A Lead-In Study on Well-Being, Visual Functioning, and Desires for Augmented Reality Assisted Vision for People with Visual Impairments

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***Abstract*. We report on the perceptions of people with low vision regarding their psychological well-being, self-perceived efficiency for performing daily activities, and needs for eyewear technology to assist and augment their visual abilities. Our observations from a lead-in study with five participants with low vision reveal difficulties in performing daily activities, but moderate to high levels of self-reported well-being as well as social life enjoyment being little affected by low vision conditions. Participants also shared their needs and desires for AR eyewear technology that they believed could enhance their visual abilities in various ways.**

Keywords: low vision; visual impairments; smart glasses; smart eyewear; vision augmentation; interviews; visual functioning questionnaire; subjective well-being scale; models of human vision.

I. INTRODUCTION

Recent work has shown that people with visual impairments can benefit from assisted vision in the context of Augmented Reality (AR) applications for smartglasses [1] and Head-Mounted Displays (HMDs) [2]. Smartglasses can increase visual acuity, *e.g.*, by zooming in on objects, highlighting edges, enhancing contrast, etc., and by providing improved visual information to the specific areas of the brain involved in vision processing [3]–[5]. However, there is still little knowledge regarding the *individual needs of people with visual impairments for vision augmentation technology,* despite the large interest in AR-based assistive computing [6]–[10]. Moreover, differences in country development levels and cultural aspects are likely to play an important role in shaping such needs and desires. Without such knowledge, assistive AR devices and applications are still being designed based on requirements for the general end-user population and, thus, opportunities to design assistive technology that meets specific and individual needs and visual abilities are missed.

In this context, we conducted a lead-in study to understand and report the individual perspectives of five participants with low vision regarding their needs and desires for vision augmentation with AR technology. In this paper, we report findings regarding (a) our participants' visual functioning, responses to vision problems, and distress levels, (b) their self-reported psychological well-being, and (c) their self-expressed needs for AR technology to assist vision.

Fig 1. A participant with low vision trying out the Microsoft HoloLens head-mounted display during our study.

II. RELATED WORK

Prior work has uncovered connections between low vision and depression [11], anxiety [12], and low perceived levels of psychological well-being [13]-[14]. It is known that visual rehabilitation should be adapted to individual needs [15], and that careful consideration of users' preferences can inform effective assistive technology [16]. Rehabilitation approaches for human vision have focused on improving reading skills, the autonomy of carrying out daily activities, mobility, and communication for people with visual impairments [15]; for example, among those approaches, mobile technology has been particularly useful to learners with visual impairments [17]. In this section, we overview AR for vision augmentation, and discuss current approaches for modeling human vision.

A. Scope of this Work

In this work, we focus on people with low vision,[1] and investigate their needs and desires for AR technology (see Figure 1) that could enhance their visual abilities.

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[1] The term "low vision" denotes reduced visual acuity that cannot be corrected by surgery and/or prescription glasses [15].

B. *Augmentation of Human Vision*

Several types of vision aids can be identified [18]: *optical* (*e.g.*, magnifier lens), *non-optical* (*e.g.*, larger print, adaptive lighting and contrast, etc.), and *computer-based assistive technology* (*e.g.*, devices, applications, and systems for vision enhancement). According to their function, these vision aids can be divided into two categories: (a) tools that convert visual information into other output modalities, such as audio or haptic feedback, and (b) tools that readjust visual information to improve perception [19]. For example, image processing techniques (*e.g.*, contrast, edge, and contour enhancement, background attenuation, and scene simplification) can maximize residual vision and improve the performance at recognizing objects and facial expressions [19]. Recent studies reported several AR4VI tools (AR for Visual Impairments) for people with low vision [20], such as the AR sign-reading assistant [21], an application for HMDs to assist people with low vision to read signs and numbers, and distance-based vision aids [22] to assist with localization and navigation.

C. *Models of Human Vision*

There are three main approaches in the literature for modeling human vision: *neurobiological*, *cognitive*, and *neurocognitive*. In the following, we overview these models to create the context for our results reported in the next section.

Neurobiological models. These approaches rely on the anatomical structures of the human body to explain the conversion of visible light into perceived images; *e.g.*, the retina transmits electrical signals to the primary and secondary visual cortex. Hubel and Wiesel [23] showed that the first visual representation that is formed represents a topological correspondence with the retinal image, except for the foveal and near-foveal regions. Then, visual information from the primary cortex is delivered to other areas of the brain for further processing [24], *e.g.*, edges and lines are detected by "simple" cells; location, direction, and speed are processed by "complex" cells; and lengths and angles are detected by "hyper complex" cells; see [23]. This processing hierarchy [25] involves more than ten cortical areas of the human brain [26], from which a unified representation of the visual reality ultimately emerges. Several anatomic structures are involved, such as the thalamic reticular mechanism [25], the extrastriate visual association cortex [27], and the thalamic bottom-up and top-down pathways that act as information filters [28].

Cognitive models. The cognitive approach to understanding human vision, located at the intersection of Computer Science and Psychology, models visual perception as a process involving input and output information. Marr [29] modeled the retinal image as two 2D matrices (left and right eyes) that help create a 3D model of the visual reality. Primary processing occurs during the pre-attentional phase of vision (the first 200 ms) and outputs a 2D sketch of edges, groups, discontinuities, blobs, and curves. In the next phase, a 2.5D sketch is produced with information about the orientation, texture, and depth of surfaces. The final 3D model is object-centered and consists of shapes that are organized spatially. In this phase, objects are identified with the contribution of the long-term memory. The feature integration theory of attention [30] focuses on the role of attentional processes in constructing the final image.

Neurocognitive models. This approach merges the previous models and relies both on biological and neurocognitive structures to model human vision [31]. To this end, the literature has identified several functional structures for constructing the visual image of the physical reality. For example, retinotopic maps are grouped in a structure called the "visual buffer," which delivers a first, rough image. The "attention window" structure selects relevant information from that image and directs it to the ventral and dorsal systems [32] for further processing in conjunction with information retrieved from the long-term memory. In case of ambiguous visual stimuli or incomplete information, the "look-up" structure is activated to formulate a hypothesis about the object to be identified by using a top-down search process.

III. STUDY

We conducted a preliminary study consisting of semi-structured interviews with a number of N=5 participants with low vision; see Table 1 for their demographic details. The goal of our study was to understand needs for vision augmentation using eyewear technology, and to correlate such findings with participants' visual functioning abilities and psychological well-being. To this end, we employed the following tools:

1) The Visual Functioning Questionnaire (VFQ-25) [33] to measure the influence of visual impairments on performing everyday tasks and on the emotional and functioning levels. VFQ-25 consists of 25 items that refer to aspects regarding 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 to perform 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?*").
2) The Subjective Well-Being Scale (SWBS) [34] measures global subjective happiness (well-being) on a 7-point Likert scale when comparing 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?*"
3) We employed semi-structured interviews to unveil preferences, needs, and desires for vision augmentation using AR and eyewear technology, including mobile and wearable devices. During this step, participants were presented with the Microsoft HoloLens[2] HMD for Mixed Reality applications (illustrated in Figure 1 on the first page), the Vuzix Blade[3] smartglasses for light AR applications, and the NorthVision Technologies NC-C05 glasses[4] with an embedded micro camera that can stream video to a connected smartphone or tablet. These devices represent various instances of eyewear computing, from holographic computers to light AR systems, and to eyewear embedding video streaming cameras.

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[2] https://www.microsoft.com/en-us/hololens

[3] https://www.vuzix.com/products/blade-smart-glasses

[4] http://northvisiontec.com/products/camera-spy/glasses-eyewear-camera/nc-c05glasses-camera19201080-avi-tf-card-videophoto-876.html

Table 1. Demographic description of our participants, including their self-reported difficulties regarding visual functioning.

	Gender / Age	Condition	Self-reported use of assistive devices	Visual functioning: self-reported difficulties						
				Walk[1]	Read[2]	Obj.[3]	Face[4]	Work[5]	News[6]	Side[7]
1	Male / 17 yrs.	Myopia	Prescription glasses, screen display settings for large fonts	☑☑☑	☑☑☑	☑☑☑	☑☑	☑☑	☑☑	☑
2	Female / 19 yrs.	Congenital cataract	Screen display settings for large fonts	☑☑☑	☑☑	☑	☑☑	☑☑☑	☑☑☑	☑☑
3	Male / 18 yrs.	Myopia and astigmatism	Prescription glasses, display settings, voice input	☑	☑	☑☑	☑☑☑	☑	☑☑☑	☑☑☑
4	Female / 18 yrs.	Retinopathy	Display settings for large fonts, text to speech applications	☑	☑	☑			☑☑☑	
5	Female / 18 yrs.	Glaucoma	Text to speech applications	☑☑	☑☑☑	☑☑☑	☑☑☑	☑☑	☑☑☑	☑☑

[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.

☑ = Little difficulty, ☑☑ = Moderate difficulty, ☑☑☑ = Extreme difficulty or impossible.

IV. RESULTS: VISUAL FUNCTIONING AND WELL-BEING

Due to the lead-in nature of our study involving just few participants, we can present our findings for each participant *individually*, highlighting their visual functioning difficulties and their self-perceived well-being levels. All the names that we use in this paper are fictional.

Andrew, 17 years old, myopia. Andrew reported extreme difficulties reading street signs and names of stores, walking down steps, and locating personal objects; moderate difficulty for seeing other people's reactions during conversations, when working, and reading ordinary print; and low difficulty for matching clothes and seeing objects off to the side. However, he felt that his social life was not affected by his low vision condition, and reported no difficulty going out, such as going to movies, sport events, or visiting other people. However, he also felt that his low vision limited his capacity to engage in sustained work and, thus, made him accomplish less than he would have wanted. Andrew mentioned physical discomfort (eye pain) that sometimes was keeping him away from the activities he would have liked doing. He reported moderate levels of frustration, low levels of irritability and dependency on other people, and a moderate level of subjective well-being.

Anna, 19 years old, congenital cataract. Anna said she could not perform activities that required seeing up close, such as cooking, sewing, etc., or reading ordinary print. She reported extreme difficulties walking down steps and stairs; moderate difficulties for seeing other people's reactions and noticing objects off to the side; and little difficulty matching clothes and locating objects on a crowded shelf. She also mentioned the need to rely on other people for most of the time as well as worrying about doing things that might embarrass her or others. Anna reported low levels of irritability, but high levels of dependency. She indicated a well-being level above average, saying that she wanted to enjoy life regardless of what happened and to get the most out of her life experiences.

Nicholas, 18 years old, myopia and astigmatism. Nicholas reported extreme difficulties seeing people's reactions, noticing objects off to the side, and reading ordinary print; moderate difficulty in locating objects on a crowded shelf; and little difficulty in reading street signs, working, and walking down steps, stairs, especially during night. However, his low vision did not affect his social life. Nicholas also reported physical discomfort in the eyes keeping him away from the things he would have liked doing. Like Anna, Nicholas worried about doing embarrassing things, but reported he felt happier than other people, with a subjective well-being above the average.

Stephanie, 19 years old, retinopathy. Stephanie reported extreme difficulties in reading ordinary print; little difficulty walking down steps, stairs, or curbs at night, reading street signs and store names, and locating objects. She mentioned that her vision did not limit her work in any way, but pointed that sometimes she experienced lack of control, and had to rely too much on other people. Stephanie reported low levels of irritability and dependency, and high subjective well-being.

Emma, 18 years old, glaucoma. Emma said that it was impossible for her to read ordinary print, street signs, and store names, or to see other people's reactions during conversations. She reported extreme difficulty locating objects on a crowded shelf; moderate difficulty walking down steps, stairs, or curbs at night, visiting other people, picking out and matching clothes, and working. She also depended on others for daily activities. Answers to our questionnaires showed low levels of irritability and moderate levels of subjective well-being.

V. RESULTS: NEEDS FOR VISION AUGMENTATION

We asked participants to describe their needs and desires for AR technology to assist vision. To this end, participants tried out the HoloLens, Vuzix Blade, and NC-C05 devices. In the following, we summarize their needs for AR technology, which we discuss from the perspective of models for human vision, following the approach from [35]-[37].

Andrew expressed hope that AR devices would enable him to see fine details on objects and with better contrast. Anna mentioned the need for augmented reading glasses to distinguish fine details on objects and to recognize people from a distance. Anna also mentioned her desire to explore virtual environments using VR HMDs. Nicholas commented about seeing better during nighttime, distinguishing faces from a distance, and reading without magnifying glasses. He also expressed his desire to drive by using technology that would enable him to see the traffic signs. Stephanie expressed the need for a magnifying writing device and for AR glasses to display explanatory texts for the physical surroundings. Emma showed interest in assistive applications for spatial orientation and provided specific ideas, such as an "auditory map" application that follows the user around, devices that describe touristic sites, and smartglasses that read street signs.

The models of human vision, discussed previously, have specific features to identify the role of AR in augmenting visual abilities. For example, vision can be augmented at two neurobiological levels: (1) retinal, where images are enhanced through magnification, noise reduction, edge enhancement, etc. and (2) cortical, where images are enhanced by top-down processing of the non-visual feedback (auditory and haptic). Regarding cognitive models, AR technology could increase the quality of the 2D sketch by clarifying edges, blobs, groups, etc. These improvements would impact the 2.5D sketch as well as the 3D model. Finally, the neurocognitive structures could be assisted by enhancing the activity of the visual buffer (*e.g.*, through magnification), and by fostering activity in the attention window (*e.g.*, by means of selective magnification). We leave such explorations for future work.

VI. CONCLUSION

We reported results from a lead-in study regarding the well-being of several people with low vision, their visual functioning, and their needs for AR technology to augment vision. We also suggested the use of models of human vision to inform and support design of AR-enhanced vision, which we connected to the needs expressed by our participants. More investigations are needed to understand such needs, and future work will focus on a larger sample of participants.

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REFERENCES

[1] Y. Zhao, M. Hu, S. Hashash, and S. Azenkot, “Understanding Low Vision People’s Visual Perception on Commercial Augmented Reality Glasses,” in *Proc. of CHI ’17*, 2017, pp. 4170–4181.

[2] J. R. Ehrlich *et al.*, “Head-Mounted Display Technology for Low-Vision Rehabilitation and Vision Enhancement,” *Am. J. Ophthalmol.*, vol. 176, pp. 26–32, Apr. 2017.

[3] R. D. Wimmer, L. I. Schmitt, T. J. Davidson, M. Nakajima, K. Deisseroth, and M. M. Halassa, “Thalamic control of sensory selection in divided attention,” *Nature*, vol. 526, p. 705, Oct. 2015.

[4] D. Marr, *Vision: a computational investigation into the human representation and processing of visual information*. MIT Press, 2010.

[5] A. M. Treisman and G. Gelade, “A feature-integration theory of attention,” *Cognit. Psychol.*, vol. 12, no. 1, pp. 97–136, Jan. 1980.

[6] E. Peli, R.B. Goldstein, G.M. Young, C.L. Trempe, S. Buzney, “Image enhancement for the visually impaired. Simulations and experimental results,” *Invest. Ophthalmol. Vis. Sci.*, 32(8), pp. 2337–2350, Jul. 1991.

[7] E. Peli, E. Lee, C. L. Trempe, and S. Buzney, “Image enhancement for the visually impaired: the effects of enhancement on face recognition,” *J. Opt. Soc. Am. A*, vol. 11, no. 7, p. 1929, Jul. 1994.

[8] E. Tanuwidjaja *et al.*, “Chroma: a wearable augmented-reality solution for color blindness,” in *Proc. of UbiComp ’14 Adj.*, 2014, pp. 799–810.

[9] A.D. Hwang, E. Peli, “An Augmented-Reality Edge Enhancement Application for Google Glass,” *Optom.Vis.Sci.* 91(8), 1021–1030, 2014.

[10] F.E. Sandnes and E. Eika, “Head-Mounted Augmented Reality Displays on the Cheap: A DIY Approach to Sketching and Prototyping Low-Vision Assistive Technologies,” in *UAHCI'17*, 2017, pp. 167–186.

[11] C. L. Nollett *et al.*, “High Prevalence of Untreated Depression in Patients Accessing Low-Vision Services,” *Ophthalmology*, vol. 123, no. 2, pp. 440–441, Feb. 2016.

[12] J. R. Evans, A. E. Fletcher, and R. P. L. Wormald, “Depression and Anxiety in Visually Impaired Older People,” *Ophthalmology*, vol. 114, no. 2, pp. 283–288, Feb. 2007.

[13] E. K. Fenwick, P.G. Ong, R.E.K. Man, C. Sabanayagam, C.Y. Cheng, T.Y. Wong, E.L. Lamoureux, “Vision impairment and major eye diseases reduce vision-specific emotional well-being in a Chinese population,” *Br. J. Ophthalmol.*, vol. 101, no. 5, pp. 686–690, 2017.

[14] G. Garcia *et al.*, “Profound vision loss impairs psychological well-being in young and middle-aged individuals,” *Clin. Ophthalmol.*, vol. Volume 11, pp. 417–427, Feb. 2017.

[15] C. Meyniel, B. Bodaghi, and P.-Y. Robert, “Revisiting Vision Rehabilitation,” *Front. Syst. Neurosci.*, vol. 11, Nov. 2017.

[16] B. Dougherty, “Assistive Technology and Future Strategies for Vision Enhancement:,” *Optom. Vis. Sci.*, vol. 95, no. 9, pp. 692–693, 2018.

[17] S. Hayhoe, “Epistemological Trends in the Literature on Mobile Devices, Mobile Learning, and Learners with Visual Impairments:,” *Optom. Vis. Sci.*, vol. 95, no. 9, pp. 889–897, Sep. 2018.

[18] R. Thomas, L. Barker, G. Rubin, and A. Dahlmann-Noor, “Assistive technology for children and young people with low vision,” *Cochrane Database Syst. Rev.*, Jun. 2015.

[19] H. Moshtael, T. Aslam, I. Underwood, and B. Dhillon, “High Tech Aids Low Vision: A Review of Image Processing for the Visually Impaired,” *Transl. Vis. Sci. Technol.*, vol. 4, no. 4, p. 6, Aug. 2015.

[20] J. M. Coughlan and J. Miele, “AR4VI: AR as an Accessibility Tool for People with Visual Impairments,” *ISMAR'17(Adj.)*, 2017, pp. 288-292.

[21] J. Huang, M. Kinateder, M. J. Dunn, W. Jarosz, X.-D. Yang, and E. A. Cooper, “An augmented reality sign-reading assistant for users with reduced vision,” *PLOS ONE*, vol. 14, no. 1, p. e0210630, Jan. 2019.

[22] M. Kinateder, J. Gualtieri, M. J. Dunn, W. Jarosz, X.-D. Yang, and E. A. Cooper, “Using an Augmented Reality Device as a Distance-based Vision Aid—Promise and Limitations,” *Optom. Vis. Sci.*, vol. 95, no. 9, pp. 727–737, Sep. 2018.

[23] D. H. Hubel and T. N. Wiesel, “Receptive fields and functional architecture of monkey striate cortex,” *J. Physiol.*, 195(1), pp. 215–243, 1968.

[24] D. J. Felleman and D. E. Van, “Distributed hierarchical processing in the primate cerebral cortex.,” *Cereb. Cortex*, vol. 1, pp. 1–47, 1991.

[25] F. Crick, “Function of the thalamic reticular complex: the searchlight hypothesis,” *Proc. Natl. Acad. Sci.*, vol. 81, pp. 4586–4590, 1984.

[26] M. Bar *et al.*, “Cortical mechanisms specific to explicit visual object recognition,” *Neuron*, vol. 29, no. 2, pp. 529–535, 2001.

[27] N. Kanwisher, J. McDermott, and M. M. Chun, “The fusiform face area: a module in human extrastriate cortex specialized for face perception,” *J. Neurosci.*, vol. 17, no. 11, pp. 4302–4311, 1997.

[28] R. D. Wimmer, L. I. Schmitt, T. J. Davidson, M. Nakajima, K. Deisseroth, and M. M. Halassa, “Thalamic control of sensory selection in divided attention,” *Nature*, vol. 526, no. 7575, p. 705, 2015.

[29] D. Marr, T. A. Poggio, and S. Ullman, *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. Cambridge, Mass.: The MIT Press, 2010.

[30] A. M. Treisman and G. Gelade, “A feature-integration theory of attention,” *Cognit. Psychol.*, vol. 12, no. 1, pp. 97–136, 1980.

[31] S. M. Kosslyn, “If neuroimaging is the answer, what is the question?,” *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, vol. 354, pp. 1283-1294, 1999.

[32] M. Mishkin and L. G. Ungerleider, “Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys,” *Behav. Brain Res.*, vol. 6, no. 1, pp. 57–77, 1982.

[33] C. M. Mangione, “Development of the 25-list-item National Eye Institute Visual Function Questionnaire,” *Arch. Ophthalmol.*, vol. 119, no. 7, p. 1050, Jul. 2001.

[34] S. Lyubomirsky and H. S. Lepper, “A Measure of Subjective Happiness: Preliminary Reliability and Construct Validation,” *Soc. Indic. Res.*, vol. 46, no. 2, pp. 137–155, Feb. 1999.

[35] M.D. Schipor and R.D. Vatavu, "Neurobiological and Neurocognitive Models of Vision for Touch Input on Mobile Devices," in *Proc.EHB'17, the 6th Int. Conf. on e-Health and Bioengineering*, pp. 353-356, 2017.

[36] M.D. Schipor and R.D. Vatavu, "Coping Strategies of People with Low Vision for Touch Input: A Lead-in Study," in *Proc. of EHB'17, the 6th Int. Conf. on e-Health and Bioengineering*, pp. 357-360, 2017.

[37] R.D. Vatavu, B.F. Gheran, M.D. Schipor, "The Impact of Low Vision on Touch-Gesture Articulation on Mobile Devices," *IEEE Pervasive Computing*, vol. 17, no. 1. IEEE, pp. 27-37, 2018.