that the 3D had surprised them positively at some point, often early in the trial. Alice, Carol, and Donna described having taken images with "negative space," that is, perceiving objects in front of the display plane, which they thought was exciting. "I am part of that world; it is not just an image" (Donna).

Alice, Betty, and Carol said that they had fun while taking the photographs. Betty and Carol said that it was fun to take photographs of everyday objects and explore their appearance in the photographs. Contrarily, Emily said that overall, she did not have a fun experience, although in the beginning of the trial, she did have fun. She said that the reason for the negative experience was that the photographs were too unnatural due to the cartoon-like effect. Carol said that she was skeptical about the 3D technology. Although it was fun to take the photographs, she did not feel the need to take photographs in 3D after the experiment. "In a way it was fun, because I could photograph anything. So I photographed things that I normally wouldn't" (Alice).

5.6 Experience and Habit

Each week, the participants described their photography with five adjectives, which are presented in Table 5. At first, the novelty of 3D photography appealed to the participants. During the first week, all participants described their photography as interesting or exciting. On the second week, three of five participants still used the same adjectives, and by the fourth week, nobody used adjectives to describe interestingness or excitement. By the third week, some participants began commenting that the novelty of the camera was wearing off, a comment that was common to all by the end of the trial. They already anticipated the 3D effects, but some participants still found their photography to be fun and rewarding at the end of week four. The positive effect of novelty is evident also in the participants' satisfaction with their photographs, as illustrated in Fig. 4a. Four of five participants were more satisfied with their photographs in the first week than the second week of the trial. In the interviews, Alice, Donna, and Emily confirmed that in the beginning, taking photographs was exciting or interesting. Alice, Carol, and Emily said that they grew bored with the 3D during the trial.

Table 5 Participant-given adjectives describing their camera use during the four trial weeks

P	Week 1	Week 2	Week 3	Week 4
A	**Curious**, varied, forgetful, artistic, enjoyable	Forgetful, lazy, successful, deliberate, consistent	Routine, creative, forgetful, varied, *bored*	Routine, coincidental, successful, consistent, lazy
B	Different, fun, new, **exciting**, useless	Lazy, experimental, **exciting**, labored, nice	Busy, speechless, experimental, self-indulgent, fun	Fast, *tired*, educational, routine, fun
C	Scarce, **interesting**, difficult, useless, indistinguishable	Artificial, apt, dark, simple, lazy	Apt, sloppy, repetitive, dark, smooth	Lazy, impractical, repetitive, easy, *boring*
D	Novel, difficult, **interesting**, varied, handy	Routine, challenging, everyday, easy, **interesting**	Different, routine, ordinary, empowering, moody	Challenging, bursty, routine, fun, different
E	Easy, experimental, disappointing, lazy, **interesting**	Frustrated, evasive, expectant, prejudiced, **curious**	Familiar, insightful, annoying, fun, scarce	Complicated, fun, *tired, boring*, challenging

Interest and excitement are marked in bold, and boredom and tiredness are in italic type

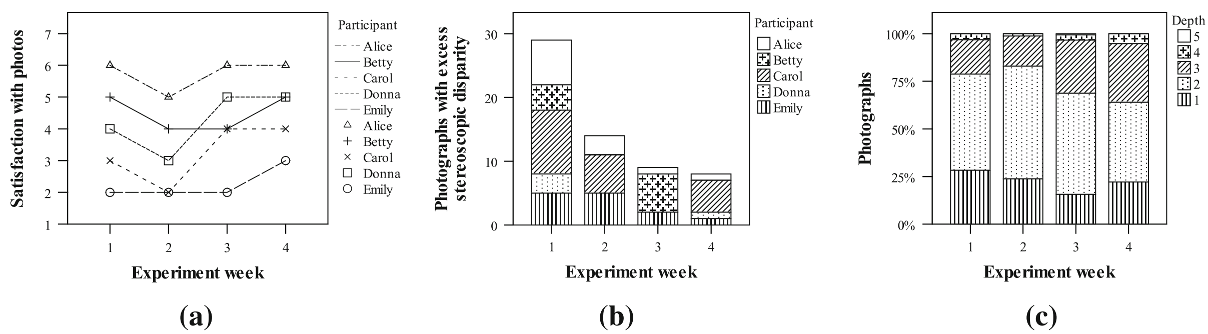

Fig. 4 **a** Participants' ratings of satisfaction with their photographs on a scale of 1–10. **b** Photographs with excess disparity. **c** Mean depth ratings of all photographs

"I like to take photographs, but it was not that fun to take 3D photos. At first, the 3D was fun, but I got bored with it really quickly" (Emily).

The participants experienced the most problems with 3D photography during the first week. Alice, Betty, and Donna commented on the difficulty of finding suitable shooting distances, a problem that all participants reported at some stage of the trial. Donna and Emily were happy to capture at least some pleasing 3D photographs. By the end of the study, Carol and Donna had managed to make the 3D effect work, Betty was able to shoot basic 3D photographs, and only few of Alice's pictures failed. The decreasing trend in the excess stereoscopic disparities of the photographs taken at too-short distances, as illustrated in Fig. 4b, shows evidence of the learning period. The number of photographs that failed due to excess disparity decreased 70 % on average after 4 weeks, while the number of photographs taken in a week decreased by only 7 %. The mean depth of the scenes also shows a weak trend towards longer distances during the trial, as illustrated in Fig. 4c. Depth rating 3 shows a slight growth at the expense of the shallower depth rating 2, meaning that the participants took photographs at longer distances and thus avoided the excess disparities. The reported quality issues shifted from 3D issues to compositional issues and factors dealing with image interestingness. "When taking the pictures I didn't notice it, but later, when I was looking at them, it has been really disturbing, and I've thought to myself that I will not take any more photographs with objects so close to the camera" (Donna).

In addition to learning the suitable shooting distance, the participants had also discovered other aspects of the subjects that worked well in 3D, which changed their photography behavior. All participants said that people looked unnatural in 3D, but only Alice said that she had stopped taking photographs of people because of that. Carol, Donna, and Emily said that they had started preferring a slightly angled perspective, which enhanced the 3D effect, instead of taking photographs directly from the front of their subjects. Emily mentioned that initially she thought that landscape photographs would work well in 3D, but had found out that they did not look as good as she had thought. Betty and Carol had considered the sizes of the subjects and arrived at different conclusions. While Carol thought that the optimal size of subjects was from half a meter to one meter, Betty felt that large objects such as buildings looked better in 3D. All participants had learned that the scene should include enough details in depth to be appealing in 3D. Carol, Donna, and Emily said that they attempted to take photographs with enough detail, but not too much, because then the photograph became confusing, and the details could draw attention away from the subject of the photograph. "First, it was difficult to understand [which subjects work well in 3D], so I was just taking photographs and then checking whether they looked good or not. At some point, I started to see already before taking the photo which subjects would be worth shooting and which would not" (Carol).

Three-dimensional photographs can only be taken in landscape orientation with the camera used in this study because the 3D effect requires the horizontal differences. Alice and Donna took some photographs in portrait orientation and noticed that the 3D in the photographs did not work unless they rotated the photograph into landscape orientation. They commented that it was disappointing and that it took some time to get used to the fact that they could not shoot in portrait orientation. The participants developed habits related to the photographing process in the sense that they learned to use the camera and to take satisfactory 3D images routinely without needing to think as much as in the beginning of the trial. We found, however, no evidence that the participants would have incorporated 3D photography in their daily routine. "At first it took some time to realize that you cannot take photographs at close distances or in portrait orientation. It took me maybe a week or so to remember these two things" (Alice).

6 Discussion

6.1 Technology Acceptance and Recommendations

The 3D camera was easy to operate, as the participants could utilize their experience with 2D cameras. Still, they had trouble capturing successful 3D photographs because of the limitations of 3D photography that they were initially not aware of, such as the distance and framing limitations. In addition, even though the participants were familiar with the overall design, the second lens caused some trouble, regardless of the warning feature implemented in the camera. In this article, we consider the technical tools as facilitating conditions for 3D photography. The automatic camera settings and the integrated 3D display helped the participants, but we found no evidence of other 3D specific facilitating conditions, which was also evident from the difficulties the participants experienced. The implementation of in-camera assistance tools for 3D photography could significantly shorten the learning period.

To answer to our research question "What are the current issues with 3D photography that contribute to the acceptance of the novel technology?" we found several contributing factors. Table 3 summarizes our findings. Three-dimensionality became a requirement for a successful 3D photograph, and the successful photographs were more natural and real. This result is in line with other studies, where scholars have found that depth makes 3D images more natural, and naturalness is the main contributor to the overall 3D visual experience [35]. We found that the 3D impairments recognized in other studies, such as the cardboard effect, double images, and edge violations, are also problems in 3D photography. The double images were most troublesome for the participants, while the puppet theater effect caused only minor problems and did not completely ruin the photographs. During the 4 weeks, the number of failed photographs due to excess stereoscopic disparity fell significantly.

One solution to the problem of excess stereoscopic disparity is to move the lenses closer to each other. This modification would reduce the maximum depth effect obtainable by the camera, unless the camera design allows the distance between the lenses to change based on the scene depth or to have more than two lenses. In light field cameras, the light from the scene travels through the main lens of the camera as well as a micro-lens array, creating an array of photographs. From the array of photographs, it is possible to select stereoscopic image pairs with varying disparities. However, the size and field of view of the main lens limit the maximum disparity. Due to the geometric limitations, macro photography is not possible in 3D unless the camera lenses are very close to each other, and so the macro feature should not be available in 3D mode in cameras where the lenses are far apart. The distance between the lenses was 7.5 cm, which is quite long considering that another study has shown that the optimal distance for indoor photography is between two and six centimeters [20].

Our participants wanted to have a distinct 3D effect in all their photographs, including outdoor photographs with distant objects. Thus, mounting the lenses close to each other might not solve the problem satisfactorily because the 3D effect decreases as the distance between the lenses shortens. We propose the implementation of an in-camera assistance feature to inform the user of the resulting disparity distribution when he or she takes the photograph so that the user can avoid overly large disparities while creating interesting 3D effects. Similarly, an assistance feature would help to reduce edge violations and photographs taken in the wrong orientation. In professional 3D cinema production, stereographers can already use a similar assistance tool [51], and an automatic camera parameter adjustment system has been developed [19]. In addition, edge violations could be prevented by shifting the images so that content integrity is maintained [10].

We found that the unnatural depth of field of the 3D photographs disturbed some participants; the effects of this issue on the viewing experience require further study. Artifacts arising from the use of the flash also impaired the viewing experience. As the flash was between the lenses, it cast shadows that are not present in natural situations. This effect could also make fusing the two images into a single percept more difficult due to increased image differences; the object that casts the shadow occludes the shadow edges in the opposite photograph, leaving the visual system with the task of combining the opposing silhouettes into a single whole shadow.

The participants had significant trouble with sharing their photographs both online and offline. Online sharing was practically impossible because their family and friends did not own 3D displays and because social networking websites do not support 3D photographs. Offline sharing was difficult because only one person could view the photographs at a time and because file transfer was cumbersome. People prefer to "huddle" when viewing photographs in a group [22], which was not possible with the limited viewing angles of the 3D displays used in this study. The same study suggested that a handheld display could be used for offline sharing by passing it around in a group, a method that might also be suitable for 3D photographs. A 3D television with multiple 3D glasses and adequate viewing angles could also be used for offline and online sharing of 3D photographs, but only if the file transfer and sharing process were effortless.

The motivations for 3D photography differed from the motivations for traditional 2D and camera phone photography. The motivations of capturing memories and sharing photographs were still evident, even though the difficulties in sharing the photographs reduced the influence of social motivations. The novelty of the experience was a strong factor in the beginning of the trial, and it created the motivation to test the 3D effect in different situations. The participants enjoyed "playing" with the device. We found that the positive effect of novelty declined rapidly after the first week of use, which corroborates the results of a study on the use of a novel mobile phone [17]. The interestingness of the 3D photographs was evident, as the participants visually explored the photographs and found new details. We also found strong evidence that the participants enjoyed the immersion created by the 3D photographs. These findings verify that concepts regarding the importance of interestingness [11] and immersion [39] are also important in 3D photography, but they might also be related to the novelty of the technology. Further research with experienced 3D photographers is required to verify the effect of novelty in the acceptance of 3D photography.

6.2 Scenes and Subjects

We observed a strong tendency among the participants to capture scenes with clear depth differences, such as staircases and other man-made structures. With these subjects, the full potential of the 3D camera was utilized. The cardboard effect impaired some photographs, particularly photographs of people. The participants thought that people looked unnatural in 3D, and thus, they took fewer photographs of people. The proportion of photographs with people was only 21 %, while another study with camera phones found that 51 % of photographs included people [18]. This other study analyzed photographs that the participants had taken with and preserved in their own devices and photographs taken outside of the trial, which also explains the difference. Photographs of objects were also common, as the participants tested the 3D effect on different object shapes and sizes.

6.3 Limitations of the Study

The sample size was five participants, but the trial lasted 4 weeks with four intermediate data gathering points and an exit interview, resulting in twenty data points in addition to the five interviews. In usability studies, scholars have studied sample sizes exhaustively and given several recommendations for the number of participants required in usability testing. The lowest suggested recommendation of four to five participants has been widely criticized, and a more recent recommendation is using around ten participants for basic usability testing methods, which should be sufficient to find 80 % of the usability problems [14]. The methods we used in this study, however, were not basic usability testing methods, as the trial duration was 4 weeks, and we used interviews and open questions as our primary data source. In a qualitative analysis based on sixty interviews, Guest et al. [9] found that after six interviews, 73 % of the final codes were found and that all the main themes were represented. Considering the number of problems that we found, we conclude that the sample size was adequate, but further studies are required after some of these problems have been solved, as other issues might be masked by the problems discovered in this study.

All the participants were young academic adult women who were inexperienced with 3D photography, which makes the sample homogeneous in these dimensions. This raises the question whether the results are gendered and whether we can generalize the results to other age groups. In domestic photography, women tend to take the role of the primary photographer and particularly the responsibility of organizing the photographs [28], which makes women desirable research subjects in this domain. We acknowledge, however, that there can be wide cultural differences of gender roles related to photography and organizing the photographs. In the subjects of photography, studies have reported only a small, if any, difference between genders. Hjorth [13] noticed only a marginal gender effect in the types of photographs taken in a study of camera phone practices. In a study about children as photographers [37], the authors found no gender effect, but a significant effect of age. Gender and age do not have a direct effect on behavioral intention or technology use [47]. They do have, however, two-way and three-way interaction effects with other factors. According to Venkatesh et al., compared to the mean, older women depend more on facilitating conditions, and hedonic motivation has a stronger effect on young men's behavioral intention. From the technology acceptance viewpoint, age and gender do not seem to have a significant effect on the results of this study. We must nonetheless bear in mind that the results on the photographic subjects pertain to the inexperienced young adult population, and further studies with participants of different ages and experience levels are required to establish the types of photographs people take with 3D cameras.

The participants knew that the researchers would view their photographs. This could have caused the participants to take photographs that they thought that the researchers would deem appropriate and to avoid taking photographs of, for example, people, to protect their privacy. They could also censor the photographs after taking them, even though we instructed them not to delete any photographs. We did not find any evidence of altered behavior or censorship, but we acknowledge this limitation regarding the proportions of photographic subjects. Another effect of the experimental design comes from extrinsic motivation in the form of compensation for participating in the trial and the instruction to take photographs, which leads to taking photographs even though the participants would have no intrinsic motivation to do so. Extrinsic motivation can also have a negative effect on intrinsic motivation. Thus, to obtain a more comprehensive understanding of the motivations for 3D photography, future research addressing these issues is needed.

7 Conclusions

We conducted an in-depth user study to analyze the effort expectancy, performance expectancy, facilitating conditions, motivations, and experience of novice users' 3D photography. We discovered several issues that affect the acceptance of 3D photography. The main problem was that the participants captured photographs at too-close distances, which resulted in large stereoscopic disparities. The participants learned to avoid excess disparities to some extent during the trial, but not entirely. We propose the use of in-camera assistance tools to reduce the time required to learn how to capture 3D photographs successfully.

A camera manufacturer alone does not have control over all the factors that affect the acceptance of 3D photography. As photo sharing and social networking websites are replacing physical photo albums, it is essential that the users can store and share their 3D photographs on these websites and that others can view the photographs effortlessly on any 3D-enabled platform. This requires collaboration with other device manufacturers as well as with social networking websites and other software developers. With the recent developments in glasses-free 3D display technology, the time for yet another 3D boom could be near, possibly in mobile devices. Solving the problems discovered in this study would ensure that the users of the novel devices could successfully capture interesting 3D photographs and fulfill their need for sharing.

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