VISUAL ASSISTIVE SMARTPHONE APPLICATION RATINGS AND PERSPECTIVES FROM OLDER ADULTS WITH LOW VISION

A thesis presented to the graduate faculty of New England College of Optometry in partial fulfillment of the requirements for the degree of Master of Science

Bethany Grace Arabic

May 2025

VISUAL ASSISTIVE SMARTPHONE APPLICATION RATINGS AND PERSPECTIVES FROM OLDER ADULTS WITH LOW VISION

Bethany Grace Arabic

This manuscript has been read and accepted by the Thesis Committee in satisfaction of the thesis requirement for the degree of Master of Science

5/12/2025

DocuSigned by:
Nicole Ross
2172A8A6E3CE41E...

Date

Nicole C. Ross, OD, MS, FAAO
Graduate Faculty Advisor

Signed by:
AF05CA1BEA7D474...

Micaela R. Gobeille, OD, MS, FAAO
Thesis Committee Member

DocuSigned by:
671B01D309E640E...

Jem Martin, OD, FAAO
Thesis Committee Member

DocuSigned by:
Chris Bradley
E2C5BF87CDDD4A0...

Chris Bradley, Ph.D
Thesis Committee Member

5/12/2025

DocuSigned by:
78A8AD972399447...

Date

Thanasis Panorgias Ph.D
Director of Graduate Studies

Abstract

VISUAL ASSISTIVE SMARTPHONE APPLICATION RATINGS AND PERSPECTIVES FROM OLDER ADULTS WITH LOW VISION

Bethany Grace Arabic

New England College of Optometry, 2025

Purpose:

This study explores how older low vision patients rate three visual assistive applications (Aira, Supervision+, and Seeing AI) and how they utilize these applications in their daily lives after training. The study also investigates how our sample of low vision older adults compares to the general low vision population in terms of demographic variables and their responses to the Activity Inventory (AI) questionnaire and to what extent there is evidence of self-selection bias in the CARE study.

Methods:

This research study was a part of a larger randomized clinical trial called CARE (Community Access to Remote EyeSight NCT04926974). Seniors age 55+ years old, naïve to the study apps, with Modified Telephone Interview Cognitive Status (TICS-M) of ≥20 and visual acuity (VA) between 0.4 and 1.3 logMAR were randomized to Aira, Supervision+, or Seeing AI for a 6-month intervention period, followed by a 3-month period where they could elect to continue with access to all study apps. Participants were provided extensive one on one training upon issue of a loaner iPhone SE, 11, or 12 with the study app, followed by

further training if needed. Questionnaires were conducted at baseline, 3, 6, and 9 months post intervention, including the Activity Inventory (AI) and a dedicated usage questionnaire.

Results:

The population of this study demonstrates some demographic and diagnostic similarities and differences to the general low vision population. The Activity Inventory was generally well-targeted and the Wright map showed good alignment overall. However, on closer examination, several bins of person measures reflected higher levels of ability than were captured by item difficulty, suggesting a potential ceiling effect, as some person measure bins indicated higher abilities than the item difficulties captured. This mismatch was statistically confirmed by a significant Kolmogorov-Smirnov (KS) test indicating that the distribution of item difficulties did not fully align with the range of person abilities. While there were consistent trends in diagnoses, living arrangements, and housing types, notable differences emerged in visual ability domains, such as reading, mobility, and visual motor function. Subjects tended to rate all three apps similarly and favorably at 9 months with reading being the most common domain of app and device use. Low vision devices continued to be used more frequently than the apps.

Conclusion:

The findings of this study exemplify the need for tailored low vision rehabilitation approaches to each patient. Smartphone apps were used more as an auxiliary tool rather than a replacement to traditional low vision devices. However, it is important to continue to consider visual assistive smartphone applications can be an affordable and convenient aid for low vision patients to accomplish tasks of daily living.

Acknowledgements

I would like to express my deepest gratitude to my research advisor, Dr. Nicole Ross for her unwavering support and guidance throughout my journey in the master's program and while composing my thesis. I am eternally grateful for the time and effort she invested to promote my academic growth. I am fortunate to have had the opportunity to work under her guidance. I will forever look up to Dr. Ross as my role model in the field of low vision and research.

I would also like to thank Dr. Ava Bittner and the rest of the CARE study team for offering their guidance and review of my poster presentation for ARVO. Additionally, I would like to thank my thesis committee, for reviewing this thesis.

I would also like to acknowledge the following funding sources which have made this research possible:

NIDILRR Award, 90DPGE0012-01-00, Community Access through Remote Eyesight (CARE)

NEI T35 Summer Research Training Fellowship

Research to Prevent Blindness Grant to UCLA Department of Ophthalmology

Table of Contents

Contents

List of Figures and Tables

Figure number and name **Page number**

Table number and name **Page number**

CHAPTER 1: INTRODUCTION

The prevalence of age-related visual impairment or low vision is on the rise in the United States (Chan et al., 2018, Congdon et al., 2004, Marques et al., 2022, & Rizzo et al., 2023). Over four million older adult Americans currently live with low vision (Chan et al., 2018) - defined as a permanent loss in visual function, i.e. permanent visual impairment, that cannot be corrected with eyeglasses or medical treatment. Data from the NHANES (National Health and Nutrition Examination Survey) study conducted from 2007-2008 determined the prevalence of visual impairment rises exponentially as a function of age (n=6016 subjects) (Chan et al., 2018). Furthermore, the weighted prevalence of nonrefractive visual impairment for adults ages 20 or older, increased by from 1.4% in 1999-2002 to 1.7% in 2005-2008 (Ko et al., 2012). In a meta-analysis of population-based studies on blindness and low vision conducted in North America, Western Europe, and Australia from 1995 to 2000 the prevalence of blindness and low vision per 100 individuals increased significantly with age, during this time period, across all racial and ethnic groups (white patients: ages 40-49: 0.11, ages 60-64: 0.10, ages ≥80 years: 4.27; Black patients: ages 40-49: 0.13, ages 60-64: 0.45, ages ≥80 years: 2.67; Hispanic patients: ages 40-49: 0.04, ages 60-64 years: 0.20, ages ≥80 years: 1.80) (Congdon et al., 2004). Based on census projections, the greatest number of individuals with visual impairment was predicted among older, non-Hispanic white women (Varma et al., 2016). Further, African Americans were projected to have the highest prevalence of legal blindness (i.e, visual acuity worse than 20/100), while Hispanics were expected to exhibit the highest prevalence of visual impairment (Varma et al., 2016). Data from the National Health and Aging Trends Study (NHATS) assessed the prevalence of visual impairment among older adults in the United States. 27.8% of individuals aged 71 years and older were found to experience visual impairment (Killeen et al., 2023). The annual incidence and prevalence of adults with low vision in the United States is expected to continue to grow and more than double by the year 2050, reaching 2.01 million individuals with blindness and 6.95 million individuals with visual impairment. This growing prevalence and incidence of low vision thereby drives a growing demand for low vision rehabilitation services(Chan et al., 2018 and Varma et al., 2016).

Not surprisingly, the number and age of patients presenting for low vision rehabilitation services are rising. Results from a national, multicenter trial (n=764) examining the demographic and clinical baseline traits of low vision patients at private clinics and academic medical centers indicated that the median age of low vision patients was 77 years old and the majority of low vision patients were female (66%) (Goldstein et al., 2012). In terms of visual impairment severity, 37% of patients presented with mild vision impairment (defined as a visual acuity (VA) of 20/60 or better), 38% had moderate visual impairment (defined as a VA of 20/70 to 20/200) and 19% had severe visual impairment/met the criteria for legal blindness (defined as 20/200 to 20/500), and 6% had profound visual impairment (defined as a VA of less than 20/500). Overall, more than half (55%), of low vision patients presenting for low vision services, were diagnosed with some form of macular disease, with the majority having either exudative or atrophic macular degeneration. In addition to ocular pathology, this patient population exhibited other health comorbidities, with 68% of low vision patients experiencing decreased physical endurance and 52% facing mobility impairments. Most stated they were unable to drive (69%) and required others to assist them in their daily life (87%). Thus, the demographic and clinical characteristics of low vision patients are: of female gender, older age, and have age-related macular degeneration as a primary ocular diagnosis.

Other studies have documented baseline characteristics of low vision patients comparable to those reported by Goldstein and colleagues. Another study surveyed 608 low-vision service centers (excluding veterans' centers) and found age-related macular degeneration was the most common cause of low vision in their population (67.1%) and almost a third of patients were 80 years or older (Owsley et al., 2009). Similarly, Killeen and colleagues in 2023 determined the prevalence of visual impairment in patients 71 years and older in the United States was 27.8% and 55.2% were female (Killeen et al., 2023). Low vision has also been correlated with limitations in activities of daily living, mobility, and independence (Gkioka et al., 2024, Lamoureux et al., 2004, and Remillard et al., 2023). Thus, as evidenced by these demographic studies, key characteristics of the low vision patient population include: older age, macular disease (Congdon et al., 2004, Killeen et al., 2023, and Owsley et al., 2009), physical mobility impairment (Gkioka et al., 2024, Lamoureux et al., 2004, and Remillard et al., 2023), and mild to moderate visual acuity loss

(Goldstein et al., 2012). Given the increasing incidence and prevalence of low vision, there is need for expanded rehabilitative services to facilitate independent living among low vision patients.

Low vision rehabilitation aims to improve vision and restore functional ability. The goal is to help individuals perform daily activities autonomously, hence improving quality of life and independence. It requires collaborative care between providers and rehabilitation specialists, to identify the ocular pathology, assess how the pathology impacts functional visual ability, and create an appropriate and individualized rehabilitation plan, including prescribing visual assistive equipment (i.e., low vision devices), to suit the person's needs.

1A. Limitations of Traditional Low Vision Devices to Meet Low Vision Patients' Goals:

For older adults, low vision is associated with an increased risk of falls (Jin et al., 2024, Mehta et al., 2022), less independence (Gkioka et al., 2024, Jones et al., 2018), and emotional conditions, such as depression (Gkioka et al., 2024, Parravano et al., 2021, Renaud and Bedard, 2013, and Schakel et al., 2024). Low vision patients often report difficulties performing activities of daily life, such as driving (Brown et al., 2014, Gkioka et al., 2024, Keeffe et al., 2002, Luu et al, 2021, Massof, Deremeik, and Park, 2005, Riazi et al., 2022, Scott et al., 1999), technology use (Aigbe and Ross, 2021, Remillard et al., 2023, Senjam and Primo, 2022), and reading (Aigbe and Ross, 2021, Brown et al., 2014, Gkioka et al., 2024, Luu et al., 2021, Riazi et al., 2022, Scott et al., 1999). Historically, most patients at low vision clinics in the United States have presented with a chief complaint of reading (Brown et al., 2014, Elliot and Plotkin, 1997, Goldstein et al., 2012, Macnaughon, Latham, and Vianya-Estopa, 2019, and Rubin, 2013). However, there has been a changing landscape of chief complaints among low vision patients and usage trends of traditional low vision devices as well as assistive applications over the past years (Nguyen et al., 2022). Although technology related goals have become more important to many individuals, especially younger low vision patients, reading continues to be the primary goal (Aigbe & Ross 2021, Nguyen et al., 2022). The most common devices demonstrated to patients during low vision exams were found to be tinted lenses (95%), hand-held magnifiers (63%) and refractive spectacles (56%) (Nguyen et al., 2022). Overall, since the COVID-19 pandemic, there has been a growing number of low vision patients who present to low vision exams with technology-related goals, but reading remains the most frequent concern expressed during low vision assessments (Aigbe & Ross, 2021).

Traditionally, most low vision patients use visual assistive equipment such as magnifiers, CCTVs (closed circuit televisions), telemicroscopes, or other low vision devices to enhance their visual function (Crossland, Macedo, and Rui, 2014). However, there continue to be limitations of these traditional low vision devices that affect their utilization rate and can lead to device abandonment, such as high financial cost (Irvine et al., 2014, Sivakumar et al., 2019, Wittenborn and Rein, 2013), close working distances (Irvine et al., 2014, Sivakumar et al., 2019, Starke et al., 2020), large size of the devices (Golubova et al., 2021, Kaur and Gurnani, 2023), small fields of view (Golubova et al., 2021, Kaur and Gurnani, 2023), and potential embarrassment low vision patients report experiencing while utilizing the devices in public (Martiniello et al., 2019, Piculo dos Santos et al., 2020, Sivakumar et al., 2019).

Hand-held magnifiers have long been a fundamental tool for patients with low vision, providing a simple yet effective method of enhancing visual accessibility and promoting independence with daily tasks. However, hand-held magnifiers present several limitations, including a restricted field of view, necessitating continuous movement of magnifier while reading (Macnamara et al., 2021). Further, patients with hand tremors or limited hand dexterity may also have difficulty with using hand-held magnifiers (Macnamara et al., 2021). Hand-held magnifiers are less suitable for sustained reading tasks, since they require frequent repositioning, leading to fatigue over time (Macnamara et al., 2021). Conversely, stand magnifiers enable sustained reading, yet require a fixed working distance that may not be suitable for all tasks (Bowers, Cheong, & Lovie-Kitchin,2007). Similar to hand-held magnifiers, stand magnifiers also have a limited field of view (Bowers, Cheong, & Lovie-Kitchin, 2007). Unfortunately, in comparison to hand-held magnifiers, stand magnifiers are heavier and less portable, which limits their use for travel (Bowers, Cheong, & Lovie-Kitchin, 2007).

Telescopes are another common low vision device employed by low vision patients for near, intermediate, and distance tasks. Despite these benefits, telescopes are often perceived by patients as aesthetically unappealing, which can deter patient use (Peli & Vargas-Martín, 2008). Telescope's narrow field of view can also complicate navigation for patients (Peli & Vargas-Martín, 2008). While telescopes are occasionally used for reading tasks, they are predominantly employed for distance viewing, due to field of view limitations (Peli, 2002). As outlined above, there are multiple low vision devices ranging from magnifiers to telescopes, but these tools are task specific, and come with several limitations. This narrow functionality of these assistive devices necessitates patients to have an array of devices, which can be inconvenient and burdensome for individuals with low vision.

In addition to traditional optical aids, electronic devices have also emerged as an alternative for low vision patients. These various electronic devices encompass a range of functionalities, some which offer magnification and visual enhancement and others that provide sensory substitution often in the forms of speech or touch (Moshtael et al., 2015). Some examples of devices in this category are text readers, talking watches, and the white cane, which transmits information through touch (Minto and Butt, 2004, Moshtael et al., 2015). CCTVs (closed circuit televisions) are another popular electronic device with a range of magnification from 3x to 100x (Minto and Butt, 2004). Most CCTVs can have a variety of features, such as the capability to reverse the polarity of images or change the contrast (Minto and Butt, 2004). However, CCTVs also have major limitations, such as a high cost and large size makes them difficult to transport (Minto and Butt, 2004). Recently, portable CCTVs (such as the HumanWare Explore 12, Eschenbach Visolux Digital XL FHD, and Optelec Compact 10 HD Speech) have been created to address the portability imitation of traditional CCTVs (such as the Optical Clearview+, Enhanced Vision

Merlin HD, and Freedom Scientific TOPAZ XL HD). Nevertheless, notable disadvantages of electronic magnifiers are they are expensive ($1,000 to $4,000 USD) and can show distortion on edges of the device (Taylor et al., 2014). Wearable assistive technology with speech output have also been developed, which allow for hands-free magnification (such as OrCam Read, IrisVision Live, and Envision glasses). Overall, a wide variety of electronic low vision devices have been invented, which incorporate advanced features, such as optical character recognition, adjustable contrast, brightness, variable zoom, voice control, and enhanced portability to optimize usability and accessibility (Moshtael et al., 2015).

1B. Smartphone Application (Apps) Based Low Vision Devices:

With the technological gains of the 21st century, conventional electronic devices such as tablets and smartphones, equipped with visual assistive smartphone applications (apps) have emerged as an alternative option to traditional low vision devices, such as magnifiers and CCTVs. In total there are more than 152 visual assistive smartphone apps on the Apple App Store and more than 86 visual assistive smartphone apps on the Android phone platform (Date assessed: 04/06/2025). The number of apps for low vision has more than doubled over the course of a year (Bano, Wolffsohn, Sheppard, 2024). Over and above using the built-in accessibility options in smartphones, visual assistive downloadable applications (smartphone apps) may also be a feasible and more convenient, low vision aid for some patients.

According to records (n=259) at the UCLA Vision Rehabilitation Center, the majority (90%) of low vision patients own a smartphone ("Many Seniors Miss Out," 2022). A survey 10 years prior (in 2012) conducted by the Spectrios Institute and Chicago Lighthouse involving patients across the age spectrum (age range 18 to 97 and mean age 60.6 years) found 24% of patients used a smartphone, 65% owned a basic mobile phone, and 11% did not own a smart phone (Bhakhri et al., 2012). As shown by the differences between the 2012 and 2022 studies, there has been an increase in smartphone use in older low vision patients over this decade ("Many Seniors Miss Out," 2022). Among the smartphone users in the study, 82% of the patients surveyed answered they purchased their phone due to its features (Bhakhri et al., 2012). 57% of the non-smartphone users stated they were interested in learning more about the visual assistive features of a smartphone (Bhakhri et al., 2012). According to Martiniello and colleagues, 87.4% of low vision patients residing in or near Quebec-based low vision rehabilitation centers, as surveyed through an anonymous online survey (n=466 participants, mean: 41 years, range 18-80 years) believed that mainstream devices, such as smartphones and tablets are increasingly replacing traditional low vision devices (Martiniello et al., 2019). A 2023 AARP survey revealed that 81% of Americans aged 60 to 69 own a smartphone and 62% of Americans aged 70 and older use a smartphone (Kakulla, 2020). This rate of smartphone ownership among seniors suggests that visual application smartphone applications and built-in accessibility features on cell phones could offer a versatile solution for patients who prefer not to manage a collection of task specific low vision traditional devices. Instead, patients can leverage a single device-the smartphone they already own- to access a wide range of functionalities that support their everyday lives (“Many Seniors Miss Out, 2022). Smartphone applications overcome many of the limitations of conventional low vision devices, such as the apps are low cost, do not have the same field of vision constraints, are mainstream in society, and are versatile for a variety of everyday tasks (Irvine et al., 2014).

In recent years, smartphone-based visual assistive apps have become more user-friendly, affordable, and portable for low vision patients compared to traditional low vision devices (i.e, $0 - $20.00 for a visual assistive smartphone app, versus $1,000 - $4,000 for an electronic CCTV), such as magnifiers and CCTVs (Irvine et al., 2014). While smartphones are widely utilized by visually impaired individuals, limitations, such as restricted field of vision (less than 20 degrees), decreased contrast sensitivity (less than 1.7 log units OU), and reduced visual resolution (leading to glare) were cited as challenges with smartphone use (Irvine et al., 2014). Since smartphone screens rely on light-emitting diodes, low vision patients can also experience disabling visual glare from the screen display (Irvine et al.,2014). Moreover for certain sub-groups of low vision patients, such as those with severely constricted visual fields, high magnification may not be beneficial, as it can further reduce field of view and stability of the image (Irvine et al., 2014). Therefore, tailored accessibility options and features may be necessary for different sub-groups of patients depending on their visual condition. Nevertheless, smartphone technology can offer distinct advantages over traditional low vision devices, such as handheld magnifiers for some patients. On smartphones, features such as adjustable contrast settings, the ability to magnify images with the "pinch and zoom" function, and voice command features like Siri can assist low vision patients. Overall, it is important to acknowledge that smartphone technology and applications are not a universal solution for all low vision patients, but can serve as valuable tools for some of the low vision population. Given the ubiquitous use of smartphone technology, utilizing a smartphone instead of carrying separate low vision aids may be more practical.

1C. The COVID-19 Pandemic and Visual Assistive Application Usage:

The COVID-19 pandemic of 2020 has accelerated the adoption of technology by both individuals and businesses (Nugent, 2022). Recent research by our lab has identified a rising trend of technology utilization among low vision patients (Aigbe & Ross, 2021). In a retrospective review of low vision patients presenting for low vision exams in 2019 and 2020 (n=121 charts) at the New England College of Optometry (NECO) Center for Eyecare, we observed that since the onset of the COVID-19 pandemic, the proportion of low vision patients who cite difficulty with using technology as their chief complaint has nearly doubled (Aigbe & Ross, 2021). A longitudinal study further explored worldwide usage data from the Supervision+ magnification app collected for 38 weeks, including during the COVID-19 lockdown (on average over 38,000 users each month with over 250,000 launches) (Luo et al., 2020). The lowest usage rates of the Supervision+ app was reported during the COVID-19 lockdown (11% decrease in usage worldwide), holiday weeks (9.5% decrease globally), and weekends (8.6% less usage than during weekdays worldwide) (Luo et al., 2020). These findings suggest that individuals with visual impairment may experience fewer challenges requiring technological assistance within their homes, compared to tasks outside the home may necessitate greater reliance on technology (Luo et al., 2020). Overall, the COVID-19 pandemic accelerated the adoption of technology and consistent with this trend there has been a notable increase in technology usage among low vision patients (Aigbe & Ross, 2021).

1D. Common Smartphone Visual Assistive Applications:

While traditional low vision devices, such as magnifiers and CCTVs remain important for many low vision patients, smartphone applications have been developed with a large variety of features and can assist low vision patients with numerous tasks. These smartphone apps can support users with tasks, such as reading printed text, recognizing faces, or even connecting to sighted volunteers or professionals. Some of the most widely utilized smartphone apps among individuals with low vision include, Seeing AI, KNFB reader app, Be My Eyes, and Aira (Adams, 2022).

In 2017, Seeing AI was created by Microsoft, and this free application employs artificial intelligence to generate auditory descriptions of people, objects, and text in the user's immediate environment. A pilot study with a small sample size conducted in 2020 found that Seeing AI was the most commonly used smartphone app among patients surveyed (n=11) with 81.8% (n=9) reporting usage (Dockery and Krzystolik, 2013).

Another optical character recognition app designed to assist individuals with low vision is the KNFB reader app. This app enables low vision patients to capture images of printed text and then it converts the text into speech. The KNFB reader app costs $99 and is available for iOS, Android, and Windows 10 devices and in eleven languages (AbouElwafa et al., 2018, Gopinath et al., 2021). One of the benefits of the KNFB reader app is the interface is very simple to navigate, and the verbal output typically starts seconds after the picture is provided (Holton, 2014). However, one of the significant drawbacks of the KNFB app is the significant cost ($99, date accessed: 04/05/2025). Some additional features of the KNFB reader app, include the field of view report, which provides feedback on if the entire paper is visible to the camera and tilt guidance, that causes vibrations of users' cellphones if they are off center with the photographs (Holton, 2014). There is also the option for batch mode processing, where the KNFB reader takes multiple pictures and then merge the pages into one document (Holton, 2014). Thus, although KNFB reader comes with a relatively high price tag, compared to free alternatives, the KNFB reader app does offer optical character recognition on a simple interface.

Be My Eyes is another commonly used free assistive smartphone app for patients with low vision. This smartphone app connects low vision users in real-time with a sighted untrained volunteer. Through the smartphone's camera, volunteers can observe the user's surroundings and provide verbal descriptions. While the smartphone app can be used for many tasks, some of the tasks commonly cited by the app developers include: color identification, object identification, and text reading. Be My Eyes was the second most commonly employed smartphone app by patients surveyed in a limited sample pilot study (63.6% or 7/11 patients) (Dockery and Krzystolik, 2013).

Another widely used smartphone app for low vision patients is known as Aira. While similar to Be My Eyes, the Aira application provides visual descriptions for participants through professionally trained agents rather than volunteers. Trained agents can offer the potential advantage of being familiar with best practices for visually impaired individuals, such as providing clear and concise directions during navigation, remaining quiet while crossing streets, and adhering to strict privacy standards. Although limited data exists on the topic, because Be My Eyes relies on volunteers there may be longer wait times compared to paid agents (Flament, 2019, Falejczyk , 2020). According to the Aira Explorer guide, users should typically expect to connect with an Aira agent in 30 seconds or less ("Aira Explorer Guide," 2023). Aira has a free 5-minute call program and there is free access available at several businesses, such as Wegmans, Starbucks, Target, Bank of America, and TD Bank. The cost of a personal Aira subscription can vary from $65 to $2,900 depending on the plan selected. For both Be My Eyes and Aira, the agent has access to the smartphone camera and can describe any images captured by the device, once the caller has provided verbal permission. In 2019, Nguyen and colleagues published an article where they performed an assessment of the needs of low vision and blind patients (self-reported visual impairment defined as <20/200 in the better eye and age 18 or older) with the Aira app. The data included in the study (n=878 participants who made 10,022 calls) was gathered from Aira call logs (Nguyen et al., 2019). The frequency of tasks associated with each Aira call were reading (35%), navigation (33%), and home management (16%) (Nguyen et al., 2019). Women demonstrated a higher rate of Aira usage compared to men (Nguyen et al.,2019). Participants with profound visual impairment (such as blind or light perception users) were determined to have higher usage rates of the Aira app compared to those with less severe vision loss (Nguyen et al., 2019). One major limitation of this study was that it utilized self-reported descriptions of vision loss and visual acuity of participants was not measured. Hence, early studies suggest that Aira has many potential uses and subjects with profound visual impairment utilized the app more often.

The National Research and Training Center on Blindness and Low Vision performed a survey about access to technology in the workplace and the use of assistance apps. This survey focused on apps known as “remote sighted assistance apps” where either trained agents or untrained volunteers aid through the smartphone (apps, such as Be My Eyes and Aira (McDonnall, 2024). This study determined that Be My Eyes was the most often used remote sighted assistance app with 83.1% of their sample utilizing the app (n=193), while Aira was used by 66.3% of subjects. 54.1% of survey participants reported using the apps once per week or less, compared to 20% of the population using the apps once a day or more frequently (McDonnall, 2024). When questioned about the importance of remote sighted assistance apps, 45.4% of participants considered the apps to be very important or crucial to their daily lives, while 3.6% of subjects rated the apps as not important (McDonnall, 2024). Thus, in early studies, the majority of low vision patients used remote sighted assistance apps and rated them as important in their daily lives.

Furthermore, Supervision+ is another commonly employed visual assistive app by low vision patients. The app is free and offers magnification features, as well as live-image stabilization, color inversion, and contrast enhancement (Luo, 2021). It was shown that for accessibility users (low vision patients who had the built-in accessibility features on their phone enables), the percentage of textual images analyzed by the app was higher (41.1%) compared to the non-accessibility users (29.8%) (total n of study= 24,295) (Luo, 2021). However, the majority of objects subjects used the Supervision+ app for were nontextual, such as indoor objects (Luo, 2021). Supervision+ was also found to be primarily employed for short spot viewing (51%) of app uses were for less than one minute in duration (Luo, 2021). In all, Supervision+ offers a simple to use smartphone-based magnifier with various features, allowing patients to discern both textual and nontextual objects.

Overall, numerous smartphone-based apps have been created to assist low vision patients with everyday tasks. These apps offer features, such as magnification, text-to-speech, and connection with sighted individuals. Initial studies suggest low vision patients value these visual assistive apps and utilize them for a variety of purposes in their daily lives.

1E. The Role of Visual Function Questionnaires in Low Vision Research:

In the field of low vision rehabilitation, it is important to understand how visual impairment impacts daily functioning and quality of life, to guide treatment and evaluate interventions (Massof et al., 2022). One of the established methods to assess these outcomes is through visual function questionnaires. These standardized and validated questionnaires are designed to capture the difficulty levels related to reading, mobility, visual information processing, visual motor tasks, and various other areas of daily life. A validated questionnaire is one that has undergone extensive rigorous testing to ensure that it accurately and reliably measures what it intends to assess. Validation often involves examining the questionnaire's structure and performance across diverse populations to ensure that it produces consistent and meaningful results. By using validated instruments, this ensures that the data collected reflects a person's functional ability, instead of being influenced by other factors, such as measurement errors. Among these visual function questionnaires, the Activity Inventory has become important in low vision research and clinical practice, as it was developed specifically for the low vision population. The AI was constructed to measure the impact of visual impairment on a large range of daily activities and allows research to determine changes in functional ability over time in response to interventions (Gobeille et al., 2021, Massof et al., 2007).

Besides the AI, studies, such as the Veterans Affairs Low Vision Intervention Trial (LOVIT I and LOVIT II) have employed the VA Visual Function Questionnaire (VA VFQ) to assess low vision rehabilitation outcomes. However, it is important to note that the LOVIT I and II studies utilized the veteran's population, which is a predominantly male and

Caucasian, potentially limiting the generalizability of the findings to the broader low vision population. The LOVIT I and II studies used the VA VFQ to demonstrate that structured low vision rehabilitation with low vision aids and rehabilitation can lead to meaningful improvements in self-reported visual function and overall quality of life among patients with et al., 2007). These two studies provided evidence that low vision rehabilitation services offer measurable benefits in various domains of daily life (Stelmack et al., 2021, Stelmack et al., 2007). Although the VA VFQ helped to validate the concept of patient-reported outcome measures, the AI offers distinct advantages outlined below, including its adaptability and ability to measure functional changes over time. Conversely, the results from forty-four studies in a large review found that low vision rehabilitation did not seem to have an impact on health-related quality of life (van Nispen et al., 2020). In all, visual function questionnaires represent an important approach for quantifying the impact of low vision services on the everyday lives of patients.

1Ei.General Structure of the AI:

The Activity Inventory (AI) is a validated adaptive visual function questionnaire that is commonly utilized in the field of low vision (Deemer et al., 2017, Goldstein et al., 2014, Goldstein et al., 2015, Massof et al., 2007, and Massof et al., 2013). The AI includes 50 overall goals with 459 tasks underlying the goals (Massof et al., 2007). During the AI, low vision patients rate the importance of each goal on a 6-point Likert scale from not important (0) to very important (5) (Massof et al., 2007). If the goal is important then the patient is then asked to rate how difficult the goal is (Massof et al., 2007). Next, the low vision patient is asked to rate the difficulty of each individual task that underlies the goal using a 5-point scale from not difficult to impossible to do without help. Only tasks that fall under the goals that rated as having some level of importance to the patient are rated. Having an adaptable questionnaire is essential to low vision (Massof et al., 2007). While this adaptive approach introduces a form of self-selection bias (as patients only rate tasks relevant to their lives) this is considered desirable in the context of low vision rehabilitation. Low vision care is goal based and two patients with the same condition may require distinct interventions, because they prioritize vastly different functional goals. The AI can help account for these variations by tailoring interventions to meet the specific needs and objectives of each patient. Although this selective rating introduces variability in item exposure among study participants, Rasch analysis accounts for this by estimating the item measures based on the available data. Therefore, the adaptive nature of the AI questionnaire improves clinical relevance, while at the same time maintaining measurement ability.

Furthermore, the difficulty of a task relies on the visually impaired person's ability to perform visually mediated activities and the ability that is necessitated by the task, the difference between the person's ability and the ability demanded by the task has been referred to as the functional reserve (Massof et al., 2007). For example, if a person's ability is much greater than the amount of ability needed for a task, then the functional reserve would be considered high (Massof et al., 2007). As a result, if the functional reserve of the patient is high, we would expect that the patient states that the task is not difficult to complete (Massof et al., 2007). In other words, when patients respond to the AI they are providing a rating to the amount of their own functional reserve for each task they respond to (Massof et al., 2007). Functional reserve estimates are based only on tasks associated with the goals that the patient identified as important, not upon all possible items within the instrument. This adaptive approach can introduce a form of self-selection, which can result in a biased estimate of functional reserve if the subset of rated tasks does not fully represent a person's functional ability across all the activity domains. However, Rasch analysis can lessen some of the bias by using person measures to estimate ability measures even when item exposure varies between individuals. Hence, through focusing on relevant tasks to each patient and leveraging Rasch analysis, the AI can provide individualized and meaningful estimates of functional ability in the low vision population.

1Eii.Overall Benefits of the AI:

The Activity Inventory was developed, implemented, and calibrated to the low vision population (Massof et al., 2007). By including only items that are both important and difficult for a patient, this allows for an outcome measure to be created that is centered on the patient's own rehabilitation plan and overall goals. The questions on the AI are grouped under 4 major functional domains: reading, visual information (general seeing), mobility, and visual motor manipulation (Massof et al., 2007). In addition, the use of calibrations permits researchers to compare across samples. Low vision is an individualized approach to care and thus the AI allows for the measurement of what goals or tasks are important to each specific patient (Massof et al., 2019). Rather than presenting a fixed set of tasks, the AI uses an adaptive format where patients first rate the importance of various goals and then only rate the difficulty of the task for the goals they view as important. This format not only prevents fatigue but also ensures that responses are collected on tasks which are meaningful to each individual patient. Although only answering questions of some important results in missing responses for non-relevant items, Rasch analysis accommodates the missing data and ensures that estimates of functional ability remain valid and comparable across individuals (Massof et al., 2007). Especially with low vision patients, it is essential that a questionnaire captures a detailed and organized functional history specific to each patient. The AI then leverages these responses to generate estimates of functional ability. Furthermore, the AI can be used to track the efficacy of low vision rehabilitation over time, by providing clinicians and researchers with a means to assess and optimize patient outcomes (Massof et al., 2007). The AI has not only been used as an outcome measure in the context of before and after low vision rehabilitation (Massof et al., 2007, Goldsten et al., 2015), but also pre and post device intervention (Pearce et al., 2011) and to compare different approaches to care, including mobile clinics (Gobeille et al., 2018) and telerehabilitation (Bittner et al., 2019). Altogether, the adaptability of the AI makes it a crucial questionnaire for evaluating and refining personalized interventions in a variety of low vision care settings.

1Eiii. Previous Works Using the AI with Low Vision Patients:

Previously, the AI has been extensively utilized in various studies (Adeyemo et al., 2017, Deemer et al., 2017, Gobeille et al., 2018, and Goldstein 2015). Specifically, in one study by Goldstein and colleagues, the AI was leveraged to measure the outcome of the low vision rehabilitation care and was administered pre and post low vision exam (Goldstein et al., 2015). The evaluation of outcomes relied on the difficulty ratings from the AI at baseline, 6, and 9 months after the initial evaluation in the study (Goldstein et al., 2015). In addition to visual ability estimated from the AI, in 2015 Goldstein and colleagues were able to further determine secondary visual ability outcome measures using subsets of AI tasks, including mobility, reading, visual motor function, and visual information processing. Minimum clinically important differences (MCIDs, the smallest improvement or enhancement that is considered meaningful or important to the patient) were calculated after rehabilitation (Goldstein et al., 2015). After rehabilitation, the prevalence of low vision patients with MCIDs greater than 1 was as follows: reading (44%), visual motor function (35%), visual information processing (33%), and mobility (27%) (Goldstein et al., 2015). For each domain, the effect sizes were considered moderate (reported as Cohen, which measures effect size or how large the difference is between the two groups d=0.40-0.51) (Goldstein et al., 2015). This AI-based data provides evidence that low vision rehabilitation services were successful in enhancing visual ability in nearly half of the patients (47%) (Goldstein et al., 2015).

A further study utilized the Activity Inventory to compare the efficacy of behavioral activation along with low vision rehabilitation with an occupational therapist (BA+OT-LVR) versus supportive therapy (ST) on the overall visual function of patients with low vision due to age-related macular degeneration (n=188, mean age=84 years) (Deemer et al., 2017). There were improvements at the goal level in the functional vision measures in both the ST and BA+OT-LVR groups (d=0.56 and d=0.71) (Deemer et al., 2017). At the task level of analysis, the most pronounced effect of the BA+OT-LVR was seen with participants who had a visual acuity of at least 20/70 (d=0.500 inside the home, d=0.568 outside the home, and d=0.360 for reading) (Deemer et al., 2017). Therefore, the behavioral activation and low vision rehabilitation with occupational therapy was more effective than only conventional low vision services for patients with mild visual impairment (Deemer et al., 2017).

A prospective cohort study that employed the AI was conducted on the effectiveness of low vision rehabilitation (LVR) services with a mobile low vision clinic (Gobeille et al., 2018). Participants in the study were recruited from patients scheduled for appointments at the mobile clinic and the participants had to meet the criteria for legal blindness. The AI was performed at baseline, 3 months, and 1 year. Significant differences were seen between the baseline and 3-month person measures as well as the baseline and the 1-year person measures in this study (Gobeille et al., 2018). Overall, this study displays how the AI was useful to show the effectiveness of mobile clinic low vision rehabilitation and how the mobile LVR was comparable to those observed in traditional outpatient settings (Gobeille et al., 2018).

Another study utilized the AI to understand how patients with ultra-low vision employ the vision they have remaining (n=46, mean age=59 years) (Adeyemo et al., 2017). Ultra-low vision was defined as having a visual acuity of ≤ 200/500 in the better seeing eye (Adeyemo et al., 2017). Focus groups were held to cover the 50 goals in the AI and there were a total of 73 hours of audio recordings analyzed by two of four possible team members from this study (Adeyemo et al., 2017). The study team members then classified the activities based on four functional domains or reading, mobility, visual motor, and visual information gathering and then based on what was the most important to their ability to interpret the visual scene (some of the categories included: luminance, familiarity, movement, distance, eccentricity, depth, and lighting) (Adeyemo et al., 2017). For the categorization of the functional domain of the task visual information gathering was the most essential to this ultra-low vision population (49%), while reading was the least important (10%) (Adeyemo et al., 2017). In terms of the categorization by the visual aspects, contrast (43%) was the most commonly the most important for the participants ability to interpret the visual scene (Adeyemo et al., 2017). Thus, activities which are enabled by ultra-low vision are focused in the visual information gathering domain and contrast plays a key role in what the participants were able to observe (Adeyemo et al., 2017). The discussions recorded were guided by the AI further illustrating its utility in identifying trends among low vision patients across various vision loss levels (Adeyemo et al., 2017).

Overall, the Activity Inventory was specifically designed for and calibrated to the low vision population. This unique questionnaire has proven useful in various studies to measure the impact of low vision rehabilitation services (Adeyemo et al., 2017, Deemer et al.,2017, Gobeille et al., 2018, and Goldstein et al., 2015).

1Eiv. Early Work with Other Questionnaires and Smartphone App Usage with Low Vision Patients:

In 2020, a study assessed the impact of Aira usage on quality-of-life outcomes, as measured by the Impact of Vision Impairment-Very Low Vision questionnaire (IVI-VLV) (Park et al., 2020). This IVI-VLV questionnaire contains 28 items with similar approach to the AI where there are 3 to 4 options on a Likert scale rating, with choices from “not at all” to “a lot” (Finger et al., 2014). The study sample included those with severe visual impairment, specified as a visual acuity of worse than 20/200 in the better seeing eye, and were 18 years of age or older (Park et al., 2020). Statistically significant improvements were observed in multiple outcome measures following Aira usage. Specifically, the IVI-VLV (Impact of Vision Impairment-Very Low Vision) questionnaire demonstrated a mean improvement of 10.0 (SD=17.6, p=0.0002), the ADLMS (Assessment of Daily Living, Mobility, and Safety) showed a mean improvement of 6.5 (SD= 13.4, p=0.001), and the EWB (Engagement and Wellbeing survey) had a mean improvement of 3.4 (SD=5.7, p=0.0001) (Park et al., 2020). Therefore, there were statistically significant improvements in the scores on three quality of life and emotional health surveys among low vision patients after Aira app usage, which suggests Aira could provide benefits to the quality of life and emotional well-being of some individuals with low vision (Park et al., 2020). However, the study sample was not necessarily representative of the typical older low vision patient, as participants generally had severe visual impairment.

In all, given the growing field of smartphone-based assistive technology for individuals with low vision, it is necessary to determine how these tools may benefit the low vision population and how to best measure their impact on rehabilitation. While visual function questionnaires, such as the Activity Inventory remain the clinical standard for capturing patient-reported outcomes, there is limited research examining how these questionnaires perform when applied to these emerging forms of intervention, such as smartphone applications. Questions remain about how representative study samples are in this area of research, particularly when participation is voluntary and more motivated and technologically advanced individuals may elect to participate and thus be overrepresented. This thesis begins an investigation to address these gaps.

1F. General Research Methods:

The data from this thesis is from a multicenter, randomized clinical trial known as the CARE study (Community Access through Remote Eyesight, NCT04926974), which explores outcomes of visual assistive apps. The CARE study was approved by the UCLA Institutional Review Board which serves as the main IRB for the project. Seniors naïve to the study apps who had previously received vision rehabilitation services and devices, with a score ≥20 on the modified telephone interview of cognitive status (TICS), aged 55+ years and visual acuity (VA) of 0.4 to 1.3 logMAR were randomized to one of three study apps (Supervision+ for magnification; Seeing AI for optical character recognition; Aira for remote visual description). Participants were provided extensive one on one training upon issue of a loaner iPhone with the study app, followed by further training or support at 2-weeks and 4-weeks (if needed). Questionnaires were conducted at baseline, 3, 6, and 9 months post intervention, including the Activity Inventory (AI). At the end of the 6-month period, the participants could elect to then explore all three study apps for an additional 3 months, at which time extensive one on one training was provided on the two additional applications. Proficiency with the smartphone was assessed at the end of the initial training session and after 2 weeks, using a standardized assessment developed by the research team which tested knowledge, such as the ability to turn on the smartphone, to launch the application, and to find the phone charging port. Participants were offered a 3rd training session if they had not achieved proficiency in 2 weeks.

1G. Participants:

Low vision patients were recruited from New England College of Optometry Center for Eyecare (n = 144) and the University of California Los Angeles Stein Eye Institute (n=50 participants in the CARE study). Criteria for enrollment was as follows:

1. English speaking
2. Age 55 years (with no upper limit)
3. Reside in CA state or New England State: MA, NH, CT, RI
4. Best-corrected visual acuity 20/40 to 20/800 in the better eye or less than 20 degrees of visual field diameter
5. No previous use of Aira, Supervision+, or Seeing AI on a smartphone (<5 uses overall)

6. No travel outside the United States for more than 2 weeks during the study time period if they do not have a useable international data plan.
7. Telephone interview cognitive status score (TICS) of greater than or equal to 20 at the baseline of the study (measures cognitive impairment)
8. No significant hearing loss that prevents communication over the telephone

1H. Research Questions and Approach:

While training (Malkin et al., 2024, Malkin et al., 2022) and outcome measures of the CARE study (Ross et al., 2022) are addressed elsewhere in other papers, this thesis will address the following research questions:

Study 1: To what extent is there evidence of self-selection bias in the CARE study investigating the use of visual assistive apps among older adults with low vision?

Approach: Potential self-selection bias will be assessed by analyzing demographic and clinical characteristics of participants in the CARE study and comparing them to those reported in larger, multicenter low vision trials. Participant responses to the Activity Inventory (AI) will be evaluated to determine whether the items are well-targeted to our sample and whether the distribution of responses aligns with patterns observed in other studies that have used this measure.

Hypothesis: We hypothesize that the CARE study sample may differ significantly in demographic and clinical characteristics from the larger low vision cohort studies, as established and not new patients were recruited, and they may have a strong interest in technology. We did find higher baseline person measures in the CARE study sample compared to the LVROS study. If CARE study participants were much more technologically advanced and well adjusted their person measures may not be well targeted to item difficulties, showing that the CARE study sample is different than the low vision population.

Study 2: How do older adults with low vision utilize visual assistive apps in their daily lives after receiving training? How do older adults perceptions, usage patterns, and reliance on these apps evolve over time?

Approach: To address this question, participants use and ratings of three visual assistive apps (Aira, Seeing AI, and Supervision+) will be longitudinally assessed at 6, and 9 months post-training. How participants integrate these technologies into their daily routines both inside and outside the home will be examined. Data will be collected through structured usage and rating questionnaires. The responses to the Activity Inventory (AI) will be analyzed with an additional component: for each activity identified as important or difficult, participants were asked whether they employed either a low vision device or app to assist with that task and if so which device or app. It will be explored whether visual assistive apps are replacing traditional optical aids or are instead being utilized for distinct, complementary tasks.

Hypothesis: We hypothesize that older adults with low vision will continue to use both visual assistive apps and traditional optical aids, with apps serving a complementary role rather than fully replacing existing tools. Participants will report satisfaction with the three visual assistive apps in this study and will utilize them particularly for tasks involving reading and mobility outside the home.

CHAPTER 2: Study 1: Assessing Self-Selection Bias in Studies of Smartphone Applications for Low Vision Patients: Indications and Implications:

2A. Introduction to Self-Selection Bias and the Activity Inventory (AI) Questionnaire:

In research studies involving technology use and human behavior, the accuracy and applicability of findings depend on how representative the study sample is of the overall population (Ahmed, 2025, Leung, 2015). If a study sample is not aligned with the larger population, the conclusions reached may not be applicable or able to be generalized to the broader population (Leung, 2015). A well-documented example of self-selection bias was a research study conducted on patients with implantable cardioverter defibrillators (Toscos et al., 2019). A large group of individuals were excluded from an informatics intervention, because they did not have access to the internet and computer (Toloscos et al., 2019). The group who was omitted from the intervention were older in age and had more medical comorbidities than those who participated (Toloscos et al., 2019). Unfortunately, this study demonstrates how self-selection based on technology access can unintentionally exclude individuals who could benefit from the intervention. Another prominent example of self-selection bias within technology research emerged during the COVID-19 pandemic, where cases could self-report symptom data on smartphone apps (Millar et al., 2022). Due to the voluntary nature of reporting symptoms, cases who entered their symptoms in the apps could not represent the general population (Millard et al., 2022). Those cases with severe symptoms could have been older and less likely to report their symptoms (Millard et al., 2022). In all, self-selection can become more pronounced and amplified in studies involving populations that inherently face equity or accessibility challenges, such as those with visual impairment (Legge, 2015).

To mitigate self-selection sampling bias, random sampling methods are commonly used to choose participants, ensuring that each individual in the population has an equal opportunity to be selected for the study (Alarie and Lupien, 2021). In other fields, it has been found that self-selection bias can skew the study sample towards participants who are highly motivated and/or possess advanced technology skills (Toscos et al., 2019, Khazaal et al., 2014). This can cause technology studies to overrepresent individuals who are likely to benefit from technology, while potentially excluding populations that may face barriers to access. **In our study of visual assistive smartphone application ratings, it was important to assess whether our sample was representative of the overall low vision population.**

When participation is voluntary, as in the research study for this thesis, there is an inherent risk the sample will overrepresent users with greater technological abilities and those who are highly motivated, while underrepresenting individuals who face barriers to access. Although randomized controlled trials, like the CARE study, are highly regarded for evaluating interventions, they are not immune to self-selection bias when enrollment is voluntary. Hence, determining the degree of self-selection bias in this study is important for determining the ability to generalize the results and understanding the impact on the low vision population.

Efforts have long been underway in the field of low vision to develop a standardized outcome measures and methodology for evaluating low vision rehabilitation interventions. There are two main ways that have been developed to determine the efficacy or utility of a low vision assistive device. The first method is to issue the device to patients and then ask the patients to rate their experience with the applications afterwards. Unfortunately, this method of evaluating outcomes can lead to sources of bias, such as response or acquiescence bias (Dockery & Krzystolik, 2013, Griffin et al., 2017, Malkin et al., 2022, and Christy & Pillai, 2021). A major limitation of this first method is the potential for unintentional interview bias, where participants may be subtly influenced by the interview, or the wording of the survey questions wording can be inadvertently suggestive of certain outcomes. The second way the efficacy of low vision assistive devices can be determined is to question patients how visually difficult it is to perform a series of visual tasks and then compare their visual function pre- and post-intervention. Visual function questionnaires, such as the Activity Inventory questionnaire, have been adopted as an outcome measure for this second method. This comparison difficulty pre and post intervention provides a more objective means of evaluating the efficacy and utility of low vision assistive devices and mitigates the response bias inherent in the first method (Brown et al., 2014, Gobeille et al., 2018, Stelmack, Tang & Reda, 2008).

2Ai. The AI's Use of Rasch Analysis:

Rasch analysis, a psychometric technique, is commonly employed in the analysis of patient-reported outcome measures, including in the field of low vision rehabilitation (Massoff et al., 2013). It estimates person and item measures on an equal interval scale, by creating a new scale from the Likert scale responses. Item measures reflect the level of the underlying trait—such as visual ability—required to endorse the item, while person measures represent the level of that trait possessed by the respondent (Massoff et al., 2013). This property allows for direct comparison between item difficulty and person ability, even in the presence of missing data, which is an important feature for adaptive questionnaires where not every respondent answers every question (Massof et al., 2007).

A critical feature of Rasch analysis is its capacity to assess targeting—how well the item difficulty distribution aligns with the distribution of person ability in a given sample (Cantó-Cerdán et al., 2021). Targeting refers to the difference between the mean person ability and the mean item difficulty (Cantó-Cerdán et al., 2021). The smaller the difference between the two means, the better the targeting (Cantó-Cerdán et al., 2021). Well-targeted instruments have overlapping item and person distributions, which supports accurate and meaningful measurement (Gobeille et al., 2021), as well as ensures that items are neither too easy nor too difficult for sample (Figure 1). Poor targeting, by contrast, can result in ceiling or floor effects, where the abilities of respondents exceed or fall below the range of item difficulty, making it difficult to detect meaningful differences between individuals at the extremes (Martin et al., 2024) (Figure 2).

Figure 1: Example of a well targeted Wright map: The person measures are located on the left side (red bars) of the histogram and the item measures are on the right side (grey bars). There is a high degree of overlap between the person and item measures. Item measures were overall well targeted to person measures, due to the high degree of overlap between the person and item measures of this Wright map.

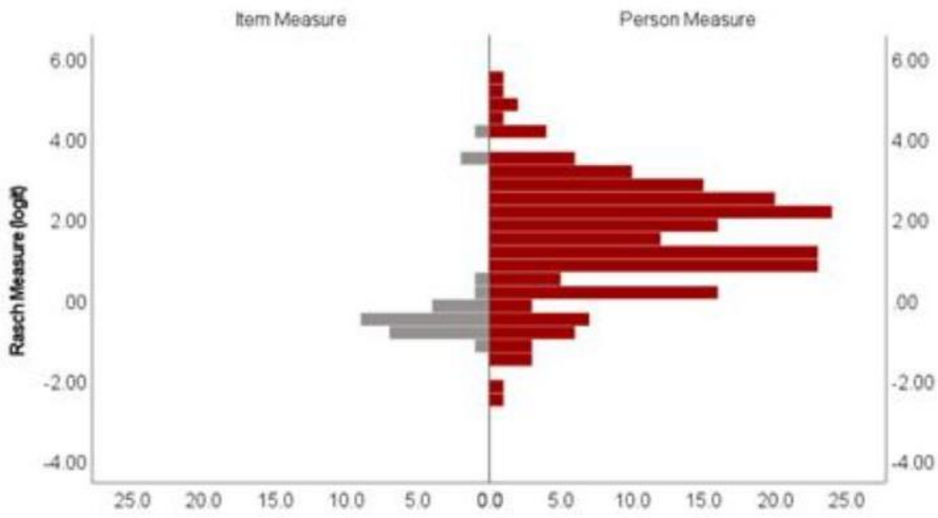

Figure 2: Example of poorly targeted Wright map: The person measures are located on the right side (red bars) of the histogram and the item measures are on the left side (grey bars). There is a low degree of overlap between the person and item measures. Item measures were poorly targeted overall to person measures, due to the low degree of overlap between the person and item measures of this Wright map.

The Activity Inventory (AI) is a well-established, Rasch-validated instrument designed to measure visual ability in individuals with low vision. Since the AI has been shown to be well-targeted in diverse clinical populations, it provides a valuable opportunity to explore potential self-selection bias in research studies. By comparing the person ability distribution of our study cohort to the known item difficulty structure of the AI, it can begin to be investigated whether participants who enrolled in the study differ meaningfully from the broader population for whom the AI was designed. If the participant sample demonstrates substantial deviation—such as clustering at the high or low ends of the ability scale—this may provide evidence of self-selection bias, wherein individuals with specific levels of visual ability are more likely to participate. Thus, Rasch analysis of AI targeting serves not only as a psychometric evaluation but also as a diagnostic tool for understanding sample representativeness.

2B. Methods For Study 1:

2Bi. The Activity Inventory (AI) Questionnaire Procedure:

The Activity Inventory (AI) was utilized at 0 (baseline), 3, 6, and 9 months. This visual function questionnaire asks participants to first rank the importance of a goal (from 0 to 3 with 0 being not important and 3 was very important). Then, participants are asked to rate the difficulty for each task under the goal (on a scale from 0 to 4 with 0 being not difficult and 4 being impossible to do without help). If a task is not an activity that a participant typically performs, N/A is recorded. Once all the responses for the tasks under the goal have been recorded, then the questionnaire administrator goes onto the next goal and once again begins with the importance question. The AI has four major functional categories including: reading, visual information, visual motor, and mobility (Massof et al., 2007). These four domains were identified by Massof and colleagues as representing the most frequent functional difficulties experienced by individuals with vision impairment (Massof et al., 2007). At each of the time points, patients were instructed to state for each task of the AI whether they use a low vision device or an app to accomplish the activity. Patterns of the usage of both low vision devices and the apps were examined at 6 and 9-months post-intervention for tasks within the AI questionnaire. After the AI was completed, participants were asked questions about their app usage, how they would rate the app, their location of app use, and if they would download the app once the study concluded onto their own mobile device or tablet.

2Bii. Rasch Analysis of the Activity Inventory (AI) Questionnaire:

Rasch analysis was applied to the Activity Inventory data using the Method of Successive Dichotomizations (MSD) using the R package ‘msd.’ (Bradley & Massof, 2018). MSD was selected, because it offers several benefits, such as accommodating the 5-point difficulty scale used in the Activity Inventory without assuming uniform distances between response categories. Per established protocols for Activity Inventory analysis, person measures were anchored to established calibrated item measure and rating category thresholds developed from Activity Inventory calibration in ~3700 low vision patients (Gobeille et al., 2021). Thus, the item measures and rating category thresholds were fixed to previously calibrated values from a large normative sample, rather than being re-estimated in the current sample. This allowed for the item measures and person measure distributions from this particular sample could be compared to previous work as a means for assessing possible sampling bias (Goldstein et al., 2012, Stelmack et al., 2008, Stelmack et al., 2017). Wright maps were produced to explore AI targeting within our sample. Good targeting in Rasch analysis occurs when the distribution of item measures closely aligns with the distribution of person measures. This alignment indicates that the questionnaire items are well matched to the abilities of the sample being assessed. Ideally, the mean item measure should be centered near the mean person measure, and the range of item difficulties should span the range of person abilities. When this occurs, the instrument can provide precise estimates of individual ability across the full spectrum of the latent trait—in this case, visual ability. Well-targeted questionnaires maximize measurement precision and minimize standard errors, especially for individuals near the middle of the item distribution. In contrast, poor targeting leads to higher measurement error, particularly for respondents whose ability levels lie far outside the item range. Therefore, similarity in the shape and central tendency of item and person measure distributions suggests that the instrument could be appropriate for the sample being studied.

2Biii. Comparison of Sample Characteristics to Previous Works:

To further assess possible sampling bias within the care study, demographic and clinical characteristics of our study sample was compared to previous works. The mean differences were calculated for this sample for the following categories: baseline visual acuity, age, reading, mobility, visual information processing, and visual motor. Student's t-tests of unequal variance, were used to compare differences in the means of continuous demographic variables (e.g, age, visual acuity), and baseline person measures to those reported in three large low vision outcome studies: (1) The Low Vision Rehabilitation Outcome Study (LVROS), (2) LOVIT I (Veterans Affairs Low Vision Intervention Trial I) and (3) LOVIT II (Veterans Affairs Low Vision Intervention Trial II) to determine if our sample is aligned with the general low vision population. (1) The LVROS was performed from 2008 to 2011 and investigated rehabilitation outcomes in low vision patients (n= 779 patients from 28 clinical centers). The Activity Inventory questionnaire was employed in this study as well as the Geriatric Depression Scale and Medical Outcomes Study 26-Item Short-Form Health Survey. LROS utilized Rasch analysis of the AI to determine person measures. (2) LOVIT I was a multicenter clinical trial from 2004 to 2006, which involved 126 patients from Veterans Affairs (VA) services. The demographics of the population in the LOVIT I study were predominantly white and male (98%). Dissimilar to our study, the LOVIT I study utilized the LV VFQ-48 questionnaire or the Veterans Affairs Low-Vision Visual Functioning Questionnaire. (3) The LOVIT II trial was conducted from 2010 to 2024 with 323 veterans with macular disease. Once again, the Veterans Affairs Low Vision Visual Functioning Questionnaire was employed, and the majority of the population was male (97.2%). Both LOVIT I and LOVIT II used Rasch analysis of the VFQ.

2C. Results:

2Ci. Comparison of the Baseline Traits of this Study Population to Overall Low Vision Population:

The LVROS study focused on the baseline traits of low vision patients (n=764 patients from 28 clinical centers). Their findings revealed 38.0% of the population were diagnosed with macular disease, a proportion comparable to our study where 40.6% of the population had macular disease (n=143). 10.0% of the population from LVROS had glaucoma, whereas our study observed a higher prevalence with 18.9% of participants affected. 8.0% of the patient population was diagnosed with diabetic retinopathy, compared to 2.8% in our study. In contrast, other low vision population studies known as LOVIT I (n=126 patients) and LOVIT II (n=323 patients) focused on veterans with macular disease and thus 100% of their study populations had macular diseases.

In terms of sex and race, the CARE study had 55% female participants and 74.1% white individuals. The LOVIT I study comprised 2.4% female subjects and 97.6% white participants, while the LOVIT II study reported similar demographics with 2.8% of the population female and 90.4% white individuals. LVROS had 66.0% female participants. 39% of the LVROS population lived alone, 61% resided with a spouse or other family members. These findings closely align with our low vision study population where 37.1% lived alone, 60.9% resided with a spouse or other family member, 1.4% with a non-family member, and 0.7% had an unknown living arrangement. Similarly, 24.6% of the LOVIT I population and 27.8% of the LOVIT II population lived alone, while 72.2% lived with a spouse or other family member. The LVROS found that 66% of their low vision population lived in a home, 13% in an apartment, 7% in a condominium, 2% in a townhouse, 7% in an independent living/retirement community, and less than 1% in a nursing home. These percentages are very similar to our study, where 79% of patients owned their home, 6% of patients lived in a family home, and 9% lived in a retirement community/senior housing. Thus, the population in this study is comparable to the low vision population in the LVROS investigation along characteristics, such as ocular diagnosis and living situation. Our study expectedly varies from the LOVIT populations, because a veterans hospital sample tends to reflect a more demographically homogenous group (primarily older, white males) due to the nature of the veteran population. However, other characteristics of the LOVIT samples are well aligned to our study population, such as ocular diagnosis and living arrangements.

		CARE study compared to:		
Characteristic	**Percent (n =143) CARE study**	**Percent (n=126) LOVIT I**	**Percent (n=323) LOVIT II**	**Percent (n=764) LVROS study**
Sex:				
Female	55.0%	2.4% (z=9.36) (p<0.00001)	2.8% (z=13.30) (p<0.00001)	66.0% (z=-2.52) (p=0.012)
Race:				
White	74.1%	97.6% (z=-5.41) (p=<0.00001)	90.4% (z=-4.62) (p<0.00001)	N/A
Diagnosis:				
Macular disease	40.6%	100% (z=-10.46) (p<0.00001)	100% (z=-15.32) (p<0.00001)	38.0% (z=0.59) (p=0.56)
Glaucoma	18.9%	N/A	N/A	10.0% (z=3.07) (p=0.02)
Diabetic Retinopathy	2.8%	N/A	N/A	8.0% (z=3.06) (p=0.002)
Living Situation:				
Alone	37.1%	24.6% (z=2.21) (p=0.03)	27.8% (z=2.01) (p=0.04)	39 (z=0.431) (p=0.67)
Spouse/ Companion /family	60.9%	72.2% (z=-1.96) (p=0.05)	63.5% (z=-0.54) (p=0.59)	61% (z=0.023) (p=0.98)
Housing Situation:				
Home	79%	N/A	N/A	66% (z=-3.39) (p=0.0007)
Retirement/ Senior Housing	7%	N/A	N/A	9% (z=0.843) (p=0.40)

Table 1: Demographic Baseline Traits of CARE Study Versus Other Low Vision Population Studies: Comparison of baseline traits, including sex, race, ocular diagnosis, living arrangements, and housing arrangements of the CARE study versus the LOVIT I, LOVIT II, and LVROS study. N/A= not available, not reported by study.

		CARE study compared to:		
Category	CARE study mean	LOVIT I mean	LOVIT II mean	LVROS mean
Age (years)	72.38	78.80 (t=-4.87) (p<0.01)	80.10 (t=-6.33) (p<0.01)	73.90 (t=-1.38) (p=0.17)
Visual Acuity (logMAR)	0.73	1.10 (t=-7.76) (p<0.01)	0.60 (t=4.72) (p<0.01)	0.69 (t=0.95) (p=0.34)
Reading (logits)	1.18	0.51 (t=4.51) (p<0.01)	0.89 (t=3.67) (p<0.01)	0.82 (t=2.32) (p<0.01)
Mobility (logits)	1.38	0.52 (t=4.49) (p<0.01)	0.71 (t=3.77) (p<0.01)	0.61 (t=4.89) (p<0.01)
Visual Information Processing (logits)	0.82	0.45 (t=2.01) (p=0.05)	0.62 (t=1.14) (p=0.25)	0.79 (t=0.28) (p=0.78)
Visual Motor (logits)	1.90	0.23 (t=8.46) (p<0.01)	0.73 (t=6.25) (p<0.01)	0.84 (t=6.57) (p<0.01)

Table 2: CARE study versus other low vision population studies: Comparison of mean age (in years), visual acuity (in logMAR), reading ability (in logits), mobility ability (in logits), visual information processing ability (in logits), and visual motor ability (in logits) of the CARE study versus the LOVIT I, LOVIT II, and LVROS study.

For the reading functional domain, there was a statistically significant difference between the CARE study and the three studies above (LVROS: $t(212)= 2.32$, $p<0.01$, LOVIT I: $t(157)=4.51$, $p<0.01$, and LOVIT II: $t(291)$: 3.67, $p<0.01$). The CARE study had a higher person measure (in logits) in the reading domain compared to the other three studies, indicating greater visual ability in this domain and less difficulty with reading-related tasks (better functional ability in this area). Similarly for the visual ability of mobility, there were also statistically significant differences between our study and the three studies (LVROS: $t(226)= 4.89$, $p<0.01$, LOVIT I: $t(157)= 4.49$, $p<0.01$, LOVIT II: $t(291)=3.77$, $p<0.01$). Again, the CARE study had higher person measures (in logits) in the mobility domain compared to the other three studies, signifying higher visual ability of participants in this domain and less difficulty with mobility-related tasks. Furthermore, for visual motor processing, there were statistically significant differences between the CARE study and the three other studies (LVROS: $t(203)=6.57$, $p<0.01$, LOVIT I: $t(160)=8.46$, $p<0.01$, LOVIT II: $t(286)=6.25$ $p<0.01$). Once again, the CARE study had higher person measures (in logits) in the visual motor domain versus the other three studies, demonstrating greater visual ability of the participants to perform visual motor processing tasks and better functional ability in this area. Conversely for visual information processing, there was not a statistically significant difference between the CARE study and the three studies listed above (LVROS: $t(546)=0.28$, $p=0.78$, LOVIT I: $t(165)=2.01$, $p=0.05$, LOVIT II: $t(306)= 1.14$, $p=0.25$). Hence, the participants of the CARE study showed similar functional ability in the visual information processing domain, based on self-reported difficulty and there was no meaningful difference in this domain between the CARE study and the other three populations. For the demographic variable of age, there was a statistically significant difference between the CARE study and LOVIT I and II trials (LOVIT I: $t(138)=-4.87$, $p<0.01$, LOVIT II: $t(301)= -6.33$, $p<0.01$), with the LOVIT I and II trials having greater average mean age than the

CARE study. When the LVROS study was compared to the CARE study of this paper, there was not a statistically significant difference in the demographic variable of age ($t(276)$: -1.38, $p=0.17$) or visual acuity ($t(905)$: 0.95, $p=0.34$). There were statistically significant differences between the CARE study and LOVIT I and II trials in terms of visual acuity (LOVIT I: $t(267)=-7.76$, $p<0.01$, LOVIT II: $t(464)=4.72$, $p<0.01$), with the CARE study participants having a better average mean visual acuity compared to the LOVIT I trial, but a worse visual acuity compared to the LOVIT II trial. Both the CARE study and LVROS examined the prevalence of depression among low vision patients. LVROS found that 24% of its sample (180 patients) were found to experience depression, whereas in the CARE study 12% of participants were classified as experiencing depression. However, for these comparisons it should be noted that the CARE study used the Beck Depression Inventory, while LVROS employed the Geriatric Depression Scale questionnaire. This methodological difference limits the ability to directly compare the prevalence estimates between the two studies. Thus, these initial comparisons suggest that there are some notable differences in the CARE study sample compared to the low vision populations in studies previously conducted in the field, in relation to reading, mobility, and visual motor functional abilities. Similarities emerged when examining the visual information processing abilities of the CARE study population compared to the LOVIT 1, LOVIT II, and LVROS study.

2Cii. Comparison of the Baseline Traits of this Study Population to Previous Low Vision Visual Assistive Smartphone App Studies:

Next, the baseline traits of the CARE study population were compared to previous low vision visual assistive smartphone app studies.

		CARE study compared to:		
Characteristic	**Percent (n =143) CARE study**	**Percent (n=259) Griffin et al., 2017**	**Percent (n=15) Christy & Pillai, 2021**	**Percent (n=166) Abraham et al., 2022**
Sex:				
Female	55.0%	56.0% (z=-0.19) (p=0.85)	N/A	40.4% (z=2.56) (p=0.01)
Race:				
White	74.1%	76.1% (z=-0.45) (p=0.65)	N/A	N/A
Age:	Mean Years:	Mean Years:	Mean Years:	Mean Years:
	72.38	44.51	22.00	Not reported Majority <34 years (45.2%)

Table 3: CARE study versus other low vision smartphone app studies
Comparison of sex, race, and mean age (in years) of the CARE study versus three other visual assistive smartphone technology studies. Boxes which show significant results are highlighted in yellow. Information on standard deviation of age was not provided for studies, thus 2 sample t test was unable to be performed. However, it can be observed that the mean age is notably younger for the other smartphone studies compared to the CARE study.

In comparing the baseline traits of the CARE study versus other visual assistive smartphone studies, it was found that the mean ages for the other smartphone studies is notably younger. There were similar percentages of female and white participants in the CARE study compared to the study by Griffin et al. in 2017. There was a significant difference in the percentage of female participants in the CARE study versus the Abraham et al. study conducted in 2022. Other demographic variables of interest, such as living situation, housing situation, and ocular diagnosis were not reported in these smartphone studies in Table 3 above, thus these rows were not included in this table.

2Ciii. Assessment of Targeting of Activity Inventory Responses in the CARE study:

In exploring how our sample of low vision older adults compares to the general population of low vision patients, we analyzed responses on the Activity Inventory (AI) questionnaire using Rasch analysis. All the item and person measures were reported in logits. The following Wright map of person and item measures shows adequate targeting of item difficulty to participant ability. The person measures range from -1.63 to 5.63 logits (Figure 3). Calibrated published item measures were used (Gobeille et al., 2021). These calibrated item measures were baseline AI (510 items) rating scale data from five low vision rehabilitation outcome studies (n=3623). The established calibrated item measures range from -4.03 to 5.21 logits (Figure 3). As displayed in Figure 3, the item measures appear to be overall well targeted to the person measures, due to the high degree of overlap between the person and item measures.

Although the Wright map indicates good overall overlap between the distributions of person measures and item measures, a closer inspection reveals several bins of person measures within the range of 5.63 to 4.54 logits that reflect a higher level of ability than is captured by the available item difficulties. This pattern suggests potential ceiling effects or a lack of sufficiently challenging items to differentiate among higher-ability individuals. To statistically evaluate whether the distribution of person and item measures differ, a Kolmogorov- Smirnov (KS) test was conducted. The results indicate a significant difference between the two distributions ($D = 0.29272$, $p < .001$, two-sided test), confirming that the item pool does not fully match the ability range of the sampled population.

Infit and outfit statistics were then investigated to determine to what degree that participant responses on the Activity Inventory (AI) fit with expectations under the Rasch model. In general, the infit statistic is sensitive to unexpected response patterns on items that are closely matched to an individual's ability level, whereas the outfit statistic is more sensitive to outlier responses on items that are substantially easier or more difficult than the participant's estimated ability. For both the infit and outfit statistics, an expected value of 1.0 indicates a perfect fit to the model. Values greater than 1.0 suggest an underfit, which reflects unmodeled noise or unpredictable responses, while values than 1.0 suggest overly predictable responses. The average infit value was 1.17 (SD: 0.41). This value of greater than 1.0 indicates that the model underfits or that there is unmodeled noise, indicating 17% more variation (noise) than predicted by the model. The average outfit measure was 1.51 (SD: 1.49), indicating an underfit to the Rasch model or that the data are less predictable than the model expects overall.

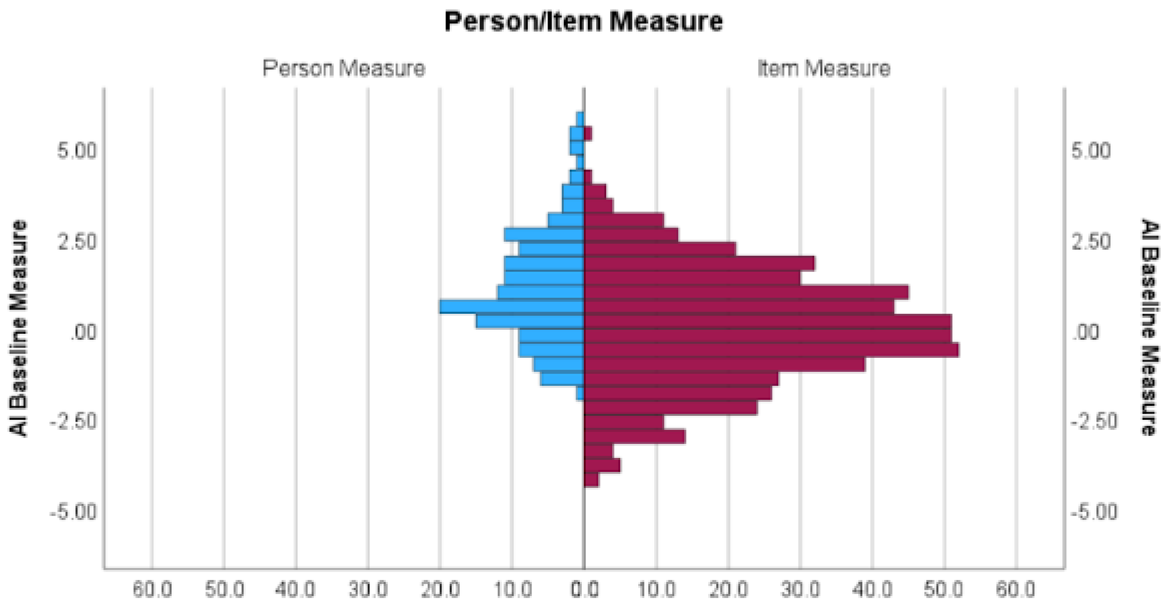

Figure 3: Wright map of person and item measures: The degree of overlap between the person (blue bars) and item measures (red bars) distributions demonstrates adequate targeting of item difficulty to participant ability, which supports the validity of the AI for this sample. The graph is on a logit scale. The x-axis represents frequency counts (or how many persons or items are at each ability/difficulty level). Calibrated item measures were sourced from baseline Activity Inventory (AI) rating scale data comprising 510 items from 5 low vision rehabilitation outcome studies (n=3,623, Gobeille et al., 2021).

2D. Conclusions:

Overall, the population of this study demonstrates similarities and differences in demographic and clinical variables in our study sample, to the general low vision population. While there were consistent trends in diagnoses, living arrangements, and housing types, notable differences emerged in certain visual ability domains, such as reading, mobility, and visual motor function, which highlights the need for tailored low vision rehabilitation approaches. The CARE study participants showed higher baseline person measures for the reading, mobility, and visual motor domains. This could be attributed to the fact that most of the participants in the CARE study were established low vision patients who had already received and been consistently using low vision aids. Whereas these other studies only recruited new low vision patients and measured outcomes of low vision rehabilitation clinical programs. To further investigate the comparability of our sample, targeting of the AI was examined to determine how well item difficulties align with subject's abilities. Good targeting suggests that the questionnaire is well-matched to the population and that the sample is representative of the broader low vision community. The appearance of the Wright map suggested overall good alignment between task difficulty and participant ability, but there were several bins of person measures where there were higher level of ability than captured by the available item difficulties. A KS test was conducted and confirmed that the item pool does not fully match the ability range of the sampled population. However, despite demographic and functional differences, our sample showed overall some alignment with the population the AI was designed for and calibrated to or the overall low vision population. Therefore, the AI questionnaire remains a valid questionnaire for assessing functional vision for the CARE study population. To further assess self-selection bias, the demographics of the CARE study sample could be compared to other samples through retrospective review. Another possible avenue to further explore self-selection bias would be to examine the demographic characteristics of those patients who enrolled in the CARE study compared to those who declined or dropped out. A last way to further investigate self-selection bias would be to analyze the participation patterns of patients in the CARE study.

In all, although there are some differences in baseline person measures on the whole the targeting investigated did not suggest evidence of self-selection bias. Even though our sample was recruited from two low vision clinics and had some demographic differences, as well as higher abilities among certain functional domains, the similarity of response distributions and appropriate targeting of the AI supports the use of the AI.

CHAPTER 3: Study 2: Usage and Ratings of Visual Assistive Apps by Low Vision Patients:

3A. Introduction to Usage and Rating Trends of Visual Assistive Apps by Low Vision Patients:

Smartphone apps, such as Seeing AI, Be My Eyes, and Aira hold significant potential to assist low vision patients in performing activities in their daily lives ranging from reading to navigation. Previous studies have explored the frequency at which low vision patients utilize low vision applications in their daily lives and for what tasks these apps are most commonly used.

One such study employed an anonymous online survey via SurveyMonkey to assess general mobile app usage among legally blind individuals (n=259, individuals with central visual acuity of 20/200 or less in the better eye with glasses or central VA of more than 20/200 with a visual field defect in the peripheral field so the widest diameter of the visual field subtends an angular distance of 20 degrees or less in the better eye) (Griffin et al., 2017). Since participants were recruited for the study through electronic communication, the sample was self-selected and may not be representative of the broader low vision population. Additionally, compared to the general population of low vision patients, the average age of the sample in the study was younger at 44.51 years, predominantly Caucasian (76.1%), urban-dwelling or cluster area (91.1%), and college attendees (86.5%) (Griffin et al., 2017). About 80% of the participants in the study utilized an iOS device (Griffin et al., 2017). The majority of visually impaired participants (90.3%) employed both free and paid apps and downloaded three to five apps of both types combined per month (61.4%) (Griffin et al., 2017). Among the visually impaired sample, the most commonly utilized standard apps (not visual assistive apps designed specifically for low vision patients) were for email (24.5%), visual assistive apps (12.5%, screen readers and identification tool apps), and entertainment (10.5%, sports or radio) (Griffin et al., 2017). Hence, most low vision patients (at least those of a younger age) are utilizing smartphone applications in their daily lives.

A more recent study, investigated smartphone usage among vision rehabilitation patients (n=26) (Maeng et al., 2020). The researchers developed and administered (either in person or over the telephone depending on patient preferences) a twenty-item technology use non-validated survey on the computer. This study was a convenience sample recruited from the Chicago Lighthouse Vision Rehabilitation Center, which is a facility with a strong emphasis on technology training. The average age of the participants was younger than the low vision patient population and was 49.8 years old (Maeng et al., 2020). The questions on the survey pertained to various topics, such as previous technology usage, low vision device utilization, and methods of geographical navigation. The majority of the participants employed an iPhone (74%) and used a smartphone to navigate public transportation and ride share services (88%) (Maeng et al., 2020). Furthermore, most patients in the study (93%) responded that their low vision care providers never mentioned a smartphone or the device's accessibility features to them, which points to a potential area of improvement needed in the delivery of low vision care and patient education in the future (Maeng et al., 2020).

Recently, a cross-sectional study was performed to determine the current trends in smartphone application usage among low vision and blind patients (n=166) (Abraham et al., 2022). The sample was recruited from two tertiary institutions and four different eye care and low vision care facilities. The mean age of the participants in the study was 26 years old and approximately half of the participants were college students (Abraham et al., 2022). A non-validated questionnaire was administered to participants either verbally or on paper, dependent on the visual acuity of each patient. The questionnaire was developed by the researchers and was available in English and Fante languages. The first section of the questionnaire had eight items, which included demographic items on age, gender, education level and visual acuity (Abraham et al.,2022). There was a second section of the questionnaire that included fourteen items and the items focused on ownership of a mobile or smartphone (Abraham et al., 2022). The final section of the questionnaire involved one item about the functionality demands participants deemed the ideal smartphone should have for low vision patients (Abraham et al., 2022). Most participants (53%) did not own a smartphone or utilized a basic landline phone exclusively (Abraham et al., 2022). Among the low vision participants who did employ a smartphone, the vast majority used the phone for social media (96%) and web browsing (92%) (Abraham et al., 2022). The most frequently employed feature on the smartphone by the low vision participants was the color description feature (44%) (Abraham et al., 2022). Overall, this study suggests many low vision patients may not have access to a smartphone and those patients who do have a smartphone mainly search the internet and social media.

3Ai. Visual Assistive Application Usage Among Older Adults with Low Vision:

Our lab solicited feedback from older adults with low vision for their first time use of three low vision assistive apps (Aira, Supervision+, and Seeing AI) in virtual focus group sessions (Ross et al., 2021). The participants (n=14, median age 66 years) received a brief training on all three apps' features and then they were allowed to test the apps for about 5 minutes (Ross et al., 2021). During this study, a greater number of the participants stated that they would utilize Aira or SuperVision+ outside the home (57% for Aira and 50% for Supervision+) compared to inside the home (28% for Aira and 21% for Supervision+) (Ross et al., 2021). This suggests that older adults would employ low vision applications more often outside the home (Ross et al., 2021).

In 2021, at the beginning of the CARE trial our group investigated why the majority of older low vision patients recruited from NECO and UCLA clinics were reportedly not utilizing visual assistive apps despite their wide availability (Malkin et al., 2022). The mean age of this specific sample was 73 years old (n=50), which is an older population than the previous studies in the field (Malkin et al., 2022). The majority of participants did not report concerns about learning how to utilize the applications or embarrassment as the reason for their non-use of the applications before the study (Malkin et al., 2022). Instead, the major reason for the lack of utilization of some of the applications was a lack of awareness of visual assistive applications (63% of participants were unaware of the three visual assistive applications in the study: Aira, Supervision+, and Seeing AI) among the first 50 participants in the study (Malkin et al., 2022). This finding of lack of awareness of low vision applications among low vision patients is aligned with the results from a previous study where the majority (93%) of the patients in the study stated that their low vision care providers never mentioned a smartphone or the device's accessibility features to them (Maeng et al., 2020). A lack of awareness of visual assistive smartphone apps continues to be cited by low vision patients as a they do not utilize smartphone apps.

3Aii. Ratings of Visual Assistive Apps By Low Vision Adults:

It is not only important to consider for which tasks low vision apps are utilized and the duration of app usage, but it is also essential to examine how low vision patients rate their satisfaction with the low vision applications. However, many studies to date have been limited by sampling bias (e.g., convenience samples of younger low vision patients, which may not be representative of the low vision patient population) and reporting bias (e.g., the results of the study are skewed because of the reporting method, such as when researchers report only certain data).

In 2017, one study reported visually impaired participants' perceptions and ratings of apps. The majority of mobile applications were rated as user friendly (83.1%) and accessible (80.7%) (Griffin et al., 2017). Both age and income were found to have no significant difference on these ratings. Low vision patients rated the apps as less accessible and user friendly compared to participants with blindness (Griffin et al., 2017). When asked about special apps designed for individuals with visual impairment, the majority of participants rated these apps as useful (95.4%) and accessible (91.1%) for individuals with visual impairments (Griffin et al., 2017). Low vision patients also rated these visual assistive apps as less accessible and user friendly compared to participants with blindness. The middle-aged participants found the special apps designed for individuals with visual impairment to be more practical compared to the younger or older adults in the study with visual impairment (Griffin et al., 2017). Therefore, the majority of these middle-age study participants rated the smartphone apps as accessible and user friendly, while less favorable perceptions were observed in patients of a younger or older age or patients with low vision.

In an app exploration workshop where participants (n=15) were asked to rate the different apps on a Likert scale from 1 to 5, where 1 is the least satisfaction with the application and 5 is very high satisfaction with the application (Christy & Pillai, 2021). The mean age of the patients in this study was 22 years old, which is significantly lower than the average age of low vision patients (Christy & Pillai, 2021). The population in this study also can be considered a self-selecting sample, because invitations to participate in the workshop were only sent to mobile users.

Due to their age and their mobile user status, the sample is not representative of the overall low vision population (Christy & Pillai, 2021). A total of 57 smartphone apps were utilized that were placed into 12 categories (Christy & Pillai, 2021). Smartphone apps in the Braille category were rated the lowest (1.2 to 2.7) and the reading category apps were rated the highest (4-5) (Christy & Pillai, 2021). Hence, despite the small and limited sample, this study offers preliminary data on mobile technology use among visually impaired individuals. In the future there is a need for visually impaired individuals to test and offer feedback on smartphone apps. Although this study identified ratings from young patients; it is important to examine ratings among the older population as well, which comprises the majority of patients living with low vision. Further research is needed to determine if smartphone apps can improve the quality of life of low vision patients and allow them to lead more independent lives.

It has been found that low vision patients highly rate smartphone apps (n=27, mean age 54 years, range of ages 29-70 years) (Dockery & Krzystolik, 2013). It is important to note that this study further supports that the majority of studies thus far have explored low vision applications in younger populations and the applications have not been as extensively studied in older adults with low vision. The population in this study may not be representative of the target population of low vision patients. To participate in the study, patients had to be over the age of 18, have a Snellen VA of less than 20/70, and have utilized low vision assistive applications for at least a month (Dockery & Krzystolik, 2013). The mean age of the participants was 54 years (n=11).[23] The two apps the participants most often utilized were Seeing AI (81.8%) and Be My Eyes (63.6%) (Both apps are free) (Dockery & Krzystolik, 2013). The average patient ratings of these two applications were 4.43 for Seeing AI and 4.75 for Be My Eyes out of 5, with 5 being excellent (Dockery & Krzystolik, 2013). The most common uses of these apps were reported to be for navigation, reading documents, and person-to-person interaction. In all, this study reported that there were high ratings by low vision patients for both the Seeing AI and Be My Eyes smartphone applications.

Although previous studies have been conducted on the ratings of visual assistive apps by adults with low vision, these studies have primarily been small, convenience samples, which thus limits the generalizability to the overall low vision population and have increased susceptibility to selection bias. The majority of the past studies performed on smartphone applications are with younger low vision patients, whereas most individuals with low vision are older. Overall, this study aims to perform a rigorous and structured investigation to address the gaps in the literature surrounding the perceptions of older low vision patients to low vision smartphone applications. By combining validated outcome measures with detailed, longitudinal assessments of assistive technology use, this study aims to produce findings that are both clinically meaningful and able to be generalized to the broader low vision population.

3B. Methods For Study 2:

The research participants were asked a usage and rating survey at 3 and 6 months of their perceptions regarding the app they were randomized to. If the patients elected to participate in the study until 9 months and were trained on all 3 applications, the research participants were asked a survey at 9 months about their perceptions of all three apps. The specific questions regarding usage that we explored are listed below.

1. 3- and 6-month usage questionnaire:
    a. On average how frequently or often have you used the Study app? (answers are on a scale from daily to I have not used it in the past month and I do not think I will use it again)
        i Possible answer choices:
            1. Daily
            2. A few times per week
            3. A few times per month
            4. I have not used it in the past month, but would plan to use it occasionally in the future
            5. I have not used it in the past month and I do not think I will use it again.
    b. How would you rate the study app? (answers are on a scale of 1 to 5, 1 being excellent and 5 being poor)
            1. Excellent
            2. Very Good

3. Good

4. Fair

5. Poor

c. Did you use the study app for tasks…..

1. Only within the home

2. Only outside the home

3. Almost equal within the home and outside the home

4. Primarily within the home

5. Primarily outside of the home

6. N/A never used the app

2. <u>9-month usage questionnaire:</u>

a. The same frequency ratings scale was used for each frequency question below for the 9-month as 6-month survey with choices of: daily, a few times per week, a few times per month, I have not used it in the past month, but would plan to use it occasionally in the future, and I have not used it in the past month and I do not think I will use it again.

b. The same rating scale was used for each rating question below for the 9-month as 6-month survey with choices of: excellent, very good, good fair, or poor.

c. On average how frequently or often have you used the Aira app?

d. How would you rate the Aira app?

e. Did you use Aira for tasks only within the home, only outside the home, almost equally within the home and outside of the home, primarily within the home, primarily outside of the home, or you have never used the app?

f. On average how frequently or often have you used the Supervision+ app?
g. How would you rate the Supervision+ app?
h. Did you use Supervision+ for tasks only within the home, only outside the home, almost equally within the home and outside of the home, primarily within the home, primarily outside of the home, or you have never used the app?
i. On average how frequently or often have you used the Seeing AI app?
j. How would you rate the Seeing AI app?
k. Did you use Seeing AI for tasks only within the home, only outside the home, almost equally within the home and outside of the home, primarily within the home, primarily outside of the home, or you have never used the app?

Descriptive statistics were used to summarize baseline demographic continuous variables (e.g. age, and visual acuity) and categorical variables (e.g. sex, race/ethnicity, education level). Associations of the proportions of participant ratings of each of the apps on the 9-month app questionnaire across categorical demographic variables were compared using the Pearson Chi-square and Cramer's V statistic, to control for nominal variables with multiple levels. Data were analyzed using SPSS version 29 (IBM, WA, USA). The sample size at 9-months is notably smaller than the 6-month sample, because after 6-months subjects could elect to continue for another 3 months with access to all three study apps. The 9-month data was analyzed for this part of the study, because each subject had access to all three applications, which allowed for comparison of usage and rating trends between the three applications of this study.

Categorical demographic variables explored included: gender, visual impairment category (mild visual impairment, moderate to severe visual impairment and severe visual field loss), study app randomization assignment, education (dichotomized as whether the individual is a college graduate), race (dichotomized as white and non-white), previous smartphone app usage, and app proficiency score following training (App proficiency was measured with a series of standard questions where participants demonstrated if they could turn on the phone, launch the app, and find specific features on each app). Usage patterns of the apps were examined across the above categorical variables.

The Activity Inventory (AI) questionnaire was also used to guide the assessment of usage patterns of the three visual assistive smartphone apps compared to traditional low vision devices (LVDs). During each administration of the Activity Inventory (AI) (baseline, 3, 6, and 9 months), for each item or tasks participants were asked if they used a device (LVD or study app) to assist with that item. The benefit to this method is by using the AI (a validated questionnaire, calibrated to the low vision population), this allows the assessment of technology usage across a wide variety of daily activities and limits interviewer bias. Usage patterns of LVDs and apps for each item of the AI were examined at 6- and 9-month post-intervention.

Subjects could respond that they either used a LVD, smartphone app, or either an app or LVD for each task of the AI. The number of items where LVDs, apps, and either were used for each subject was averaged in relation to the total number of tasks per domain. These values were then aggregated across subjects to calculate the overall average usage per domain of each assistive technology (LVD, app, and either). Tasks that were rated as not important by participants were filtered out of the data, in order to capture tasks low vision patients, find meaningful in their daily routines.

3C. Results:

3Ci. 9-month sample demographics:

Characteristic	Percent (n =70)
Female	56%
College Graduate	70%
Home Ownership	80%
Moderate Visual Impairment (VA worse than 20/70)	63%
Previous Smartphone App Usage	82%

Table 4: Demographic Characteristics of the 9 Month Sample: The majority of the 9-month sample was female, college graduates, owned their own home, had moderate visual impairment, and had used a smartphone in the past (n=70 participants).

In exploring the demographic characteristics of participants who completed the 9- month study questionnaire, it was found 56% were female, 70% college graduates, 80% own their home, and 82% of the participants had previous experience with using smartphone apps (Table 4). The majority of participants, 63%, had mild to moderate visual impairment (mean 0.66 logMAR, SD 0.34), moderate contrast sensitivity loss (mean 0.93 logCS, SD 0.46), and a normal TICS score (mean 37, SD 4.3, Table 5). In addition, most participants had a logMAR VA of 0.3 to 0.99 (Figure 4). The most common ocular diagnosis of patients in the 9-month sample was macular disease (41%). Glaucoma was another frequent diagnosis among patients (19%) in this sample (Figure 5).

Characteristic	Mean	Maximum	Minimum	Standard Deviation
Age (n=70)	71	91	55	9.5
TICS Score (n=70)	37	49	23	4.3
VA OU LogMAR (n=68)	0.66	2	0	0.34
Contrast Sensitivity Spot (n=68)	0.93	2	0	0.46

Table 5: Descriptive Statistics of the 9 Month Sample: The average age of the sample was 71 years old with an average visual acuity of 0.66 logMAR and 0.93 contrast sensitivity level (moderate impairment).

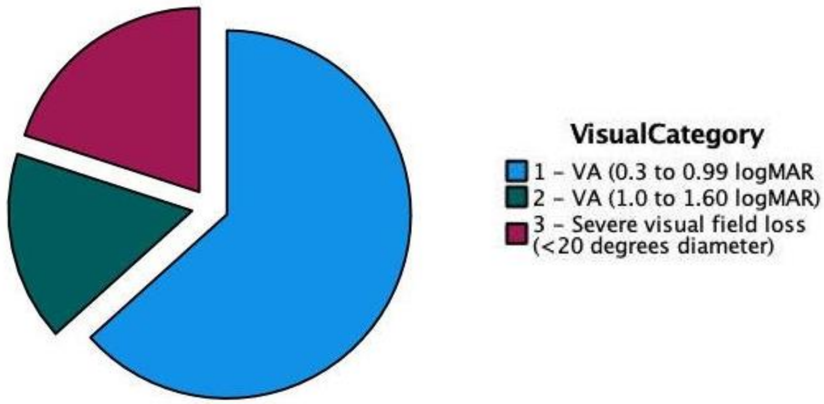

Figure 4: Pie graph of the visual category of the subjects: The majority of participants had logMAR visual acuity levels of 0.3 (~20/40 Snellen) to 0.99 (~20/200 Snellen).

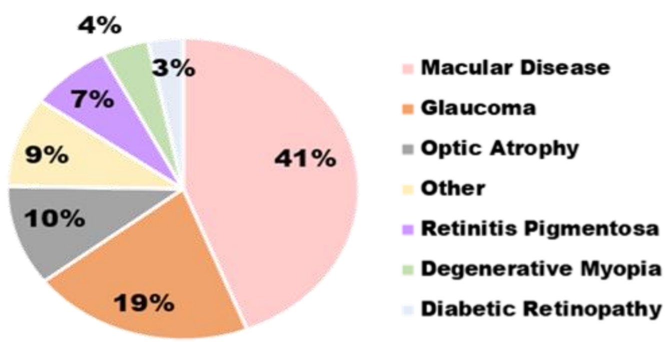

Figure 5: Pie graph of the participants' ocular diagnosis: Macular disease was the most common ocular diagnosis of low vision patients of this study (41%), with glaucoma as the second most common ocular diagnosis (19%).

<u>3D. Overall App Ratings Trends:</u>

The overall app rating trends for the 3 applications at 9 months were examined.

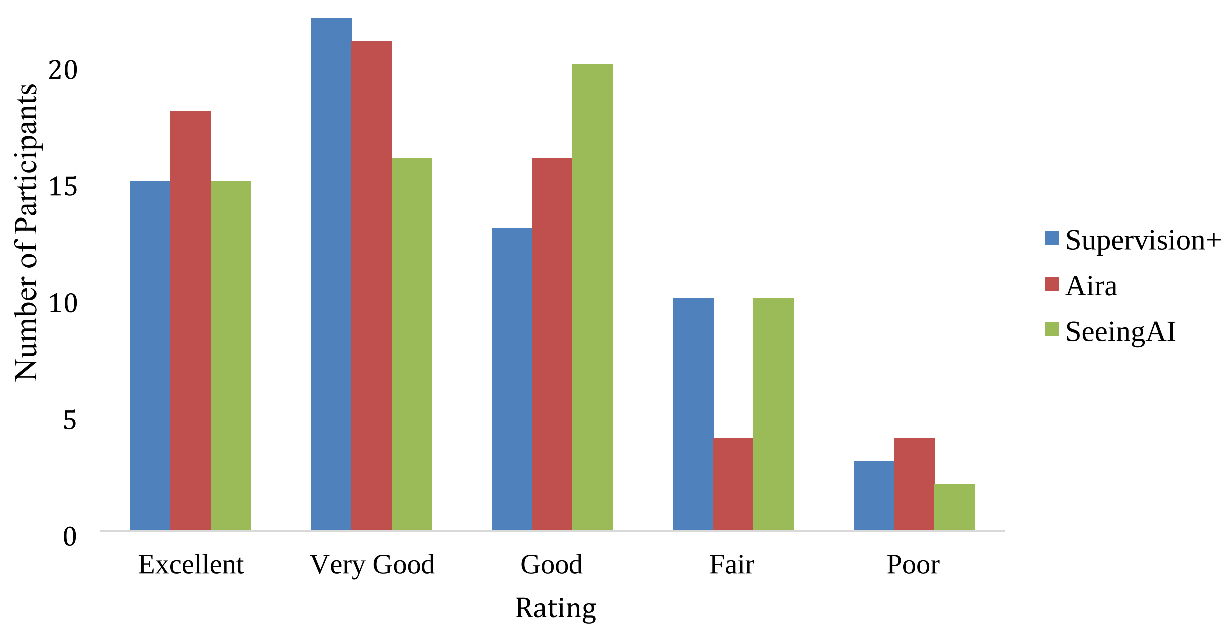

Figure 6: Ratings of the 3 study by participants at 9 months: Most participants rated the three study apps (Supervision+, Aira, and Seeing AI) as good, very good, or excellent.

Figure 6 displays how the majority of participants rated the low vision assistive applications favorably, with few responses of fair or poor ratings. There was no significant difference in the ratings between study apps. The average app rating for was 2.27 for Aira, 2.41 for Seeing AI, and 2.38 for Supervision+. Thus, all three apps had similar average ratings by participants. Ratings were also examined across different visual acuity groups and ocular diagnoses and there were no difference in preferences between groups.

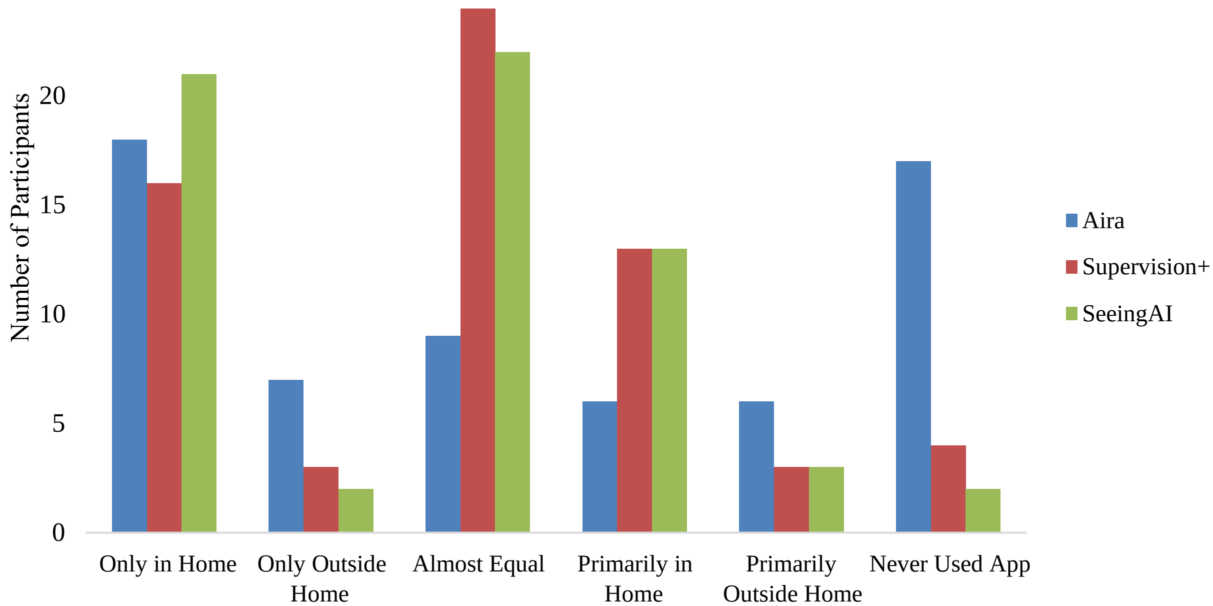

Figure 7: Location of app usage of the 3 apps at 9 months: The above graph depicts the number of participants who reported they used each app (Aira, Supervision+, and Seeing AI) only in the home, only outside the home, almost equal inside and outside the home, primarily in the home, primarily outside the home, and never used the app at 9 months. There was variability in the distribution of usage locations for each app, with Aira having the highest usage inside the home.

The most common location the participants utilized the Aira app was only in the home (29%, n=18) (Figure 7). For the Supervision+ app, the most common locations the participants employed the app were almost equal inside and outside the home (38%, n=24) (Figure 7). Among Seeing AI users, the most common locations participants used the app was equal inside and outside the home (35%, n=22) and only within the home (33%, n=21). When examining all three apps, there were equal number of participants who utilized the apps only within the home and equal inside and outside the home (29%, n=55) (Figure 7).

3E. Overall Usage Trends of the 3 Smartphone Applications:

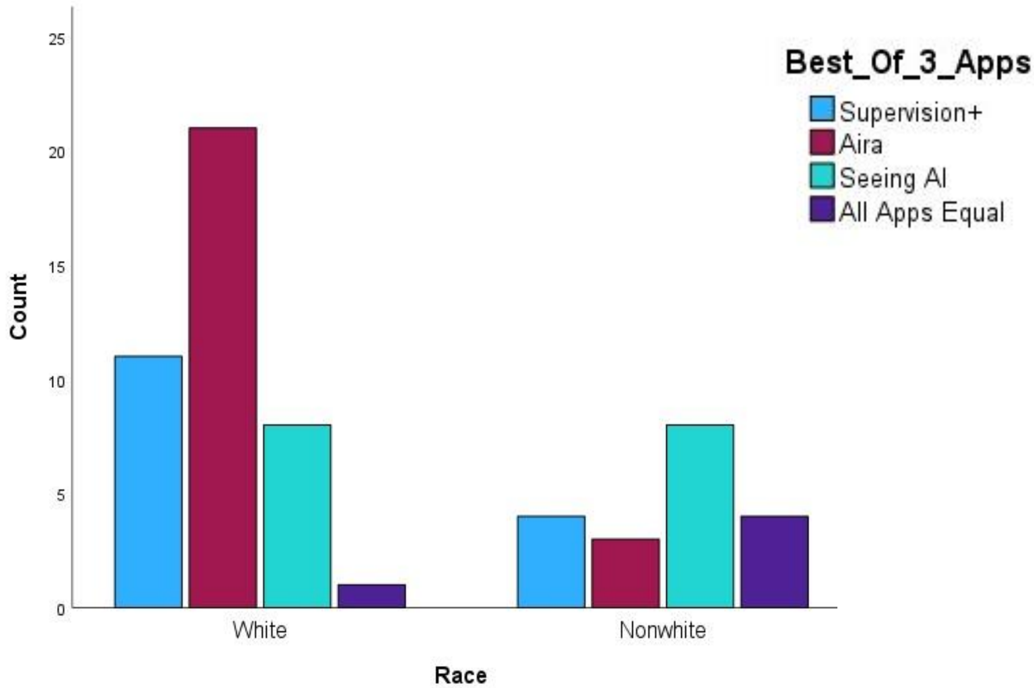

Figure 8: Best of 3 apps according to race: The graph displays participants' responses to the question, "which is the best of the 3 smartphone apps?", according to race. Blue-colored bars indicated those who preferred Supervision+, the maroon-colored bars represent those who preferred Aira, the turquoise-colored bars are those who preferred Seeing AI, and the purple-colored bars indicate those who stated they liked all the smartphone apps equally. White participants showed a preference for the Aira app.

Racial Category	CARE Study (n=143)	NHIS Survey (n=87,500)
White	74%	73%
Black/African American	16%	12%
Asian	3%	4%
More than 1 Race	3%	2%
Other	3%	Not reported

Table 6: Racial Demographics of CARE Study Versus NHIS (National Health Interview Survey) Data: This table depicts the racial background of CARE study participants compared to NHIS.

In exploring how participants responded to the question of which was the best of the 3 smartphone apps, we found that those of white race seemed to indicate preferences for a specific app, most often Aira, while those of a non-white race were more likely to rate all apps equally. There was a significant difference in the proportion of ratings between racial groups, X^2 (3, N=70)=12.13, p=0.007. There were no significant differences in participant responses for the other demographic variables (all $p<0.05$). According to Table 6, there were similarities in the racial demographics of the CARE study compared to the National Health Interview Survey (n=87,500), which is a national health survey conducted by the U.S. Census Bureau. For the CARE study, 74% of the population was white, while for NHIS 73% of the population was white. Similarly, for the CARE study 16% of the population was Black or African American, while the percentage for NHIS was 12%. In addition, 3% of the CARE study population was Asian, while 4% of the NHIS study population who reported vision loss was Asian.

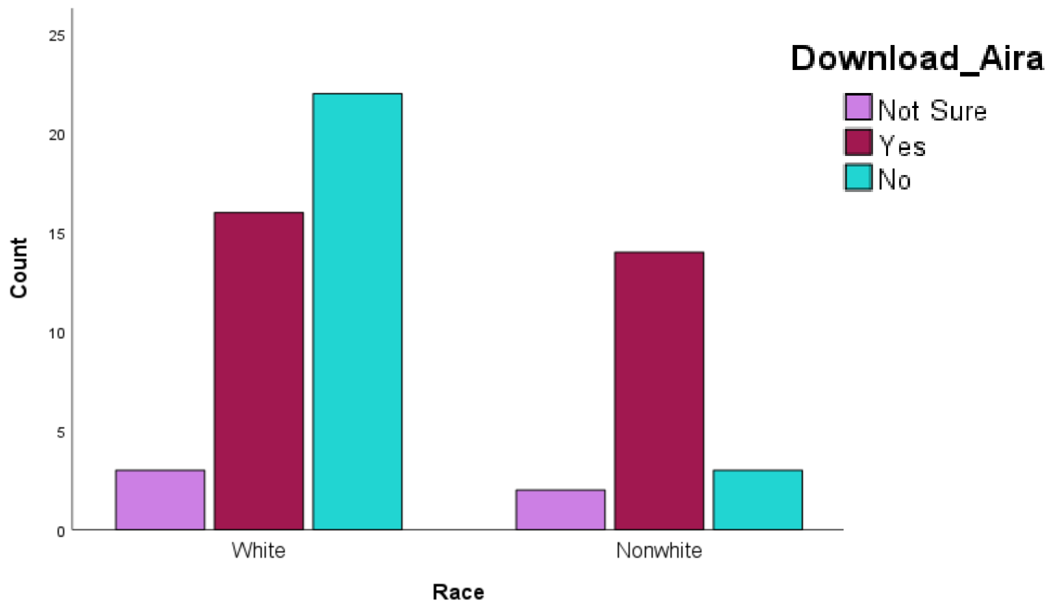

Figure 9: Download Aira versus race: The graph displays the responses to the question, "will you download Aira on your own mobile device or tablet after the study is over and keep using it at the same frequency," according to race. White participants showed preference for not downloading Aira at the conclusion of the study.

In exploring participant responses to specific questions concerning each of the study apps, we again found a significant difference in ratings for white and non-white participants. A chi-square test of independence (Pearson Chi-Square) was completed to determine the relation between race and if the participants would download Aira at the conclusion of the study onto their own smartphone or tablet. The relation between these variables was significant X^2 (2, N=70)=7.75, p=0.021. As shown in Figure 9, there were a higher proportion of white participants than nonwhite participants stated they would not download the Aira app at the conclusion of the study. There were no significant differences in responses for any of the other demographic variables. Future investigations are needed to continue to explore if this difference found between individuals of different races persists.

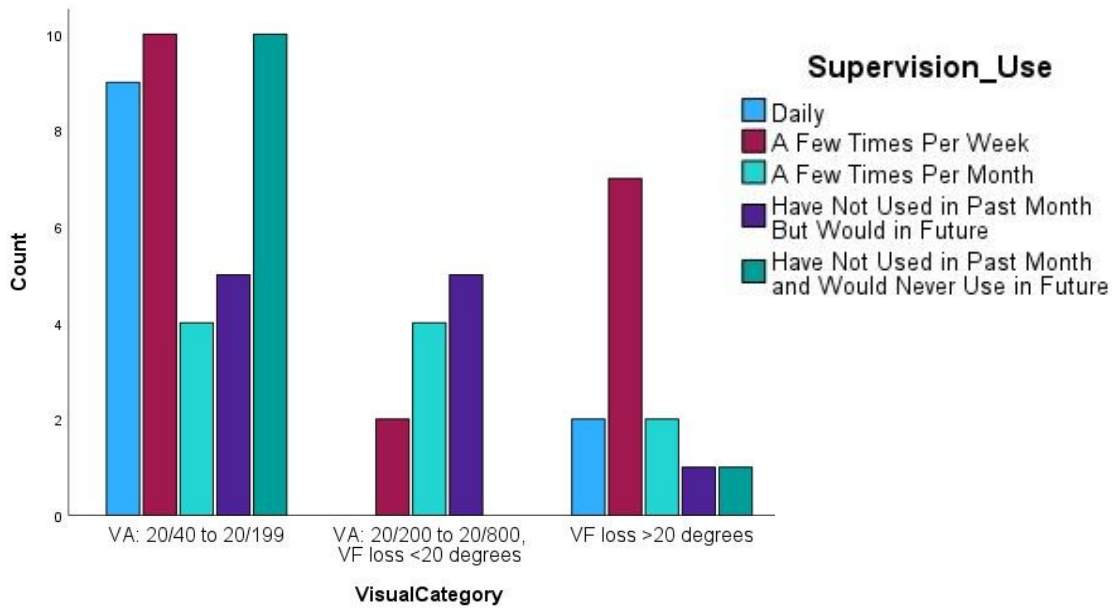

Figure 10: **Frequency of Supervision+ usage according to visual category:** Self-reported usage rate of the Supervision+ app across visual impairment categories. The visual acuity categories were as follows: VA: (1): 20/40 to 20/199, (2): VA: 20/200 to 20/800, Visual field loss of less than 20 degrees, (3) Visual field loss of greater than 20 degrees. The different color bars display the usage category choices the participants were provided with, including daily, a few times per week, a few times per month, have not used the app in the past month, but would plan to employ the app in the future, or have not used the app in the past month and plan to never utilize the app in the future again. There were differences in Supervision+ usage found according to the visual category of the participants.

There were differences in Supervision+ usage between participants according to visual impairment category. The categories of visual impairment were those with mild to moderate visual impairment had a visual acuity between 0.3 and 0.99 logMAR, those with severe visual impairment (VA between 1.0 to 1.6 logMAR) and severe visual field loss of 20 degrees or less. A chi-square test of independence (Pearson Chi-Square) was completed to determine the relationship between participant responses of self-reported use of the Supervision+ app and the visual impairment category. We found a significant difference in self-reported use X^2 (8, N=62)=19.58, p=0.012. As shown in Figure 10, there were a higher proportion of participants who stated they used Supervision a few times per week in the visual field loss group. In the severe visual impairment category, there were a higher proportion of participants who responded a few times per month and that they had not used the application in the past month, but would plan to use Supervision+ in the future. Furthermore, in the moderate visual impairment category, there were a higher proportion of participants who had not used Supervision+ in the past month and responded they would never use Supervision+ again, compared to the other two categories (Figure 10). All other demographic variables were not significantly related to self-reported use of the Supervision+ app.

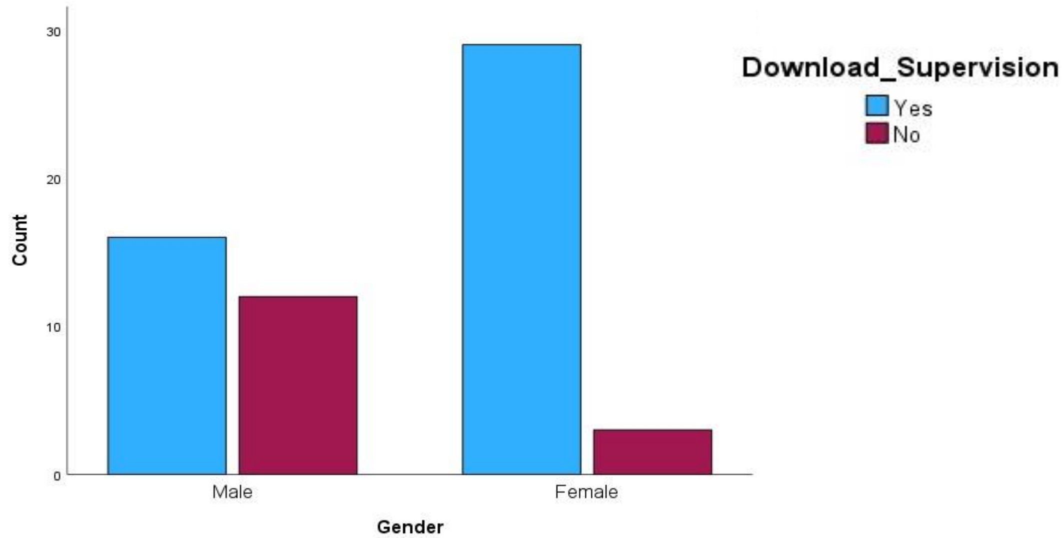

Figure 11: Download Supervision+ versus gender: Responses to the question, "will you download Supervision+ on your own mobile device or tablet after the study is over and keep using it at the same frequency," according to gender are displayed. Females showed preference for downloading Supervision+ at the conclusion of the study.

Figure 11 illustrates differences in the willingness to download the application onto the participants' own mobile device or tablet after the study concluded and to keep utilizing it at the same frequency, according to gender. Females were more likely to respond that they would download the app following the study, X^2 (11, N=70)=8.93, p=0.003. All other demographic variables were not significant.

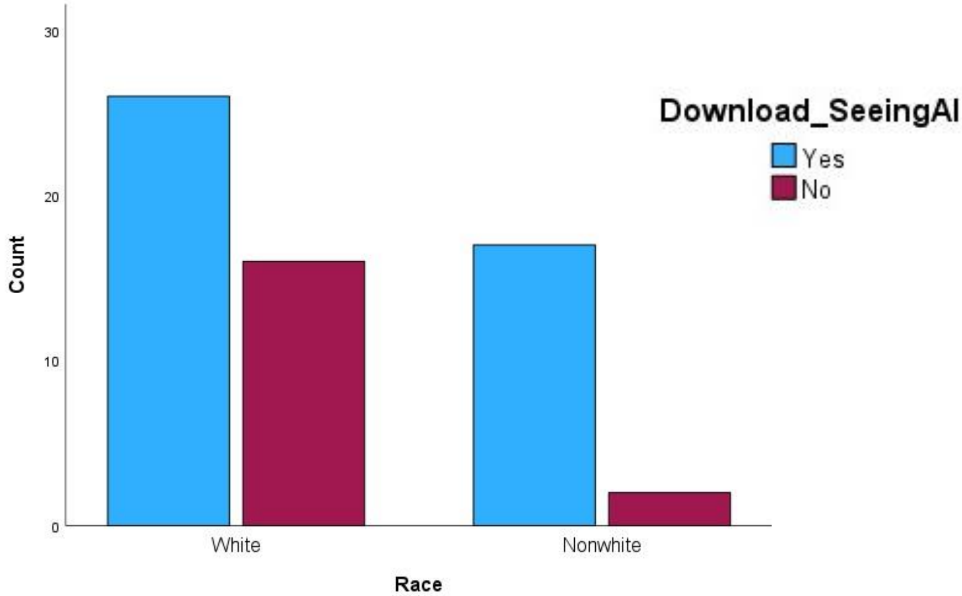

Figure 12: Download Seeing AI versus Race: The graph displays the responses to the question, "will you download Seeing AI on your own mobile device or tablet after the study is over and keep using it at the same frequency," according to race. There were significant differences in the download preferences of Seeing AI according to race.

In addition, Figure 12 displays the differences between the nonwhite and white participants in their selection if they would download Seeing AI onto their own mobile device. Again, we find there were significant differences in responses between racial groups, with a larger proportion of white participants answering they would not download Seeing AI at the conclusion of the study, X^2 (1, N=61)=4.780, p=0.029. All other demographic variables were not significant.

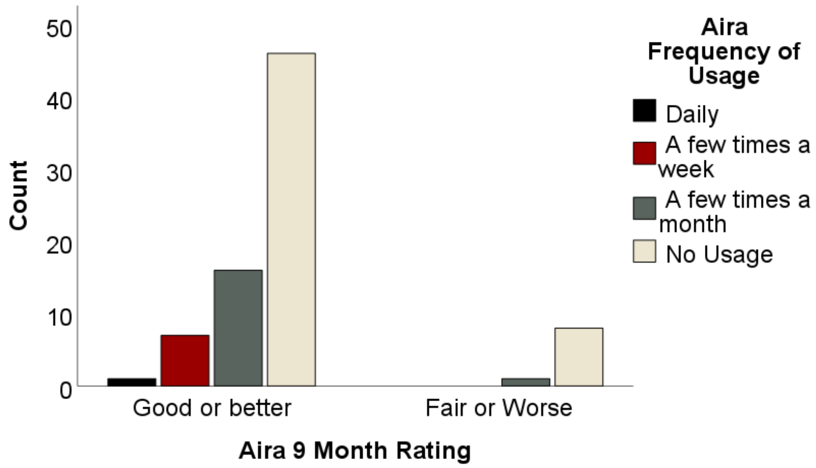

Figure 13a: App Ratings and Frequency of Usage for Aira

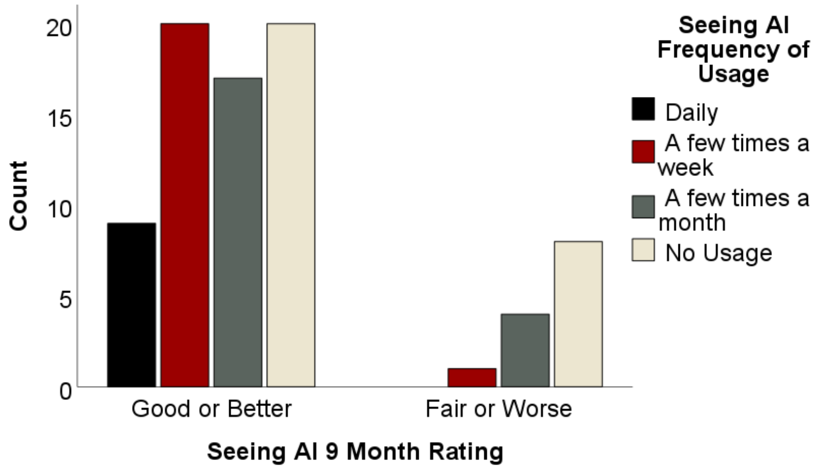

Figure 13b: App Ratings and Location of Usage for Seeing AI

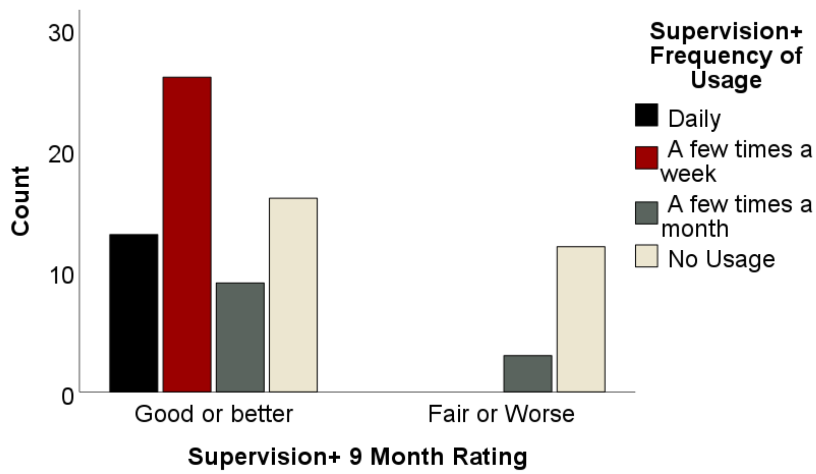

Figure 13c: App Ratings and Location of Usage for Supervision+

Figure 13: App ratings versus location of usage. Ratings were grouped into two categories: good or better or fair or worse. 11a: Aira, 11b: Seeing AI, 11c: Supervision+

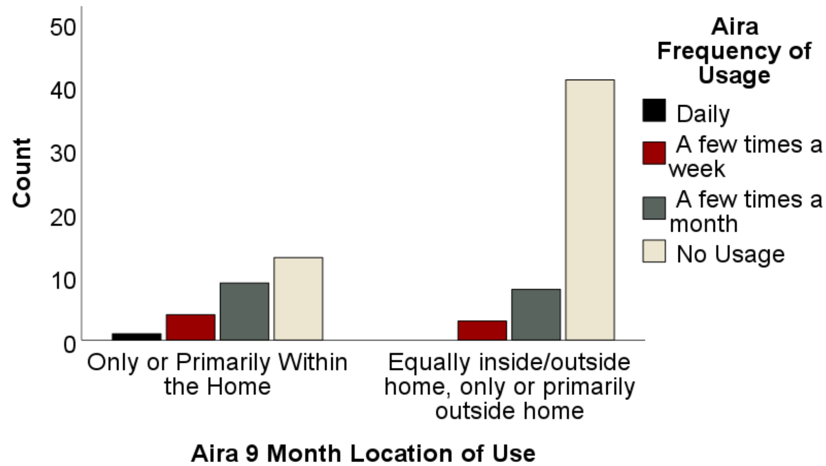

Figure 14a: Frequency of Usage and Use Location for Aira

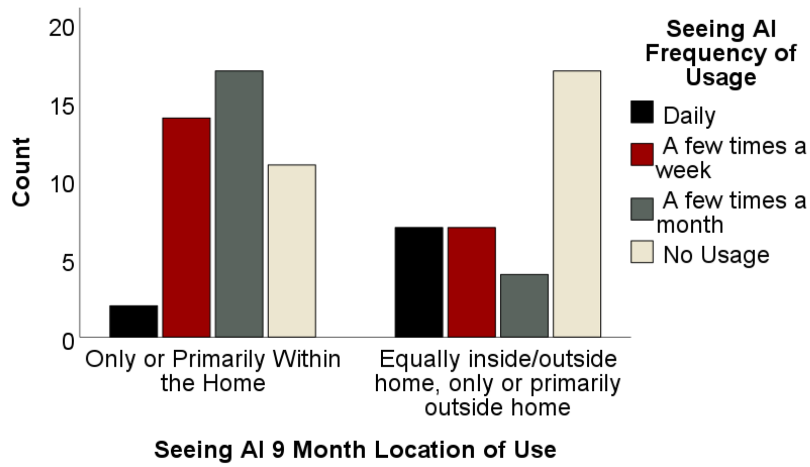

Figure 14b: Frequency of Usage and Use Location for Seeing AI

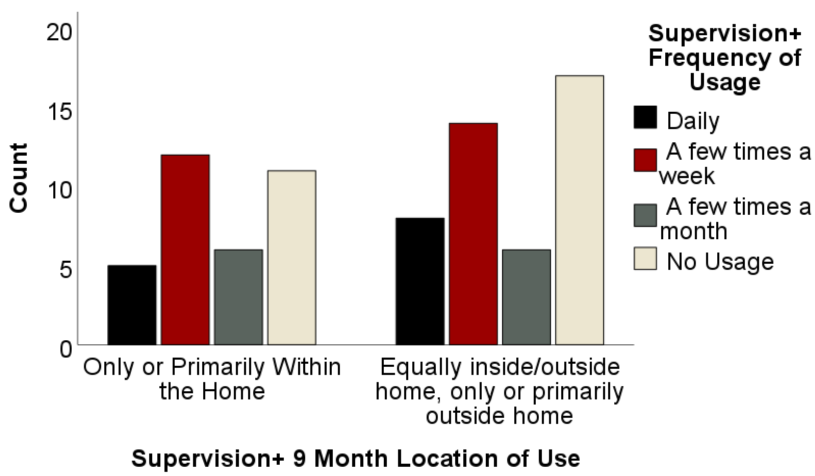

Figure 14c: Frequency of Usage and Use Location for Supervision+

Figure 14: Frequency of app usage and location of app usage for each app. Location responses were grouped into two groups either (1) only or primarily within in the home or (2) equally inside/outside the home or primarily outside the home. 12a: Aira, 12b: Seeing AI, 12c: Supervision+

There were no significant differences between app ratings and frequency of use for Aira (p value: 0.54, CV: 0.166) or Seeing AI (p value: 0.073, CV: 0.30). Supervision+ app ratings were found to be significantly related to frequency of use (p value: <0.001, CV: 0.501). Participants who used Supervision+ most often (daily or a few times a week) tended to rate the app as good or better.

The relationship between frequency of app usage and location of app usage was also investigated. The location of use of Supervision+ and Aira were not significantly related to the frequency of app usage. For Seeing AI, participants who reported using the app tended to employ the app inside the home instead of in public. Overall, frequency of Seeing AI use was significantly associated with location of use (p value: 0.004, CV: 0.42). be consistent whether you report the p values or not

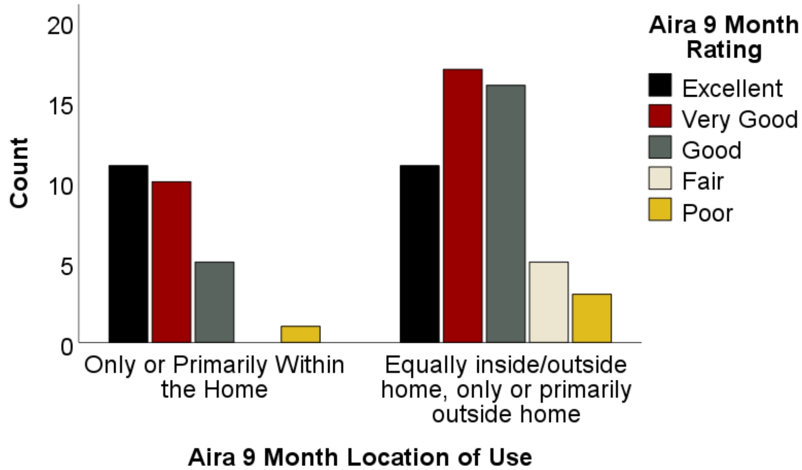

Figure 15a: App Ratings and Location of App Usage for Aira

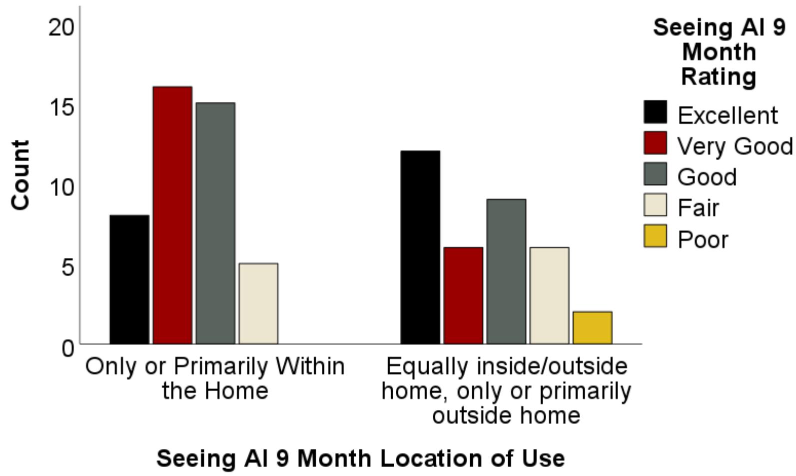

Figure 15b: App Ratings and Location of App Usage for Seeing AI

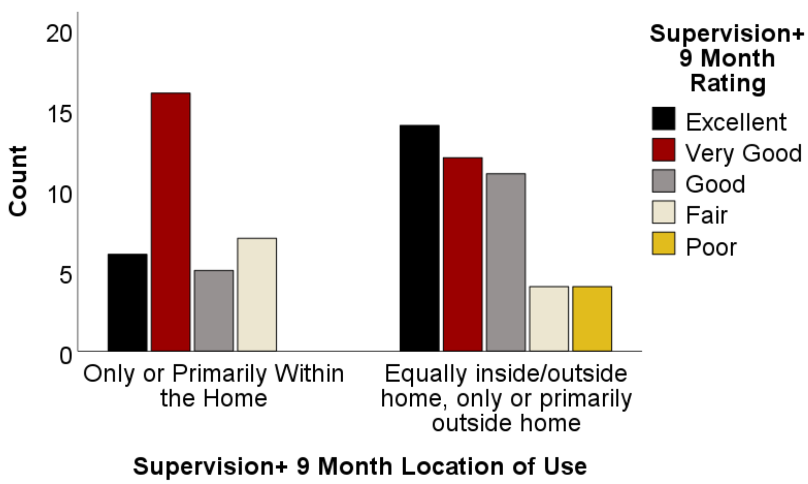

Figure 15c: App Ratings and Location of App Usage for Supervision+

Figure 15: App ratings and location of app usage for each app. Location responses were grouped into two groups either (1) only or primarily within in the home or (2) equally inside/outside the home or primarily outside the home. 13a: Aira, 13b: Seeing AI, 13c: Supervision+

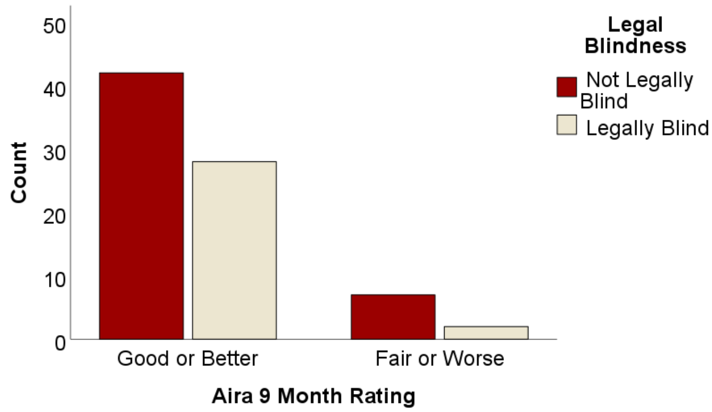

Figure 16a: Legal Blindness and App Ratings for Aira

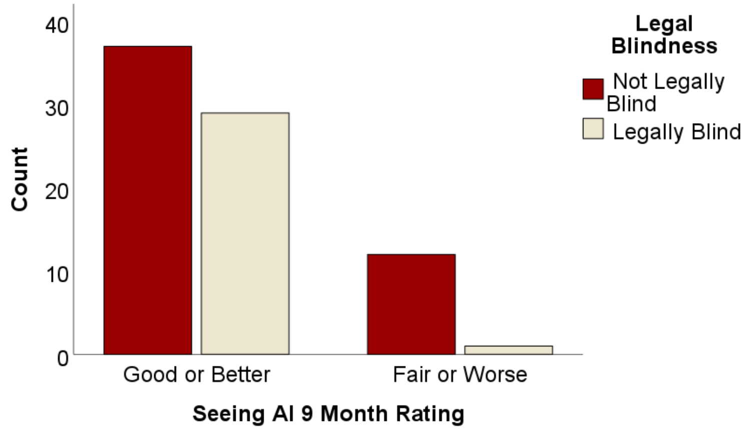

Figure 16b: Legal Blindness and App Ratings for Seeing AI

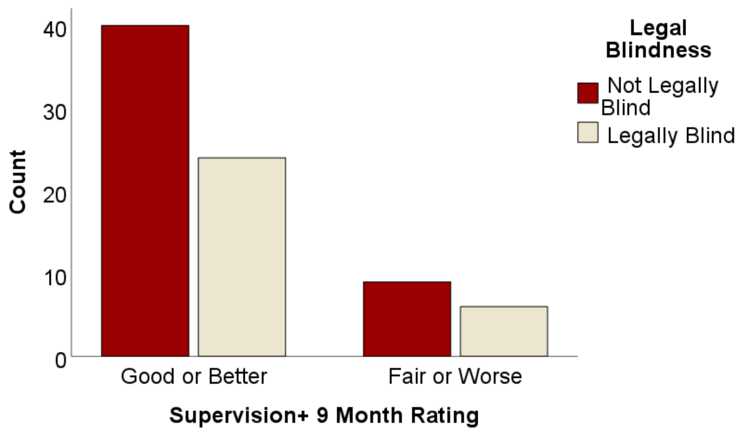

Figure 16c: Legal Blindness and App Ratings for Supervision+

Figure 16: Legal blindness status and app ratings. Ratings were grouped into two categories: good or better or fair or worse. Participants were classified as legally blind or not legally blind. 14a: Aira, 14b: Seeing AI, 14c: Supervision+

The relationship between app rating and location of app usage was also considered. There were no significant relationships found between app ratings and usage at home versus in public for all three apps of the study (Aira: p value: 0.62, CV: 0.15, Seeing AI: p value: 0.091, CV: 0.32, Supervision+: p value: 0.05, CV: 0.35).

Legal blindness was found to not be associated with app ratings for Supervision+ or Aira (Supervision+: p value: 0.86, CV: Aira: p value: 0.470, CV: 0.301). There was a significant difference found in Seeing AI app ratings according to legal blindness status, with a larger proportion of legally blind patients rating Seeing AI as good or better compared to fair or worse (p=0.01, CV: 0.28).

3F. Categorizing Usage of Visual Assistive Devices and Apps for Daily Tasks Using the Activity Inventory:

Domain of AI	6 Months (n=100)	9 Months (n= 68)
Reading (# tasks=126)	11.91 (9.45%)	12.43 (9.86%)
Visual Information (# tasks=99)	1.20 (1.21%)	1.28 (1.29%)
Visual Motor (# tasks=116)	0.44 (0.38%)	0.51 (0.44%)
Mobility (# tasks=39)	0.13 (0.33%)	0.06 (0.15%)
No Category (# tasks=81)	0.70 (0.87%)	0.76 (0.94%)

Table 7: Average low vision device usage by AI domain: Average number of tasks and average percentage of overall answered questions per subject by domain where low vision devices were used at 6 and 9 months. Items rated as not important were filtered out of analysis.

Domain of AI	6 Months (n=100)	9 Months (n=68)
Reading (# tasks=126)	6.07 (4.82%)	6.66 (5.29%)
Visual Information (# tasks=99)	0.82 (0.83%)	0.78 (0.79%)
Visual Motor (# tasks=116)	0.31 (0.27%)	0.32 (0.28%)
Mobility (# tasks=39)	0.12 (0.31%)	0.059 (0.15%)
No Category (# tasks=81)	0.39 (0.48%)	0.41 (0.51%)

Table 8: Average smartphone app usage by AI domain: Average number of tasks and average percentage of overall answered questions per subject by domain where visual assistive apps (Aira, Seeing AI, and Supervision+) were used at 6 and 9 months. Items rated as not important were filtered out of analysis. At 6 months, subjects had access to only one study (the one they were randomized to), while at 9-months the subjects had access to all three study apps. The 9-month averages in this table are reflective of the usage across all three applications.

Domain of AI	6 Months (n=100)	9 Months (n=68)
Reading (# tasks=126)	4.41 (3.5%)	4.82 (3.83%)
Visual Information (# tasks=99)	0.37 (0.37%)	0.43 (0.43%)
Visual Motor (# tasks=116)	0.11 (0.09%)	0.13 (0.11%)
Mobility (# tasks=39)	0.03 (0.08%)	0.03 (0.08%)
No Category (# tasks=81)	0.28 (0.35%)	0.26 (0.33%)

Table 9: Average smartphone app usage or low vision device ("either") usage by AI domain: Average number of tasks and average percentage of overall answered questions

per subject by domain where subjects answered that "either" visual assistive apps (Aira, Seeing AI, and Supervision+) or low vision devices were used at 6 and 9 months. Items rated as not important were filtered out of analysis. The 9-month averages in this table are reflective of the usage across all three applications, while the 6-month averages are based on the one app that each subject was randomly assigned to.

Domain of AI	Aira (n=23)	Seeing AI (n=38)	Supervision+ (n=39)
Reading (# tasks=126)	3.57 (2.83%)	6.29 (5.00%)	9.59 (7.61%)
Visual Info (# tasks=99)	0.57 (0.57%)	0.47 (0.48%)	0.90 (0.91%)
Visual Motor (# tasks=116)	0.48 (0.41%)	0.079 (0.068%)	0.23 (0.20%)
Mobility (# tasks=39)	0.17 (0.45%)	0.026 (0.67%)	0.10 (0.26%)
No Category (# tasks=81)	0.22 (0.27%)	0.34 (0.42%)	0.33 (0.41%)

Table 10: Average Aira, Seeing AI, and Supervision+ usage by AI domain at 6 months: Average number of tasks and average percentage of overall answered questions per subject by domain where each visual assistive app (Aira, Seeing AI, and Supervision+) were used at 6 months. Items rated as not important were filtered out of analysis. Each subject was randomized to one app at 6 months. 23 subjects completed the AI questionnaire who were randomized to Aira, 38 subjects to Seeing AI, and 39 subjects to Supervision+ at 6 months.

Reading was the most frequently reported domain of the AI for which an app or low vision device (LVD) or either used, at both 6-months (n=100; 4.82% with apps, 9.45% with LVDs, 3.5% with either) and 9-months (n=68; 5.29% with apps, 9.86% with LVDs, 3.83% with either) (Tables 7, 8, 9, 10). Low vision devices were used for an average of 11.91 items at 6 months and 12.43 items at 9 months per subject in the reading domain (Table 7). At 6 months, subjects utilized their assigned smartphone app for an average of 6.07 items in the reading domain of the AI. At 9 months, when subjects had access to all three smartphone applications, subjects used the apps for an average of 6.66 items in the reading domain. In contrast, mobility had the lowest reported usage at both 6-months (n=100, 0.33% with LVDs, 0.08% with either) and 9-months (n=68, 0.15% with apps, 0.15% with LVDs, 0.08% with either), besides visual motor had the lowest usage at 6- months for apps (n=100, n=0.27%) (Tables 7, 8, 9). When app usage was separated by each app, reading remained the most common AI domain where apps were used, for all three applications (Aira: 2.83%, Seeing AI: 5.00%, Supervision+: 7.61%), while visual motor was the domain of lowest average app usage (Aira: 0.41%, Seeing AI: 0.068%, Supervision+: 0.20%) (Table 10). In other words, Aira was used for an average of 3.57 items in the reading domain per subject, while Seeing AI was utilized for an average of 6.29 items in the reading domain per subject, and Supervision+ had the highest usage with an average of 9.59 items in the reading domain per subject. Furthermore, the most common reading task performed with a traditional LVD was reading medication instructions and this closely mirrored the most frequent task accomplished using smartphone apps which was reading price tags. Overall, both low vision devices and apps were utilized predominantly for tasks in the reading domain of the Activity Inventory.

3G. Conclusions:

In all, subjects tended to rate all three applications (Aira, Seeing AI, and Supervision+) similarly and favorably at 9 months. This finding is consistent with previous results by other studies which have found that low vision patients generally rate visual assistive smartphone applications highly and provide consistently positive feedback about visual assistive apps (Al-Razgan et al., 2021, Branham & Kane, 2015, Pundlik et al., 2023). In particular, participants who used Supervision+ frequently (daily or a few times a week) were more likely to rate the app as favorable (good or better). This suggests that for Supervision+ there was a potential relationship between regular engagement with the app and user satisfaction. For Seeing AI, subjects who reported usage of the app tended to employ the app inside the home. There were no significant relationships found between app ratings and usage inside or outside the home for all three apps of the study. There were differences in ratings of the app across different racial and gender groups, with females being more likely to download Supervision+ at the conclusion of the study. For Seeing AI there was a significant relationship according to legal blindness status with a larger proportion of legally blind patients rating Seeing AI favorably (good or better) but not for Aira or Supervision+. Our study suggested that those of the white race indicated preference for Aira, while those of the non-white race were more likely to rate all three visual assistive smartphone applications equally. A larger proportion of white participants reported that they would not download Seeing AI at the conclusion of the study. The racial demographics of the CARE study were compared to the NHIS and it was found that our population showed similarities to the estimates provided by this survey of vision loss by racial identity.

Reading was determined to be the most frequently reported domain of the AI for which an app or low vision device was used at both 6 and 9 months, while mobility had the lowest reported app and low vision device usage. This finding is consistent with prior research which identified reading as a top priority among individuals with vision impairment (Brown et al., 2014, Renieri et al., 2013, Virgili et al. 2018). Some studies have also found mobility and navigation as essential goals for low vision patients (Brown et al., 2014), especially those with glaucomatous field loss (Deemer et al., 2022). However, the older adults in our study did not use the smartphone apps regularly for mobility tasks. There were similarities in the most common task where low vision devices and apps were utilized. Participants continued to rely more heavily on traditional low vision devices compared to smartphone apps, implying that patients use apps more as a supplemental tool rather than a replacement to traditional devices. This outcome is in stark contrast to findings by Martiniello and colleagues, where the majority (62.5%) of participants strongly agree that their smartphone or tablet or computer has replaced the use of their other assistive devices, while 24.8% of participants somewhat agreed with the statement (Martiniello et al., 2019). However, younger participants and those who were more proficient with technology were more likely to answer more strongly to the question about replacement. This is an important difference considering our study participants were all 55 years and older, which could account for these differences in findings.

Therefore, these findings suggest that while assistive applications are overall well-received by low vision patients, their impact is influenced by a range of factors including frequency of use, functional needs, and user demographics. Overall, these results highlight the importance of tailoring low vision assistive technology to the specific needs of each patient.

CHAPTER 4: Strengths, Limitations and Conclusion:

4A. Strengths and Limitations of this Study:

One strength of this investigation was that it utilizes the Activity Inventory, which is a validated and adaptive questionnaire, and this allows for meaningful comparisons to be made to previous low vision studies. In Study 1, through exploring potential self-selection bias in the CARE study sample, this establishes the validity and generalizability of the findings. In Study 2, usage of low vision devices and smartphone apps on the AI questionnaire were examined at both 6 and 9 months, which provides insight into app usage over time instead of relying on a single-post intervention time point. This longitudinal design offers information on the real-world usage patterns of both low vision devices and smartphone applications over time. This study also focused on older low vision patients, while historically smartphone-based technology studies have focused more on younger patients.

As previously discussed, although the CARE study is a randomized controlled trial, these studies can still experience the effects of self-selection bias, since enrollment is voluntary. One limitation of Study 1 is that although demographic and clinical characteristics were utilized to assess self-selection bias, other factors, such as general health status, motivation, and confidence with technology were not evaluated. These other factors could influence which subjects elect to continue to remain in the study.

Furthermore, one limitation of Study 2 was that usage data was self-reported by patients and there was limited data available to confirm usage of the Seeing AI app. In addition, subjects were aware that the research was being conducted by their low vision provider(s) at NECO, which could skew some of the behavior and responses by participants, believing they should respond favorably to the intervention since their provider is involved in the study. Although the AI was created to capture the importance and difficulty of everyday tasks, responses may not fully encompass the complex-decision making process and contextual factors behind how low vision patients select whether to utilize a low vision device, smartphone application, or either to perform a task. Another limitation of this study was that for some participants extensive training was required to utilize the smartphone devices.

4B. Conclusions:

This study aimed to explore two research questions: (1) whether there was evidence of self-selection bias in the CARE study sample of older adults with low vision and (2) how older adults with low vision utilize and perceive visual assistive applications over time after training.

For Study 1, we hypothesized that the CARE study sample would differ significantly in demographic and clinical characteristics from participants in larger low vision trials, but that their Activity Inventory (AI) responses would remain well-targeted and consistent with these other low vision cohort studies. Our findings from this study support this hypothesis. While there were some demographic differences compared to other larger multicenter trials, the CARE study sample aligned well with the overall low vision population overall in terms of diagnostic and functional characteristics. There was good alignment between item difficulty and participant ability on the whole, as seen by the Wright map, but there were several bins of person measures where there were higher level of ability than captured by the available item difficulties, suggesting that the item pool did not fully match the ability range of the sampled population. However, in all, the targeting investigated did not provide strong evidence of self-selection bias and based on many of the overall similarities supports the continued use of the AI for assessing the CARE study population.

For Study 2, we hypothesized that older adults with low vision would continue to utilize both traditional low vision devices (LVDs) and visual assistive apps with the apps serving a complementary rather than replacement role. This hypothesis was supported by our data. Subjects rated the three visual assistive applications (Aira, Seeing AI, and Supervision+) favorably across multiple time points. Reading emerged as the most common task for which both low vision devices and apps are employed, while mobility tasks show the lowest usage of both low vision devices and apps. There were similarities in the most common tasks conducted with low vision devices and apps. Traditional low vision devices continued to be utilized more often than apps. Hence, visual assistive smartphone applications were used as supplementary tools rather than replacements for traditional devices. Usage patterns indicated that participants selectively integrated these technologies into their daily routines, especially for reading tasks.

Overall, this study adds to the literature on smartphone apps in older adults and demonstrates the importance of considering low vision apps as an option for older low vision patients to meet their daily needs. The older adults of this study rated the apps favorably and utilized the apps more as an auxiliary tool than a replacement to their traditional devices. In the future, other potential avenues of exploration for this study could involve examining app abandonment, training methods, and barriers to continued use of applications. Therefore, this study highlights the importance of tailoring low vision exams to each patient and how visual assistive apps continue to be an affordable and convenient aid for some patients.

CHAPTER 5: References:

Abraham, CH, Boadi-Kusi, B, Morny EKA, Agyekum, P (2022). Smartphone usage among people living with severe visual impairment and blindness. Assistive Technology. 34(5): 611-618.

AbouElwafa, A, Selim, N, Alateeq, H, Alzaid, D, Al-Megre, S (2018). Design And Implantation of a Voluntary Mobile Application for People who Are Visually Impaired. International Symposium on Innovative Technologies in Engineering and Science.

Adams, L (2022). What Are the Best Mobile or Web Apps for Blind People. American Council of the Blind.

Adeyemo, O, Jeter, P, Rozanski, C, Arnold, E, Dalvin, L, Swenor, B, Dagnelie, G, and PLoVR Study Group (2017). Living with Ultra-Low Vision: An Inventory of Self-Reported Visually Guided Activities by Individuals with Profound Visual Impairment. Translational Vision Science & Technology. 6(3).

Ahmadian, L, Massof, R (2008). Impact of general health status on validity of visual impairment measurement. Ophthalmic Epidemiol. 15(5):345-55.

Ahmed, S (2025). Sample size for saturation in qualitative research: Debates, definitions, and strategies. Journal of Medicine, Surgery, and Public Health. 5(100171).

Aigbe, S & Ross, N. Chief Complaints of Low Vision Patients in 2019 compared to 2020 (2021). Integrative Ophthalmology & Visual Science. 62(3602).

Aira Explorer Guide (2023). Aira. https://aira.io/aira-explorer guide/?utm_

Alarie, S, Lupien, SJ (2021). Self-selection bias in human stress research: a Systematic review. Psychoneuroendocrinology, 131: 105514.

Al-Razgan, M, Almoaigel, S, Alrajhi, N, Alhumegani, A, Alshehri, A, Alnefaie, B, Alkhamiss, R, Rushdi, S (2021). A systemic literature review on the usability of mobile applications for visually impaired users. PeerJ Comput Sci, 7(771).

Bano, T, Wolffsohn, JS, Sheppard, AL (2024). Assessment of visual function using mobile Apps. Eye (Lond), 38(12): 2406-2414.

Bhakhri, R, Chun, R, Coalter, J, Jay, W (2012). A Survey of Smartphone Usage in Low Vision Patients. Investigative Ophthalmology & Visual Science, (53): 4421.

Bittner, A, Green, K, Khan, R, Mitesh Mistry, A, Barnes, Maryn, Ross, N. Changes in Reported Difficulty with Near Reading following Telerehabilitation for Low Vision. Invest Opthal & Vis Sci, 60(9).

Bowers, A, Cheong, AM, Lovie-Kitchin, JE (2007). Reading with optical magnifiers: page navigation strategies and difficulties. Optom Vis Sci, 84(1): 9-20.

Bradley, C, Massof, R (2018). Method of successive dichotomizations: An improved method for estimating measures of latent variables from rating scale data. PLoS One. 13(10)

Branham, S, Kane, S (2015). The Invisible Work of Accessibility: How Blind Employees Manage Accessibility in Mixed-Ability Workplaces.

Brown, JC, Goldstein, JE, Chan, TL, Massof, R, Ramulu, P (2014). Characterizing Functional Complaints in Patients Seeking Outpatient Low-Vision Services in the United States. Ophthalmology. 121(8):1655-1662.

Cantó-Cerdán, M, Martínez, P, Lacárcel, F, Muñoz, A (2021). Rasch analysis for development and reduction of Symptom Questionnaire for Visual Dysfunctions (SQVD). Sci Rep 11, 14855.

Chan, T, Friedman, DS, Bradley, C, Massof, R (2018). Estimates of Incidence and Prevalence of Visual Impairment, Low Vision, and Blindness in the United States. JAMA Ophthalmology, 136(1): 12-19.

Christy, B, Pillai, A (2021). User feedback on usefulness and accessibility features of mobile applications by people with visual impairment. Indian J Ophthalmol. 69(3): 555.

Community Access Through Remote Eyesight (CARE) Study (CARE). Clinical Trials.gov. New England College of Optometry.

Congdon, N, O'Colmain, B, Klaver, C, Klein, R, Munoz, B, Friedman, D, Kempen, J, Taylor, H, Mitchell, P (2004). Causes and prevalence of visual impairment among adults in the United States. Arch Ophthalmology, 122(4): 477-85.

Crossland, M. D., S. Silva, R., & Macedo, A. F. (2014). Smartphone, tablet computer and e-reader use by people with vision impairment. Ophthalmic and Physiological Optics, 34(5): 552–557.

DeCarlo, DK, Scilley K, Wells J, Owsley C (2003). Driving habits and health-related quality of life in patients with age-related maculopathy. Optom Vis Sci, 80(3): 207-213.

Deemer, AD, Massof, RW, Rovner, BW, Casten, RJ, Piersol, CV (2017). Functional Outcomes of the Low Vision Depression Prevention Trial Age-Related Macular Degeneration. Invest Ophthalmol Vis Sci. 017;58(3):1514-1520.

Deemer, AD, Bradley, CK, Ross, NC, Natale, DM, Itthipanichpong, R, Werblin, FS, Massof, RW (2018). Low Vision Enhancement with Head-mounted Video Display Systems: Are We There Yet? Optom Vis Sci. 95(9): 694-703.

Deemer, AD, Goldsten, J, Ramulu, P (2022). Approaching rehabilitation in patients with advanced glaucoma. Nature Review Article. 37, 1993-2006.

Dockery, DM, Krzystolik, MG (2013). The Use of Mobile Applications as Low-Vision Aids: A Pilot Study. R I Med J, 103(8): 69-72.

Elliott, D & Plotkin, A (1997). Demographic characteristics of the vision disabled elderly. Investigative Ophthalmology & Visual Science. 38(12): 2566-75.

Falejczyk, J (2020). Aira VS Be my Eyes: Which is Better? Kern Countys and the Central Valley's Premiere Training Center for the Blind. https://commtechusa.net/aira-vs-be-my-eyes-which-is-better/?utm_

Finger, R, Tellis, B, Crewe, J, Keeffe, J, Ayton, L, Guymer, R (2014). Developing the Impact of Vision Impairment-Very Low Vision (IVI-VLV) Questionnaire as Part of the LoVADA Protocol. Investigative Ophthalmology & Visual Science, 55: 6150-6158.

Flament, D (2019). Live Visual Assistance: Comparing BeMyEyes and Aira. Second Sense Beyond vision loss. https://www.second-sense.org/2019/05/live-visual-assistance-comparing-bemyeyes-and-aira/?utm_

Gkioka, M, Almpanidou, S, Lioti, N, Almaliotis, D, Karampatakis, V (2024). Daily Functionality of People with Low Vision: The Impact of Visual Acuity, Depression, and Life Orientation- A Cross-Sectional Study. Behavioural Neurology, 4366572.

Gobeille, M, Malkin, A, Jamara, R, Ross, NC (2018). Clinical outcomes of low vision rehabilitation delivered by a mobile clinic. Ophthalmic Physiological Optic. 38(2): 193-202.

Gobeille, M, Bradley, C, Goldstein, J, Massof R (2021). Calibration of the

Activity Inventory Item Bank: A Patient-Reported Outcome Measurement Instrument for Low Vision Rehabilitation. Translational vision science & technology; 10(6).

Gobeille, MR, Fujiwara, K, Massof RW (2023). Application of Rasch Analysis to Timed Instrumental Activities of Daily Living in Low Vision: A Validation Study. Optom Vis Sci, 100(6):397-405.

Goldstein, JE, Massof, RW, Deremeik, JT, Braudway, S, Jackson, ML, Kehler, KB, Primo, SA, Sunness, JS (2012); Low Vision Research Network Study Group. Baseline traits of low vision patients served by private outpatient clinical centers in the United States. Arch Ophthalmology, 130(8): 1028-37.

Goldstein, JE, Chun, MW, Fletcher, DC, Deremeik, JT, Massof, RW (2014); Low Vision Research Network Study Group. Visual ability of patients seeking outpatient low vision services in the United States. JAMA Ophthalmol. 132(10): 1169-77.

Goldstein, JE, Jackson, ML, Fox, SM, Deremeik, JT, Massof, RW (2015). Clinically Meaningful Rehabilitation Outcomes of Low Vision Patients Served by Outpatient Clinical Centers. JAMA Ophthalmol. 133(7):762.

Golubova, E, Starke, S, Crossland, M, Wolffsohn, J (2021). Design considerations for the ideal low vision aid: insights from de-brief interviews following a real-world recording study. Ophthalmic and Physiological Optics, 41(2): 266-280.

Gopalakrishnan, S, Velu, S, Raman, R (2020). Low-vision intervention in individuals with age-related macular degeneration. Indian J Ophthalmol, 68(5): 886-889.

Gopinath, A, Babu, S, Claudius, A, Ismail, S, Sandeep, OS (2021). Product Design and development of a reading aid for the visually impaired. International Conference on Innovations in Mechanical Sciences, 1131.

Griffin, S, Banda, D, Ajuwon, P, Cheon, J, Lee, J, Park, H, & Lyngdoh, S. (2017). A survey on the use of mobile applications for people who are visually impaired. Journal of Visual Impairment & Blindness, 111(4), 307–323.

Irvine, D, Zemke, A, Pusateri, G, Gerlach, L, Chun, R, Jay, WM (2014). Tablet and Smartphone Accessibility Features in the Low Vision Rehabilitation. Neuro-Ophthalmology. 38(2): 53- 59.

Jin, H, Zhou, Y, Stagg, B, Ehrlich, J (2024). Associations between vision Impairment and increased prevalence of falls in older US adults. Journal of the American Geriatrics Society, 72(5): 1373-1383.

Jones, N, Bartlett, H, Cooke, R (2018). An analysis of the impact of visual Impairment on activities of daily living and vision-related quality of life In a visually impaired adult population. Sage Journals, 37(1).

Kakulla, B (2020). Older Adults Keep Pace on Tech Usage, Tech Trends of the

50+. AARP Research.

Kaur, K, Gurnani, B (2023). Low Vision Aids. StatPearls Publishing.

Keeffe, JE, Jin CF, Weih, LM, McCarty, CA, Taylor HR (2002). Vision impairment and older drivers: who’s driving. Br J Ophthalmol, 86(10): 1118-1121.

Khazaal, Y, Singer, M, Chatton, A, Achab, S, Zullino, D, Rothen, S, Khan, R, Billieux, J, Thorens, G (2014). Does Self-Selection Affect Samples’ Representativeness in Online Surveys? An Investigation in Online Video Game Research. Journal of Medical Internet Research. 16(7).

Killeen, O, Lott, L, and Zhou, Y (2023). Population Prevalence of Vision Impairment In US Adults 71 Years and Older: The National Health and Aging Trends Study. JAMA Ophthalmol. 141(2): 197-204.

Ko, F, Vitale, S, Fang, C, Cotch MF, Saaddine, J, and Friedman, D (2012). Prevalence of nonrefractive visual impairment in US adults and associated risk factors, 1999-2002 and 2005-2008. JAMA. 308(22): 2361-8.

Lamoureux, E, Hassell, J, Keeffe, J (2004). The Impact of Diabetic Retinopathy on Participation in Daily Living. Arch Ophthalmol. 122(1): 84-88.

Legge, G (2015). Visual Accessibility: A Challenge for Low-Vision Research. Optom Vis Sci. 91(7): 696-706.

Leung, L (2015). Validity, reliability, and generalizability in qualitative research. J Family Med Prim Care. 4(3): 324-327.

Luo, G (2020). How 16,000 people used a smartphone magnifier app in their daily lives. Clinical and Experimental Optometry. 103(6):847-852.

Luo, G (2021). What Visual Targets Are Viewed by Users With a Handheld Mobile Magnifier App. Transl Vis Sci Technol. 15;10(3):16.

Luu, W, Kalloniatis, M, Bartley, E, Tu, M, Dillon, L, Zangerl, B (2021). A Holistic model of low vision care for improving vision-related quality of Life. Clinical and Experimental Optometry, 103(6): 733-741.

Macnamara, A, Chen,C, Davies, A, Sloan, C, Loetscher, T (2021). Low vision devices for age-related macular degeneration: a systemic review. Disability and Rehabilitation: Assistive Technology, 18(7):998-1010.

Macnaughton, J, Latham, K, &Vianya-Estopa, M (2019). Rehabilitation needs and activity limitations of adults with a visual impairment entering a low vision rehabilitation service in England. Opthalmic Physiol Opt, 39(2): 113-126.

Maeng, M, Grant, P, Szlyk, JP, Seiple, WH (2020). Smartphone Usage in a General Low Vision Clinic Population. Investigative Ophthalmology & Visual Science. 61(7): 931.

Malkin, AG, and Massof, R (2018). Baseline traits of patients presenting for low vision services in a community health center. Investigative Ophthalmology & Visual Science, (59): 1062.

Malkin, AG, Ross, NC, Chun, MW, Bittner, AK, & CARE Study Team

(2022). Why Are Visual Assistive Mobile Applications Underused by Low Vision Patients? Optom Vis Sci. 99(4): 333-334.

Malkin, AG, Bittner, AK, Knizak, M, Peterson, B, Estabrook, M, Idman-Rait, C, Ho, J, Chun, M, & Ross, N. Factors related to proficiency following training to use new visual-assistive smartphone apps in seniors with low vision. Invest. Ophth & Visual Sciences, 63(7): 4053-FOO17.

Malkin AG, Bittner AK, Ho J, Idman-Rait C, Estabrook M, Ross NC; CARE Study Team. Factors related to training time and achieving proficiency with visual-assistive mobile applications in visually impaired older adults. Optom Vis Sci. 2024 Jun 1;101(6):351-357.

Many Seniors Miss Out on Assistive Apps for Low Vision (2022). *Review of Optometry*.

Marques, AP, Ramke, J, Cairns, J, Butt, T, Zhang, J, Jones, I (2022). The Economics of vision impairment and its leading causes: A systemic review. E Clinical Medicine, 46(101354).

Martin, J, Bradley, C, Kran, B, Ross, N (2024). Rasch analysis and targeting assessment of the teach-CVI survey tool in a cohort of CVI patients. Front. Ophthalmol. 4:1495000.

Martiniello, N, Eisenbarth, W, Lehane, C, Johnson, A, Wittich, W (2019). Exploring the use of smartphones and tablets among people with visual impairments: Are mainstream devices replacing the use of traditional visual aids. Assistive Technology, 34(1): 34-45.

Massof, RW, Deremeik, JT, Park, WL (2005). Self-Reported Importance and Difficulty of Driving for a Low Vision Clinic Population. Investigative Ophthalmology & Visal Science, (46): 1903.

Massof, RW, Hsu, CT, Baker, FH, Barnett, GD, Park, WL, Deremeik, JT, Rainey, C, Epstein, C (2005). Visual disability variables. I: the importance and difficulty of activity goals for a sample of low-vision patients. Arch Phys Med Rehabil, 86(5): 946-53.

Massof, RW, Ahmadian, L, Grover, LL, Deremeik, JT, Goldstein, JE, Rainey, C, Epstein, C, & Barnett, GD (2007). The Activity Inventory: an adaptive visual function questionnaire. Optom Vis Sci, 84(8): 763-74.

Massof, RW, & Stelmack, J (2013). Interpretation of Low-Vision Rehabilitation Outcome Measures. Optometry and Vision Science 90, 788–798.

Massof, RW. Patient-Reported Measures of Effects of Vision and Low Vision Rehabilitation on Functioning in Daily Life (2022). Annu Rev Vis Sci, 8: 217-238.

McDonnall, M (2024). Remote Sighted Assistance App Use and Thoughts About “Sighted” Assistance from Artificial Intelligence. Access World Home, American Foundation for the Blind.

Mehta, J, Czanner, G, Harding, S, Neewsham, D, Robinson J (2022).

Visual risk factors for falls in older adults: a case-control study. BMC Geriatrics, 22(132).

Millard LAC, Fernández-Sanlés A, Carter AR, Hughes RA, Tilling K, Morris TP, Major-Smith D, Griffith GJ, Clayton GL, Kawabata E, Davey Smith G, Lawlor DA, Borges MC (2022). Exploring the impact of selection bias in observational studies of COVID-19: a simulation study. Int J Epidemiol. 2023 Feb 8;52(1):44-57.

Minto, H, & Butt, IA (2004). Low vision devices and training. Community Eye Health. 17(49): 6-7.

Moshtael, H, Aslam, R, Underwood, I, and Dhillon, B (2015). High Tech Aids Low Vision: A Review of Image Processing for the Visually Impaired. Transl Vis Sci Technol, 4(4): 6.

Nguyen, A, Nguyen A-T, Hemenger, RP, Williams, DR (1993). Resolution, field of view, and retinal illuminance of miniaturized bioptic telescopes and their clinical significance. J Vis Rehab; 7: 5–9.

Nguyen, BJ, Chen, WS, Chen, AJ, Utt, A, Hill, E, Apgar, R, Chao, DL (2019). Large-scale assessment of needs in low vision individuals using the Aira assistive technology. Clin Ophthalmol. 13: 1853-1868.

Nguyen, JD, Tan, SM, Azenkot, S, Chu, MA, Cooper, EA (2022). Longitudinal Trends in Case Histories and Rehabilitative Device Assessments at Low Vision Examinations. Optom Vis Sci. 99(11): 817-829.

Nugent, D (2022). Covid Positive: The Technological Upside To

The Pandemic.

Owsley, C, McGwin Jr, G, Lee, P, Wasserman, N, Searcey, K (2009). Characteristics of low-vision rehabilitation services in the United States. Arch Ophthalmol. 127(5): 681-9.

Palumbo, R, Di Domenico A, Piras F, Bazzano B, Zerilli, M, Lorico, F, & Borella, E (2020). Measuring global functioning in older adults with cognitive impairments using the Rasch model. *BMC Geriatr*, 20(1): 492.

Park, K, Kim, Y, Nguyen, BJ, Chen, A, Chao, DL (2020). Quality of Life Assessment of Severely Visually Impaired Individuals Using Aira Assistive Technology System. Translational Vision Science & Technology. 9(4):21.

Pearce, E, Crossland, M, Rubin, G (2011). The efficacy of low vision device training in a hospital based low vision clinic.

Peli, E (2002). The Optical Functional Advantages of an Intraocular Low-Vision Telescope. Optometry and Vision Science, 79(4): 225-233. British Journal of Ophthalmology, 95(1): 105.

Peli, E, Vargas-Martín, F (2008). In-the-spectacle-lens telescopic device. J Biomed Opt, 13(3).

Piculo dos Santos, A, Ferrari, A, Medola, F, Sandnes, F (2020). Aesthetics and the perceived stigma of assistive technology for

Visual impairment. Disability and Rehabilitation: Assistive Technology, 17(2): 152-158.

Pundlik, S, Shivshanker, P, Luo, G (2023). Impact of Apps as Assistive Devices for Visually Impaired Persons. Annu Rev Vis Sci, 15(9): 111-130.

Quillen, DA (1999). Common Causes of Vision Loss in Elderly Patients. American Family Physician, 60(1): 99-108.

Remillard, E, Koon, L, Mitzner, T, and Rogers, W (2023). Everyday Challenges for Individuals Aging With Vision Impairment: Technology Implications. The Gerontologist, 64(6).

Renaud, J, and Bedard, E (2013). Depression in elderly with visual impairment and its association with quality of life. Clin Interv Aging, 19(8): 931-943.

Renieri, G, Pitz, S, Pfeiffer, N, Beutel, M, Zwerenz, R (2013). Changes in quality of life in visually impaired patients after low-vision rehabilitation. Int J Rehabil Res., 36(1): 48-55.

Riazi, A, Gharebaghi, R, Heidary, F (2022). Seven-year experience in a low vision rehabilitation clinic at a tertiary referral center. Medical hypothesis, discovery & innovation in optometry, 3(4): 128-135.

Rizzo, JR, Beheshti M, Hudson TE, Mongkolwat P, Riewpaiboon W, Seiple W, Ogedegbe OG, Vedanthan R. The global crisis of visual impairment: an emerging global health priority requiring urgent action. Disabil Rehabil Assist Technol. 2023 Apr;18(3):240-245.

Ross, N, Ho, J, Chun, M, Idman-Rait, C, Malkin, A, & Bittner, A (2021). Input following first time use of visual assistance mobile apps by seniors with low vision. Investigative Ophthalmology & Visual Science, 62, 3570.

Ross, N, Ho, J, Bradley, C, Malkin, A, Estabrook, M, Knizak, M, Peterson, B, Idman-Rait, C, Chun, M, & Bittner, A (2022). Exploring Smartphone Visual Assistive Applications in Seniors with Low Vision. Investigative Ophthalmology & Visual Science, 63(7):4054.

Rubin, G (2013). Measuring reading performance. Vision Research. 90(20): 43-51.

Schakel, W, Bode, C, van de Ven, P, van der Aa, H, Hulshof, C, van Rens, G, and van Nispen, R (2024). The multiple mediating effects of vision-specific factors and depression on association between visual impairment severity and fatigue: a path analysis study. BMC Psychiatry, 24(572).

Scott, I, Smiddy, W, Schiffman, J, Feur, W, Pappas, C (1999). Quality of life of low-vision patients and the impact of low-vision services. American Journal of Ophthalmology, 128(1): 54-62.

Senjam, S, Primo, S (2022). Challenges and Enablers for Smartphone Use by Persons With Vision Loss During the COVID-19 Pandemic: A Report of Two Case Studies. Front Public Health, 6(10): 912460.

Sivakumar, P, Vedachalam, R, Kannusamy, V, Odayappan, A, Venkatesh, R, Dhoble, P, Moutappa, F, Narayana, S (2019). Barriers in utilization of low vision assistive products. Eye, 6;34(2): 344-351.

Starke, S, Golubova, E, Crossland, M, Wolffsohn, J (2020). Everyday visual demands of people with low vision: A mixed methods real-life recording study. Journal of Vision, 20(3).

Stelmack, JA, Stelmack, TR, Massof, RW (2002). Measuring low-vision Rehabilitation outcomes with the NEI VFQ-25. Invest Ophthal Vis Sci, 43:2859-68.

Stelmack, JA, Tang, XC, Reda, DJ, Rinne, S, Mancil, RM, Massof, RW (2008); LOVIT Study Group. Outcomes of the Veterans Affairs Low Vision Intervention Trial (LOVIT). Arch Ophthalmol. 126(5): 608-17.

Stelmack, JA, Tang, C, Wei, Y, Wilcox, D, Morand, T, Brahm, K, Sayers, S, Massof, R (2017). Outcomes of the Veterans Affairs Low Vision Rehabilitation Trial II. JAMA Opthlamol. 135(2): 96-104.

Taylor,J, Bambrick, R, Dutton, M, Harper, R, Ryan, B, Tudor-Edwards, R, Waterman, H, Whitaker, C, & Dickinson, C (2014). The p-EVES study design and methodology: a randomized controlled trial to compare portable electronic vision enhancement systems (p-EVES) to optical magnifiers for near vision activities in vision impairment. OPO, 34(5): 558-572.

Toscos, T, Drouin, M, Pater, J, Flanagan, M, Pfafman, R, Mirro, M (2019). selection biases in technology-based intervention research: patients' technology use relates to both demographic and health-related inequities. J Am Med Inform Assoc, 26(8-9): 835-839.

Van Nispen, RMA, Virgili, G, Hoeben, M, Langelaan, M, Klevering, J, Keunen, J, van Rens, GHMB (2020). Low vision rehabilitation for better quality of life in visually impaired adults. Cochrane.

Varma, R, Vajaranant, T, Burkemper, B, Wu, S, Torres, M, Hsu, C, Choudhury, F, McKean-Cowdin, R (2016). Visual Impairment and Blindness in Adults in the United States: Demographic and Geographic Variations from 2015 to 2050. JAMA Ophthalmol. 134(7): 802-809.

Virgili, G, Acosta, R, Bentley, S, Giacomelli, G, Allcock, C, Evans, J (2018). Reading aids for adults with low vision. Cochrane Database Syst Rev. 17;4(4).

Wittenborn, J, Rein, D (2013). Cost of Vision Problems: The Economic Burden of Vision Loss and Eye Disorders in the United States. Prevent Blindness America. NORC at the University of Chicago.

Wittich, W, Lorenzini, M, Markowitz, S, Tolentino, M, Gartner, S, Goldstein, J, Dagnelie, G (2018). The Effect of a Head-mounted Low Vision Device on Visual Function. Optom Vis Sci. 95(9): 774-784.