Technology-Mediated Sight: A Case Study of Early Adopters of a Low Vision Assistive Technology

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ABSTRACT

A case study of early adopters of a head-mounted assistive device for low vision provides the basis for a sociotechnical analysis of technology-mediated sight. Our research complements recent work in HCI focused on designing, building, and evaluating the performance of assistive devices for low vision by highlighting psychosocial and adaptive aspects of digitally enhanced vision. Through a series of semi-structured interviews with users of the eSight 2.0 device and customer-facing employees of the eSight company, we sought to better understand the social and emotional impacts associated with adoption of this type of low-vision assistive technology. Four analytic themes emerged from our interviews: 1) assessing the value of assistive technology in real life, 2) negotiating social engagement, 3) boundaries of sight, and 4) attitudes toward and expectations of technology. We introduce the concept of *multiplicities of vision* to describe technology-mediated sight as being a form of skilled vision and neither fully-human nor fully-digital, but rather, assembled through a combination of social and technical affordances. We propose that instead of seeing low-vision users through a deficit model of sight, HCI designers have more to gain by viewing people with low vision as individuals with a distinct type of skilled vision that is both socially and technologically mediated.

CCS Concepts

H.5.1. Information Interfaces and Presentations: Multimedia Information Systems; K.4.2. Computers and Society: Social Issues.

Keywords

Low vision; assistive technology; head-mounted systems; qualitative research.

1. INTRODUCTION

Globally, 246 million people have "low vision," an umbrella term for moderate to severe visual impairments [39]. While much of this population is completely blind, a larger portion has partial vision. These individuals can experience acuity loss, high sensitivity to light, blind spots, and other disruptions of the visual field.

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A growing set of assistive technologies (AT) for people with low vision are emerging that take advantage of recent developments in computer vision, wearable technologies, and battery life. In contrast to permanent and invasive treatment like surgery, these devices provide a temporary, relatively low risk option for those with vision loss. However, users of low vision head-mounted displays (HMDs) are still in the minority among the population of people with low vision. In adopting this technology, tradeoffs are often made between social, emotional, and biological factors. Our study contributes empirical evidence in the form of rich, qualitative descriptions of users' psychosocial experiences when integrating technology-mediated sight into their daily lives.

We conducted a case study of early adopters of the second release of the eSight eyewear (Figure 1), a hands-free assistive device marketed to people with low vision throughout the U.S. and Canada. Through this case study, we ask:

- What is the emergent, social, and emotional nature of visual experience made available to low vision users through AT, specifically the eSight HMD?
- How is this experience of vision assembled via a combination of social and technical affordances?
- What are the implications of these experiences for the design of assistive and augmentative technologies in the future?

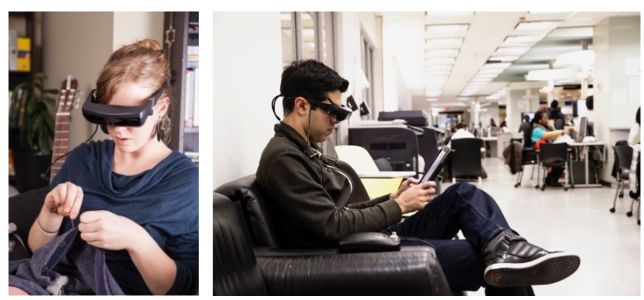

Figure 1. Users of the eSight 2.0 device. Credit: eSight Corporation.

To explore these questions, we conducted semi-structured interviews with thirteen users of eSight 2.0 and three eSight employees who direct and conduct customer screening interviews, initial fittings, and training sessions. User narratives about integrating AT into their daily lives surfaced themes regarding 1) assessing the value of AT in real life, 2) negotiating social engagement, 3) boundaries of sight, and 4) attitudes toward and expectations of technology. We introduce the concept of *multiplicities of vision* to describe technology-mediated sight as being 1) a form of skilled vision and 2) neither fully human nor fully digital, but rather, continuously assembled through a combination of social and technical affordances.

2. BACKGROUND

We describe the experience of low vision, provide a brief overview of current AT for people with low vision, and then describe the eSight 2.0 device used by the participants in our study.

2.1 The experience of low vision

Vision is typically described in terms of three characteristics: visual acuity, contrast sensitivity, and visual field perception [3,16]. There are four levels of visual acuity: normal vision, moderate visual impairment, severe visual impairment, and blindness. "Normal" or typical vision is described as 20/20. If you have reduced visual acuity, for example 20/60 vision, you can see detail at 20 feet that a typically sighted person can see at 60 feet. You are considered legally blind if either: 1) your vision is 20/200 vision or worse, even with corrective lenses, or 2) your visual field is 20 degrees or less [2].

Refractive errors cause conditions such as myopia (nearsightedness), hyperopia (farsightedness), astigmatism (irregular curvature of the lens), or presbyopia (inelasticity of the lens) that can typically be treated with corrective lenses or surgery [38]. However, if these refractive conditions cannot be corrected, the person is considered to have low vision. Other low vision conditions include macular degeneration (degeneration of the retina), diabetic retinopathy (diabetes related disease of the retina), amblyopia (dim vision), glaucoma (distress on the optic nerve caused by pressure within the eyeball), and Stargardt disease (juvenile macular degeneration) [1]. In these cases, people often have some functioning sight but can experience significant blind spots, limited field of view or have other disruptions to their visual field; significant acuity loss; trouble seeing at a distance; and particular sensitivity to light levels. Many also suffer from headaches and eye tremors. Visual impairments such as these "cause a number of disabilities including difficulty with reading, writing, recognizing faces, watching television, orientation and mobility, and completing activities of daily living" [16, p. 495].

2.2 Assistive technologies (AT) for people with low vision

There are currently multiple technologies available to help people with low vision accomplish daily tasks [18,35]. Many of these tools provide access to digital devices such as desktop computers, laptops, mobile phones, and public kiosks [6,34] through screen magnification, text-to-speech, and speech-to-text (dictation and command-and-control) software and hardware. Applications built into operating systems also enable users to enlarge the size of text and elements on the screen using font and zoom settings. Many of these technologies require the text to be in a readable format through Optical Character Recognition [12]. Audio books and video-camera-based magnifiers, including closed circuit televisions (CCTVs), are common tools for people with low vision to access print media. People with low vision use mainstream mobile phone cameras to zoom in on faraway objects and use applications for specific functionality such as scanning a barcode on a product while shopping [35]. However, these strategies are unreliable due to screen glare, poor photo resolution, and concerns about having the phone lost or stolen while in outdoor, public spaces.

As mainstream technology has moved toward mobile and wearable devices, so has the low vision field. A recent trend has been portable HMD, like the eSight device, that provide magnification and contrast enhancements using optoelectronics and video technology. Two notable early examples of HMD for individuals with low vision are the Low Vision Enhancement System (LVES) [23,36] and Jordy [13]. LVES, released in 1994 by Johns Hopkins University and NASA, is a battery-powered, portable system providing real-time video image processing and eye-tracking capabilities [22]. Jordy, launched in 1998 by Enhanced Vision Systems, provides 16 levels of magnification and can be head mounted or used with a docking station [13]. Recently, HCI researchers have turned to augmented reality devices, including Google Glass and custom prototypes [e.g., 10,42,43]. For example, Zhao et al. created ForeSee [42], a general purpose real time video system with five enhancement methods: magnification, contrast enhancement, edge enhancement, black/white reversal, and text extraction. Other HMD for people with low vision have been designed and optimized for specific scenarios, such as exercise [29], theaters [21], and video games [41].

2.3 eSight eyewear

For our study, we focused on early adopters of eSight 2.0 eyewear. Marketed since 2013 by Ottawa-based eSight Corporation, the device is currently used by over one thousand individuals with low vision in the US and Canada and has received attention in popular media [8]. The eSight device is classified as a Class 1 Medical Device and is appropriately registered with the US Federal Drug Administration (USFDA) and Health Canada. It has been the subject of a study conducted by the Canadian National Institute for the Blind (CNIB) which established that it "offers a statistically significant improvement in visual acuity and contrast sensitivity for users" [9].

The head-mounted camera system captures live video sent through a small portable computer (about the size of a paperback book) that is worn or carried by the user. Proprietary software is used to process the video one pixel at a time, optimizing for the user's visual impairment. A full-color digital image is displayed in real-time on high-resolution near-to-eyes organic-LED (OLED) screens that are held in place by an eyeglass frame with adjustable headband. The screens provide 35-degree field of view and 4x3 aspect ratio, with adjustable pupil spacing and integrated prescription lenses. The 2.0 version of the eyewear weighs less than 200 grams, has a battery life of about four hours, and costs approximately US$15,000. (The recently released eSight 3.0 is smaller with improved performance and costs US$10,000 [9] but was not yet available at the time of data collection.)

The device uses a combination of automated settings and physical user controls located on a portable CPU/battery pack. The system permits immersive and bioptic use, including magnification (up to 14x) and color, contrast, and brightness enhancements. Users can instantly switch from near vision (reading a document) to midrange vision (looking up to see who just entered the room) to long range vision (looking out the window to see if it is raining). It is also possible to connect the device directly to a monitor or TV (bypassing the camera) and to take and store still images from video output.

2.4 Challenges to Assistive Technology Acceptance

While HMDs offer promise for the future, there are challenges to getting AT for low vision to the people who stand to benefit most. Potential users can have limited awareness of emerging or established technologies that could meet their needs [25]. Often, acquiring an AT is a decision made not only by the end user, but is a negotiation with family, educators, therapists, and employers. Power dynamics among these stakeholders can influence the priorities assigned to the user's needs, the allocation of resources, and the social acceptance of AT use. [27]. Related concerns have been raised about the expense of devices like eSight and the lack of financial support provided through federal programs or private health insurance [6].

Having a vision impairment and using AT can influence a person's identity and their social interactions in profound ways [17,24], depending on factors such as age of onset or having families members with similar conditions [26]. Users of AT report that mastering their AT gave them an increased sense of independence and productivity [31]. However, social stigma is a key deterrent to use [26,27,31]. Some individuals felt that using non-mainstream technology brought attention to their disability and increased the perceived "otherness" of having a disability. They felt that they were subject to misperceptions that people with disabilities have a continual need for assistance and would be "helpless without their device" [27, p.705]. While social acceptability is a primary concern [18,42], some believe that social stress will lessen as awareness of technology-mediated accommodations grows and social norms change [28].

Further challenges to AT use over time are related to changing user needs depending on task, context, and stage of visual condition [37]. The value that people with progressive or chronic diseases place on AT can change over time, as their condition evolves, degrades, or improves [26]. People with low vision can have complex relationships with technology as a result of personal experiences devising adaptive strategies to work around accessibility issues [18,19]. In spite of the potential for peers and colleagues to express limiting views about their technology-mediated abilities [25], in Lazar's study, blind individuals exhibited a higher tolerance for frustrating web experiences than sighted users.

In summary, the changing landscape of AT for low vision spurred by mainstream advances in mobile, wearable and virtual technologies has highlighted the need to better understand how the use of these technologies unfolds in the real world. Researchers in low vision AT and augmented reality have called for deeper exploration of the lived experiences and friction points of using low vision AT [12,32] and, specifically, wearables [20,42]. Our research contributes to this growing area of research by examining the psychosocial dynamics of vision and AT through the experiences of early adopters of the eSight eyewear.

3. Methods

3.1 Participants

For the user interviews, we worked with eSight to identify 13 users (6 female, 7 male) over the age of 25 (average age of 52) who had a minimum of 5-10 years with vision loss and experienced profound shifts in vision when using the eSight device, as measured by Best Corrected Visual Acuity (BCVA). We conducted interviews over Skype or telephone, which allowed us to reach a broad geographic range across the U.S. and Canada. The participants were trained or employed in, or retired from, occupations such as information technology support, nursing, marine engineering, teaching, electrician, office administration, kitchen design, and visual art.

Many but not all of our participants participated in social services established by government and community organizations such as the CNIB. These services included education services for disabled students in elementary and post-secondary education, vision rehabilitation, occupational therapy, and adaptive sports groups. Our interview participants described having a range of visual conditions, acuity, and physiological experiences with vision loss (Table 1).

Most of our participants described changes in their experience of visual impairment over time, such as lessening eyesight due to chronic degenerative eye disease; unexpected loss of sight due to medical complications; and progressive worsening of congenital eye conditions over time, especially as a result of aging. One participant reported improvement in sight over time.

Participants reported using a variety of low vision aids (LVAs) and AT over time, typically spurred by changes in their visual condition and evolving needs. LVAs included hand held magnifiers, binoculars, CCTVs, large print books, audio books, canes, and guide dogs. For digital access, many reported using the screen magnifier and text-to-speech functions of software such as ZoomText and Kurzweil. Hardware adaptations included large print keyboards and hand-held magnifiers. One participant had previously owned two early HMDs, LVES and Jordy. All participants had been using the eSight eyewear for at least one year.

Table 1. Visual and sensory conditions of participants who use eSight.

#	Visual Condition	Onset
P01	Stargardt disease (Central blind spot; sees colors as tones)	Child
P02	One eye totally blind; other eye low acuity	Adult
P03	Folia of eye unusable; low acuity	Birth
P04	Low acuity; color blind	Birth
P05	Optic Nerve Hypoplasia; low resolution; eyes rotate. Also: Congenital hearing loss; Hand and head tremors	Birth
P06	Macular degeneration	Adult
P07	Macular degeneration; Peripheral vision is green	Adult
P08	Stargardt disease (Central vision is disappearing)	Adult
P09	One eye Glaucoma and Uveitis resulting in loss of eye; other eye Global rupture resulting in no central vision	Child
P10	Myopia; lazy eye; stigmatism; Macular degeneration	Birth
P11	Usher's Syndrome (No colors; no night vision; cannot see faces anymore). Also: Hearing loss	Adult
P12	Visual Ocular Albinism; Nystagmus	Birth
P13	Legally blind. Also: Multiple Sclerosis	Adult

We supplemented the eSight user interviews with semi-structured interviews with three eSight employees who are involved in demonstrating eSight to potential users as well as fitting and training new users. These activities have given these individuals insight into non-use, barriers to adoption, and typical challenges faced by new users.

3.2 Data collection

Our one hour interviews followed a semi-structured format based on the critical incident technique of eliciting and documenting participant narratives [11]. This technique asks participants to recall a specific, significant activity and recount what they "saw, heard or felt" [11, p. 329] during the unfolding of that event. Early transitional experiences with the eSight eyewear were positioned as critical incidents in the long-term adaptation to technology-mediated sight.

Semi-structured interviews with eSight employees focused on initial customer screening, fitting, training, and post-purchase support. The participants were asked to describe the necessary visual qualifications for using eSight, and customers' concerns about adoption and daily use.

3.3 Analysis

Our analytic process followed a grounded and inductive approach [4,5]. Three members of the research team reviewed interview notes and transcripts, collectively identifying a set of emergent *initial codes*, reflecting the concerns, discourse and perspectives of the individuals in our study. Further discussion and review of interviews resulted in these initial codes being refined to a set of 14 *focused codes* across 4 main analytic themes (Table 2).

Table 2. Main themes and focused codes. Frequency of each code is in parentheses ( ).

Assessing the value of AT in real life
• *Rationale*- Why AT was used or not used in a given situation (265) • *Sharing AT*- Accounts of sharing AT with others (both with and without visual impairment), often for the purpose of showing the benefits (48) • *Impairment positives*- Instances where a lack of fully functioning eyesight was described in positive terms (14)
Negotiating social engagement
• *Inclusion*- Having (or lacking) ability to fully participate or perform in social life with a sense of equity or parity (87) • *Independence*- Having (or lacking) ability to accomplish day-to-day tasks without assistance (60) • *Contributing*- Having (or lacking) ability to provide, give, or share through work, wages, labor, etc. (52) • *Discernibility*- Instances where a visual impairment went unnoticed or unnoted (or should/could have) (28) • *Nonverbal communication*- Social interactions that relied on body language, facial expressions, physical proximity, or other nonverbal expressions (19)
Boundaries of sight
• *Depth, distance and transitions*- Instances where the experience of vision was described in terms of space (87) • *Seeing yourself see*- Reflections on what it is like to see, both with and without AT (75) • *Superpowers*- AT giving users the ability to do things that people with typical eyesight could not do (19)
Attitudes and expectations of technology
• *Responses to visual impairment*- Actions taken as a direct response to visual impairment (e.g., help sought, changes to living environment, lifestyle changes) (140) • *Expectations*- Assumptions, anticipations, or suppositions about what the future will hold (125) • *Attitudes and experiences with technology*- References to involvement with or feelings towards technology in general (not just AT) (79)

These codes were applied to the 13 eSight user interviews through a multistep process using nVivo qualitative analysis software. At least two researchers coded each interview; and at least two researchers reviewed each coded segment. Differences were deliberated until consensus was reached. Codes were applied parsimoniously by focusing on the primary concept being discussed by participants in each passage. However, because some emergent themes were complex and inter-related, a small portion of the coded passages were assigned more than one code (approximately 13%). Throughout this process, *analytic search* was used to identify key corroborating and potentially conflicting examples, resulting in a refined annotated codebook (available upon request) [4]. Thematic analysis was also performed on the research memos from the eSight employee interviews.

4. Findings

Here we provide brief summaries of each of the four main themes that emerged from our interviews with eSight users, highlighting focused codes most relevant to our research questions.

4.1 Theme 1: Assessing the value of AT in real life

We observed that the decision to purchase and use a given AT is a fluid, dynamic choice, influenced by growing awareness of different AT and access to financial resources. This finding expanded related research on the challenges of AT use by highlighting the perceived value of AT over the course of a lifetime. As people's visual conditions fluctuated and life circumstances shifted, they experienced changes in their emotional readiness to adopt AT. The majority of our participants had experimented with two or more visual aids. As children, choice of AT was typically initiated by parents or school staff. As the participants became adults, the scope of influence on AT use widened to include key family members, workplace policies, available resources, and advocacy by community organizations like CNIB.

Experimentation with AT use was primarily driven by a need for mobility and to be able to see things at different focal planes. For example, P05 explained: *"Using binoculars were not flexible enough. Constantly having to adjust them for different distances. I'm better off to stand next to [the] presentation screen."* Participants described using more traditional AT, such as walking canes or guide dogs, with mixed feelings about inclusion and stigma. For instance, P02 relied on his cane, saying, "*I don't go anywhere without it*," whereas P09 said "*I'm embarrassed to use my white cane*."

Participants described situations where AT was sufficient in providing fundamental visual access but contextual factors impacted use:

"Using a magnifier…was great for looking at something on paper, but if I was looking at something through a window obviously…I wouldn't be able to do anything with it. If I was in a store, if I could hold it, if it was in my hand…I could see the price on it but if it was something up on a shelf, a magnifier was no good to me." (P06)

"You're trying to scan over a tablet with a magnifier that's only like an inch and a half off the screen. You're always touching something…With the Jordy, I hold it at a reasonable distance from my face. And I use my hands to read the screen while on my own I have all the accessibility [features] turned up." (P04)

With regards to the decision to start using the eSight eyewear, our participants expressed a strong, hopeful reaction when they first learned about the device on TV, online, or at a vision trade show. Our participants learned about the device either first-hand or were passed along information by family, co-workers, and friends. For all but one of our participants this led to contacting eSight for screening and then scheduling a demonstration. (The exception to this process was P04, who purchased eSight after the screening but without a demonstration, relying on his past experiences with HMD (LVES and Jordy) and discussions with eSight.)

In contrast to our participants who ultimately purchased eSight, some individuals who contact the company decide not to pursue this AT. According to the eSight employees we interviewed, the initial screening process can include a recommendation that someone who is experiencing drastic changes in their vision or overall health might not be ready to start using a new AT. Some potential users want to delay their purchasing decision until they can try eSight in specific scenarios that are important to them, such as using their iPad. Others are simply not receptive to eSight after hearing more about the product, citing that they are content with their current AT and workarounds. An eSight employee equated this reported satisfaction with the status quo with generalized resistance to change, citing this as a significant barrier to the adoption of products such as eSight.

The demonstration that follows initial screening is often an emotional experience since the success of eSight, or lack of success, is usually evident upon initial use. Our participants vividly described their first experiences using eSight, many tearing up as they talked about the *"night and day difference"* (P03) in their vision, and feeling *"blown away"* (P06) and overwhelmed:

"Now my first, I still get a little emotional…I put the glasses on and [my wife] is sitting in the conference room and I look at her… I've never seen her face. She cried, I cried. That was a big thing, that was the reason for trying them out." (P11)

P12 got her wish that *"it wouldn't be something that would help just a little bit, … but it was going to be a significant improvement, [if] it's really going to help me then I would know right away. Thankfully it was a big difference."*

The financial commitment required to purchase the eSight device (approximately US $10,000 to $15,000) played an important role in assessing the technology's value. P09 experienced a series of severely degenerative medical events that led at one point to her having complete vision loss. She summarized her decision to spend the money:

"It was super emotional but kind of ridiculously funny at the time. I was like are you kidding me, if someone had told me when I was in the complete dark that for $10,000 you could have some eyesight back I think that would have gotten me through…I can't even explain the emotional component of that. Like how insignificant $10,000 seemed at that time." (P09)

P08 described the mental process of weighing financial costs versus benefits:

"When I saw the cost of it … I thought oh my God you know, how would I, I mean that just seemed like a lot of money for this, but on the other hand it depends on how much you feel the difference it's going to make in your life…if you could make it work somehow." (P08)

Both of these statements reflect the emotional, aspirational, and practical dimensions of embracing AT devices like eSight. The relatively high cost of this technology is not without controversy due to socioeconomic challenges faced by many people living with visual impairment. Most of our participants had concerns about the cost, balancing personal value with available resources. None of the participants in our study expressed regret about purchasing the eSight eyewear, an outcome that we saw as directly related to eSight's deliberate screening and demonstration process. While some individuals paid for the device out of pocket using savings or by selling a car that was no longer needed because of deteriorating vision, the relatively high price tag for eSight meant that many participants engaged closely with a social support network to raise the needed funds. This ranged from families pooling resources to collections at church to social media campaigns like gofund.me. At least two participants received their eSight eyewear as the result of a donor who covered the entire cost of the device.

4.2 Theme 2: Negotiating social engagement

The discernibility of a visual condition influenced social interactions for our participants, contributing to their sense of social acceptance or stigma of disability and AT use. Our participants talked about "passing" as a person without visual impairment. For example, one person described being surprised to learn that people could identify his visual limitations at first sight, for many years not realizing that his eyes were noticeably small and sunken:

"I walk into a room [and]…they'll say would you like some help? Well, I'm okay but I'm kind of wondering why the person, like I ask them did I stumble when I came through the door? Like did I knock something? Like how did they know I had a vision impairment?" (P04)

Others talked with pride about realizing that a co-worker or acquaintance were not aware that they were visually impaired: *"He actually has no idea I can't see…I'd kind of like to keep it that way, like I'm just a person." (P01)*

In talking about the impacts of bringing eSight into their lives, participants directly associated technology-mediated sight with social engagement. While sharing a range of stories about how they were active, social, and adventurous, many participants described situations in which their visual impairments constrained the ways they contributed to their families, communities and work environments. When asked to describe instances when they particularly felt the impacts of adopting the technology, many gave the device credit for greatly supporting their abilities to work, help their children with sports or school work, or more effectively complete household chores like shopping. In contrast to research focused on barriers to social acceptance, technology-mediated sight in these instances was described as explicitly connected to a sense of self-worth and societal value. For example, one participant described what it was like to try to do the family grocery shopping before eSight:

"He won't let me do the grocery shopping because I don't buy any of the right stuff that everybody likes…I would never come home with anything that anybody liked. I thought I was picking the, you know, this jar of peanut butter looks like this jar of peanut butter." (P01)

This person went on to explain that with eSight, she is now able to see small differences in labels, making her better able to respond to her family's preferences. This increased acuity also made her keenly aware of all the things she missed without the device, contributing to feelings of inadequacy and, at times, depression. Here we see evidence of technology-mediated sight being used to negotiate ongoing attempts to balance inconveniences, even stigmas, associated with head-mounted AT with desires for more robust social practices in spite of differences in visual abilities.

Related aspects of social engagement included experiencing degrees of inclusion and independence through use of the eSight eyewear. Having the ability to observe and use non-verbal communication through eye contact, facial expressions and proximity were considered a strong benefit of the device. However, many of the stories shared by participants highlighted challenges to achieving true parity and equity to those without visual impairment. More often they described what could be called satisficing. Their visual experience was a not a replacement for unmediated sight, but offered enough of the same social affordances to be considered valuable:

"It wasn't normal vision but it was vivid enough for me to feel like I was there experiencing it with him again, like I was part of the world that he was living in, I wasn't in a different excluded weird cold place." (P09)

Many people told us that they decided *not* to use the device in some social situations because the opacity and bulkiness of the headgear interfered with their ability to interact in a naturalistic manner:

"...when I first met a client I would not wear my eSight because part of my job with sales was selling the kitchen design and if a person can't see your eyes they have a hard time trusting you…. I'm used to not seeing anyone's eyes, I'm used to using other points, but most people are not, so when they're talking to you they want to see your eyes." (P10)

The eSight device (and similar technology) is not a cure-all for challenges of inclusion, independence, and social integration faced by individuals with low vision. The social reality created using these devices for interpersonal communication and engagement is distinct, valued, and not entirely similar to unmediated interactions. Some users expressed initial disappointment about this gap, yet adjusted to this alternate social reality.

4.3 Theme 3: Boundaries of sight

Measures of visual acuity are typically presented in terms of distance: if my eyesight is 20/80, I can see at 20 feet what normally sighted people can see at 80 feet. In our interviews, we learned that the relationship between sight and space or distance is more complex than that pair of numbers might imply. In addition to the obvious challenges of navigating physical space with a visual impairment, participants also described building skills related to calibrating their own non-visual mental models of the world with versions of the world encountered through social interactions with sighted individuals. For example, where a sighted companion might think of the path to a favorite coffee shop as a series of left and right turns, for someone with low vision, this path might be described in terms of a sound and temperature scape. Many adaptations described by our participants involved developing the skills and insights to reconcile these disparate representations.

In talking about how navigating their physical surroundings changed through use of the eSight eyewear, most people placed a particularly high value on the ability to see at a distance. For many, especially those with degenerative conditions, visual experience of the world became increasingly shallow in depth as their eyesight deteriorated.

One participant described the challenge of having such shallow depth of field: *"To be able to see my wife's face what I would call clearly without the eSight, she has to be within a few inches of my face" (P06)*. Another participant told us that while she could see her son's nose and eyelashes if she held him close, she longed to be able to watch him play: *"I don't see far away, I see stuff but it's super blurry and … I'd love to be able to sit on my deck and watch my son play in the sandbox." (P09)*

In contrast, another participant described discovering what it meant to "people watch" while using eSight:

"I was sitting in the choir at our church and someone was singing in the front of the auditorium and I could zoom in and I could see the people's faces for the first time…there were people there that weren't there very often and I was asking [my mom] who is this, who's this, and so I was watching them and I told my mom, 'I feel like I'm spying on people because I can see them and they don't know I'm looking at them,' and she said, 'Well, dummy, that's how everybody is!" (P12)

These examples illustrate important ways that seeing over distance impacts social inclusion.

Another way that the boundaries of sight were described by participants had to do with reflective self-awareness of the activity of seeing. We began interviews by asking people to describe to the best of their ability what the world looks like for them. Many people described blind spots, tunnel vision, blurriness, problems with light, and needing to hold things very close to their eyes. Five of the 13 participants also explicitly spoke about the connection between their eyes and brain when describing their experience of sight, for example:

"My eyes tend to move. In my case they rotate in a counterclockwise football shape which makes it hard to try and stabilize the image that I'm looking at. It's very, very hard on the brain because the brain is very good at rectifying that and sort of stabilizing it, integrating it into a stable image, but it still is tiring after a while." (P05)

Some described needing breaks from seeing the world, finding the visual world over-stimulating. None of our participants used the eyewear every moment of the day. Most people reserved hours of use for work or specific tasks. Such intermittent use of the device led P01 to track changes she perceived in her mental model of the world:

"...I took it off and … then I looked at the TV and then all of a sudden it was like I couldn't process anything. Like everything that I knew in the room when the unit came off was different." (P01)

Participants also spoke about the ways in which using the eSight device increased their awareness of differences between their own experience of sight and those of fully sighted friends and loved ones. Over half of the participants referred at one point or another to being aware that the device gave them "*super powers*," or the ability to see in more detail, at greater distance or under dimmer lighting conditions than fully sighted individuals could. One participant described herself as appearing to look like *"a super hero"* or a *"cyborg mom"* (P01) when she wore the device to pick up her son at school. Another participant described working in a warehouse using eSight to magnify product information:

"I'll be like Robocop and just read everything… They would say, 'What was that part number?' and I'd be like, '1234567 and the serial number ABCD,' and I'd just read it off and it was like they were talking to a walking computer." (P11)

In perhaps one of the best examples from our interviews of the sociotechnical implications of this aspect of AT, a grandfather described what it was like for him to return to watching his grandson's hockey matches after he started using the eSight eyewear:

"[My grandson] was all excited because I was his super fan and he came running up and he still had his skates on and he called to me and said, 'Grandpa, could you see me?" And I said, 'I could see the puck! I could follow the puck all around the rink!'...My grandson got a penalty and he was opposite of me in the arena and he was sitting in the penalty box and my son said, 'I'd like to know what he's doing right now,' and I just beamed up and I told him what he's doing right now. So we had to go find him and [tell him to] be careful when he was in the penalty box because we could see what he was doing." (P06)

4.4 Theme 4: Attitudes and expectations toward technology

Our interviews revealed tensions between an individual's desire to enhance their visual experiences, their confidence in their skills using technology, and their expectations of what technology can deliver. Although our participants exhibited a baseline trait of being comfortable with technology, that is not the case of all potential users. During the screening process, eSight assesses the potential customer's familiarity with technology by asking about their use with everyday technology such as TV remote controls and cell phones.

Our participants exhibited an openness to technology, which appeared to play an important role in their initial willingness to try eSight:

"My first reaction was just yes I'll try anything." (P01)

"I'm a geek to begin with so it was technology based, so sure, I mean I do a lot of reading and I'm willing to try things and that sort of thing." (P05)

Beyond being comfortable with technology, many of our participants had an aspirational attitude toward innovation. This attitude influenced how participants imagined the future, whether speculating about the ways in which devices like eSight could be improved or prospects for even better AT in their lifetime:

"... I figure eventually it will have various overlays. I could see it having sort of two layers, the assistive technology layer and a layer on top of it that will let you say add Android apps or something like that." (P05)

As mentioned previously, participants described sensing a gap between their own mediated encounters with the visual world and what those with more fully functioning sight experience. Few participants expected technology alone to bridge that gap, at least in their lifetime, but many expressed hope for future generations, with at least six of the thirteen referencing their own children or grandchildren in their hopes for the future. Twelve explicitly stated that they actively and enthusiastically shared information about eSight with others, with P06 referring to himself as a kind of "Johnny Appleseed." Many simply wanted others to share in the experience of sight offered by eSight. Others had a more global vision of the possible impact of the technology: "*...My thought was if this works, this is like, this is a historical moment." (P01)*

Overall, the people we spoke with were highly cognizant that their visual status would likely be fluctuating over time. P09 was particularly eloquent in talking about a recent, though possibly temporary, improvement in her sight:

"I don't know what my future will entail sight-wise. The doctors...have no idea how long it will last, what it will look like, eventually they think it will even out but it still fluctuates. It does scare me, I do live in a little bit of a fear ... that I will go back to what I had at that one time of [complete vision loss] and I do not want to do anything to cause that or inhibit my vision from staying where it's at right now, but I do recognize that I can't live in fear for the rest of my life, it's not healthy for me, it's not healthy for anybody around me." (P09)

These anticipated changes and the need to remain adaptive balance positive attitudes towards the HMD.

5. Discussion

We argue that the narratives of eSight users are not just about the adoption of ATs but also provide important insights into the ways in which ATs and HMDs become entwined with personal and social understandings of sight, creating new "ecologies of the visual" [30, p. 4]. Our participants support this sociotechnical argument through their descriptions of the many ways in which, as users of AT for low vision, their experiences of sight have been assembled through a combination of hardware, software, physiology and social engagement.

5.1 Multiplicities of vision

The participants in our study explicitly stated that the eSight device did not "cure" them of their visual impairment, was not a replacement for more fully functional sight, and was not appropriate for all situations. Not only do physical and material variations in the surrounding environment affect what can be seen with the eSight device, individual variations in sight occur on a yearly, monthly, daily and even hourly basis. Rather than describing a stable, static, or standardized experience, many instead referred to visual experiences they had with eSight as something different, a new type of sight that provided them with *an* experience of the visual, if not *the* singular notion of "vision" that they might have held when they first heard about the device.

Caren Yglesias, a visual culture scholar, points out that, "Seeing is more than an optical operation; understanding what is seen is a thoughtful experience" [40, p. 86]. We learned that not just seeing, but *understanding the personal value* of what is being seen was an important aspect of how and why AT is integrated into someone's life. The value that eSight users placed on what was being seen (e.g., the face of a loved one, paperwork involved in a desk job that enabled someone to support a family, the panorama of the Grand Canyon), was entangled with their assessment of the technology, the concessions they were willing to make to use the device (including cost), and ultimately what they came to describe as "adequate" or "enough" sight. In this way, the eSight device (and similar technologies) plays an important role in creating an awareness of the multiplicities of vision, highlighting that sight is not just one thing for all people in all situations.

This observation has implications for more holistic, situated, and longitudinal evaluation of HMD like the eSight eyewear. While measures of visual acuity can describe the ability for AT to replicate more typically functioning eyesight, they do little to help us understand so many of the other types of visual experiences described by the individuals in our study. Replication of normative vision is just one possible outcome; some devices might be far better positioned to introduce entirely new types of visual experiences for low vision users and others. Another outcome may be technologies that focus on creating a rich social or task supports using modalities other than vision to enhance a person's holistic experience. Given the different roles of AT, different desired combinations of modalities, both the design and evaluation of technologies would need to be more nuanced and situated to the person and their abilities, social environment, and task goals.

5.2 Low vision as skilled vision

Technology-mediated vision has been a staple of scientific observation for centuries, initially through microscopes and telescopes and more recently through technologies such as x-rays, MRI and spectroscopy [7]. With new these imaging techniques, novel forms of visual literacy have evolved resulting in new forms of *professional* [14] or *skilled vision* [15]: the process of learning to see the most important or informative details of a visual display through the eyes of a specific community of practice. This type of visual expertise is often tied to professional discourse and norms, and tends to be situated, contextual, and material, involving an apprentice-like experience to acquire.

However, this case study on eSight provides evidence of "vernacular" skilled vision [33], in which daily practices of non-professionals entail adaptive and specialized visual skills. eSight users have learned, often through trial and error, how to make the best use of the visual input they receive. They are developing expertise in learning how to make sense of the visual information provided by the eSight device. For example, one of the distinct differences between a device like eSight and other ATs like magnifiers or smartphone apps is its ability to simultaneously pan, zoom, and focus. This functionality enables users to see *through* space; the visual experience afforded by the eSight device is not just a series of interactions with flat planes, but aspires to provide users with a more fluid ability to make seamless transitions through foreground, middle ground, and background. A majority of our participants have a radically shortened depth of view (e.g., only being able to see things that are inches away from their eyes). Therefore, for many this was the first time (or the first time since the onset of a visual condition) that they had the ability to navigate depth of field using sight.

Recognizing people with low vision – as they navigate their worlds through un-mediated and technology-mediated sight – as people with expertise in skilled vision can open new avenues of investigation and innovation in other visual and multi-modality domains. Designers can gain a deeper understanding of the choices these skilled users make in adopting and operating vision technologies, and therefore, design technologies that are more compatible and usable based on people's specialized sensory abilities.

5.3 Limitations and future work

Case studies enable researchers to dive deeply into a bounded set of experiences in order to surface themes, observations, and opportunities that can then be applied and tested more broadly. For this study, we closely examined one form of AT available to people with low vision. Future work comparing the experiences of eSight users with users of other AT for low vision will enable us to better understand the range of social affordances associated with these emergent technologies. Related, and also previously noted, is that the users in our study were all relatively enthusiastic, no doubt as a result of our recruiting methods. Although our study does focus on the integration of HMD AT in the lives of individuals with low vision, necessarily focusing on those who have gone through this process, interviews with eSight employees helped us to contextualize the choices faced by potential users and to learn more about those who were not enthusiastic adopters. Future work looking more closely at non-use will help us build a more holistic picture of sociotechnical factors in technology-mediated sight. Methodological limitations include relying on self-report rather than benefiting from the richness of direct observation.

6. Conclusion

Interviews with early adopters of eSight eyewear for low users provided the basis for a sociotechnical analysis of technology-mediated sight. Our findings describe 1) sociotechnical experiences of vision offered through this device, and 2) the ways in which these experiences are assembled through a combination of social and technical affordances. In doing so, we argue that the narratives of eSight users are not just about the adoption of ATs but also help us to better understand the way in which technology-mediated sight represents new and emerging sociotechnical ecologies of the visual. This concept of multiplicities of vision can be instrumental to designing nuanced and situated assistive and augmentative technologies.

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