Preferences of People with Visual Impairments for Augmented and Mediated Vision: A Vignette Experiment

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Abstract We examine in this work the desirability and preferences of people with visual impairments for assistive vision, *i.e.*, vision rehabilitation and enhancement, delivered by smart eyewear devices. We present results from a vignette experiment with N=17 participants with visual impairments, who reported their preferences regarding 32 hypothetical scenarios that we formulated for assistive vision, *e.g.*, long-distance vision, peripheral vision, highly sensitive perception of colors, thermal vision, night vision, and others. Our results show higher desirability (average score of 4.21 out of 5) for assistive vision scenarios addressing rehabilitation of lost vision functions compared to scenarios that propose Augmented Reality-based enhancements of human vision (3.76) or visual perception in other regions of the electromagnetic spectrum, such as thermal or infrared vision (3.36). To understand these results, we conduct a second vignette study involving N=178 participants

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without visual impairments, for which we report lower desirability for vision augmentation (3.44/5) compared to participants with visual impairments (3.75/5). We discuss implications of our results for augmented and mediated vision delivered by smart eyewear devices.

Keywords Augmented Reality · Mediated Reality · Alternate Reality · Mediated vision · Smartglasses · Head-Mounted Displays · Visual impairments · Assisted vision · Vignette study · Questionnaire · Interview

1 Introduction

Smart eyewear devices with built-in video cameras, Wi-Fi connectivity, and see-through displays [38] provide wide opportunities for researchers and practitioners to design, engineer, and evaluate new applications for assistive vision. Common examples include magnification, contrast enhancement, and color replacement [8, 33, 36, 37, 40, 69, 70, 76, 92, 95] that address and aim to correct specific vision deficiencies. Such applications represent instances of *mediated vision* [47] by implementing vision rehabilitation and compensating lost vision functions. The emergence of Augmented Reality (AR) and Mixed Reality (MR) technology [9,15] readily available on mobile and wearable computing devices has enabled *augmented vision* that, unlike mediated vision, superimposes computer-generated content on top of the visual reality perceived by the user. Augmented vision enables new types of applications for assisted vision, including assisted navigation [94], face recognition and person identification [98], sign and text reading [36], scene recognition [25], as well as new experiences for home entertainment [80, 83], to name just a few. Moreover, combining augmented and mediated realities toward *augmediation* [48] opens up new opportunities for applications in assistive technology for human vision.

However, while researchers and practitioners develop technology for smart eyewear and assistive vision, it is equally important to understand the needs, preferences, and desirability of end users for assistive vision, such as of people with visual impairments. This desideratum implies conducting user studies, interviews, and surveys to unveil such preferences, an approach that has been adopted recently to inform design of AR technology for specific application domains [60, 64, 80]. However, in what regards smart eyewear, accessible computing, and people with visual impairments, only a handful of such studies have been conducted to date [23,64,93,99]. While this prior work has unveiled important findings about the perceptions of people with visual impairments regarding smart eyewear devices, little is still known about their needs and preferences for augmented and mediated vision scenarios that are possible with today's technology, such as face recognition [98], color correction [40], night vision [54], extended peripheral vision [20], or thermal vision [1]. In this work, we present results from a vignette experiment [6, 13, 28] in which participants with visual impairments were elicited for their preferences for assisted vision. Our work equally covers people without visual impairments as well, for which we want to understand their preferences for the various ways in which human vision could be mediated, augmented, and augmediated with smart eyewear leading towards Verbeek's [82] posthuman vision scenarios through technological mediation and, respectively, to practical application opportunities of Chambel *et al.*'s [19] concept of Alternate Realities, where new devices, transmission paradigms, and content formats enabled by multimedia technology make new kinds of immersive experiences possible for end users.

The contributions of our work are as follows:

1. We conduct an examination of the preferences for augmented and mediated vision of N=17 participants with visual impairments of various types and severity. In order to collect preferences for a wide range of possible scenarios for assisted vision (including applications readily accessible today, such as color correction and contrast enhancement, but also applications not yet achievable with today's technology, such as X-ray vision), we conduct our examination in the form of a vignette experiment [6, 13, 28].
2. To instrument our user study, we introduce a taxonomy of vision augmentation and mediation with four categories: (1) human vision with no impairments, (2) extended vision in the visible spectrum, (3) augmediated vision in the visible spectrum, and (4) augmediated vision in other regions of the electromagnetic spectrum with a total of 32 subcategories representing possible scenarios for assistive vision.
3. We replicate our vignette experiment with N=178 participants without visual impairments constituting a control group to contrast the findings obtained with people with visual impairments. Informed by our empirical observations, we discuss implications for assisted, mediated, and augmented vision for smart eyewear computing.

2 Related Work

We discuss in this section prior work on applications of assistive vision for people with visual impairments. We also overview interaction challenges with computing technology experienced by users with visual impairments and connect to prior work that documented well-being and coping strategies adopted by people with visual impairments in everyday life. Before proceeding further, we define several key concepts employed in our work.

2.1 Definitions

Smart eyewear. In this work we focus on "smart eyewear" devices that, according to the classification of Kress *et al.* [38] and their discussion on the segmentation of the Head-Mounted Display (HMD) markets, feature integrated optical combiners and prescription lenses, *i.e.*, Rx functionality. Smart eyewear extend smartglasses that incorporate displays (either occlusion or see-through), but for which the optical combiner is not part of the Rx lens. At their turn, smartglasses extend the functionality of connected glasses that pack Bluetooth and/or Wi-Fi connectivity, digital imaging through embedded video cameras, but (usually) no display according to Kress *et al.* [38].

Mediated and Augmented Vision (M&A vision). We are interested in this work in understanding desirability for applications for smart eyewear that assist human vision, either by means of *augmentation* or *mediation*. The distinction between the two, clarified by Mann [47], consists in that augmentation superimposes digital content on top of the perception of visual reality, *i.e.*, Augmented Reality, whereas mediation is about presenting the user with a modified version of the visual reality, such as by employing computer vision and image processing algorithms or, for short, Mediated Reality [47,48]. In this work, we are interested in all techniques that enhance visual perception, including augmediation that combines augmentation and mediation, *i.e.*, Augmediated Reality [48].

Visual impairments. The term "visual impairments" includes a range of visual abilities that can be classified according to distance visual acuity from mild to moderate, severe, and blindness [85]. Low vision represents vision loss that cannot be corrected by medical or surgical treatment or prescription glasses. Unlike people who are blind, people with low vision do rely on their visual abilities to perform everyday activities, but face considerable challenges and physiological discomfort [86]. In this work, we address people with visual impairments, which equally include people who are blind that could benefit from M&A vision by means of sensory substitution, *e.g.*, haptic feedback for interaction in virtual worlds [67].

2.2 Augmented Vision for People with Visual Impairments

Prior work in accessible computing has examined the benefits of AR technology to reduce accessibility gaps for people with visual impairments [21, 73, 91], but also for people without visual impairments that may experience temporary decrease of visual acuity under specific circumstances, such as low ambient light or eye fatigue, known as "situationally induced impairments and disabilities" (SIIDs) [65, 89]. AR applications for assistive vision have been proposed for smartglasses [8, 36, 40, 59, 70, 76, 94] and HMDs [25, 34, 37, 49, 59, 75, 95–97], but also smartphones [33], finger-worn devices [69], and VR gear [92]. Researchers have implemented and evaluated various techniques for assistive vision, such as magnification, edge enhancement, brightness and contrast adjustment, text extraction, and black/white reversal; see the ForeSee [95], SeeingVR [92], and FlexiSee [57] prototypes for representative examples. Itoh and Klinker [37] proposed a system designed to filter out optical abnormalities by superimposing a restorative image on the user's field of view rendered via an HMD; Tang *et al.* [75] adopted a similar approach for see-through lenses; and Melillo *et al.* [49] employed video see-through technology to render video with a restorative filter. Other representative prototypes are ChromaGlasses [40] and Chroma [76], designed to shift the color scheme in the video acquired by the built-in camera according to the specific type and severity of color vision deficiency. Regarding the control of such features, Aiordăchioae *et al.* [3] performed an inventory of voice input commands for assistive applications for smartglasses.

Some AR systems for assistive vision were designed to help with specific tasks, such as mobility [25], providing easier access to physical interfaces in the real-world [33], obstacle avoidance [34], or sign reading [36]. For example, Everingham *et al.* [25] employed Computer Vision and classification techniques to identify obstacles, vehicles, and road pavement in video, which were highlighted for users with distinct colors to assist mobility in urban environments. For indoor scenarios, the CueSee system [96] was designed to highlight specific objects to assist users with low vision to be more effective at performing specific visual search tasks. Hicks *et al.* [34] leveraged residual vision to deliver information to users about the size and localization of obstacles: a low-resolution black and white image was used to indicate the distance, encoded using brightness levels, to nearby objects. Indoor way-finding was equally explored, such as by Huang *et al.* [36], who developed a prototype for sign identification on walls and doors, displayed magnified to users and read using text-to-speech; and Zhao and Azenkot [94] used AR to assist people with low vision for navigation by displaying visual highlights aligned with stairs. Aiordăchioae *et al.* [2] proposed wearable devices to address situations of innattentional blindness, where objects and phenomena automatically detected in the video captured by the camera embedded in a pair of glasses are presented to the user in the form of vibrotactile patterns delivered at finger, wrist, and forearm level. To support remote assistance, Pamparău and Vatavu [57] presented FlexiSee, a system for vision mediation that enabled secondary users, in the form of vision monitors and vision assistants, to view and control the mediation presented to the primary user via the HMD display, from a distance. And Pamparău *et al.* [56] described "do you control what I see" scenarios for the remote control of vision mediation, which they contrasted to the conventional "do you see what I see" feature. Other applications have targeted reading tasks. For example, Sterns *et al.* [69, 70] developed a prototype using the HoloLens HMD and a finger-worn camera, and Guo *et al.* [33] introduced VizLens, a mobile application that enabled users to capture a photograph of a real-world physical interface, *e.g.*, of a microwave oven, and receive guidance about how to use it.

2.3 Interaction Challenges with Computing Technology for Users with Visual Impairments

Several approaches have been adopted in the scientific literature to understand the interaction challenges experienced by people with visual impairments with computing technology. One promising approach, suggested and applied by Schipor *et al.* [66] and Rusu *et al.* [63], relies on the use of models of human vision (neurobiological, cognitive, and neurocognitive models) to inform design of accessible computing technology solutions in accordance with the type and severity of the visual impairment; see, for example, the interpretation of gesture recognition results for people with low vision in relation to such models [79]. Other approaches have employed direct observation of people with visual impairments while using assistive technology or indirect observation to collect and document interaction challenges. For example, Szpiro *et al.* [74] observed eleven participants with low vision during simple tasks involving smartphones, tablets, and computers. They found that their study participants often preferred to access information with the help of visual assertive tools, *e.g.*, magnification and contrast enhancement, rather than via aurally feedback. However, they also found that this strategy led to considerable delays in performing tasks. Brady *et al.* [17] conducted a large-scale study involving more than 5,000 blind people that asked more than 40,000 questions via the VizWiz social application. By analyzing this large dataset, the authors derived several categories of questions that people with visual impairments wanted answers for, from object identification to description and help with reading text and signs. And other approaches have employed interviews to elicit people with visual impairments regarding their needs, preferences, and desires for assistive technology. For example, Sandnes *et al.* [64] reported, from interviews conducted with three individuals with visual impairments, that face and text recognition were the most important features for smartglasses-based assistive vision. Rusu *et al.* [63] employed semi-structured interviews with five participants with visual impairments and documented their difficulties encountered while walking, reading public signs, locating objects, recognizing faces, working, or reading news. And Zhao *et al.* [98] interviewed eight people with visual impairments to understand their needs for on-line social activities. In another study, Zhao *et al.* [93] compared the performance of twenty participants with low vision against a control group regarding the use of mainstream AR smartglasses. The tasks considered in their study involved shape and text recognition while sitting and walking. Results showed that the differences in performance found for the sitting and walking experimental conditions followed a similar pattern for both groups of participants with and without visual impairments, which led the authors to suggest the possibility of applying similar assistive strategies for people with and without visual impairments alike.

AR-based assistive vision also comes with several challenges that need to be overcome by careful design. For example, one challenge in the design of assistive technology in general, and assistive vision in particular, is represented by the stigma related to using and wearing visual aids in public [64], *i.e.*, the "AT effect" [61]. Another challenge is to reduce frustration in using AR devices, which may induce delays, present synchronization issues between the virtual content and the real world experienced via the see-through display [76], and that necessitate additional interactions [74].

2.4 Well-Being and Coping Strategies for People with Visual Impairments

In this work, we collect measurements of well-being and subjectively perceived quality of life from our participants with visual impairments, and we connect these measurements to their preferences for M&A vision. In this section, we overview prior work that examined well-being and coping strategies for people with visual impairments.

Prior work has shown that vision deficiencies influence social functioning and autonomy and are related to higher levels of emotional distress, depression, anxiety, frustration, anger, stress, financial strain, loneliness, and low levels of well-being [7, 18, 24, 26, 27, 30]. Also, visual impairments in children and young adults lead to more negative emotions and lower levels of physical, psychological, and social well-being compared to the general population [7,62]. Furthermore, children with visual impairments have lower levels of social-emotional competences compared to children without visual impairments [39] since vision represents a crucial factor during development. For adults, vision impairments may affect family life (*e.g.*, by increasing family stress and lowering marital quality) and work life alike (*e.g.*, by contributing to unemployment and financial strain) [26]. Since vision represents a key factor in social interaction, as it mediates processes such as facial recognition, eye contact, and so on, people with low vision are at high risk of social isolation and loneliness [18]. Also, prior work has reported that older adults with visual impairments exhibit higher levels of depression compared to people without impairments [24].

People with visual impairments experience challenges with functioning, autonomy, and social interactions that are known sources for emotional problems. Empirical research has indicated that vision loss is associated with negative consequences for emotional well-being, social participation, and career goals and motivation [30]. Furthermore, visual impairments seem to affect not only the people who have them, but also the members of their families. For instance, prior work has reported that parents of children with visual impairments experience helplessness, guilt, anxiety, stress, and insomnia [44]. Also, spouses of people with sensory deficiencies may show low levels of psychological and relational well-being [41, 42]. People with visual impairments employ various coping strategies to compensate for their vision loss. For example, problem-focused coping (*e.g.*, taking actions, making plans, and focusing on solutions), positive refocusing (thinking of positive and joyful issues), re-engagement in alternative, meaningful goals, family acceptance, and optimism represent effective strategies that contribute to lowering depression [14, 31, 42, 71]. In contrast, avoidance coping (*i.e.*, distracting from the problem) and rumination (*i.e.*, repetitive thinking about negative experiences and feelings) have been related to depressive symptoms and low levels of life quality [31, 72]. Electronic aids for low vision that enable people with visual impairments to be more independent also have a positive effect on their psychological well-being [30].

2.5 Eliciting Responses to Hypothetical Situations using Vignettes

In this work, we focus on understanding desirability and preferences for new technology, including technology that is not yet widely available or affordable, such as high-definition thermal cameras or X-ray vision. Therefore, we conduct our examination in the form of a "vignette study" [6, 13, 28], in which participants are asked to react to and express their preferences for fictional situations regarding M&A vision. Since vignette studies have been little applied in HCI [32, 35, 43] compared to other fields, such as psychology and sociology [6, 12, 13, 16, 28, 88], we briefly present in this section their main characteristics and highlight their suitability for our scientific investigation.

Finch [28] described vignettes as *"short stories about hypothetical characters in specified circumstances, to whose situation the interviewee is invited to respond"* (p. 105). More generally, a vignette is *"a short, carefully constructed description of a person, object, or situation, representing a systematic combination of characteristics"* [6, p. 128]. Barter and Renold [13] identified many use cases for vignette studies, such as eliciting interpretations of actions, clarifications of individual judgments, and explorations of sensitive topics in ways that are less personal and threatening to the participants of a study. Regarding the actual implementation, vignettes may be presented to participants in various forms, from keywords to text (dialog and narratives) and graphical formats (cartoons and pictures) up to multimedia content [6, 13]. Vignette studies have also been applied in HCI, but to a lesser extent. For example, Vatavu and Vanderdonckt [81] reported the results of a vignette study in which participants were presented with visual mock-ups of graphical menus for smartglasses from a large design space, which they were asked to evaluate in terms of visual aesthetics, a challenge that was addressed by using a randomized A/B technique [78] for comparing user interface design alternatives via the web; Hoyle *et al.* [35] conducted a vignette study using Amazon Mechanical Turk to collect judgments regarding the appropriateness of posting private photographs online; and Lindgaard *et al.* [43] employed a vignette study to inform the design of a diagnostic decision support system.

In the case of M&A vision, a vignette represents a hypothetical description of assisted vision enabled by smart eyewear devices, such as technology for providing better contrast, higher resolution, better peripheral vision, better vision during nighttime, etc. An important characteristic of a vignette is that it enables the participants of a study to define the situation depicted by the means of the vignette in their own terms [13]. This aspect limits any influence from the interviewer, such as inflicting of perspectives, on the interviewee. Our choice of the instrument of vignettes for our investigation enables us to collect needs, preferences, and feedback regarding a wide variety of M&A vision scenarios, including applications not yet available. By adopting such an approach, we aim to collect data to inform further research and development in assistive vision.

3 A Working Taxonomy for M&A Scenarios for Assistive Vision

In this work, we collect and report preferences for M&A vision in order to derive implications for assistive vision and smart eyewear devices. To instrument our vignette study, we devised a taxonomy of M&A vision informed by prior work and our brainstorming of possible applications of Mediated and Augmented Reality for vision rehabilitation and vision enhancement. In this section, we present the categories of this taxonomy.

Prior work has described various applications of smart eyewear devices to assist visual perception [8,29,33,36,40,49,64,69,70,75,76,95,96,99], which we used to extract scenarios for M&A vision. Also, prior work in computer-generated and computer-mediated realities has presented many theoretical and practical developments in Augmented [9,15], Mixed [51–53], Mediated [47], Multimediated [48], Alternate [19], and Cross-Reality [58], which we used to envision possible application scenarios for what mediated and augmented vision may look like in these hybrid physical-virtual realities. Based on this prior work, we identified four categories of M&A vision scenarios, enumerated below. For each scenario we devised, for the purpose of examination in our vignette study, a number of eight possible implementations of that scenario by addressing specific characteristics of human vision (*e.g.*, contrast, resolution, long-distance vision) or possibilities for sensing and visualization technology to enhance visual perception (*e.g.*, by means of 360° video cameras or AR visualizations); see Table 1. Our four categories of M&A vision are:

Category #1: **Human vision with no impairments.** This category includes scenarios in which computing technology implements vision rehabilitation to compensate vision deficiencies, such as correcting color perception [40, 76], improving contrast and magnification [95], etc., to the levels expected for human vision in the absence of any impairments, *e.g.*, 20/20 visual acuity, 190° visual field for binocular vision, etc.

Category #2: **Extended human vision in the visible spectrum.** This category includes scenarios in which video cameras are used to extend the limits and capabilities of human vision. Examples include remote vision, where users can see events taking place in a remote location by means of live video streaming; panoramic vision enabled by 360° video cameras; alternated perspectives, where the same scene can be viewed from multiple points of view as in video surveillance systems, and so on. Any scenario that employs video cameras to extend the natural limits of human vision typically falls into this category.

Category #3: **Augmediated vision in the visible spectrum.** In this category, we place applications that apply Artificial Intelligence technology (*e.g.*, Machine Learning, Computer Vision) to recognize objects and extract meaning from videos in order to present users with relevant information about objects from their field of view, *e.g.*, face and emotion recognition and AR applications fall into this category. By augmediated vision we understand live streaming videos that are both augmented and mediated [48].

Category #4: **Augmediated vision in other regions of the electromagnetic spectrum.** This category extends the applications from Category #3 to other regions of the electromagnetic (EM) spectrum, beyond visible light. Examples include infrared vision and thermal vision that can be implemented with sensors active in those Hz ranges, but also futuristic scenarios that we imagined in our brainstorming, *e.g.*, material vision, where the type of material from which an object is made of can be identified by mere eyesight. This also includes AR applications that operate in other ranges of the EM spectrum, but also applications that address other senses beyond vision, *e.g.*, the ability to appreciate distances to objects by means of sensory substitution.

4 Study #1: Preferences of People with Visual Impairments for M&A vision

We conducted a vignette study to collect the preferences of people with visual impairments for possible application scenarios for augmented and mediated vision enabled by smart eyewear devices.

4.1 Study Design

Participants. Seventeen people with visual impairments (10 female) with ages between 17 and 73 years (M=25.1, SD=16.8 years) participated in our experiment; see Tables 2 and 3 for their demographic details.

Apparatus. Participants were demonstrated several features of the Microsoft HoloLens HMD [50], the Vuzix Blade AR smartglasses [84], and the NorthVision Technologies NC-05 camera glasses [55] representing various instances of eyewear devices from HMDs with photorealistic graphics rendering and see-through displays (both eyes) to light AR glasses with see-through display (one eye) and limited graphics

No.	**Scenario**	**Description, ”I would like to ...”**
Category #1: Human vision with no impairments		
S_1	Long-distance vision	... see better over a long distance, such as a few meters away
S_2	Close-up vision	... see better at close distance, such as a few centimeters away
S_3	Color vision	... see colors more clearly
S_4	Contrast	... see with better contrast
S_5	Ambient light	... see better under strong ambient light
S_6	Peripheral vision	... have better peripheral vision
S_7	Night vision	... see better during nighttime
S_8	Resolution	... see more details on the objects I'm looking at without moving closer
Category #2: Extended human vision in the visible spectrum		
S_9	Alternative perspective	... see from inaccessible viewpoints, *e.g.*, behind an object, after the corner
S_{10}	Remote vision	... see over very long distances, *e.g.*, at 2 km away, as if I were there
S_{11}	Shared vision	... see from the perspective of another person
S_{12}	Slow motion	... see events progressing in slow motion
S_{13}	360° vision	... see panoramically at 360° around me
S_{14}	Multiple perspectives	... see the same scene from multiple perspectives at the same time
S_{15}	Rewind vision	... see again an event or action that has just happened
S_{16}	Rear-view vision	... see what happens behind me
Category #3: Augmediated vision in the visible spectrum		
S_{17}	AR vision, v1	... see objects of interest highlighted, *e.g.*, street signs, my phone, etc.
S_{18}	Diminished Reality (DR) vision	... not be distracted by unimportant objects from the background; those objects should be faded out or eliminated from my field of view
S_{19}	Audio-rendered vision	... hear the text I'm watching, *e.g.*, street signs
S_{20}	Face recognition	...be able to identify easier the people I'm talking to
S_{21}	Emotion recognition	... to recognize easier face expressions and emotions of the people I'm talking to
S_{22}	Motion-sensitive vision	... perceive better motion and the objects that are moving
S_{23}	Sound localization	... visually identify the location from where sound comes
Category #4: Augmediated vision in other regions of the electromagnetic spectrum		
S_{24}	AR vision, v2	... perceive extra information about the to the objects I'm looking at
S_{25}	Distance-sensing vision	... appreciate better the distance to objects
S_{26}	X-ray vision	... see through objects as if they were transparent
S_{27}	Infrared vision	... see in total darkness
S_{28}	Thermal vision	... evaluate by eyesight the temperature of nearby objects
S_{29}	High color sensitivity	... distinguish more colors
S_{30}	Material vision	... identify by eyesight the material of the objects I'm looking at
S_{31}	Radio vision	... see radio waves and wireless Internet communications
S_{32}	UV vision	... see ultraviolet light

Table 1 Scenarios for M&A vision examined in this work grouped under four categories, from "human vision with no impairments" (*e.g.*, 20/20 visual acuity) to "augmediated vision in the full electromagnetic spectrum" (*e.g.*, thermal vision).

capability, and glasses with an embedded video camera and Wi-Fi connectivity, but no optical lenses. HoloLens was used to project 3-D holograms in the room (*e.g.*, a floating island) with the built-in Holograms app and participants were invited to discover and explore those holograms by moving around the room and inspecting them closely. Our demonstration of the Vuzix Blade consisted of the built-in Photos app for picture visualization, where participants could browse through images and videos stored on the glasses and view them on the optical lenses. Finally, participants used the NC-05 glasses with an embedded micro video camera to stream live video to a connected smartphone where the image could be magnified. Figure 1 illustrates a few snapshots from the experiment.

Task. Participants followed a six-step procedure consisting in questionnaires, a visual function test, interview, and feedback elicitation regarding M&A vision scenarios, as follows:

Participant (age, gender)	Eye condition	Visual acuity[†]	Contrast threshold[††]
P$_1$ (18 yrs., male)	congenital cataract, strabismus	0.706	0.518
P$_2$ (17 yrs., male)	high myopia[†††]	0.263	1.564
P$_3$ (19 yrs., female)	congenital cataract	0.883	0.844
P$_4$ (18 yrs., female)	cataract, strabismus, glaucoma	0.921	0.322
P$_5$ (18 yrs., male)	myopia, astigmatism	0.903	0.354
P$_6$ (18 yrs., female)	bilateral retinoblastoma, blind	n/a	n/a
P$_7$ (18 yrs., female)	retinopathy	1.167	0.008
P$_8$ (17 yrs., male)	high myopia	0.117	1.561
P$_9$ (18 yrs., male)	myopia, strabismus, nystagmus	0.745	0.826
P$_{10}$ (18 yrs., male)	congenital cataract	0.492	0.890
P$_{11}$ (18 yrs., male)	glaucoma, blind	n/a	n/a
P$_{12}$ (18 yrs., female)	glaucoma, blind	n/a	n/a
P$_{13}$ (65 yrs., female)	age-related presbyopia	0.668	0.946
P$_{14}$ (73 yrs., female)	age-related presbyopia	0.662	0.629
P$_{15}$ (24 yrs., female)	high myopia, nystagmus, astigmatism	0.417	1.398
P$_{16}$ (23 yrs., female)	myopia	0.349	0.916
P$_{17}$ (26 yrs., female)	astigmatism, complex mesotropy	0.003	1.567

[†] Values of visual acuity represent the decimal logarithm of the Minimum Angle of Resolution [68].

[††] Values of contrast represent the decimal logarithm of the inverted Weber contrast threshold [11].

[†††] Myopia is classified by degree of refractive error into *low* (-3.00 diopters (D) or less), *moderate* (between -3.00 and -6.00 D), and *high* (-6.00 D or more) [5]. Hyperopia is classified into *low* (+2.00 D or less), *moderate* (between +2.25 and +5.00 D), and *high* (refractive error over +5.00 D) [4].

Table 2 Description of participants with visual impairments (continues with Table 3).

Fig. 1 Participants with visual impairments trying out the Microsoft HoloLens device (left) and the Vuzix Blade AR smartglasses (middle). Right: a blind participant explored the HoloLens device using their hands to get an understanding of its form factor.

1. *Preliminary questionnaire.* The goal of the study was presented to participants and their consent to participate in the study was acquired. We collected demographic information (age, gender, visual impairment).
2. *Visual acuity and contrast test.* We conducted visual acuity and contrast testing with the Freiburg Vision Test (FrACT) application (v3) [10]. To evaluate visual acuity, we used the Tumbling E 24-trial test and the decimal logarithm

Part.	**Self-reported use of assisting devices**	**Visual functioning (self-reported)**						
		Walk[1]	**Read**[2]	**Obj.**[3]	**Face**[4]	**Work**[5]	**News**[6]	**Side**[7]
P_1	prescription glasses, magnifying lens, screen settings (large fonts), text-to-speech, voice input	-	-	✓✓	-	-	✓✓	✓✓
P_2	prescription glasses, screen settings (large fonts)	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓	✓✓	✓
P_3	screen settings (large fonts)	✓✓✓	✓✓	✓	✓✓	✓✓✓	✓✓✓	✓✓
P_4	n/a	-	✓✓	✓	-	-	✓	-
P_5	prescription glasses, screen settings (large fonts), voice input	✓	✓	✓✓	✓✓✓	✓	✓✓✓	✓✓✓
P_6	prescription glasses, screen settings (large fonts), voice input	✓✓✓	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
P_7	screen settings (large fonts), text-to-speech	✓	✓	✓	-	-	✓✓✓	-
P_8	prescription glasses, screen settings (large fonts), text-to-speech	✓✓	✓	✓✓	✓	✓	✓	✓✓
P_9	prescription glasses, text-to-speech	-	✓✓	-	✓✓	✓	✓✓	✓
P_{10}	magnifying lens	-	-	-	-	✓	✓	-
P_{11}	text-to-speech, voice input	-	✓✓✓	✓	✓✓✓	✓✓	✓✓✓	✓✓
P_{12}	text-to-speech, voice input	✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓✓	✓✓
P_{13}	prescription glasses, magnifying lens	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
P_{14}	prescription glasses, magnifying lens	✓✓✓	✓✓✓	✓✓	✓✓	✓✓	✓✓	✓✓✓
P_{15}	prescription glasses	✓✓	✓✓	✓✓	✓	✓	✓	✓
P_{16}	prescription glasses	✓✓	✓	✓	-	✓	✓✓	✓
P_{17}	prescription glasses	-	-	-	-	-	-	-

[1] Walking down steps, down stairs, or walking during night time
[2] Reading street signs or store names
[3] Locating personal objects
[4] Seeing other people's reactions during conversations
[5] Working, hobbies, or other activities that involve vision
[6] Reading ordinary print, such as from newspapers
[7] Seeing objects off to the side
Interpretation: ✓= Little difficulty; ✓✓= Moderate difficulty; ✓✓✓= Extreme difficulty or impossible

Table 3 Description of participants with visual impairments (continuation of Table 2).

of the Minimum Angle of Resolution, measured in arcminutes;[1] see [68]. To evaluate the contrast threshold, we used the Landolt C 18-trial test and the decimal logarithm of the inverted Weber contrast threshold [11]. We also asked participants to report any assistive devices and/or technology that they were using at the time of the study, such as prescription eyeglasses, magnifying lenses, specific software settings for computer screens and mobile devices, *e.g.*, larger fonts, use of screen readers, voice input, etc.

3. The *Visual Functioning Questionnaire (VFQ-25)* [46] measures the influence of the visual impairment on the physical, social, and emotional well-being. The questionnaire has 25 items that target general health and vision (*e.g.*, *"At the present time, would you say your eyesight using both eyes is excellent, good, fair, poor, or very poor, or are you completely blind?"*), the difficulty of performing various activities (*e.g.*, *"How much difficulty do you have reading street signs or the names of stores?"*), and vision problems (*e.g.*, *"Do you accomplish less than you would like because of your vision?"*). Items were rated using 5-point and 6-point Likert scales. For our study, we used just 23 items of the VFQ-25 questionnaire and discarded two items that referred to driving.

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[1] One arcminute equals 1/60 of 1°.

4. The *Subjective Happiness Scale (SHS)* [45][2] is a 4-item scale designed to assess the global subjective happiness (*i.e.*, well-being) relative to other people, *e.g.*, *"Some people are generally very happy. They enjoy life regardless of what is going on, getting the most out of everything. To what extent does this characterization describe you?"* The items from the SHS questionnaire are rated using 7-point Likert scales.
5. *Smart eyewear technology showcase.* We presented participants with the Microsoft HoloLens HMD [50], Vuzix Blade light AR glasses [84], and the NorthVision Technologies NC-05 video camera glasses [55] and let participants explore those devices and specific applications; see Figure 1 for photos captured during the study. We chose these devices for their different capabilities regarding computing resources and photorealism for rendering AR applications, representing different instances of eyewear devices according to the classification from Kress *et al.* [38].
6. We employed a *semi-structured interview* to unveil the preferences, needs, and desires for vision mediation and augmentation using eyewear technology, including mobile and wearable devices. At this stage of the study, we introduced to our participants the 32 M&A vision scenarios enumerated in Table 1 in the form of hypothetical situations, *e.g.*, *"I would like to see better under strong ambient light"* or *"I would like to be able to identify easier the people I am talking to."* We elicited participants' desirability of each scenario in the form of a preference rating on a scale from 1 (scenario very little desirable or not applicable to the participant) to 5 (scenario very desirable and important to the participant). Figure 2 shows photos captured during this part of the study. To make sure that all participants understood the scenarios and to avoid any reading difficulties they might have had, the questionnaire was read and explained by a qualified psychologist. Each scenario from Table 1 was followed by detailed explanations, *e.g.*, *"this means that you could perceive more nuances of the same color, for example more tones of yellow or pink"* for scenario S_{29} (high color sensitivity); *"imagine that you could see with your eyes the data being transfered in the wireless network"* for S_{31} (radio vision); and *"this means that you could perceive that part of radiation that is responsible for tanning and sunburns"* for scenario S_{32} (UV vision), respectively.

Design. Our study was a within-subject design with one independent variable: SCENARIO, nominal variable with 32 subcategories representing scenarios of assistive M&A vision for people with visual impairments; see Table 1.

Measures. We used the following measures:

1. DESIRABILITY-RATING, ordinal variable, expressing participants' desirability and preferences for each M&A vision application scenario from Table 1, which we measured using a 5-point Likert scale with the following items: 1 - "Not at all or very little desirable (this scenario does not apply to my case)", 2 - "'Little desirable," 3 - "Undecided (beneficial scenario, but I do not necessarily need or desire it)," 4 - "Desirable," and 5 - "Very desirable (this scenario is very important to me)."

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[2] `https://www.rand.org/health-care/surveys_tools/vfq.html`

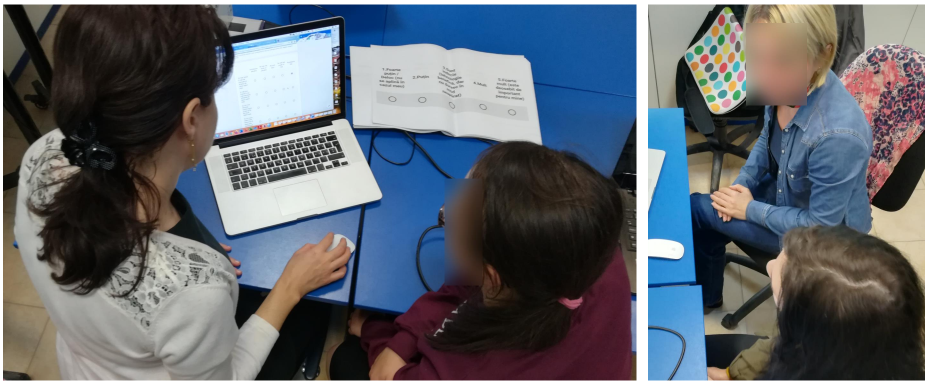

Fig. 2 Photos captured during our study. *Left*: administration of the well-being questionnaire to a participant with visual impairments. *Right*: an interview with a participant with visual impairments to elicit preference ratings regarding our M&A vision scenarios.

2. VFQ25, ratio variable, computed by averaging the vision-targeted subscale scores, *i.e.*, general vision, ocular pain, near activities, distance activities, vision specific social functioning, vision specific mental health, vision specific role difficulties, vision specific dependency, color vision and peripheral vision [46]. VFQ25 takes values between 0 (worst possible visual functioning) and 100 (best possible visual functioning); see the VFQ-25 manual [77].
3. SHS, the Subjective Happiness Score, computed by averaging participants' answers to the items of the SHS scale. The range of the SHS values is from 1 to 7 with higher scores representing greater well-being.

4.2 Results

We used the VFQ25 and SHS measurements to understand the impact of our participants' visual impairments on their functioning and general life and, thus, to better characterize our sample of participants besides the demographic information from Tables 2 and 3. Participants reported low levels for general health (M=42, SD=21.22), general vision (M=52.94, SD=24.43), near activities (M=57.47,22.62), role difficulties (M=63.97, SD=23.75), peripheral vision (M=64.06, SD=27.33), and distance vision (M=64.70, SD=24.91), on scales ranging from 0 to 100. Higher scores were reported for color vision (M=79.68, SD=29.18), dependency (M=72.42, SD=25.77), ocular pain (M = 69.11, SD=26.92), social functioning (M=68.38, SD=30.97), and mental health (M=67.05, SD=25.25), respectively. Overall, our participants reported moderate levels of general subjective happiness (M=5.10,SD=1.41). We found positive inter-correlations between visual functioning and subjective happiness. For instance, significant positive correlations between SHS and general health ($r_{(N=17)}$=.51, p<.05), ocular pain ($r_{(N=17)}$=.67, p<.01), near activities ($r_{(N=17)}$=.56, p<.05), distance activities ($r_{(N=17)}$=.57, p<.05), vision functioning mental health ($r_{(N=17)}$=.62, p<.01), role difficulties ($r_{(N=17)}$=.59, p<.05) and dependency ($r_{(N=17)}$=.48, p<.05).

Figure 3 shows participants' individual preferences for each M&A vision scenario in the form of histograms and mean preference ratings; ratings closer to 5

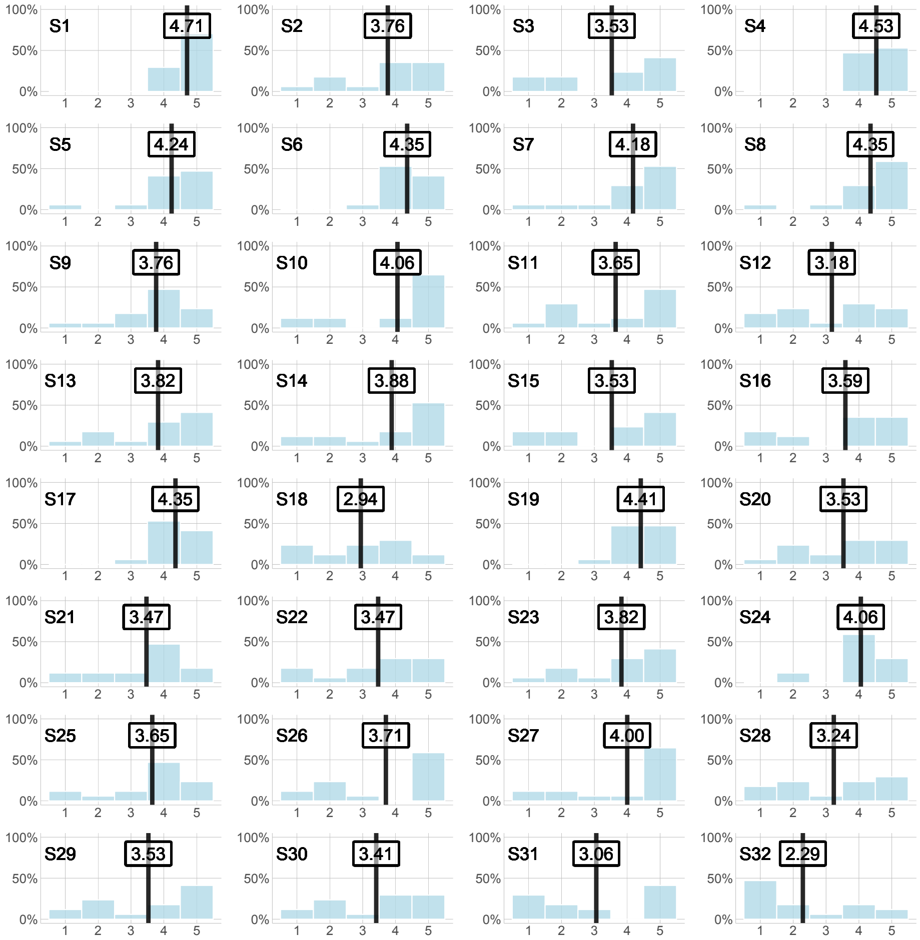

Fig. 3 Preferences expressed by participants with visual impairments for each M&A vision scenario; see the scenarios listed in Table 1 and the preferences expressed by participants without visual impairments in Figure 4.

denote higher desirability. Shapiro-Wilk tests indicated significant deviations from normality at α=.05, and a Levene's test showed the presence of heteroscedasticity in our data ($F_{(31,512)}$=1.798, p<.01). Thus, we employed the Brunner-Domhof-Langer method,[3] an improvement on Friedman's test in terms of power, designed to be sensitive to differences among average ranks [87, p. 543] for data analysis. Results showed a significant effect of Scenario on Desirability-Rating ($F_{(7.893)}$=3.021, p<.005). Overall, the mean Desirability-Rating across all the M&A vision scenarios was 3.75 (SD=1.38), close to 4 that denotes "desirable" scenarios, according to the items of our 5-point Likert scale; see the experiment description in the previous section. The top-rated scenarios were, in order, S_1 (participants wished for better long-distance vision with an average rating of 4.71

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[3] Implemented with the `bprm(...)` function from R. Wilcox's Rallfun-v37 R library, available from `https://dornsife.usc.edu/labs/rwilcox/software/`

out of a maximum of 5); S_4 (better contrast, rating 4.53); S_{19} (audio-rendered vision, 4.41); S_6, S_8, and S_{17} (representing desires for better peripheral vision, better resolution of their current vision, and AR-enhanced vision in the form of text and sign reading, all scenarios scoring an average rating of 4.35); S_5 and S_7 (better vision in ambient light and during nighttime, average ratings 4.24 and 4.18, respectively); and three other scenarios were rated closely to 4, S_{10}, S_{27}, and S_{24}, respectively (preferences for remote vision, infrared vision, and AR-enhanced vision where more details about objects are displayed in real time). Overall, eleven scenarios (34.4%) received desirability preferences that averaged greater than or equal to 4. At the opposite end of the scale, the least preferred scenarios were S_{32} (little preference for UV vision with an average rating of 2.29 out of 5) and S_{18} (little preference for diminished reality, rating 2.94). The rest of the nineteen scenarios examined in our study were rated between 3 (corresponding to the Likert item "undecided: beneficial scenario, but I do not necessarily need or desire it") and 4 ("desirable") by our participants with visual impairments. These results indicate a large preference for M&A vision scenarios from the first category, "human vision with no impairments," while the rest of the scenarios were found potentially useful, but not necessarily desirable or applicable for the needs of our participants.

We performed a correlation analysis between participants' DESIRABILITY-RATING for various M&A vision scenarios and their visual functioning scores. Specifically, we found positive significant correlations for alternative perspectives (seeing from inaccessible viewpoints) and vision specific mental health (r=.49, p<.05) and dependency on others (r=.51, p<.05), a positive correlation between desirability for better vision at a distance (to appreciate better the distance to objects) and vision specific role difficulties (r=.48, p<.05), as well as between desirability for face recognition to identify people easier and general health (r=.53, p<.05). Other significant correlations were negative, such as between emotion recognition to identify face expressions and emotions and social functioning ($r=-.56$, p<.05), between rewind vision (seeing again an event or action) and general vision ($r=-.49$, p<.05), and between multiple perspectives and near vision activities ($r=-.61$, p<.05).

5 Study #2: Preferences of M&A vision of People without Visual Impairments

To understand better the preferences for M&A vision scenarios, we conducted a second vignette study in which we targeted people without visual impairments representing the control group. To collect data from a large sample of participants, we organized this second study online.

5.1 Study Design

Participants. A total number of 178 participants (100 female) without any known visual impairments with ages between 17 and 75 years (M=32.4, SD=12.8 years) volunteered for our study. Participants had various occupations and technical backgrounds and were recruited via mailing lists; about half were students in Computer Science, Psychology, and Educational Sciences.

M&A vision category	Desirability-Rating results: mean (SD)	
	Visual impairments (Study #1)	No visual impairments (Study #2)
1 Human vision with no impairments	4.21 (0.54)	3.61 (0.86)
2 Extended vision (visible range)	3.68 (1.10)	3.53 (0.90)
3 Augmediated vision (visible range)	3.76 (0.57)	3.40 (0.90)
4 Augmediated vision (EM spectrum)	3.36 (1.02)	3.24 (0.78)
Overall	**3.75 (1.38)**	**3.44 (1.28)**

Table 4 Average desirability results for each category of M&A vision scenarios based on preference ratings collected from participants with and without visual impairments.

Apparatus. We used a Google Forms questionnaire that presented participants the descriptions of the M&A vision scenarios from Table 1.

Task. Participants were asked to fill in the questionnaire and to indicate their preferences for M&A vision scenarios that they believed were useful to them. For this study, we did not use the VFQ-25 and SHS questionnaires regarding visual function and subjective well-being.

Measures. The only measure of this study was the DESIRABILITY-RATING dependent variable with values between 1 ("not at all or very little desirable; this scenario does not apply to my case") and 5 ("very desirable; this scenario is very important to me").

5.2 Results

Figure 4 shows the individual preferences of the participants without visual impairments for each M&A vision scenario. Shapiro-Wilk tests indicated significant deviations from normality at α=.05, and a Levene test detected heteroscedasticity ($F_{(31,5664}$=3.384, p<.001). The Brunner-Domhof-Langer test [87, p. 543] revealed a significant effect of SCENARIO on DESIRABILITY-RATING ($F_{(19.934}$=21.803, p<.001).

The mean DESIRABILITY-RATING computed across all the M&A vision scenarios was 3.44 (SD=1.28), slightly lower (-8%) than the mean rating of participants with visual impairments (3.75; see the previous section). To analyze this difference, we compiled the DESIRABILITY-RATING data from the two studies into one dataset and considered participants without visual impairments as the control group by introducing the VISUAL-IMPAIRMENT independent variable, nominal with two conditions. A between-by-within ANOVA procedure based on ranks and the Brunner-Domhof-Langer method [87, p. 554],[4] showed a significant effect of VISUAL-IMPAIRMENT on DESIRABILITY-RATING for M&A vision scenarios ($F_{(1,22.504)}$=4.379, p=.047), a significant effect of SCENARIO ($F_{(19.467,\infty)}$=4.379, p<.001), and a significant interaction between VISUAL-IMPAIRMENT and SCENARIO ($F_{(19.467,\infty)}$=2.280, p=.001). To understand these results, we looked at the individual preferences of the participants without visual impairments for the thirty-two scenarios examined in our study; see Figure 4. We found that only one scenario

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[4] Implemented with the `bwrank(...)` function from R. Wilcox's "Rallfun-v37" R library, available from `https://dornsife.usc.edu/labs/rwilcox/software/`

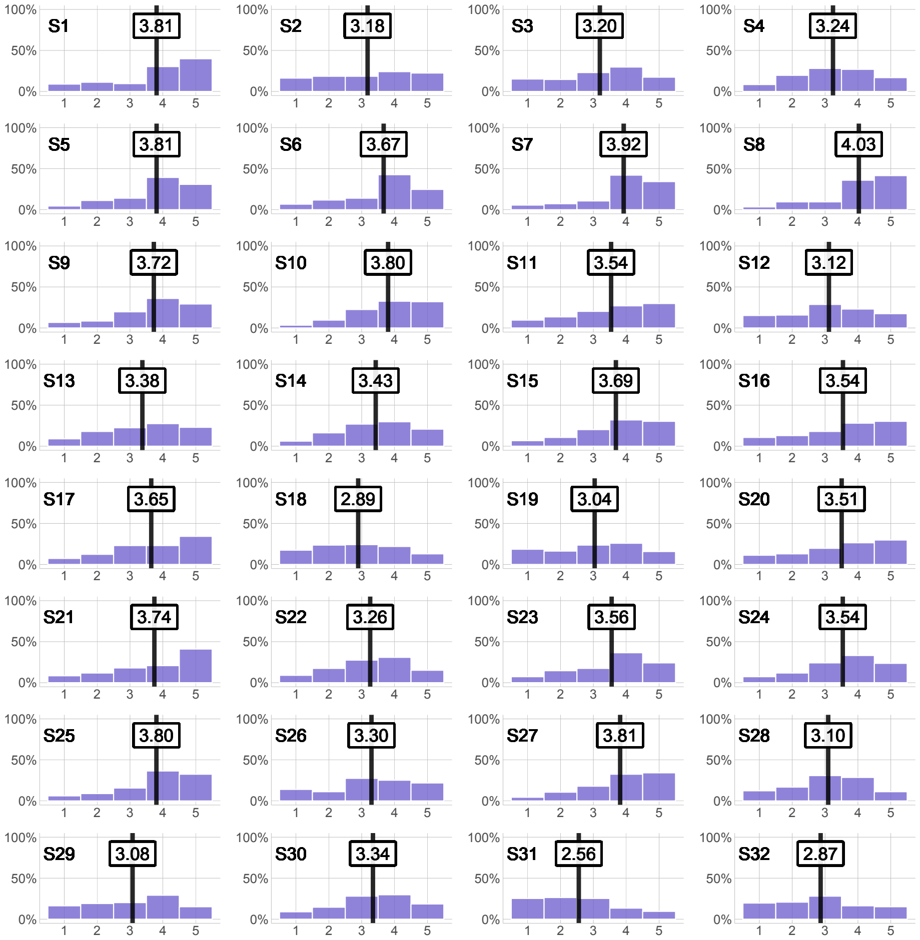

Fig. 4 Preferences expressed by participants without visual impairments for each M&A vision scenario; see the scenarios listed in Table 1 and the preferences expressed by participants with visual impairments in Figure 3.

received a mean rating greater than 4 (S_8, better resolution) compared to eleven scenarios rated above 4 by the participants with visual impairments. We also found three scenarios with preference ratings lower than 3 ("undecided"), while the majority of the scenarios (28 of 32 representing 87.5%) had mean DESIRABILITY-RATING scores between 3 and 4. Table 4 lists the mean scores for each M&A vision category, revealing that the desirability of enhanced vision expressed by participants with visual impairments was higher not just overall (3.75 *vs.* 3.44), but also on each individual category compared to that expressed by the participants without visual impairments. The largest difference (4.21 *vs.* 3.61) was recorded for the first category, human vision with no impairments. In the next section, we discuss implications of these findings.

6 Discussion

Our results show different preferences for M&A vision for people with and without visual impairments. In this section, we use these results to derive a number of implications for smart eyewear that implement assistive mediated and augmented vision, as follows:

1. *Focus on vision rehabilitation applications for which people with visual impairments express the highest desirability.* We found that participants with visual impairments expressed higher desirability for M&A vision compared to participants without visual impairments, not just overall (3.75 *vs.* 3.44) but equally for each of the four categories from our working taxonomy; see Table 4. The largest difference emerged for human vision without impairments (4.21 *vs.* 3.61). These results motivate the need for more research and development toward new solutions for vision rehabilitation, *e.g.*, eyewear devices that are easier to use [74] and have improved technical capabilities such as regarding the synchronization between virtual content and the real world perceived via the see-through display [76], and form factors that do not attract unwanted attention [61]. Future work could focus on understanding preferences for the first category of M&A vision in more depth, for example with in-the-lab and in-situ studies, where end users could provide feedback regarding eyewear application prototypes with actual implementations of M&A vision scenarios.
2. *Differentiation between sighted and visual impaired individuals.* In some scenarios, the preference ratings were similar for the two groups (*e.g.*, 3.76 and 3.72 for S_9, alternative perspectives; 3.18 and 3.12 for S_{12}, see events in slow motion; and 3.59 and 3.54 for S_{16}, rear-view vision). One consequence of these similarities is that M&A vision applications could be designed to address end users with and without visual impairments alike, which supports a previous conclusion from Zhao *et al.* [93]. However, we did find a significant effect of VISUAL-IMPAIRMENT on DESIRABILITY-RATING with the largest difference observed for the first category of M&A vision, human vision without visual impairments (4.21 *vs.* 3.61), which suggests that user-centered and ability-based design approaches are needed; see next.
3. *Specificity for various types of visual impairments and ability-based design.* Our study included participants with different types and severities of visual impairments. Due to the limited number of participants (N=17), we did not run statistical tests for sub-categories (*e.g.*, N=3 blind participants *vs.* N=14 with low vision). However, our discussion from Section 2 revealed a vast body of literature that highlighted the specificity of visual impairments and, consequently, the need to adapt assistive applications to individuals, *e.g.*, user-centered design [22], but also in the form of ability-based design [90]. According the former paradigm, *"users and their experience of a product, system, or service [are placed] at the center of the design process and allows the user to contribute to every stage"* [22, p. 67]; according to the latter, *"by focusing on users' abilities rather than disabilities, designers can create interactive systems better matched to those abilities"* [90, p. 62]. In the support of this recommendation we highlight our findings that showed that general health and vision, visual disability, and the difficulty of performing various activities were related to preferences manifested explicitly by the participants with visual impairments for specific

M&A vision scenarios. Participants rated the following M&A vision scenarios as being the most desirable: long-distance vision, contrast, audio-rendered vision (*i.e.*, hearing the text that is watched such as street signs), AR vision (seeing objects of interest highlighted), and resolution (seeing more details on the objects they are looking at). In contrast, the least desirable scenarios were UV vision, Diminished Reality vision (not being distracted by unimportant objects form the background), radio vision, slow motion, and thermal vision. In particular, we found that general health and visual functioning (vision-related health, emotional well-being, and social functioning) affected positively the preferences for some of our scenarios. These results recommend future work to look more closely at user-centered and ability-based design of assistive M&A vision.

4. *Specificity vs. universality in the design of assistive systems for M&A vision.* Our results revealed that some M&A vision scenarios were rated higher than others, *e.g.*, S_{19} (audio-rendered vision) received an average preference rating of 4.41, while S_{18} (diminished reality) only 2.94 for participants with visual impairments; see Figure 3. These findings indicate preferences for scenarios in which computing technology could help correcting vision deficiencies, *e.g.*, by highlighting objects or improving the contrast and resolution of human vision. Also, our results revealed a preference for scenarios in which AI techniques could be used to present more information about objects, *e.g.*, audio-rendered vision. Given their difficulties in perceiving objects in the visible spectrum, participants with visual impairments were less interested in scenarios addressing other regions of the electromagnetic spectrum, such as UV vision, radio vision, and thermal vision, for instance. Based on these results, we can distinguish between *univalent*, single-purpose systems for assistive vision that focus on one aspect of vision rehabilitation or vision enhancement, *e.g.*, [40, 76], and *multivalent*, multi-purpose systems that implement several M&A vision scenarios, such as [92, 95, 97].
5. *Activity-based M&A vision.* Some of the scenarios considered in our work could be implemented in multivalent systems to assist people with visual impairments with specific activities such as walking, cooking, finding specific objects, working, etc. This implication is supported by (1) existing prototypes from the scientific literature that focused on improving performance for specific activities, such as stair navigation [94], sign reading [36], visual product search [96], or interacting within VR environments [92]; and (2) our participants' self-reported visual functioning (see Table 3) that revealed various challenges with specific activities. Based on these findings, we recommend design of assistive systems and applications that combine multiple types of mediated and augmented vision toward improving the performance of specific tasks and activities.
6. *Design for the portability of M&A vision on various assistive devices.* In our study, we presented participants with visual impairments with three types of eyewear with various capabilities for rendering photorealistic computer-generated content, embedded sensors, and computing resources. For instance, the HoloLens HMD [50] was the most advanced device used in our study, but was perceived by participants bulky and they feared it would draw unwanted attention if worn in public; also, it was the most expensive of the three devices. At the opposite end was the camera glasses [55] that had no see-through dis-

play, but it was affordable and inconspicuous (unless warned, there is no way to see the micro video camera hidden inside the temples). Future work will look at ways in which M&A vision could be implemented on devices with various hardware and software capabilities and resources toward highly portable M&A vision.

7 Conclusion and Future Work

We reported preferences of people with visual impairments for thirty-two scenarios regarding mediated and augmented vision, which we compared to the preferences of a large group of people without visual impairments. Based on our findings, we proposed a number of implications for assistive eyewear systems and M&A vision to guide future work. One limitation of our study is represented by potential individual differences in understanding the M&A vision scenarios and future work could employ actual implementations of AR systems for confirmation of our findings and further discoveries. Besides the development of technical prototypes, future work could further explore the relationship between assistive vision and subjectively-perceived well-being. For example, we found positive associations between vision functioning and subjective happiness, results that are consistent with prior work from psychology documenting lower levels of psychological and social well-being and higher levels of negative emotions, such as depression and anxiety, for people with visual impairments [7,18,27,30]. We believe that careful design of assistive M&A vision may have a positive impact on well-being and reduce negative emotions for people with visual impairments. We hope that our results will be useful to inform such future developments in assistive vision for smart eyewear.

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