Validating Usability Heuristics for Augmented Reality Applications for Elderly Users

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***Abstract*— Literature has shown that Augmented Reality (AR) technologies can positively influence older people's quality of life. However, to achieve its potential, we need to ensure the usability of AR for elderly users. One of the most common usability evaluation methods is testing a product towards heuristics. Usability heuristics are also used to guide the interface design to improve usability. Unfortunately, the well-known general usability heuristics do not consider aspects specific to AR technologies as well as elderly users' needs. Therefore, there is a need to develop and validate heuristics specifically tailored for AR for elderly users. In our previous study, we developed a set of usability heuristics for elderly users and validated it by collecting feedback from usability experts. In this study, we have further validated the heuristics by asking designers/developers to use them for creating an AR application prototype. The results show that the heuristics are useful in the design phase of creating usable AR applications for elderly users. According to the participants, it can also be used in other phases of the application development cycle.**

Keywords-augmented reality; elderly; usability; heuristics.

I. INTRODUCTION

Augmented Reality (AR) technologies can help the elderly to increase their quality of life, enhance their care and autonomy, develop social interactions, and improve their overall wellbeing [1]. However, to achieve these potential benefits, we need to ensure the usability of AR applications for elderly users [2][3]. Usability is overall an important aspect in designing technologies for older people [4]. Due to age-related difficulties, most elderly experience challenges using Information and Communication Technologies (ICT) [5]. Thus, this group of users has specific usability needs and requires special attention [6]. For instance, modern game interfaces often use sounds, lights, and colors that are pleasant for younger users but often cause an adverse reaction from older users [7].

Heuristic evaluation is a common recognized method for testing the usability of ICT systems [8][9]. In addition, using heuristics as a guide for interface design to improve usability is a commonly adopted practice [10]. Unfortunately, well-known generic sets, such as Nielsen's heuristics [11], do not address characteristics specific to some types of ICT [9]. For instance, AR has certain hardware features, safety and privacy issues, and high importance in the surrounding environment [8]. That is why there is a need for new sets of heuristics that cover features specific to particular technologies [12]. All of the above-mentioned AR characteristics, as well as the specific needs of elderly users [6], need to be considered by new usability heuristics [8][13].

In our previous paper, we developed a set of usability heuristics for AR systems for elderly users [14]. However, it should not be the end of the process once heuristics for a specific domain are proposed, further validation needs to be conducted [12]. According to the systematic review by Nurgalieva et al. [15], only 11.5% of the selected papers reported validating the developed guidelines and heuristics. At the same time, the rest of the studies did not include the validation stage. That is why we have validated the developed heuristics through the expert judgment method [16] (interviews with AR experts with industrial and academic backgrounds). However, it should be further validated to ensure the quality of the set of heuristics and its applicability for creating usable AR.

Usability heuristics are commonly used for evaluating the usability of products, with most studies validating their effectiveness for this purpose. Despite this, designers also widely use usability heuristics to guide their design decisions. That is why, in this research, we have further validated the developed set of heuristics by using it to design an AR application interface and gathering feedback from the designers and front-end developers about the usefulness of the heuristics.

This paper has the following structure. Section 1 introduces the importance of usability heuristics specifically tailored for AR and elderly users. Section 2 reviews related work on AR usability and methodologies for new heuristics development. Section 3 describes the methods used for the validation of previously developed heuristics. Section 4 presents the study's results, including the prototype design created by the participants and their feedback on the set of heuristics. Section 5 discusses the results and implications of our findings and compares them with the reviewed literature. This paper's main contribution is presented in section 6, and it states that the developed set of usability heuristics can help to create usable AR applications for elderly users.

II. RELATED WORK

The following section presents a review of the related work on usability heuristics for AR and older users, along with the methodologies for developing and validating new heuristics.

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A. Usability Heuristics

Usability evaluation of AR applications needs to address certain technological aspects specific to AR, such as hardware, its features, and potential limitations; privacy, safety issues, and related concerns that might appear due to using of cameras and video in users' environment; the importance of users' surroundings as a part of application interface; ease and comfort of use [8].

Several studies have focused on AR usability and presented new developed sets of heuristics or usability checklists tailored or adapted to AR specifics, including some aspects listed in the paragraph above. Franklin et al. [17] presented heuristics adopted for collaborative distributed AR systems and validated with a case study method. Another study focused on mobile AR usability and mapped and adapted Nielsen's heuristics to the specific features of AR home design applications [18]. Derby and Chaparro [13] created and validated a usability heuristics checklist for AR and Mixed Reality applications. Guimaraes and Martins [19] adapted the ISO 9241-11 [20] and Nielsen's heuristics and presented a checklist for AR usability evaluation. Yet, none of the studies mentioned above have focused on elderly users' usability needs. To our knowledge, only a few studies investigated AR usability in elderly users' context. Liang [2] developed general AR design principles for elderly users, however, they focus only on mobile AR [21].

In our previous study [14], we developed a set of usability heuristics that focuses on elderly users and considers aspects specific to AR applications. The developed set can be used as guidelines for creating AR systems for older people and heuristics for performing usability evaluation of existing AR applications.

B. Validation methodologies

When we discuss establishing new usability heuristics for a specific domain, two recommended methodologies are commonly used in the studies: [22] and [16]. Quiñones et al. [16] also mentioned other proposed methodologies for the heuristics development [12][23][24][25][26]. However, they do not provide a defined approach for validating the developed heuristics [16]. They also lack a comprehensive description of the formal steps involved in the development process [16].

Both Quiñones et al. [16] and Rusu et al. [22] recommended methods for validating the new developed heuristics. Rusu et al. [22] recommended evaluating the set of heuristics against Nielsen's heuristics in specific case studies. The authors recommended evaluating the same system with one group of experts using the new set of heuristics and a second group using Nielsen's heuristics and comparing the results. Quiñones et al. [16] recommended three methods of heuristics validation. First, using heuristics evaluation to compare the new heuristics with a control set of traditional heuristics. The second method is to involve experts and ask for their feedback on the developed set. And a third one is to compare the results of the heuristic evaluation with the developed set with the results of user testing. However, in both cases, the authors perceived the heuristics as a tool only for usability evaluation and proposed the methods of heuristics' validation for this purpose only.

Nurgalieva et al. [15] mentioned two other methods of heuristics validation that have also been used in research: first, designers using the proposed guidelines to design applications and giving feedback, and second, end-user testing of the applications developed following the guidelines.

III. METHOD

The process of heuristics development [14] was inspired by the eight-step methodology [16] and included a systematic literature review and interviews with usability experts. The developed set contains 55 heuristics divided into six categories: User involvement, Cognitive and physical load, Usability and accessibility, Privacy, Hardware, and Gamification. Eighteen heuristics have supplementary information added as a note to clarify the meaning of the heuristic.

We propose further validating the developed set of heuristics by using it to design and develop an AR application and then gathering feedback from the designers/developers about the set's usefulness. We have involved three experts (P1-P3) that work with frontend design and development and have usability and elderly users' needs knowledge and experience with AR. The participants were recruited by contacting IT companies by email. More detailed information about the participants' work experience is presented in Table 1.

TABLE I. INFORMATION ABOUT THE PARTICIPANTS.

Information	**Participants**		
	P1	***P2***	***P3***
Type of work	Front-end developer and UX designer	Front-end developer, has experience with design tasks	UX designer specializing in user research
Years of experience	4.5	9.5	4
Experience with AR	Yes, as a user	Yes, as a developer	Yes, as a designer
Usability knowledge	Yes	Yes	Yes
Experience designing for and/or testing with elderly	No experience, but has knowledge of elderly users' needs	No experience, but has knowledge of elderly users' needs	Included elderly in user testing

First, the participants received the task instructions that specified: the user group of the project (elderly people), the product that needs to be produced (augmented reality application for performing physical exercises), the exercise that needs to be included in the game (move the hands over the head during 30 seconds), game scenario (the users need to imagine that there are flying over a canyon) and the task that the participants need to complete (create a prototype of an AR application with 3-5 interface sketches using the set of heuristics). The participants did not get instructions on how

to proceed with the task since we wanted to make the task closer to a real design/development project. We also wanted to see how the participants would approach the heuristics and how they would work with them.

The participants were supposed to choose a hardware technology for the project. They had three options: a smartphone (mobile AR), a combination of Microsoft Kinect and TV, and a head-mounted device. The participants were also asked to make notes throughout the process and mark heuristics that were especially helpful or/and influenced their prototypes and overall results.

Within a week after the task instructions were sent, the interview sessions with the participants were arranged. The interviews were semi-structured, and their purpose was to discuss participants' experiences with the task and collect their feedback on the set of heuristics. Each interview session lasted approximately one hour. The interviews were audio-recorded, and notes were taken during the process. In addition, during the sessions, the interviewer went through the notes of the participants together with them and asked clarifying questions. The recorded interviews were transcribed and analyzed by creating inductive semantic codes and categories using the conventional approach to content analysis [27].

IV. RESULTS

We interviewed three participants, each focusing on a different hardware device (P1 – Microsoft Kinect and TV, P2 – smartphone (mobile AR), P3 – head-mounted device). All the participants independently chose the following way to proceed with the task: first, quickly looked through the list of heuristics; then made initial prototypes; after that, went through the list again more carefully, paying attention to the details, checking if the prototypes were compliant with the heuristics and, if not, made corresponding changes in the process.

The interview sessions demonstrated that the participants found the task interesting and engaging. All of them expressed a positive attitude toward the set of heuristics.

The remaining section is organized based on the categories established through the content analysis.

A. The design of the prototype made by the participants

The participants made several changes to their initial prototypes to make them compliant with the heuristics. For instance, in accordance with the heuristic number 31, "Use representative figures and icons that the user can distinguish and differentiate. Note: Elderly people may not be familiar with many standard Internet icons, so, when possible, to use short text, use it instead of an icon" P1 added a text to a button "Back" in the interface sketches to make the purpose of the button clearer for the users (Figure 1).

Based on the heuristic number 15, "Use large fonts and virtual objects," P1 reduced the number of elements on the screen in each sketch and made them and the text even bigger than in the initial sketches. To make the prototype compliant with the heuristic number 39, "Ensure the transparency of information regarding content privacy, data collection, and its purposes," P1 added a section "About" and later decided to include it in the package of the product since it could be difficult to read a lot of text from the screen. P1 has also decided to make the base version of the app available without an internet connection, based on the heuristic number 5 "Consider the greater care needs of the residents and the institutional infrastructure (e.g., internet accessibility)."

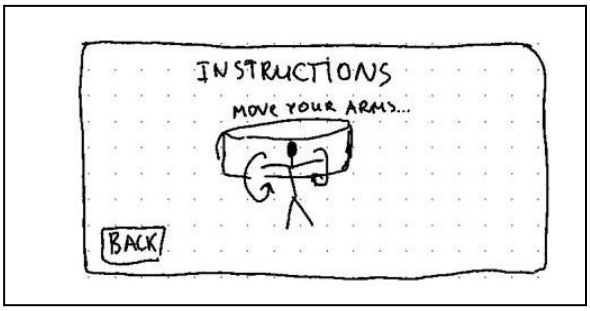

Figure 1. A sketch of Participant 1 with the added text "Back" to the button.

P2 added a navigation bar with text instead of buttons with icons to make the sketches more consistent following heuristic number 29, "The system and its response and user interface should be consistent in appearance and behavior, predictable, clear, and transparent," and heuristic number 31, "Use representative figures and icons that the user can distinguish and differentiate. Note: Elderly people may not be familiar with many standard Internet icons, so, when possible, to use short text, use it instead of an icon". Based on section 2 of the heuristics' set "Cognitive and physical load" and the heuristic number 9 "Design the interface to enable the user to focus on the actual task and reduce the cognitive overhead needed to interact with the application", P2 added a possibility to play the game without a login. P2 made the text on the sketches bigger, based on the heuristic 15, "Use large fonts and virtual objects." P2 decided to add video instructions instead of pictures to make it easier to understand the instructions and added a possibility to repeat the video (Figure 2), based on the heuristic 8 "Consider older adults' individual needs and skill levels" and heuristic number 28 "When relevant, provide guidance (including visual instructions) in a step-by-step manner."

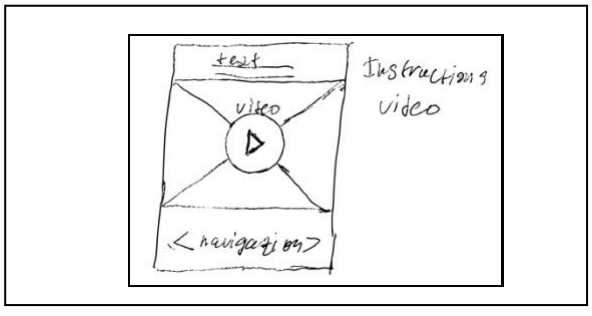

Figure 2. A sketch of Participant 2 with the video instructions. It has a text field on the top of the screen, followed by a video content and navigation bar at the bottom.

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P3 decided to reduce the number of elements on the screen in each sketch and made the design more minimalistic, based on the heuristic number 9 "Design the interface to enable the user to focus on the actual task and reduce the cognitive overhead needed to interact with the application" and heuristic number 13 "Consider that virtual elements hide real content." P3 also added a two-players mode to support the social aspect of the game and increase users' motivation to exercise (Figure 3), based on the heuristic number 51 "Consider adding an optional multi-player mode, since playing together with family or friends can motivate elderly users to start and continue playing." During the interview, P3 mentioned that they also should add "Back" buttons to each screen.

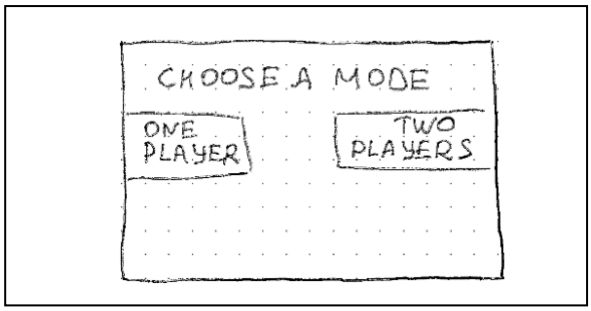

Figure 3. A sketch of Participant 3 with different game modes.

B. Applicability

All participants agreed that some heuristics should be used before sketching the interface, and some will be used later in the development process. Participants 1 and 2 also discussed that heuristics cover tasks typically related to the work of different roles in the team, such as UX researcher, UX designer, front-end developer, hardware developer, and product manager.

P2 stated that the set overall is very good for the refinement stage and can be a good checklist, while P3 noted that the set is a good start for the research and design process and usability testing at the end of the project.

C. Understandability

Overall, all the participants stated they had no issues understanding the heuristics. P3 said that the set is well structured, mostly understandable, and turned out to be useful for creating a usable AR application for the elderly. The majority of the heuristics were also understandable. They did not cause any confusion and were easy to use and apply. All the participants agreed that the additional notes for some of the heuristics were highly helpful and explained some details that needed to be clarified with the notes. The only heuristic that raised some questions and was unclear to 2 out of 3 participants (P1 and P2) is heuristic number 7: "Involve and stimulate older adults' social networks." Both participants perceived it as a recommendation to incorporate multiple players mode, however, the intended meaning was to incorporate the social networks of older adults into the research and design process. Participants suggested that adding an additional note clarifying this heuristic could prevent misunderstanding and improve understandability.

P2 claimed that all the heuristics are well decoupled, even though some of them are overlapping, for instance: heuristic number 11, "Users should be able to accomplish a task with minimal interaction steps; avoid "unnecessary" interventions by the user" and heuristic number 24 "Menu navigation and general navigation within the application should be logical, with clear and minimal steps." However, the participant stated that it is not a disadvantage of the list: "The heuristics are talking about the same issue, but they cover it from different angles."

D. Familiarity and novelty

P2 stated that some of the heuristics were common knowledge for an experienced UX designer, but still, having them in the set as a reminder and a part of a checklist that needs to be completed is good. P1 agreed that some heuristics were evident for a designer, such as those that concern the interface's simplicity, logical navigation, screen brightness, and big text (the participant mentioned that it mainly concerns category 3. Usability and Accessibility). However, P1 also highlighted that this set of heuristics is a good checklist and "nothing needs to be cut." P3 mentioned that some of the heuristics are familiar from more general usability heuristics and guidelines, however, it also contains heuristics more specific for elderly people that are not mentioned in other lists.

There were also things the participants hadn't considered relevant for the prototype before reading the heuristics. For instance, P1 claimed that they would not think about the higher importance of outdated technology consideration for the elderly (heuristic number 33); the greater care needs of the elderly residents and the institutional infrastructure (heuristic number 5); older adults' privacy needs and concerns (heuristic number 38) and most privacy heuristics overall (category 4 – Privacy); also, a need to consider specific conditions of older adults living environments (heuristic number 3). Overall, P1 highlighted that the heuristics that are specific for elderly users were the most useful ones. P2 mentioned that they wouldn't think about the support the user's procedural and semantic memory to enhance the learnability and usability of the interface (heuristic number 25).

E. Context and hardware

P1 also commented on the heuristics that concern hardware. They mentioned that it is not always possible to develop hardware in the project, or even sometimes choose it, so designers and developers do not always have an influence on the hardware.

There was also a heuristic that got different feedback from the participants. P2 and P3 found the heuristic number 13, "Consider that virtual elements hide real content." very useful since they designed for hardware that "projects" the computer-generated elements on the real content. While for P1, who was covering the Microsoft Kinect and TV hardware, this heuristic was not useful at all.

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Overall, the participants provided useful feedback demonstrating the usefulness of the developed set of heuristics for creating usable AR applications for elderly people. The set includes general information about usability in the form of a well-structured checklist with decoupled and understandable heuristics, and, according to the participants, is important to have. Moreover, it also includes heuristics specific to AR technologies and elderly users, which the participants found the most useful. Based on participants' feedback, the set of heuristics is useful for the starting point of the research and design process, as well as for the refinement stage of the project and usability testing at the end.

V. DISCUSSION

Previous studies demonstrated that well-known general heuristics do not cover all the aspects specific to AR applications [8], and there is a need to create a set of heuristics that consider AR specifics [12], such as hardware, surrounding environment, privacy, security and comfort of use [8]. All these aspects were considered, and recommendations towards them were included in the developed set of usability heuristics [14]. The set has a separate section covering potential privacy issues and proposed solutions. The study participants expressed that heuristics concerning privacy were valuable and important to consider. P1 stated that a designer might not be aware of the older adults' special privacy needs and concerns. Regarding the surrounding environment, most participants highlighted the importance of the heuristic number 13, "Consider that virtual elements hide real content," which covers an issue specific to AR that combines a real environment with computer-generated elements [1].

The developed set of heuristics considers AR hardware. It has a dedicated section covering guidelines that can help to overcome potential issues related to AR hardware, for instance, comfort and safety of use, consider the weight of the wearable devices and time of use, consideration of existing elderly aids, and different input and output devices. However, the participants' feedback did not include much information about their opinions and attitude toward this category of heuristics. P1 commented that a project often predetermines hardware, and designers and front-end developers mostly do not have an influence on the hardware decisions. That is why P1 did not find this section of heuristics particularly useful for the design of AR applications. The other participants did not have many comments about the heuristics from this section. This might be due to the fact that none of the participants had experience working on a project in which hardware was developed as an in-house solution.

The developed set of heuristics is trying to cover recommendations for all types of AR hardware devices, even though they can have some differences [1]. The interview with participants demonstrated that some heuristics are only relevant for some types of AR but not others. The heuristic number 13, "Consider that virtual elements hide real content," was very useful for mobile AR and AR with a head-mounted display since these types of AR "project" virtual elements on the users' surroundings. While P1, who focused on the Microsoft Kinect and TV hardware, did not find this heuristic relevant.

Research has also shown that elderly users have specific usability needs [6], so the developed heuristics included recommendations for this user group. The results of the study demonstrated that the heuristics that were explicitly focused on elderly users were found the most useful by the participants and helped them to adjust the created prototypes to elderly users' needs. Examples of these heuristics include consideration of elderly users' environment, particular privacy concerns, and a higher focus on outdated technologies.

A. Limitations

One of the study's limitations is the small number of participants. However, they performed an extensive task, developing and adjusting prototypes of an AR application interface using the heuristics and providing thorough feedback about the process and the set of heuristics. Their design has also covered all types of hardware devices.

Another limitation is that the task that participants received was covering only the initial design phase of a project. Therefore, they provided us with low-fidelity prototypes, while the heuristics covered more stages, including user research, hardware decisions, and some parts of front-end and back-end development. However, during the interview sessions, we gathered participants' feedback on all heuristics considering the AR prototype, including those that did not apply to the initial design phase.

In addition, not all participants had experience designing for and testing with elderly users, which may have limited the findings of the study.

VI. CONCLUSION AND FUTURE WORK

In this study, we aimed to validate the set of usability heuristics for AR for elderly users by creating an AR prototype by design and front-end development experts. The participants were asked to prototype an AR application interface using the set of heuristics. After they had completed the prototypes, interview sessions were arranged to collect participants' feedback on their experiences using the set of heuristics. Overall, the participants expressed a positive attitude towards the heuristics and stated its usefulness, ease of use, and understandability. The set of heuristics was found to be a good checklist that can be used at different stages of the AR design and development process.

In the future, it is important to validate the heuristics for the whole AR development process. In addition, the effectiveness and usefulness of the heuristics should be evaluated with a user study to investigate how designers/developers following the heuristics can influence the usability of an AR application.

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