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Characteristics of Technology Adoption by Older Adults with Visual Disabilities

Hyung Nam Kim

Industrial and Systems Engineering, North Carolina Agricultural and Technical State University, Greensboro, North Carolina, USA

ABSTRACT
As technology is advancing, a great number of people with disabilities try out and adopt various mainstream and assistive technologies. However, there has been less attention paid to older adults with visual disabilities, leading to poor user experience and technology abandonment. A convenience sample of 20 older adults with visual disabilities (visual acuity ranging from 20/70 to blind with no light perception at all; duration of vision loss, 28.35 ± 23.04 years; age, 72.85 ± 7.96 years) participated in semi-structured interviews and shared their experiences with technology adoption and abandonment. The diffusion of innovation theory helped to obtain a deep understanding of how older users with visual disabilities adopt or decline technologies, various characteristics of which were discussed through relative advantage, compatibility, observability, trialability, and complexity. The relative advantage was further analyzed for usability, safety, and accessibility, and the usability aspect was broken down into more details: effectiveness, efficiency, and satisfaction. This study sheds light on the detailed characteristics that would ultimately contribute to designing, developing, and implementing future innovative technologies that meet the needs of the aging populations with visual disabilities.

1. Introduction

The number of people who are visually impaired and blind is increasing in the United States. In 2015 over 1 million people had blindness, approximately 3.22 million had visual impairments (i.e., 20/40 or worse visual acuity with best possible correction), and another 8.2 million had visual impairments due to uncorrected refractive error (Varma et al., 2016). National Institute of Health (2016) reported that the number of people with visual impairments and blindness is predicted to double to more than 8 million by 2050 and another 16.4 million Americans are expected to have difficulty seeing due to correctable refractive errors (e.g., myopia nearsightedness or hyperopia farsightedness) that can be fixed with glasses, contacts, or surgery. According to a recent report by the Center for Disease Control and Prevention (2020), over 12 million Americans aged 40 years and older have poor vision, including 1 million who are blind, 3 million who have visual impairments after correction, and 8 million who have visual impairments due to uncorrected refractive error. Today, approximately 14.5% (46.3 million) of the U.S. population was aged 65 or older, which is anticipated to reach 23.5% (98 million) by 2060 (Colby & Ortman, 2015). Over 14 million Americans have low vision (Lighthouse International, 2015) while each year 75,000 more people are expected to be visually impaired (National Federation of the Blind, 2015). Two thirds of people with low vision in the United States are older adults (age 65 and over) (American Foundation for the Blind, 2013). One of every six people aged 70 and over is visually impaired and this number has doubled among people aged 80 and over (Dillon et al., 2010).

Despite visual challenges, people with visual disabilities have been using a variety of mainstream technology applications in a range of contexts. A number of research studies have made effort to advance technology in order to support people with visual disabilities in terms of education (Wong & Cohen, 2011), quality of life (Scherer, 1996), rehabilitation (Jutai et al., 2009), electronic mobility aids (Roentgen et al., 2008), Internet access (Perfect et al., 2018), healthcare (Lazar et al., 2014), and shopping (Elgendy et al., 2019). People with visual disabilities try out and use different technologies, such as communication applications (e.g., e-mail and chatting tools), music applications (e.g., Windows Media Player, iTunes and other multimedia players), networking systems (e.g., Bluetooth and Wi-Fi), office suites, online search, e-shopping, portable devices (e.g., smartphones, Kindles, and tablet PCs), and assistive technologies (e.g., optical character readers, screen readers, and Braille note takers) (Kim, 2018). Kelly and Wolffe (2012) found that over 40% of younger people with visual impairments (aged 21 to 25) in their study used the Internet regularly. Older adults with visual impairments (n = 20) in the interview study by Okonji et al. (2015) perceived that the Internet has the potential to promote their ability to perform daily tasks independently, cope with visual impairments, and feel socially included. Today, the voice technology (e.g., Google Home, Siri, and Amazon Echo) is considered beneficial to older adults who have visual impairments as it can deliver information via voice user interfaces instead of graphical user interfaces (Kim, 2019b; Kim & Oumarou, 2020). The voice technology typically assists users through a series of pre-programmed prompts by

CONTACT Hyung Nam Kim hnkim@ncat.edu Industrial and Systems Engineering, North Carolina Agricultural and Technical State University, Greensboro, North Carolina, USA

recognizing human voice and responding accordingly. Piper et al. (2017) also found that even older adults with late-life visual impairments (i.e., vision loss later in life – age 60 to 99 – caused by health issues such as macular degeneration, diabetic retinopathy, glaucoma, and cataracts) were motivated to explore new technologies (e.g., iPhone, iPad, and blogs) and used them in daily life in order to stay connected and engage online.

However, there has been less attention paid to user experience of users with visual disabilities, leading to poor user experience, such as invisibility of system status, lack of user control and freedom, inconsistency, ineffective error prevention, inefficiency of use, and lack of support for troubleshooting (Kim, 2018). There has been research on use and adoption of various technology applications by either sighted older users or younger users with visual disabilities; yet, there is still paucity of research on characteristics of technology adoption by older adults with visual disabilities. Okonji (2018) interviewed 20 older adults with visual disabilities in England to study the user experience of assistive technologies, but it did not focus on mainstream technologies. As older adults with visual disabilities are likely to be influenced by both visual disabilities and aging effects, there is no guarantee that technologies that meet the needs of older users without visual disabilities or younger users with visual disabilities would also accommodate the needs of older adults with visual disabilities. Instead of focusing on micro aspects dealing with a specific technology application in a particular context of use, which were already been studied and well documented in the literature, this study focuses on exploring macro aspects of user experience with mainstream and assistive technologies used by older users with visual disabilities in order to advance knowledge of how older adults with visual disabilities tend to adopt, reject, or abandon technologies.

Many research studies on technology adoption refer to the diffusion of innovation theory (Rogers, 2003) to understand how users try out and adopt a new idea and technology (Mitzner et al., 2010; Olson et al., 2011; Wang et al., 2011). Technology adoption is influenced by various factors, such as relative advantage of the technology, compatibility, complexity, trialability, and observability. Users seek a relative advantage over other options, and they tend to adopt a better one. The relative advantage would be associated with a single aspect or a combination of multiple aspects (e.g., user-friendly, accessible, and user satisfaction). The compatibility factor refers to the degree to which a technology is well integrated into a user's life without requiring a significant lifestyle change or additional resources to make the new technology work. Thus, an adopted technology is expected to be well aligned with the user's attitudes, behavior, and technology. Complexity indicates how difficult it is for users to understand and use a technology. The more complex a technology, the more difficult it would be for users to adopt it. Another factor trialability describes how easily users can experience a technology without making a commitment to purchasing a technology. Users might experience and appraise the technology via free trials, demonstrations, and simulations such that they could imagine for themselves what life would be like once the technology is adopted. The last factor observability refers to the degree to which the benefits of adopting and using the technology are visible to users around. If an individual has an opportunity to observe others who have already been using the technology (e.g., friends and family), he/she is likely to be motivated to adopt the technology. Observation of others using the technology would help to stimulate awareness of the technology and facilitate conversations about the technology, eventually contributing to technology adoption. This study will refer to the diffusion of innovation theory to obtain a deep understanding of how older adults with visual disabilities adopt or decline mainstream and assistive technologies.

2. Methods

This study relied on a descriptive research design that is typically used to describe systematically and accurately the characteristics of individuals, situations, tasks, or tools without experimental manipulation or control of variables (Dulock, 1993). This study conducted semi-structured interviews with older adults who had visual disabilities. Approval for this study was obtained from the Institutional Review Board (IRB).

2.1. Participants

A convenience sampling method helped to invite 20 older adults with visual disabilities residing in the State of North Carolina (See Table 1). Research participants should speak English, be 65 years old or older, and have visual disabilities (i.e., visual acuity level worse than 20/70, (World Health

Table 1. Characteristics of the participants.

Participants	n = 20
Visual acuity	
Between 20/70 and 20/200	2
Between 20/200 and 20/400	11
Between 20/400 and 20/1200	1
Less than 20/1200, but has light perception	1
No light perception at all	5
Duration of visual disabilities (years)	28.35 ± 23.04
Age (years)	72.85 ± 7.96
Gender	
Male	4
Female	16
Race/Ethnicity	
African American	8
European American	12
Marital status	
Married	6
Not Married	4
Widow/Widower	4
Divorced	6
Education	
High school or equivalent	7
Bachelors	7
Masters	5
Doctorate	1
Occupation	
Full time	1
Unemployed	6
Retired	13
Household income	
< $25,999	8
$26,000 – $51,999	7
$52,000 – $74,999	2
≥ $75,000	2
Declined to say	1

Organization, 2008)). A participant's visual acuity was measured with a Snellen chart. The majority of participants were female (80%), European American (60%), and retired (65%).

2.2. Procedures

An interview (~ 60 minutes) was conducted at each participant home. Participants were asked to share their experience with and insights into technology adoption and abandonment. A semi-structured interview method facilitated the interview, the sample guiding questions of which include "*How and what kinds of mainstream-, assistive-, and/or emerging-technologies have you been using (or used)?*" and "*Would you like to share your experience with or insights in adopting or abandoning them?*" Participants were given follow-up and probing questions by depending on their responses. As the interviews were conducted at each participant's home, they were allowed to show (or demonstrate) technologies they owned, and an interviewer took pictures.

2.3. Data analysis

It is well documented that regardless of a specific type of content analysis, the primary purpose of all content analysis methods is to classify many words/ideas into much smaller content categories (Burnard, 1996; Weber, 1990). In the present study, the constructs of the diffusion of innovation theory were applied in conducting the content analysis (Burns & Grove, 2005; Cho & Lee, 2014) via QSR International's NVivo 11 software (QSR International Pty Ltd, 2015). More specifically, three main phases were involved: preparation, organization, and reporting results (Elo & Kyngäs, 2008). The preparation phase contributed to collecting suitable data for content analysis, reading/understanding the data, and selecting the unit of analysis. The organization phase helped to analyze/review the data in-depth and code accordingly by referring to the constructs of the diffusion of innovation theory: advantage, observability, trialability, complexity, and compatibility. Thus, aspects from the data did fit the constructs (i.e., categorization frames) while, alternatively, aspects that did not fit were allowed to find/create their own codes and/or be broken down into much smaller codes (Elo & Kyngäs, 2008). The code *advantage* was further broken down into usability, safety, and accessibility. The code *usability* was divided into such smaller codes as effectiveness, efficiency, and satisfaction. The code *compatibility* was further categorized into attitude, behavior, and technology. In the reporting phase, the content analysis results were documented. Another coder was invited to assess the inter-rater reliability using Cohen's kappa statistic. There was substantial agreement among the raters as the inter-rater reliability was found to be $\kappa = 0.8$ (95% CI: .538 to 1.075).

3. Results

The participants adopted technologies that provided advantages in terms of accessibility, safety, and usability. For example, they preferred technologies that could help them to reduce cognitive and physical workload. Their decision to adopt technologies were also affected by the degree to which technologies can help them to achieve specific goals accurately, completely, and successfully. In addition to such technical benefits, subjective satisfaction played an important role in adopting technologies. Even if technologies could provide advantages associated with accessibility, safety, and usability, the participants would still review the degree to which technologies could fit with their attitude, behavior, and existing technologies. Yet, the participants shared their experiences that it was often not easy for them to install technologies and/or difficult to learn how to use them, which would eventually prevent them from adopting technologies even though technologies provide various advantages and a good fit. The participants were also likely to adopt technologies by observing others using technologies and trying them out. Those multiple factors influenced the participants in appraising and adopting (or rejecting) technologies (see Figure 1). Participants reported that they used various technology applications such as smartphones (e.g., iPhone and Android phones), desktop computers (e.g., iMac), laptop computers (e.g., MacBook Pro), portable computing devices (e.g., iPad), navigation apps (e.g., BeMyEyes, Seeing AI, Soundscape, NearbyExplorer, and TapTapSee), calling apps (e.g., FaceTime), reminder apps, health apps (e.g., MyChart app), a color reader device or apps, cooking utensil/tools (e.g., a talking-microwave, an oven, and an audible meat thermometer), magnifier apps, smart speakers (e.g., Google Home, Echo, and Alexa), a smart bulb, text-to-speech software (e.g., NFB Reader, JAWS®, ZoomText™, and OrCam MyEye), smart watches (e.g., Apple watch), voice-enabled technologies (e.g., VoiceOver), multimedia applications (e.g., Apple TV, Amazon Fire TV Stick and Echo Cube), and a flip phone. The detailed findings are presented below.

3.1. Relative advantage

The participants preferred to adopt (or already adopted) technologies that showed better accessibility, safety, and usability (i.e., efficiency, effectiveness, and satisfaction) as compared to conventional devices, methods, and tools.

3.1.1. Accessibility

The participants appreciated the greater accessibility of new technologies as compared to those that they used previously (or those available in the market). They acknowledged that a mobile platform (e.g., smartphones) was available at any

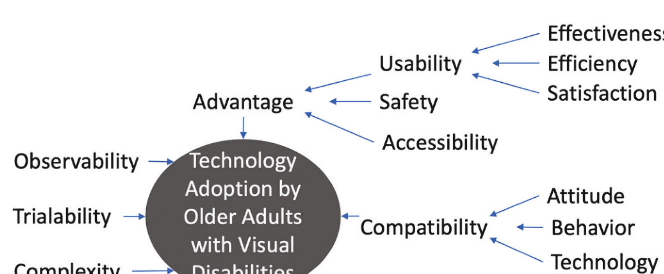

Figure 1. Characteristics of technology adoption by older adults with visual disabilities.

location while a desktop platform (e.g., desktop computers) was available at home only (P1, 2, 7, 11, 15, 14, and 19). For example, a participant (P1) stated, "*More and more people are going to a phone only, an iPad, or something mobile instead of a computer*." They were willing to adopt mobile applications (apps) (e.g., TapTapSee – a mobile camera application that helps to identify objects) because the apps provided service around-the-clock while the personal help (e.g., family members) would be available only when people are around him/her (P2, 7, 11, and 19). The participants preferred the user interfaces of iOS mobile operating system (e.g., iPhone) as compared to those of other operating systems (e.g., Android) due to more accessible user interface designs (P1, 2, 4, 5, and 20) (see Figure 2). For example, a participant (P1) stated, "*Apple is ahead in the accessibility options of it. They [Android] are not near as good as Apple today*."

3.1.2. Safety

The safety issue was another component the participants considered in making a decision to adopt or decline new technologies and tools. For instance, as the participants had visual disabilities, they typically relied on other senses (e.g., sound, touch and smell) to orient themselves to surroundings. While they walked outside, they used sound as a substitution for sight, and some used echolocation to navigate around objects. The electric car, quieter than conventional cars, would be attractive to sighted people but is less likely to be adopted by people with visual disabilities due to the safety issue. An individual with a visual disability and his/her service dog may not hear any noise of the electric cars coming to them, ultimately leading to increases in the risk of hitting (P10). Another example was associated with cooking, which is one of essential daily living activities. As people with low vision could still somewhat rely on their remaining vision, they were able to cook at home but concerned about their safety because of their visual impairments and blindness (P4, 5, 10, 15, 16, and 17 and 18). One day, one participant (P18) was cooking with a frying pan, but she ended up with burning her foot, legs, and hands, which made her abandon the cooking utensil and stop cooking for her safety. The participant's statement is, "*I was preparing hash browns in hot oil and the frying pan. All of a sudden, I did not feel it, it fell, and it cooked my foot, part of my leg, and the back of my hands. My hand doctor told me that my cooking days were over, and he does not want me to cook*." On the other hand, other participants did not abandon but modified a tool to better accommodate their needs, i.e., adaptation (P3, 5, 10, 11 and 17). For example, the participants attached large printed labels or tactile stickers onto the regular microwave (or oven) panel to control safely. A participant (P5) stated, "*My biggest challenge is cooking. I have got my oven and microwave marked. I have got an audible meat thermometer. He [cousin] was really wondering how my first whole chicken would turn out perfectly*."

Figure 2. The participants emphasized the accessibility factor in deciding to adopt technologies (e.g., iOS over android).

3.1.3. Usability

Technology adoption characteristics were also associated with usability that could be broken down into efficiency, effectiveness, and satisfaction.

3.1.3.1. Efficiency. ISO 9241 (International Organization for Standardization, 2010) views efficiency as the total resources (e.g., cognitive and physical workload) expended in a task. The participants adopted technologies that could help them to reduce their cognitive workload (P1, 11, and 17). For example, they appreciated a reminder app that will not let them forget anything important (see Figure 3). They marked various events (e.g., medication alerts, personal errands, and doctor's appointments) in the calendar (or to-do list) app installed on their smartphone and received voice reminders on time, which contributed to optimal use of mental resources. A participant (P1) stated, "*I have five alarm sets for activities I have to do. Yeah, I use this [smartphone] as a tool. Blindness is about the only aspect, I am a little older, I slow down, my memory, and I have got other medical conditions. So, all these things are forcing me to use an off-board assistance and this phone*."

They also sought a way of reducing their physical workload. They appreciated the lighter weight of a device; for example, they preferred the latest model of MacBook Pro as it was lighter and easier to carry (P8, 12, 14, and 18). A participant (P12) stated, "*I like this computer. It is not that new, but it is a MacBook Pro. Oh my gosh! It is so much lighter than previous one.*" They liked a technology application that helped them to remotely control a system in everyday life; for instance, they adopted a Google Home Speaker to remotely manage their home (e.g., remote control for lights via voice commands) (P1, 2, 4, 10, 17, and 20). Thus, they would not need to walk around the house to find the switch, which

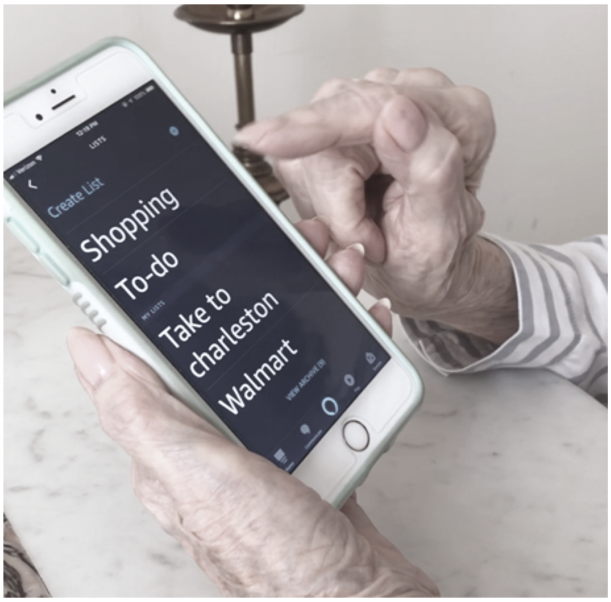

Figure 3. The participants preferred a new technology that helped to reduce their cognitive workload.

could be a challenge for them due to visual disabilities. A participant (P2) stated, "*I have a Google Home. My son put the special smart bulbs. We also have another Google Home in the bathroom that works the lights in the bathroom and the bedroom. It is a smart home*." They also adopted technologies that enabled them to do multitask. They adopted an Internet-based phone call application such as FaceTime (P1, 12, and 15) as it enabled them to make a single phone call to connect with multiple persons at the same time. Another determinant was associated with saving cost. The Internet phone call app helped them to control the monthly maximum amount of spending per phone as the Internet call was free and would not affect the monthly maximum of regular phone call services. They appreciated the user-friendly *all-in-one* user interfaces (P6, 9, 10, 12, and 13). As they had visual disabilities, it would not be easy for them to manage several devices on a daily basis. For example, heavy thick books could be managed simply via a single smartphone app (P12). They would not need to undergo cumbersome processes such as making effort to find a particular book among books, put the book under a magnifier to read it (or boot up a personal computer and run assistive technology applications to read them, e.g., text-to-speech). Everything could be accomplished through fewer steps as compared to conventional means.

3.1.3.2. Effectiveness. Effectiveness is associated with the degree to which users achieve specified goals accurately and completely. The participants adopted a larger computer monitor such that the readability would be enhanced, ultimately contributing to accurate user control (P1, 11, 12, and 19). For example, assistive technology applications such as ZoomText™ can enlarge everything on the computer screen. However, enlarged texts or images would then be partially viewed in the smaller screen such that the larger screen could contribute to readability, which would help users to accomplish their task more effectively. A participant (P12) stated, "*I like this computer. It is very user-friendly. You can make everything larger*." Voice-enabled technology could also promote the technology adoption among those with visual disabilities. Due to the visual disabilities, the participants used talking-products such as a talking-microwave in the kitchen (see Figure 4) to facilitate more accurate control via various audio guides such as setting cook time, running cook time, current power level, and microwave running (P10, 15, and 20). A participant (P20) stated, "*You see that microwave. The same as yours, except mine speaks!*"

The participants preferred technologies that were designed to empower users and help to complete a task successfully. Mobile health technologies typically keep informing users about the degree to which they have successfully completed a range of daily living activities. The participants have argued that a simple tracking technology is less likely to be adopted by people with visual disabilities (P1, 2, 4, and 6). They expected that mobile health technologies should provide a summary of their daily (or weekly) health data, but more importantly provide a set of recommendations to improve their health (e.g., encouraging alerts to do exercise) customized based on his/her own health data – i.e., evidence-based recommendations. A participant (P1) stated, "*It [tracking system] could give a summary of how much activities I had. I think it can measure certainly how much I walked and give a daily summary on that, and then maybe a weekly summary. The other thing it might want to do is it might want to say – I [tracking system] have noticed you [a user] have not moved in the last hour; I noticed you have not moved lately; you need to get up and move occasionally*." The participants also acknowledged a variety of

Figure 4. The participants perceived that the products equipped with voice user interfaces (e.g., talking microwave) were effective in controlling the system.

choices available for them to accomplish a task (P1 and 4). For example, they adopted different walking aids, i.e., a combination of non-technological and technological tools including a white cane, a service dog, and a navigation mobile app. In case an individual is not a dog person and/or a white cane is not available at the moment, a navigation app would be an alternative choice or vice versa. A participant (P1) stated, "*I have several O&M devices [Orientation and Mobility]: one is a white cane and the other is my guide dog. So, I do not use either one of those inside, but if I am outside, I pretty much have to have one or the other. So, there are a lot of instances where you use either a white cane, a dog, or an app to help you navigate indoors.*"

3.1.3.3. Satisfaction. Besides such technical benefits as effectiveness, efficiency, safety, and accessibility, the subjective satisfaction was also important for the participants to adopt a technology (P2, 3, 11 and 12). For example, the participants were satisfied with resources available for them to obtain technical help while using their smartphones, which is free of charge, such as the Apple Accessibility Support where they could request a call right away or schedule a time (P2 and 4). They have access to Apple representatives who are professionally trained in providing support for users with visual disabilities. Such accessibility technical support from the manufacturer is one of factors contributing to user satisfaction and technology adoption among those with visual disabilities. A participant (P2) stated, *"They have the Apple Accessibility Support service. There is no charge. It is not like Apple Care. Apple Care I think they sell that as a paid service, but this Apple Accessibility Support is a separate identity for the visually impaired and handicapped. They are my teachers. That is why I have chosen iPhone over Android or other phones. That is why I really like it. iPhone is better."*

3.2. Compatibility

The compatibility factor is relevant to the following aspects: attitude, behavior, and technology, e.g., "*How does the innovation fit with potential adopters' attitude, behavior, and existing technologies?*"

3.2.1. Attitude

The participants shared their negative attitudes toward certain technologies, leading them to be hesitant to adopt the technologies. For instance, they were concerned about privacy as smart technologies with cameras would be vulnerable to hacks (P1, 4, and 9). They also observed other family members (e.g., grand children) using the smartphones in the midst of having a meal or conversation, which was the instance where they felt social isolation even though family members were present right next to them (P9, 11, 12, and 13). A participant (P9) stated, "*Oh, they [family members] are just looking at the smartphones instead of your face. They just text! I think they are going to become more and more isolated as individuals. That might block socialization."* Thus, they might develop a negative attitude and were less likely to adopt the smartphone technology as it could interfere with existing social values that they would desire to sustain or strengthen.

3.2.2. Behavior

The participants presented various behavioral factors influencing technology adoption. They were interested in technology applications, specially designed for users with visual disabilities. For example, they have been using various smartphone apps such as BeMyEyes, Seeing AI, Soundscape, and NearbyExplorer, all of which aimed at helping people with visual disabilities to identify objects/people and walk around safely (P1, 2 and 19). The participants who already adopted the smartphone and used it on a daily basis believed that the best practice of completing tasks in daily activities would be through a smartphone, and they were less likely to abandon it (P1, 5, 11, and 12). The participants (P11 and 1) stated, "*I could not live without it [smartphone]*" and "*If I leave my phone and don't have my phone with me, it is a very unpleasant feeling for me.*"

Another behavioral factor was associated with education and knowledge. The participants (P1, 2, 10, 11, and 17) used smart speakers (e.g., Alexa) and performed the cognitive exercise via Alexa's Quiz of the Day feature, which was expected by them to stimulate their cognitive ability in order to combat age-related memory loss. A participant (P11) stated, "*I love Alexa! Let me show you. Alexa, what is the question of the day? [Alexa's quiz here] It is amazing. Every week, it come out with more.*" The participants (P4, 12, 15, and 17) shared a concern about a technology that required a password and a username as it would become harder for them to recall passwords and usernames correctly as they age. A participant (P12) stated, "*It is almost like MyChart app. They keep saying they have my test results on MyChart, and I am going like Oh, that is nice, but I cannot get to it because I forgot my password."* Sighted older adults may take advantage of a sticky note to recall the login credentials, which would not be easily accessible to their peers who cannot see due to visual disabilities.

They are likely to be influenced by "socially" acceptable behaviors. For example, they adopted a color reader device or apps to distinguish different colors of their objects/clothes as they could identify colors and dress appropriately for any occasion (P1, 2, 19 and 20). A participant (P20) stated, "*It [color reader device] will tell you everything. It will tell you if light is in the room. I use it when I do my laundry. I have one here and I have another one upstairs because when I pick out my clothes. I need to know that pink does not go with purple."* The participants who lived together with other family members would like to consult with their family members to decide whether they should adopt and place a new technology in the home in case it was a smart home technology monitoring their living environments (P1 and 4). They would adopt the technology if family members agree to adopt a new technology.

They tended to adopt technologies that were consistent with surrounding environmental conditions. Those (P1, 4, 8, 9, 10, 12, 14, and 15) who keep actively walking around in/between rooms in the house preferred a portable technology (e.g., mobile sensors) instead of a stationary one (e.g., sensors installed in a particular place in the home); however, if a portable option is not feasible, they would like to have sensors to be installed in a particular room/place where they spent most of the time during the day (e.g., in the living room) or near walking routes in the home. A participant (P4) stated, "*If there is just one sensor to install, I would choose somewhere here in the living room because I walk this way. This is my pattern, back and forth, from this door to that door. I would say at least eight hours a day to be monitored because that is my get up and go time.*" A participant (P1) also recommended that the sensor technologies in the home distinguish a target individual from other individuals as people live with other family members or have frequent visitors, e.g., friends, social workers, and other family members. They (P3 and 12) also shared a concern that they were less likely to carry a smartphone at home because they tended to take it out from their trouser pocket and put it on the table while staying at home; therefore, any health tracking apps on the smartphone cannot track adequately while they stay at home, leading to lower adoption of such technology. They also wanted to purchase the same brand and model of technology that is already used by their family members and friends (P1, 4, 11, 15, and 19). For example, if their family members have the iPhone, they would also like to purchase the iPhone over android smartphones as they could easily obtain help from them when they need to troubleshoot a technical issue.

3.2.3. Technology

The participants easily adopted a number of different mobile apps because they already owned smartphones and had access to the Internet. They owned multiple smartphones, e.g., one iPhone and one Android smartphone (P1 and 15). They had only one data plan for a single smartphone device, but did not abandon the other smartphone(s). They used them all as they had a wireless router installed on their home network and connected to it via the Wi-Fi enabled smartphones. A participant (P1) stated, "*I am primarily an Apple user. Also, I have some Android phones although I do not have cell service and data plan for them, but I can still do anything else with Android phones with Wi-Fi. So, that is the nice thing.*" They found that a certain application worked better on a particular operation system (e.g., iOS) than the other systems (e.g., Android), leading to adopting a particular model of a smartphone only (P19 and 20). A participant (P19) stated, "*I took lessons from Services for the Blind. They trained me on it. I was told that this app NFB Reader worked better with the iPhone than it did with the Android, so that is why I chose the iPhone.*" Another technology-related compatibility factor is associated with connectivity between devices. The participants purchased computing devices (e.g., MacBook, iPad, and iPhone) that shared the same operating system (i.e., Apple iOS) (see Figure 5) (P1, 2, 4, 14, and 19). Those devices have coherent designs of user interfaces and interactions such that it was easy for the participants to learn quickly how to use a new device, but also convenient for them to begin work on one device and switch to another device to pick up where they left off (i.e., a handoff feature). For example, they received a quick notification for a new e-mail via the Apple watch and then read the e-mail message via the Mac computer that was equipped with various assistive technology applications. A participant (P1) stated, "*What is happening is, at least in my community, the increasing use of smart devices. For instance, right now, I take most of my messages from my Apple watch. So, I know that a message just came in on my phone. But I do not necessarily go to my phone to read that, I might do it on my Apple watch. Same thing, I got Apple products, an Apple watch, a smart phone, an iPad, a Mac Book Pro and an iMac. The neat thing about that is that you can move between those devices.*"

Figure 5. The participants tended to purchase a new technology that used the same operating system of other technologies they already owned (e.g., iPhone and iPad).

3.3. Complexity

The participants often encountered challenges understanding how to operate a system (P1, 4, 15, 16, and 18). Although they were eager to adopt a new technology (e.g., iPhone) or already purchased it, they still struggled and were frustrated with the complex steps of operations. A participant (P16) stated, "*It was too many directions. I would need to click here and there. It was just too much. It's got to be simple where I can hit this button and I do not have to worry about hitting another button.*" In general, conventional user manuals (e.g., paper-based booklets) were not accessible to those with visual disabilities (see Figure 6). Those manuals were not easy for them to understand even if assistive technologies (e.g., text-to-speech software) were used because the manuals were originally designed by focusing on sighted users' mental models.

In addition, the participants preferred a device that could easily be installed, e.g., plug-in (P1 and 4). Many accessibility features equipped in a technology application would ultimately result in meaningless to them if it is difficult for

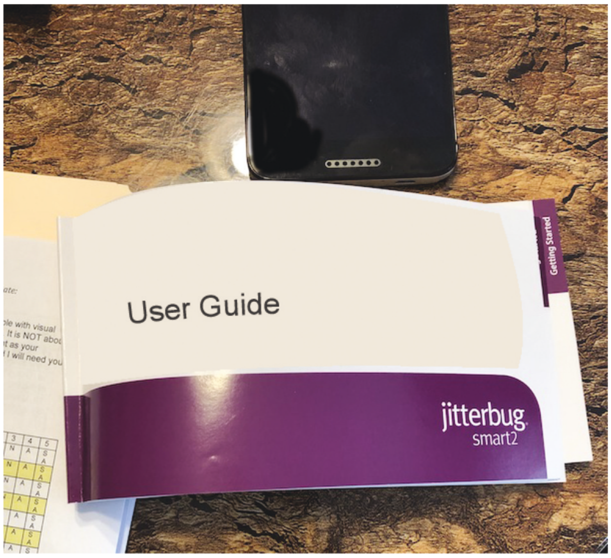

Figure 6. The participants who purchased a smartphone were likely to abandon it due to complexity, and the user guide booklet was inaccessible and difficult to understand.

them to install the technology independently or turn the accessibility features on. The participants recommended that customers with disabilities purchase technologies that must come with an easy, direct access to human representatives providing support for their consumers with disabilities than a digital customer service representative or chatbot.

3.4. Observability

Observability refers to the degree to which a person encounters other persons already using the technology, which would increase the likelihood of adopting it. The participants had opportunities to observe that many sighted people used smartphones (P1, 15, 17, and 20). It would not be necessary for them to go outside to be exposed to technologies. Their family (e.g., grown children or grandchildren) and friends used technologies when visiting their home. They also saw social workers using technologies, and community support groups (e.g., Lions Club) introduced or demonstrated technologies. In addition to sighted people using technologies, the participants also observed that their peers with visual disabilities used technologies; however, they have also observed that their peers with visual disabilities had lack of opportunities to use smartphone technologies. A participant (P1) stated, "*I have had a lot of opportunities to notice a smart phone being used by people around me. The adverse is also true, I have noticed that they do not use it. She [friend with a visual impairment] actually has a smart phone, but she does not know how to use it very well.*" Yet, not everyone lived under the same condition, e.g., those with visual disabilities did not live with others who could show them technologies; had no visitors; and/or did not participate in any community support groups. As the participants have been obtaining a great amount of benefits from the smartphone technology on a daily basis, they wish that more peers with visual disabilities benefit from the technology.

3.5. Trialability

Trialability indicates the degree to which a technology is experimented by potential users, and they are more likely to adopt the technology if they have an opportunity to try out. The participants had opportunities to experience various mainstream technologies, for example, smartphones through their family members (e.g., a spouse and older children) who already used the smartphones and encouraged the participants to try out (P1, 4, and 11). Besides family members, social workers and eye specialists typically introduced various technologies in order to help their clients (i.e., people with visual disabilities) to live independently (P15, 17, and 20). Participants stated, "*I told my daughter 'I did not want the phone [smartphone]', and she said, 'Well just try it and see'. Well, that is how I started with this phone.*" and "*They [social workers] came and introduced us to the latest technology for the blind and visually impaired. They recommend the iPhone. They explained that iPhone is better for people visually impaired because it has the capability of VoiceOver. So naturally, I purchased the iPhone.*" Besides smartphones, other examples included smart bulbs, smart speakers (e.g., Echo), magnifier apps, computers (laptops and tablet PCs), multimedia applications (Apple TV, Amazon Fire TV Stick and Echo Cube), and assistive technologies (e.g., JAWS). The participants recommended that novice users with disabilities begin with a technology application that has simpler user interfaces and then move to one with more complex user interfaces (e.g., from a flip phone to a smartphone) instead of beginning with a complex one in the first place (see Figure 7) (P7, 11, and 17).

Even if the participants had no one who could let them try out technologies, they would not necessarily need to purchase technologies in the first place as they could visit a local Apple store and a community center that provided classes to community members for free of charge (P10). They were allowed to try out and learn how to use technologies. Yet, for the participants who were from low-income family groups, purchasing a high-priced technology was not their intention. Even if they had an opportunity to try the technology out, they could not afford the technology, access to the Internet, cellular data plans, or a combination of the aforementioned (P1, 10, 12, and 17). A participant (P17) stated, "*It was OrCam MyEye. They were advertising it on Facebook. It is some kind of little device that fits on your glasses and it reads. But the starting price is from 3,000 USD!*"

4. Discussion

This study reported a set of different characteristics leading older adults with visual disabilities to technology adoption (or abandonment). Although there have been ample research studies on technology use by sighted people, there is little understanding of technology adoption by older adults with disabilities, especially visual disabilities. Furthermore, those previous research studies (Gell et al., 2015; Hunsaker & Hargittai, 2018) tended to merely focus on types and prevalence ration of technology adoption, but not in-depth understanding of how, why, and when they resulted in adopting (or abandoning) technology. This study sheds light on the

Figure 7. The participants felt more comfortable with the transition from a simpler technology (e.g., a flip phone) to a more complex one (e.g., a smartphone).

detailed characteristics that would ultimately contribute to designing, developing, and implementing future innovative technologies that meet the needs of the aging populations with visual disabilities. For example, with regard to technology adoption via relative advantage, the participants appraised the degree to which technology applications were accessible to users with visual disabilities. Many previous studies (Khan & Khusro, 2019; Kim & Oumarou, 2020) emphasized the importance of designing user interfaces to be accessible to users with visual disabilities, which would, however, be insufficient for those with visual disabilities to willingly adopt technology. Besides user interface designs, the accessibility should also be taken into account for other aspects such as "place" and "time" of technology use in that they wanted to adopt a technology that could be available in any place (e.g., portability) at any time (e.g., round-the-clock services) to promote their independent living.

Safety is another critical factor that affects their decision to adopt technology. While an innovative technology is beneficial to sighted people, the same technology could be detrimental to people with visual disabilities, leading to technology abandonment. For example, according to a recent report via the society of automobile engineers (Pliskow et al., 2011), a hybrid electric vehicle traveling at slow speeds is likely detected by pedestrians with visual disabilities at a shorter distance and with less time to passing as compared to traditional internal combustion engine vehicles. As stated by the participants in this study, the quietness of electric cars may be a merit to sighted drivers and pedestrians, but the same merit could put pedestrians with visual disabilities at a great risk of being hit by the electric car because they and their service dog could not hear the car coming to them. As different user interfaces would typically be integrated to improve accessibility for users with visual disabilities, adequate system requirements should also be considered to ensure safety for those with disabilities.

Older adults with visual disabilities preferred a technology application that helps them to achieve a goal accurately and completely; to save their resources (e.g., physical and cognitive workload) in completing a task; and to feel satisfaction. Their views are consistent with the Technology Acceptance Model (TAM), i.e., the widely used framework to explain user acceptance of information technology (Davis et al., 1989). The TAM framework suggests that users are likely to decide to adopt (or decline) a new technology by considering two factors: usefulness and ease-of-use, which is associated with usability. The present study further examined usability in more detail in terms of efficiency, effectiveness, and satisfaction.

The participants shared their insights into how a new technology fits with their attitude, behavior, and technologies. They expressed a negative attitude toward certain technologies due to the concern about privacy. For example, they were concerned about their own data protection as many home-based tracking sensors collect and keep monitoring the daily living activities, and such low trust issue can be worsening as they cannot see any user interfaces (e.g., warning popup messages). The negative attitudes and concerns about technology and online privacy were also discussed in other research studies (Ahmed et al., 2015; Akter et al., 2020; Napoli, 2018); for example, Ahmed et al. (2015) reported that technology users with visual disabilities had a range of privacy concerns, including visual eavesdropping (i.e., shoulder surfing by bystanders) and aural eavesdropping (i.e., overheard of private information by bystanders while they use voice technologies that read out loud). Any technology applications that are likely to cause users with visual disabilities to be affected by the privacy issues should incorporate adequate means to address their negative attitudes (Ahmed et al., 2015).

The participants did not appreciate a simple tracking tool (e.g., simple provision of walking speed and distance daily/weekly) but would adopt a tracking tool-based user-centered system for an individual. For example, a system keeps monitoring his/her daily living activities and provides customized-recommendations or information, leading to improving the quality of his/her life. Personalized supports for each individual could be feasible based on a personal big data analysis approach (Blobel et al., 2016; Jagadeeswari et al., 2018). For instance, a gerontechnology research team by Courtney et al. (2008) conducted interviews with 14 community-dwelling older adults and found that although privacy can be considered as a barrier to adoption of smart home technologies equipped with sensors (e.g., motion sensors, kitchen safety sensors, and falls detection sensors), older adults in their study were willing to override their privacy concerns and adopt sensor technologies, and they argued that personalized algorithms for data analysis and provision of adequate supports would contribute to alleviate their informational privacy concerns.

They had also encountered many people using a variety of technologies, which is associated with the observability in

Rogers' diffusion of innovation theory; however, they have ironically developed negative attitudes such as social isolation and loneliness when encountering their family members preoccupied with texting during family mealtimes or conversation. The social isolation was often discussed in previous gerontology studies (Kadylak et al., 2018; Rainie & Zickuhr, 2015); for example, older adults (n = 77) in focus groups (Kadylak et al., 2018) believed that the mobile phone use during face-to-face interactions was disruptive and even offensive, eventually hindering them to develop the sense of co-presence. There has been new attention to user experience research on "phubbing" that is derived from two words: "phone" and "snubbing." Phubbing describes a user's attitude of thinking of on-going conversations with his/her companion(s) as a less priory and paying more attention to his/her mobile devices (e.g., texting, emailing, and Internet surfing) (Benvenuti et al., 2020; Kadylak, 2020). Phubbing was found to be related with loneliness and low satisfaction with life (Ergün et al., 2019). The present study argues that the observability does not always lead to technology adoption in that the technology adoption could be influenced by such external factors as how other people around him/her use technology, eventually leading to positive or negative attitude (e.g., developing willingness to adopt technology or reluctance to do so).

Various user behaviors influenced the participants in adopting technology. As they were older adults struggling with visual disabilities, they were highly interested in and/or eager to try out technology applications that were designed to help with the activities of daily living impacted by both aging and poor vision. Among those who adopted, for example, a smartphone technology, they stated that the technology improved the quality of life in multiple ways (e.g., navigation, identification, reading, entertainment, shopping, healthcare, and online social networking), which were also addressed in other studies (Hakobyan et al., 2013; Kim, 2018, 2019a, 2019b). Yet, the participants stated that they had a fear of being detached from the mobile phone connectivity, and the fear was related to the loss of immediate access to information, social supports, and other benefits from the smartphone. There are many research studies on similar fear among sighted users, which is, however, more relevant to the problematic use of the Internet technology (Ayar et al., 2018; Moreno-Guerrero et al., 2020) with the increase in time simply for online activities (e.g., social media) (Yildirim & Correia, 2015); that is, nomophobia (an abbreviation for no-mobile-phone-phobia) (Bhattacharya et al., 2019). Four participants expressed the concern about people paying too much attention to a smartphone while communicating with other people. They observed such poor interpersonal relationship, especially among young people (e.g., teenagers looking at their smartphone while speaking with others). As technology is advancing today, people can obtain many benefits; on the other hand, technology could make people feel more isolated although technology is designed and built to help people to be more connected (Anderson, 2019). In the empirical study by Abeele et al. (2019), young people (20.49 ± 2.17 years) were observed while having a dyadic conversation. Co-present phone use occurred in 62% of the observed dyads. Turkle (2016) argued that the family dinner time tended to be interrupted by both parents and children as they all constantly used their mobile devices, eventually leading to decreasing the quality of conversation and weakening the empathic connection. The participants who pointed out the concern also discussed the benefits of using the smartphone in daily life. The participants were likely to think of the smartphone technology as one of their assistive technologies necessary for independent living (e.g., navigation, reading texts and images), which would not be relevant to nomophobia.

The degree to which they adopt technology would also be influenced by family members and friends. They would like to consult with their spouse in order to decide whether a home monitoring system for self-care should be installed in the home. Although their spouse was not the primary intended user for the monitoring system, they wanted to involve their spouse in decision making as the home is shared with their spouse. Their decision making was also influenced by technology application types and models used by their family and friends as they expected to readily obtain supports from them who are familiar with the same type and model. Prior user research (Steehouder, 2002) also found similar user behaviors; that is, users are more likely to appreciate and adopt "in-person" assistance; for example, users prefer tailored information and supports (i.e., a straight answer to their individual questions and needs) rather than documentation (i.e., user manuals), and users would value communication more than documentation because they could directly describe the technical problems in detail, expecting a quick, tailored answer to their problems.

The participants would like to adopt technology applications that are compatible with their daily living activities and lifestyles. For example, they preferred to install a motion tracking system (e.g., Kinect sensors) near their walking routes in the home such that rich data would be captured and to have the system equipped with data analysis modules that can distinguish the intended user's activities from other family members and visitors (e.g., biometrics, (Podio, 2002)). Many previous studies on smart home environments tried to identify ideal locations to place sensors in the home (Cook et al., 2013; Dawadi et al., 2014; Synnott et al., 2015; Thomas et al., 2016) by using various mathematical models based on a Monte Carlo algorithm, a hill climbing algorithm, and a genetic algorithm (Thomas et al., 2016). However, those prior research did not take into account a systematic analysis of living contexts of end users, especially those with disabilities associated with user preferences, tools, tasks on a daily basis, users' capabilities and limitations that affect the system implementations – i.e., a sociotechnical systems analysis approach (Hendrick & Kleiner, 2001; Kleiner et al., 2015). Further research is needed to determine adequate locations in the home to place such sensor technologies by considering various user contexts, especially for those who are visually impaired.

This study may have limitations that affected the results. This study included 16 female and 4 male participants. As previous research studies argued that male and female technology users might show different technology adoption patterns (Aguirre-Urreta & Marakas, 2010; Dutta & Omolayole, 2016; Venkatesh et al., 2000), they study may result in different outcomes if it included more male older adults with visual disabilities. Household income may be another factor as 75% of the participants indicated their household income was lower than 51,999 USD (i.e., 40% was below 25,999 USD and 35% was between 26,000 USD and 51,999 USD). The pew research center (Anderson & Perrin, 2017) reported that only 27% of sighted older adults with household income below 30,000 USD owned a smartphone and slightly over 30% of those with household income below 50,000 USD owned a smartphone while over 80% of those with household income over 75,000 USD owned a smartphone. The digital divide among older adults in low-income families (Choi & DiNitto, 2013) may have affected the results of this study. Future research on technology adoption will be conducted by considering more comprehensive socioeconomic status among older adults with visual disabilities.

5. Conclusion

Older adults with visual disabilities in this study adopted mainstream technologies, assistive technologies, or both in order to overcome their visual challenges, obtain the support they need to live independently, and improve the quality of life. Their decision to adopt technologies was influenced by various factors: relative advantage over existing technologies, compatibility with their attitude, behavior, and other technologies that they own, observability, trialability, and complexity. The factor relative advantage was associated with accessibility, safety and usability, and the subfactor usability was influenced by effectiveness, efficiency, and satisfaction. Professionals and researchers can use the research findings (i.e., characteristics of technology adoption) could be used as heuristics, contributing to "technology designs" customized for older adults with visual disabilities but also "technology implementation strategies" to promote the adoption of a newly designed and developed technology application. Besides the primary constructs of Rogers' diffusion of innovation theory (i.e., advantages, compatibility, observability, trialability, and complexity), the new elements (i.e., usability, effectiveness, efficiency, satisfaction, safety, accessibility, attitude, behavior, and technology) ought to be applied to the target user group, older adults with visual disabilities.

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About the Author

Hyung Nam Kim is an Assistant Professor in the Department of Industrial and Systems Engineering at the North Carolina Agricultural and Technical State University. He earned his PhD in Industrial and Systems Engineering from Virginia Tech. His research interests include human factors, human-computer interaction, health informatics and safety.