Beyond eye charts, the daily challenges for people with impaired vision

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I hope my work adds to the collective knowledge of clinical vision science and becomes a source of inspiration for future scholars, just as I have been inspired by those who walked this path before me.

Abstract

Visual impairment, which affected an estimated 596.5 million people globally in 2020, can lead to numerous challenges in daily life. However, those challenges can't always be captured by standard clinical vision tests, such as visual acuity tests, contrast sensitivity tests, or visual field tests. This dissertation focuses on understanding real-life challenges encountered by people with visual impairment. Chapter 1 provides an overview of the dissertation. Chapter 2 examines the relationship between visual acuity measurements and people's daily viewing experience. The results demonstrate that visual acuity, as measured on letter charts, can be estimated by people's responses to a set of Yes/No questions asking what they can or cannot see in real-life viewing scenarios. Chapter 3 describes an online survey focusing on the reading behavior of individuals with low vision in the digital era. The results show that reading with vision was still the primary way to read, although audio or tactile methods can be used to access digital materials. Digital reading was also found to be used more than hardcopy reading. Chapter 4 reports on a longitudinal study that examined the impact of the first year of the pandemic on social isolation in older people with vision or hearing loss. The findings demonstrated that older people with visual impairment were more likely to experience social isolation and loneliness during the early pandemic in 2020. The studies presented in the thesis provide three perspectives on understanding the daily challenges encountered by people with visual impairment. These findings can be directly applied to better rehabilitation programs for improving the quality of life in people with visual impairment.

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Chapter 1: Overview

Vision is the primary sense for perceiving and interacting with our surroundings. As such, visual impairment can lead to functional deficits, including difficulty in identifying objects in daily life, reading, mobility, and social interactions. Bourne et al., (2017) estimated that 596.5 million people worldwide were visually impaired, representing 7.5% of the world population of 7.89 billion in 2020. In the United States (U.S.), an estimated 5.7 million people in the US had visual impairment in 2017, which is expected to increase to 9.6 million by 2050 due to the aging of the population (Chan et al., 2018). This dissertation focused on three aspects of everyday challenges encountered by people with impaired vision: (1) seeing everyday objects at typical viewing distances, (2) reading digital materials, and (3) social isolation during the COVID-19 pandemic.

The extent of vision loss is usually captured by three clinical measures: (1) visual acuity, (2) contrast sensitivity, and (3) visual field. Visual acuity is a fundamental aspect of human vision that allows us to see fine details in the world around us. It is often measured by having a person read letters of decreasing size on an eye chart. A modern standard acuity chart is the Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Figure 1-1A) This chart contains letters of progressively smaller sizes viewed from a standard distance, with the smallest size that can be read, defining the individual's visual acuity (VA). A standard VA threshold for normal vision in Snellen notation is 20/20. In the United States, the acuity criteria for low vision and legal blindness are 20/40 and 20/200. The Snellen acuity can also be converted into the Logarithm of the Minimum Angle of Resolution (logMAR), so that 20/20, 20/40, and 20/200 correspond to 0, 0.33, and 1 logMAR. In the thesis, logMAR is the primary unit used to describe a participant’s visual acuity.

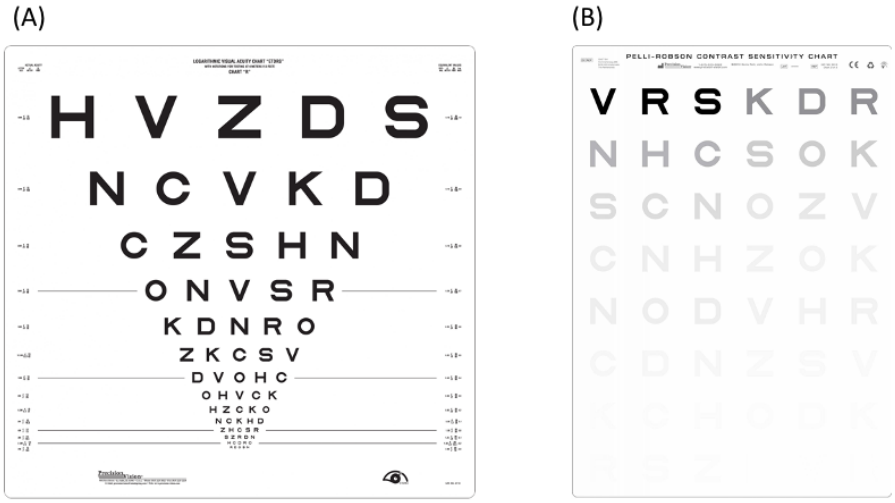

Figure 1-1 Visual Acuity chart and Pelli-Robson chart
The figure shows two commonly used letter charts for measuring visual acuity and contrast sensitivity: (A) ETDRS visual acuity chart, and (B) Pelli-Robson contrast sensitivity chart.

Contrast sensitivity is a fundamental aspect of vision that describes our ability to detect differences in luminance in a scene. It measures the minimum contrast required by a person to distinguish a target from its background. An individual's contrast sensitivity is often measured with a Pelli-Robson chart (See Figure. 1-1B). The chart consists of sets of letters on a white background, gradually decreasing in contrast. An individual's contrast sensitivity is determined by the reciprocal of the lowest contrast at which the individual can recognize letters on the chart. Low-vision individuals with visual acuity reduction are likely to experience reduced contrast sensitivity as well.

The third method for evaluating vision loss is measuring the visual field. The visual field is the entire area the eye can perceive simultaneously. It includes the visual information processed by the retina and transmitted to the brain. A typical visual field measurement uses automated perimetry. It uses a computer-controlled display to present points of light at different locations within the visual field. The patient is asked to press a button when they see a stimulus, and the machine records their responses to create a visual field map (Figure 1-2). A visual field map with a deficit in the surroundings represents peripheral vision loss, commonly seen in patients with glaucoma or retinitis pigmentosa (RP). In contrast, a deficit in the center is

central vision loss, which is common in patients with age-related macular degeneration (AMD). Visual field measurements are essential for assessing the progress of various eye conditions.

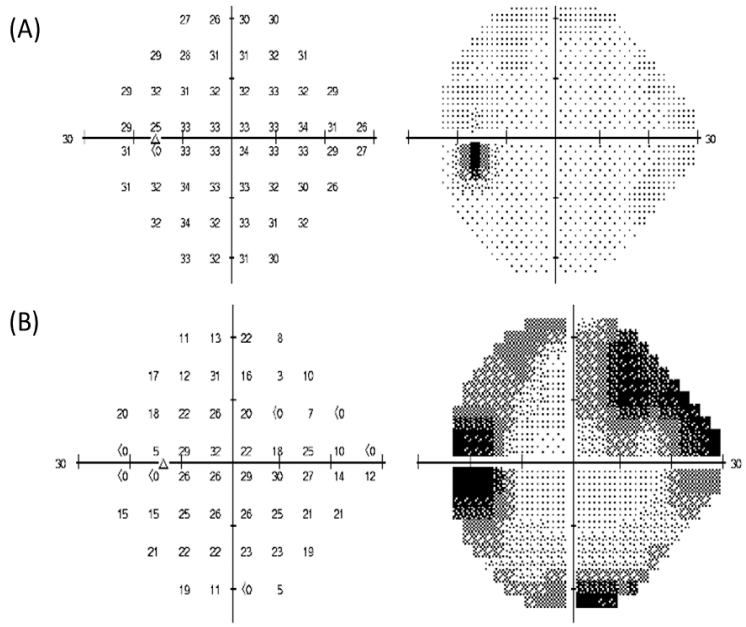

Figure 1-2 Visual field maps

This figure shows two different visual field test results. The numbers in the left panel represent light sensitivity at different positions of one eye's visual field. The dark areas in the right panel represent lower light sensitivity. (A) is a monocular visual field test result from a normal eye. (B) is a visual field test result from an eye with glaucoma.

Although the three primary measurements capture the pathological effects of different ocular diseases on visual perception, they do not tell us directly about the real-life impact of visual impairment. For example, what challenges might a person with a visual acuity of 20/200 encounter daily? How do they differ from the challenges associated with visual acuity of 20/40?

This thesis aims to understand the real-life challenges encountered by people with visual impairment. Three chapters in the thesis are individual studies formatted for journal publications, depicting different aspects of real-life challenges in people with visual impairment. Chapter 2 discusses the association between visual acuity measurements and daily viewing experiences. Chapter 3 focuses on how people with visual impairment read in the digital era. Chapter 4 examines the impact of the Coronavirus Disease 2019 (COVID-19) pandemic on social isolation in older people with sensory loss.

Study 1: Estimating visual acuity without a visual acuity chart.

The study in Chapter 2 was designed to understand the association between standard visual acuity measurements and low vision people's daily viewing experience. Visual acuity is an essential factor in determining a person's ability to see details of objects. We turned the tables to determine if the visual acuity measured through a letter acuity chart can be estimated through a person's ability to recognize familiar objects in daily life.

In the study, one hundred Yes/No questions were created to test participants' vision in daily life to challenge a wide range of visual acuities. In the survey, each question includes a familiar object viewed at a given viewing distance. A sample question created to challenge participants with normal acuity was, "Would you be able to see the eye of a needle if you hold it at arm's length?" A sample question designed for participants with ultra-low vision was, "When walking down a sidewalk, are you able to see the outline of the sidewalk path if it is bordered by green grass?"

Three hundred eighty-five participants (18 to 93 years, mean age = 56.66 years, SD = 20.72),) from four testing sites in the U.S., the University of Minnesota, The Ohio State University, Johns Hopkins University, and the University of Alabama at Birmingham, were asked to answer the 100 Yes/No questions. visual acuity was obtained from each participant with an ETDRS visual acuity chart. Their VA ranged from -0.3 to 2 logMAR (mean = 0.58 logMAR, SD = 0.45). 68% had acuity in the low vision range.

A two-parameter logistic (2PL) model based on Item Response Theory (IRT) was used to analyze responses to the 100 questions. The IRT method can be employed to provide an estimate of each participant's acuity and an estimate of the acuity required for each of the 100 questions.

The average prediction error between acuity estimated from the questionnaire data and measured chart acuity was 0.23 logMAR (SD = 0.18, approximately equivalent to two lines on the eye chart.). The IRT model also estimated the acuity required for each question. For instance, the acuity required to distinguish a half-moon from a full moon on a clear night was estimated to be 20/200 or better (1 logMAR).

This study showed that a set of Yes/No questions about vision in daily life can be used to estimate a person's acuity, making it potentially useful for telehealth. The item responses also provide insights into the real-world visual capabilities of people with low vision across a wide range of acuities.

Study 2: Online Survey of Digital Reading by Adults with Low Vision

Chapter 3 describes a study focused on reading, one of the essential visual activities. Reading is a typical daily challenge for people with low vision. Traditionally, when reading materials were predominantly in hard copy form, people with low vision relied on optical magnifiers to facilitate their reading. However, with the advent of digital reading materials, such as online websites and electronic documents, reading has become more accessible. Nowadays, individuals with low vision can access digital materials using assistive technologies like screen readers, which enable them to use audio for reading. Electronic documents can also be rendered in braille for tactile reading. Additionally, low-vision readers can easily customize the digital text for visual reading, such as switching between regular contrast polarity (black text on a white background) and reversed contrast polarity (white text on a black background) to enhance their reading experience.

However, the impact of widespread digital materials on how people with low vision read in the digital era is not well understood. In the current study, an online survey of people with low vision was designed to determine what assistive technologies they use for digital and hardcopy reading, their preferred text characteristics, and the time they devote to reading digital and hard-copy text.

One hundred and thirty-three low-vision participants completed the online Qualtrics survey. The three most frequent eye conditions of the participants were albinism (36), retinitis pigmentosa (20), and glaucoma (15). Mean self-reported acuity was 0.93 logMAR (range 0.1 to 1.6). The mean age of the sample was 46 years (range 18 to 98). Participants reported the nature and history of their low vision, their use of different assistive technologies, and time devoted to different visual reading activities, including news reading, work and education-related reading, pleasure reading, spot reading, and reading on social media.

The results showed that vision was still the primary sensory modality for reading in the digital era because 75% of our participants did more than 50% of their reading using vision, with a lesser reliance on audio, and very little reliance on braille. Across five categories of reading activities, participants reported more time spent on digital reading than hardcopy reading. Eighty-nine percent of our participants reported using at least one assistive technology for visual reading. The three most popular assistive technologies were smartphones, screen readers, and tablets, which are primarily used for reading digital materials.

Despite the growing availability of text in audio or braille formats, our findings from an online sample of people with low vision indicate the continuing importance of visual reading. Our participants use

technology to access both hard-copy and digital text, but more time is devoted to digital reading. The findings highlight the need for continued research and development of technology to enhance visual reading accessibility.

Study 3: The early impact of the COVID-19 pandemic on social isolation in older people with vision loss or hearing loss

Sensory impairment has a significant impact on people's social life and mental health. Past studies have found that individuals with visual impairment are more likely to experience social isolation, depression, and anxiety, compared to individuals without visual impairment. Similar issues have been found in individuals with hearing loss as well. The issues of social isolation and poor mental health might have been exaggerated in the early COVID-19 pandemic because of the stay-at-home order, worries of getting infected, or other public health measures.

Chapter 4 reports on a study in which we collected longitudinal data throughout 2020 to understand the impact of pandemic restrictions on the social interactions and emotional well-being of older adults with sensory impairment. Three groups of older adults – 13 with vision loss, 24 with hearing loss, and 18 age-matched controls, were recruited from the Minneapolis-St. Paul community (mean age = 68.18). Participants were interviewed every 5 to 7 weeks from the end of April to the end of October in 2020 using the same set of questions. The initial interview at the end of April 2020 included retrospective responses to questions regarding participants' status at the beginning of March 2020, before the pandemic restrictions, and the beginning of April 2020, after the onset of pandemic restrictions.

The results showed a significant decline in in-person contact in all three groups after the onset of the pandemic. This decline was not compensated for by increased electronic social contacts. From late April to October 2020, the average numbers of in-person contacts were higher in the control and hearing-loss groups than in the vision-loss group. A higher sense of loneliness was also observed in the vision loss and control group after the pandemic started. The reduced in-person contact and a higher sense of loneliness remained stable in all the pandemic sessions, while the vision loss group had a higher sense of loneliness than the two other groups during the pandemic. Participants with vision impairment were more concerned

with the inability to touch things. Participants with hearing loss worried more about understanding the speech of mask wearers.

The findings show the widespread impact of the pandemic on social interactions and the mental health of older adults with sensory impairment. The negative impact of the pandemic was sustained throughout the seven-month testing period from late April to October 2020. Older people with visual impairment were especially vulnerable to changes that led to a loss of independence. Although mask-wearing impaired speech intelligibility for older people with hearing loss, the quieter acoustic environment during restricted gatherings may have mitigated the negative effects.

Summary

This thesis contains three studies focusing on understanding the daily challenges people with visual impairments encounter. The studies demonstrated that typical vision measurements, such as a visual acuity test, can directly relate to a person's everyday visual experience. Moreover, although impaired vision results in difficulties with reading, vision continues to be the primary sensory modality used for reading. These results provide insights into the everyday lives of people with low vision.

Chapter 2: Estimating visual acuity without a visual acuity chart

Introduction

Visual acuity (VA) is a critical visual function that describes a person's ability to see small details in visual patterns. It has been widely used to screen for vision disorders, to assess treatment effectiveness, and to evaluate the need for rehabilitation training. Common methods for measuring visual acuity use letter charts, such as the Snellen, the ETDRS, or the Landolt C or tumbling E charts. Past studies have also examined the relationship between VA and the performance of daily tasks. It is often assumed that acuity measurements from a letter chart are informative about a person's everyday visual capabilities. This study was designed to develop a visual acuity questionnaire to establish the relationship between visual acuity and daily viewing experience.

The quantification of vision acuity on eye charts is assumed to provide information regarding a person's ability to complete significant daily tasks with vision. Studies have shown that people with lower VAs were more impaired in specific daily tasks. For example, West et al., (2002) found that people with VA worse than 20/40 experience difficulty reading and face recognition. In the same study, mobility was not much affected until VA was worse than 20/200.

Rubin et al., (2001) found that visual acuity was significantly associated with self-reported difficulties reading street signs and watching television after controlling for demographic factors and other vision measurements, like contrast sensitivity, field loss, and glare sensitivity. Goldstein et al., (2014) found that visual acuity was associated with low vision patients' estimated vision abilities using the Activity Inventory (Massof et al., 2005a, 2005b, 2007) in doing some daily living tasks, such as reading-related activities (e.g., reading medication labels), activities involved in seeing objects (e.g., seeing food on a plate), visual-motor tasks (e.g., threading needles), and mobility (e.g., getting in the bathtub). Arditi et al., (2021) also demonstrated that visual acuity was associated with properties of visual imagery, including spatial resolution and viewpoint.

Other studies have developed questionnaires to screen for acuity below normal. Coren and Hakstian, (1987) demonstrated that a participant's responses to two questions regarding difficulties reading book text and recognizing faces could be used to detect if the participant had VA worse than 20/40. Owen et al., (2006)

also found that older people with lower overall scores on the National Eye Institute Visual Function Questionnaire-25 (NEI VFQ-25) were likelier to have VA lower than 20/60.

These studies imply that VA is associated with people's subjective experiences of seeing objects or recognizing object details in daily life. However, no studies have demonstrated that a participant's acuity score could be estimated by their answers to questions concerning the ability to see everyday objects.

The previous studies using acuity screening questions have not explicitly considered viewing distance. Associating acuity with daily viewing experience requires considering both object size and viewing distance. A familiar object viewed at different distances can result in different angular sizes on the retina. A person with a visual acuity of 20/40 may recognize a friend’s face 6 feet away but not across a street.

We designed a set of 100 yes-no questions about a subject’s visual experience in seeing everyday objects at particular viewing distances. The questions were selected to span a wide range of demands on acuity. The answers were analyzed by Item Response Theory (IRT). The analysis yielded an ability measure for each participant, which we expected to be closely related to acuity. The analysis also yielded item difficulty scores which we expected to be related to the acuity requirements associated with the item.

Such a questionnaire may be helpful in the remote assessment of a person's acuity or in self-evaluation of acuity. The item difficulty scores may also help link numerical acuity estimates and real-world vision abilities.

Methods

Participants

Three hundred eighty-five participants were recruited from four testing sites, including the University of Minnesota, The Ohio State University, Johns Hopkins University, and the University of Alabama at Birmingham. All participants were older than 18 and had their visual acuity (VA) measured at an eye clinic or in a vision lab using an ETDRS logMAR chart. Two hundred and eighty-nine participants also had their contrast sensitivity measured using a Pelli-Robson chart. All VA measurements were converted into logMAR units for data analysis. To cover a wide range of VA, participants with a wide range of low vision were recruited. Participants with VA better than 20/40 were enrolled in the study as well.

Our research protocol was approved by the Institutional Review Boards at the four testing sites. The study followed the tenets of the Declaration of Helsinki. All participants provided signed or electronic consent before participating in the study.

Visual Acuity Survey

One hundred Yes/No questions were created to assess participants' ability to recognize details of a familiar object viewed at a given distance. For example, Q68 was “Would you be able to recognize a friend's face if they were sitting directly across a dinner table from you?". In the example question, a commonly seen object, a human face, was viewed at an approximately standard distance, in this case, the width of a dining table. Participants were asked to answer the question assuming good lighting and normal viewing conditions.

The objects chosen in the survey and their sizes were expected to be familiar to most people living in the United States. The full list of 100 questions can be found in Appendix Table A1-1. The items were selected with the goal of distributing likely demand on visual acuity across a wide range from normal vision to ultra-low vision. An example question expected to require high acuity was, “Would you be able to see the eye of a needle if you hold it at arm's length?”. A question expected to require low acuity was, “When you are standing at a curb preparing to cross a street at a crosswalk, are you able to see the white stripes that make up the crosswalk?”.

Participants completed the Visual Acuity Survey with a trained interviewer over the phone or in a clinic at our testing sites. Every participant was encouraged to give either a yes or no response to each question. However, the participants could give a “not applicable” response if they were unfamiliar with an object in a question. In addition to the 100 yes/no questions, demographic information was obtained, including race, ethnicity, age, cause of visual impairment, age of onset of visual impairment, and types of visual field loss. Some participants also had their contrast sensitivity measured and reported in the survey.

Item Response Theory (IRT)

In the current study, Item Response Theory (IRT) was employed to analyze participants’ responses to the survey items and evaluate the reliability of each item. IRT is a psychometric method to estimate the relationship between a participant's latent trait (or ability), represented by a variable theta (θ), and responses to test items. IRT assumes a participant's response to a test item is based on the interaction between the

participant's ability and a set of item characteristics. One form of IRT, Rasch Analysis, has been used to build tools for evaluating people's vision abilities to perform daily tasks. For example, the Activity Inventory (Massof et al., 2007) was a tool to estimate people's vision abilities for daily activities.

The item characteristics included in the current study were item difficulty (b) and item discriminability (a). The interaction between the participant's ability and the two item parameters can be represented by a non-linear probability function called the Item Characteristic Curve (ICC, see Figure 2-1 and Eq. 2-1). An ICC depicts the probabilities of responses to an item given at different ability levels of θ. Higher θ values represent better abilities. In the current study, the latent trait (θ) is a participant's ability to see object details in daily life. We hypothesize that a person's value of θ is associated with their logMAR acuity measured on the ETDRS chart. .

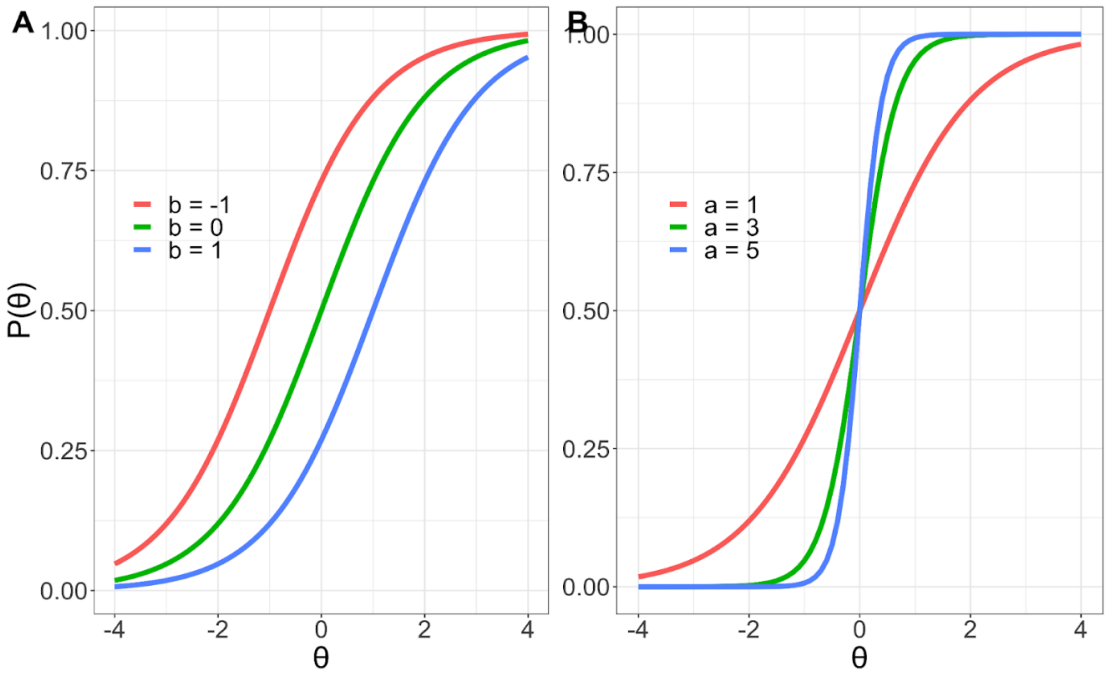

Figure 2-1 Item characteristics curves.

The figure shows different item characteristic curves (ICCs). (Panel A) Three ICCs represent different item difficulty (b) levels when sharing the same item discriminability (a), (Panel B) Three ICCs show different levels of item discriminability (a) when sharing the same level of item difficulty (b).

$$P\ (X = 1|\theta, a, b) = \frac{e^{a(\theta - b)}}{1 + e^{a(\theta - b)}} \qquad (Eq. 2 - 1)$$

P(X): The probability of X response to an item from a participant
θ: A participant's estimated ability
a: An item's discriminability
b: An item's difficulty

In IRT, the prediction of a participant's response (*X, see Eq. 2-1*) to an item depends on both the participant's ability level (θ) and item characteristics. One important item characteristic is item difficulty (b). An IRT logistic model including only the difficulty parameter is called the 1-parameter logistic (1PL) model or sometimes Rasch model. Higher difficulty values represent more difficult items and vice versa. Since both θ and item difficulty (b) are aligned on the same one-dimensional scale, we can compare a participant's estimated θ relative to an item's difficulty. If a participant's estimated θ is higher than the item's difficulty, the model predicts that the participant has more than a 50% chance to endorse it correctly. In the current study, a more difficult item would put a demand on acuity in terms of object size and viewing distance.

In addition to the difficulty parameter, a discriminability parameter (*a, see Eq. 2-1*) was added to build a two-parameter logistic IRT model (2PL) in the current study. The discriminability parameter determines the slope of an ICC curve. Items with higher discriminability had ICC curves with steeper slopes (See Figure 2-1B). In Figure 2-1B, all three items share the same difficulty level, but the item with a higher ability can differentiate participants. In the context of the Visual Acuity Survey, for an item with a higher discriminability, the probability of a yes response increases more rapidly as the ability (θ) increases.

The mirt package from R was employed to build the 2PL model. To obtain the full list of the IRT parameters, we estimated all n/a responses, which were less than 1% of the total responses, based on a preliminary 2PL model built with the incomplete dataset. The parameter estimation between the full and the preliminary model was almost identical (See Appendix Figure A1-1).

After each participant's vision ability (θ) was estimated using the 2PL model, a linear regression was built between the estimated vision ability and VA. The linear function converted each participant's vision ability into an estimated VA. The same linear function was used to convert each item's difficulty level into

an estimated VA threshold. The VA threshold for an item indicates where a participant with the corresponding VA would have a 50-50 probability of responding Yes or No to the item.

Results

Sample Characteristics

Three-hundred-and-eighty-five participants with VA ranging from -0.3 logMAR to 2 logMAR were recruited from four testing sites. Appendix Figure A1-2 shows a histogram of VA. Table 2-1 lists the sample characteristics across the four sites.

Site	N	Gender (Female %)	Age (range, mean (SD))	VA (logMAR, mean (SD))
University of Minnesota	65	62%	18 to 89 (mean = 48.71, SD = 20.7)	0.83 (0.51)
The Ohio State University	151	54%	18 to 90 (mean = 48.32, SD = 18.23)	0.60 (0.38)
Johns Hopkins University	130	54%	20 to 92 (mean = 66.65, SD = 17.61)	0.51 (0.44)
The University of Alabama at Birmingham	39	62%	20 to 93 (mean = 59.18, SD = 21.28)	0.33 (0.36)
All	385	57%	18 to 93 (mean = 55.71, SD = 20.54)	0.58 (0.44)

Table 2-1 Characteristics of the sample.

2PL IRT Results

Figure. 2-2A shows the two distributions of person estimates and item estimates aligned on the same dimension of theta. The mean person estimate for the sample was 0.01 logit (SD = 0.94 logits), ranging from -2.81 logit to 2.03 logit. The item difficulty estimates ranged from -2.65 to 1.29 (mean: 0.81 logit; SE: 0.82 logits). The two distributions overlap between -2.65 logit and 1.29 logit. Eighty-six percent of the person scores had thetas within the range of item difficulties in our survey. The other fourteen percent of the person scores had estimated thetas higher than the item scores with maximum difficulty. The average measured VA

of the 14% of participants was 0.05 logMAR (SD = 0.17), which implies that the 100 items covered the participants with low vision having acuities less than 20/40. In the survey, the most difficult item (b = 1.29) was "Q6. Would you be able to see the eye of a needle if you hold it at arm's length?". The easiest item (b = -2.65) was "Q85. If you are standing in the middle of a parking space in a parking lot, would you be able to see the white lines that border the spot you are standing in?". The two easiest and most difficult examples matched our expectation that the more difficult an item was, the smaller the angular size of the object.

Figure 2-2B shows the relationship between the estimates of item difficulty and item discriminability. The items on the two ends of the distribution of difficulty had lower discriminability than those in the middle. The average item discriminability estimate was 2.91 (SD = 0.76), ranging from 1.43 to 5.45. The item with the highest discriminability was “Q89. If a toothbrush is sitting on the counter in front of you, can you see which end has the bristles?” (a = 5.45). Item Q89 had an estimated difficulty of -1.31 logit. Item Q83, “When holding a soccer ball an arm’s length away, are you able to see the individual black hexagons among the white hexagons that make up the ball?” had the lowest discriminability (a = 1.43) with the estimated difficulty of -2.22 logit.

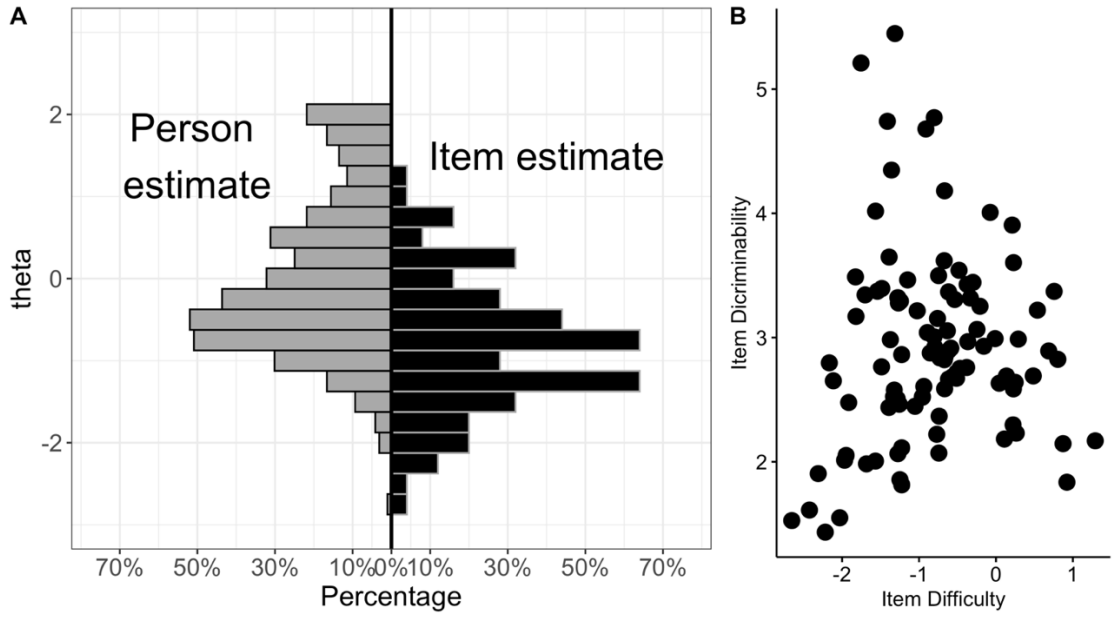

Figure 2-2 Item difficulty and discriminability

(A) The figure shows the distributions of estimated thetas and item difficulty. (B) The scatterplot shows the relationship between the estimated item difficulty and item discriminability.

Figure. 2-3A and 2-3B show the relationship between standard errors and item estimates. In Figure 2-3A, the less difficult items had larger standard errors because there were relatively few participants with very low theta values corresponding to the lowest acuities. In contrast, participants with the highest thetas had higher standard errors because fewer items had high difficulty values corresponding to high acuities. Fewer participants with worse thetas and fewer items with higher difficulties resulted in higher standard errors in our estimates.

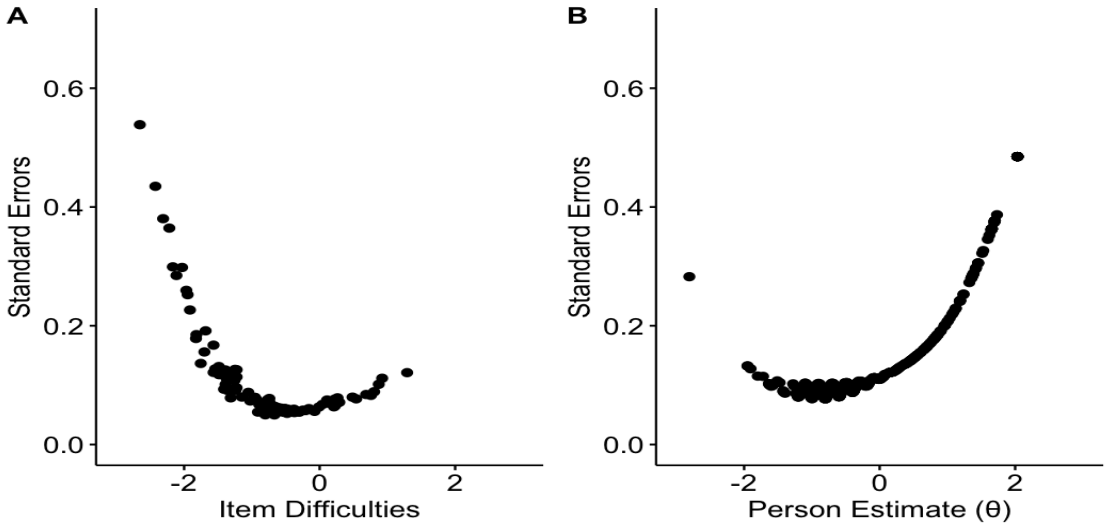

Figure 2-3 Standard errors of item difficulty and discriminability estimate
The two plots show the standard errors of item difficulty and person ability estimates. (A) The left panel shows the relationship between item difficulty estimates and standard errors. (B) The right panel shows the relationship between person estimates and standard errors.

IRT also provides the goodness of fit for items and participants. We evaluated the item fit by using the signed chi-squared test[6]. There were only 5 out of 100 items (Q3, Q32, Q34, Q49, Q50) that had significant S_X2, which indicates that those items had poor fits. Among the five items with the poorest fit, Q49 (Can you see if the person eating dinner directly across the table from you is wearing glasses?) had the lowest fit ($p < .01$). The goodness of person fit in our 2PL model was quantified using the Zh statistic[7]. Zh is a standardized index developed to quantify whether a participant's response pattern fits the built IRT model. Participants who had a Zh value lower than -1.96 or higher than 1.96 were considered misfits. Among 385 participants, 60 participants were considered outliers with poor fits. To keep the consistency of the analysis, the items and participants with poor fits were not excluded in the following analysis.

Estimating visual acuity from person estimates

After estimating each participant's ability (θ), a linear regression model was built between thetas and measured VAs. In the linear model, theta was a significant predictor of measured VAs (slope = -0.33, 95% Confidence Interval (CI) = (-0.37, -0.3), See Figure 2-4). The linear relationship between estimated thetas and measured VAs was used to transform each participant's estimated theta into estimated VA. For example, a person with an estimated theta of 0 would have an estimated VA of 0.59 logMAR.

$$Estimated\ VA\ =\ 0.59 - 0.33\ \times\ \theta \qquad (Eq. 2-2)$$

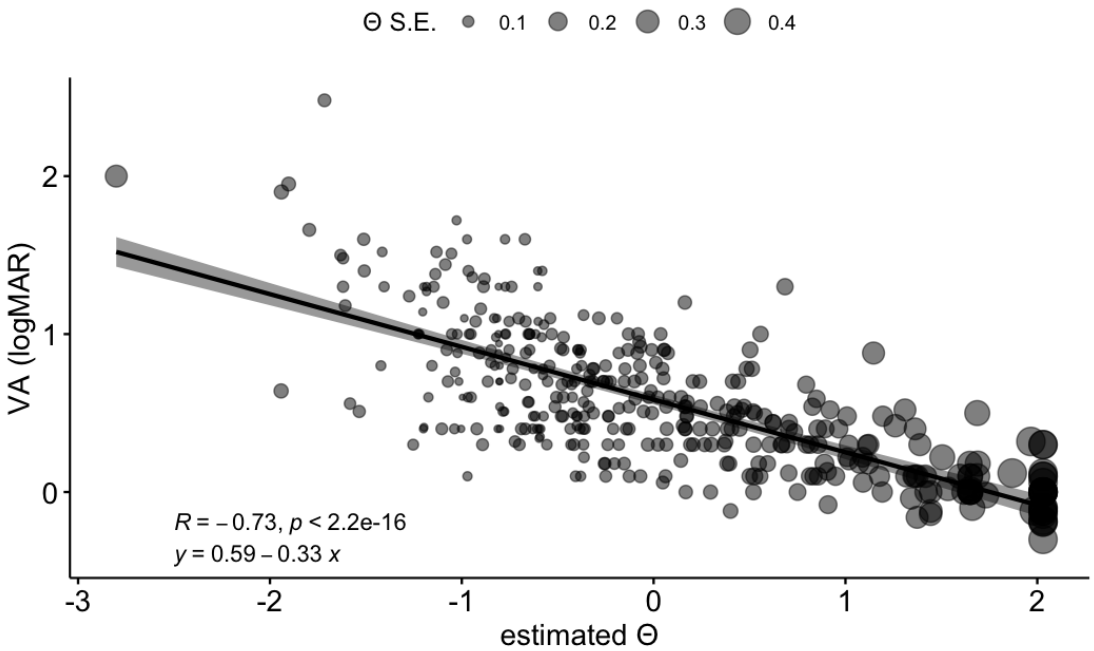

Figure 2-4 IRT personal estimate and measured VA
The scatterplot shows the relationship between person estimates and measured VAs (logMAR). The size of the dots represents the standard error of each participant's person estimate.

Figure 2-5. shows the relationship between the estimated VAs and the measured VAs. There was a significant correlation between estimated VA and measured VA ($r = 0.73$, $p < 0.001$). Prediction errors were calculated by taking the absolute differences between estimated VAs and measured VAs. The average prediction error was 0.23 logMAR (SD = 0.19 logMAR, See Figure 2-6A). A significant positive correlation

was found between the prediction error and measured VAs ($r = 0.33$, $p < 0.001$, Figure 2-6B), which indicates that worse VA was associated with larger prediction errors.

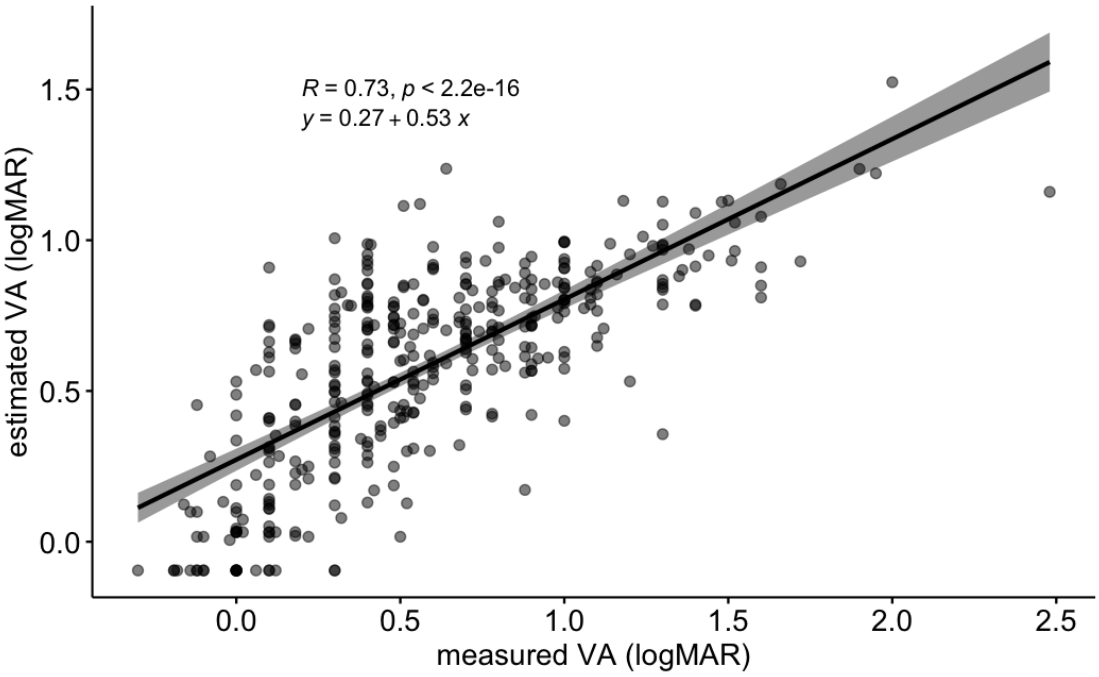

Figure 2-5 Estimated VA and measured VA

The scatterplot shows the relationship between measured VA and estimated VA. Estimated VAs were transformed from person estimates.

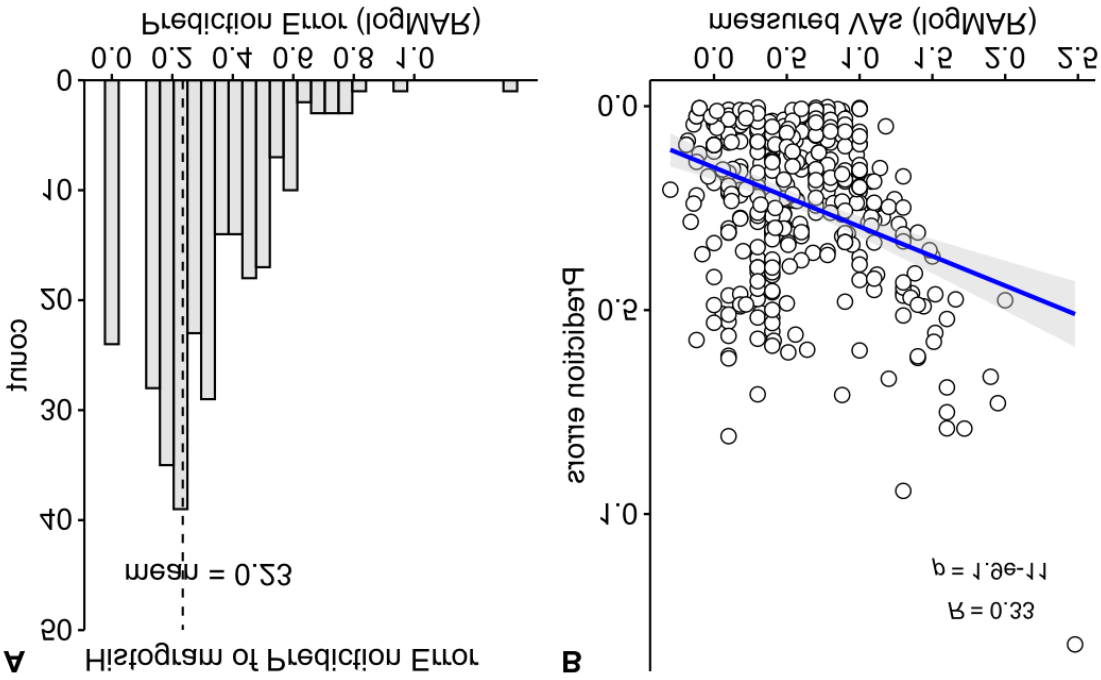

Figure 2-6 Prediction errors

(A) The histogram of prediction errors (logMAR). The prediction errors were the absolute differences between the measured VAs and the estimated VAs. (B) The scatterplot shows the relationship between measured VAs and prediction errors.

VA threshold for items

We can also use the same linear equation (Eq. 2-2) to transform each item's estimated difficulty threshold in logit, where a participant has a 50/50 chance of a yes response, into VA in logMAR. The transformed VA threshold is expected to be where a participant had a 50-50 chance to say yes or no. In other words, if a participant had a VA better than the VA threshold, the participant was more likely to say yes to the item. The item "Q6. Would you be able to see the eye of a needle if you hold it at arm's length?" had an estimated VA threshold of 0.15 logMAR, the highest threshold among the 100 items. The item "Q85. If you are standing in the middle of a parking space in a parking lot, would you be able to see the white lines that border the spot you are standing in?" had an estimated VA threshold of 1.47 logMAR, which was the lowest in the item pool.

Some items had estimated VA thresholds close to some screening criteria. For example, the item "Q2. If you are standing on a sidewalk, would you be able to see an ant that you are about to step on?" had an estimated VA threshold of 0.29 logMAR, which was close to the VA boundary of logMAR 0.33 (Snellen

20/40) often used for impaired vision. Another item, "Q82. When looking at a bunch of bananas on a table in front of you, are you able to count the individual bananas?" had an estimated VA of 1.0 (Snellen 20/200) logMAR, which was close to the criteria for legal blindness in the United States. The threshold VA values for all 100 items are shown in Appendix Table A1-1.

Discussion

The current study aimed to determine if a person's visual acuity can be estimated from self-reported answers to questions about their daily viewing experiences. We designed a questionnaire tool that includes 100 yes/no questions asking if a participant could see an object at a given viewing distance. By estimating participants' abilities to answer the 100 questions using IRT, the result demonstrated a strong correlation (r = -0.73) between measured VAs and estimated abilities. We further transformed the estimated abilities into estimated VAs using the linear relationship between estimated abilities and measured VAs. The average prediction error was 0.23 logMAR.

Several factors may have affected the precision of VA prediction. One factor is increasing prediction errors for participants with VA better than 0.3 logMAR or worse than 1.5 logMAR. In the 2PL model results, the larger standard errors of person and item estimates suggest larger prediction errors for participants with VA on the two ends of the VA spectrum. For participants with normal VA better than 20/40, the Visual Acuity Survey only included a few items that could challenge their visual abilities. For participants with VA close to ultra-low vision, the current study did not include enough participants to accurately calibrate the items with low VA thresholds. However, these issues could be improved by adding more items with high VA thresholds and testing more participants with ultra-low vision in the future. Nevertheless, the current survey includes items covering a wide range of low vision.

Although we designed the questions to target participants' visual acuity, other factors, such as contrast sensitivity, likely had an impact on responses. Xiong et al., (2020) had shown that visual acuity is significantly correlated with contrast sensitivity in low-vision participants with different diagnoses. Although the level of association between acuity and contrast sensitivity varied across different diagnoses, lower acuity was usually expected to accompany worse lower contrast sensitivity. Moreover, an item that might have had a distinct impact from contrast sensitivity was Q. 81, "If you accidentally drop a credit card on the floor,

would you be able to see where it is to pick it up?". When answering the question, some participants asked if they had to consider the color of the card and the flooring. Similarly, Owsley and Sloane, (1987) found that contrast sensitivity was associated with real-life object identification and recognition (i.e., faces, road signs, and commonplace objects.).

The imperfect mapping between the estimated abilities and VAs in the current study might also imply that letter chart acuity is not entirely representative of everyday acuity-related visual tasks. It is already known that different chart optotypes reveal different aspects of visual experience. For example, Wittich et al., (2006) have demonstrated that the differences between resolution acuity, measured by Landolt-C acuity chart, and recognition acuity, measured by ETDRS charts could be 5 lines in patients with macular holes.

Future work

The next step is to develop a computer adaptive testing method (CAT). The current 100-questions tool took 30 to 60 minutes for a participant to complete. A CAT tool could help reduce the duration of estimating a participant's visual acuity by automatically picking more informative items and using less questions. Another possible application would be using some of our items as screening tools for epidemiological studies.

Conclusion

The current study examined the relationship between visual acuity and participants' real-life viewing experiences. By analyzing participants' responses to one hundred questions and using Item Response Theory, we found a strong correlation between the estimated abilities to answer the questionnaire and measured visual acuity. The linear relationship can be used to transform the estimated abilities into estimated visual acuity. The Acuity Questionnaire may be useful in telehealth or other public health studies.

Chapter 3: Online Survey of Digital Reading by Adults with Low Vision

Introduction

By a recent estimate, there are 5.7 million people in the United states with acuity poorer than 20/40 (Chan et al., 2018). For many of them, the primary consequence of their low vision is difficulty reading (Owsley et al., 2009).

The advent of digital media and the ever-expanding variety of digital reading devices on the market have changed people's reading habits. People can now easily access digital materials, such as web pages, e-books, and online user manuals. Hence, digital reading has become a major activity in modern society. A 2010 survey (White et al., 2010) revealed that 83% of normally sighted participants spent more time on digital reading than before. However, over 90% of participants in the same study preferred hard-copy material to digital material for reading (White et al., 2010). While these percentages may have changed, it seems clear that normally sighted readers make use of both digital and hardcopy text.

Current digital devices offer low-vision readers flexibility in customizing the layout and appearance of text. Magnification can be achieved by zooming functions on smartphones and tablets. Laptops and desktop computers with bigger displays can present larger print sizes and in turn can enable a low-vision user to achieve a higher level of magnification. These useful features make digital media more accessible to people with low vision. An online survey of visually impaired people conducted in the UK found that over three-quarters of participants (81%) had a smartphone and almost half of them used tablets (Crossland et al., 2014). Another study showed that normally sighted and visually impaired people were equally likely to own a handheld video device, like an iPad or a PlayStation Portable (Woods & Satgunam, 2011).

Some laboratory studies have demonstrated the benefit of using these digital devices for reading. For instance, people with AMD can read faster on an iPad than on hard-copy paper or an E-book reader when given the same print size across all media, but hard-copy paper was still considered easier to use (Gill et al., 2013). In another study testing reading ability with the iPad in a large group of people with low vision, 87% were able to read a digital news article comfortably by zooming in and changing the contrast polarity (Haji et al., 2014). Morrice et al., (2017) found that only experienced low-vision iPad readers can read as fast as low-vision closed-circuit television (CCTV) readers, but average reading speed was not significantly

different between an iPad and CCTV for non-experienced readers. Helpful built-in features, like zoom and contrast polarity, can possibly make mainstream digital devices accessible to visually impaired users (Irvine et al., 2014).

People with low vision are no longer limited to the use of optical magnifiers but instead have a variety of choices to help them read in their daily lives. Fok et al., (2011) showed that many digital devices and technologies, such as screen magnification software, large monitors, and screen reader software, serve as important and useful assistive technologies for people with low vision. Another online survey conducted by an online community, Web Accessibility In Mind (WebAIM), also reported that people with low vision make use of different assistive features, such as screen readers, zooming and contrast polarity options, to access web content (Web Accessibility In Mind (WebAIM), 2018).

We have reported detailed results from one section of the survey in a separate publication (Granquist et al., 2018). This part of the survey asked participants to view a sample text passage on their primary reading display and report on the viewing distance, screen size, number of lines visible, and number of characters per line. Our goal in obtaining this information was to determine how people with low vision arrange their viewing configuration to achieve adequate magnification. In brief, most of the low-vision participants from our sample achieved their desirable magnification by a combination of two factors: reduced viewing distance compared to normally sighted controls and increased on-screen letter size. A majority (72%) of those who completed this part of the survey relied more on increased on-screen letter size.

The primary aim of our online survey was to understand the reading behavior of people with low vision in the digital era. This report describes findings from our survey concerning what devices people with low vision use for visual reading, their preferred display settings, how much time they spend on different reading activities, and how their acuity affects their choice of device or the amount of time they spend on reading.

Methods

Participants

The research protocol was approved by the University of Minnesota institutional Review Board and followed the tenets of the Declaration of Helsinki. Online consent was provided by each participant before

proceeding to the survey. One hundred and thirty-three participants were recruited by word of mouth and through several visual-impairment related organizations in the United States, such as the American Council of the Blind and Foundation Fighting Blindness. One hundred and twenty-six of our participants were from 33 U.S. states, two from Canada, one from Taiwan, one from Uruguay, and three undesignated. The three most cited states were Minnesota (n = 31), California (n = 9) and Pennsylvania (n = 9). Screening questions ensured that participants were aged 18 or older, read visually in their daily lives for some purposes, and had low vision with no major changes to their vision within the past year. For purposes of this survey, low vision was defined as an acuity of less than 20/60 with best-corrected glasses in the better eye or a visual field less than 20 degrees.

Materials

Participants completed the online survey on their own time and with their own devices between January 2017 and March 2018. The online survey was designed to be accessible by screen-magnification and screen-reading software. The questions used in the survey can be found in the appendix.

The survey consisted of five sections:

1. Demographics: Questions about age, education level, and employment status.

2. Nature and history of low vision: Questions about the participant's cause of low vision, visual acuity, type of visual field loss, if any, and percentage of time spent on visual, audio and braille reading.

3. Usage of assistive devices/technologies: Participants reported the devices they used for visual reading. Two categories of assistive technologies were included in this section: Digital Content Magnifiers and Hard-Copy Magnifiers. Digital Content Magnifiers refer to hardware or software that magnify text within digital materials, such as online webpages, online news, e-books or scanned materials. This category includes smartphones, tablets, E-book readers, laptops, desktop computers and screen magnification software installed on laptops or desktops.

Hard-Copy Magnifiers include devices that are designed for reading hard-copy materials, such as printed books, newspapers, medicine labels and food packaging. This category includes optical magnifiers (handheld, stand, and mounted on glasses), CCTVs, and portable handheld electronic magnifiers. Magnification apps on mobile devices were included in this category because these apps use the built-in camera to magnify hard-copy text.

4. Assessment of Magnification: The participant viewed a paragraph of text from Alice in Wonderland on their chosen reading display and reported properties of viewing configuration, including the viewing distance, dimensions of the display, and the number of characters on a line. These data were used to estimate the roles of viewing-distance magnification and letter-size magnification in relation to the participant's acuity. Detailed findings from this section of the survey were reported in Granquist et al., (2018) and will not be further described here.

5. Reading habits: Participants rated how much time they spent on several categories of reading in digital or hard-copy format in the past year, using a five-point scale -- 1 = rarely or never; 2 = occasionally, once a week or less; 3 = frequently, at least a few days per week; 4 = almost every day, at least once; and 5 = daily heavy use. Five different activities were (I) Work or educational reading, (II) News reading, (III) Pleasure reading of books or articles, (IV) Spot reading, such as recipes, food labels, restaurant menus, phone numbers, TV listings, etc., and (V) Social networking, such as email communication and social media. For all except social networking, participants provided separate ratings for hard-copy and digital reading. Participants who learned to read prior to the onset of low vision were also asked to provide ratings for their reading habits while they had normal vision, but these data on reading with normal vision are not included in this report.

Results

Characteristics of the Participant Sample

The mean age of our 133 participants was 46.03 (SD = 17.42, Median = 48, range: 18 to 98). Most of the participants reported acuity as Snellen ratios. We converted these values to corresponding logMAR values for purposes of calculation. The average self-reported binocular acuity was 0.93 logMAR (SD = 0.35 logMAR, range: 0.1 to 1.6 logMAR) from a subgroup of 106 participants providing numerical acuities. Fifty-four percent of our participants reported that they experienced nystagmus. The group with nystagmus had a significantly worse average acuity (0.99 logMAR, SD = 0.31) than those without nystagmus (0.85 logMAR, SD = 0.39, t (78.11) =2.01, $\boldsymbol{P} < .05$). We did not find important differences in our other measures between the participants with and without nystagmus. Forty-six percent of participants reported they had peripheral-field vision loss, 14% had central-field loss, and 38% had no visual field loss. Nine percent of our participants reported they had hearing loss.

Participants were asked to report the cause(s) of their low vision. The three most common causes were albinism (36), retinitis pigmentosa (RP) (20), and glaucoma (15). Twelve participants listed multiple causes of their low vision. Table 3-1 lists the self-reported diagnoses.

Seventy-five percent of the participants identified as female, and 78% of them had a college/university degree or higher. Forty-nine percent of them were employed, 30% were unemployed, and 21% were retired. Sixty-three percent had low vision since birth, 14% developed low vision before 18 years old and 20% had late onset low vision after age 18. The late-onset group had better average acuity (mean: 0.63 logMAR, SD: 0.36) and was older (mean: 61.8, SD: 12.92) than the rest of the sample.

Causes	n	Causes	n
Albinism	36	Cone-rod dystrophy	4
Retinitis Pigmentosa	20	Stargardt's disease	3
Glaucoma	15	Uveitis, inflammatory and autoimmune diseases	3
Miscellaneous retinal disorders	11	Achromatopsia	2

Retinopathy of prematurity	10	Other macular disorders.	2
Optic nerve disease	9	Multiple sclerosis	1
Cataract	8	Traumatic brain injury	1
Anterior segment (meaning cornea, lids, etc.)	7	Unknown	9
Age-related Macular Degeneration	6		

Table 3-1 Reported diagnoses.

Number of Participants Reporting Diagnoses: Unknown includes those who did not report a cause, or the responses were not specific (e.g. poor vision, genetics, inherited genetic factors, etc.)

To assess the reliability of self-reported acuities, we assembled data for 20 participants for whom we had both self-reported acuities and lab-measured acuities. Figure 3-1 shows a scatterplot of the values. The mean difference was 0.03 logMAR (SD = 0.18), and the mean absolute difference was 0.13 logMAR (SD = 0.11). The correlation between the two measures was 0.93 ($p < .001$). Our results were similar to our analysis of findings from Zhao et al., (2017) for 17 participants with low vision—mean difference between self-reported and measured acuity was 0.06 logMAR (SD = 0.24), and mean absolute difference was 0.16 logMAR (SD = 0.18). The generally good agreement between self-reported and lab-measured acuities gave us confidence in using self-reported acuities in additional analyses.

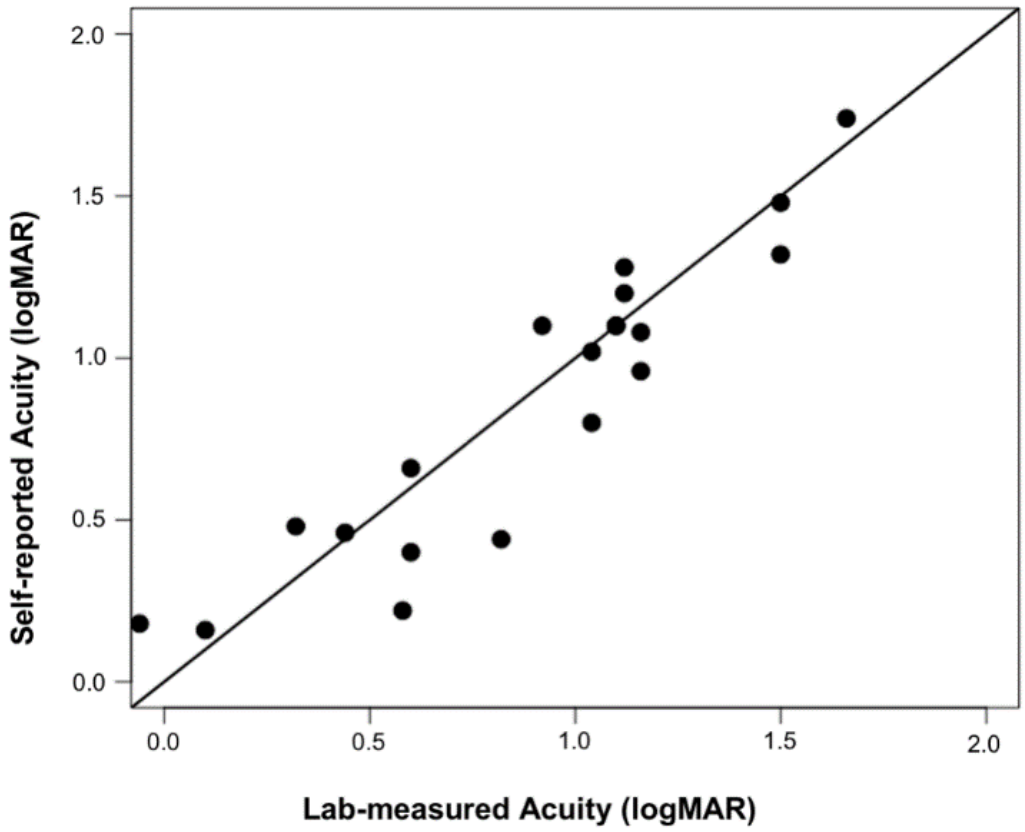

Figure 3-1 Self-reported VA and measured VA
The scatterplot shows the relationship between self-reported visual acuities and lab measured visual acuities from a sample of 20 participants. The solid, diagonal line represents equality between the two measures.

Reading Habits:

In Section 2 of the survey, we asked our participants how they distributed their daily reading between visual, auditory and braille sources. Figure 3-2 plots the proportion of visual reading as a function of acuity. Averaged across all participants, 64% of reading was visual, 33% was auditory and 3% was braille. Twenty-two participants reported some braille reading, ranging from 1% to 60% of their total reading. Only seven of them did more than 10% of their reading with braille. For a subgroup of participants with self-

reported hearing loss (9%), the proportion of reading time on the three modalities was not different from the rest of the sample.

A chi-square goodness-of-fit test revealed that the number of participants who spent more than 50% on visual reading (n = 101), was significantly greater than the number who spent more than 50% of time on auditory reading (n = 31) or Braille reading (n = 1) ($\chi^2(2) = 118.8$, $\boldsymbol{P} < .001$). The effect size (Cohen's W) was 0.95. Forty-four percent of our participants did more than 75% of their reading visually (Vision Primary subgroup), and only 11% did less than 25% of their reading visually (Nonvisual subgroup). The Vision Primary subgroup had a better average acuity (mean: 0.82 logMAR, SD = 0.3 logMAR) than the Nonvisual subgroup (mean: 1.18 logMAR, SD = 0.31 logMAR, $t(11.58) = 3.18$, $\boldsymbol{P} < .01$), with Cohen's effect size (d) value of 1.18.

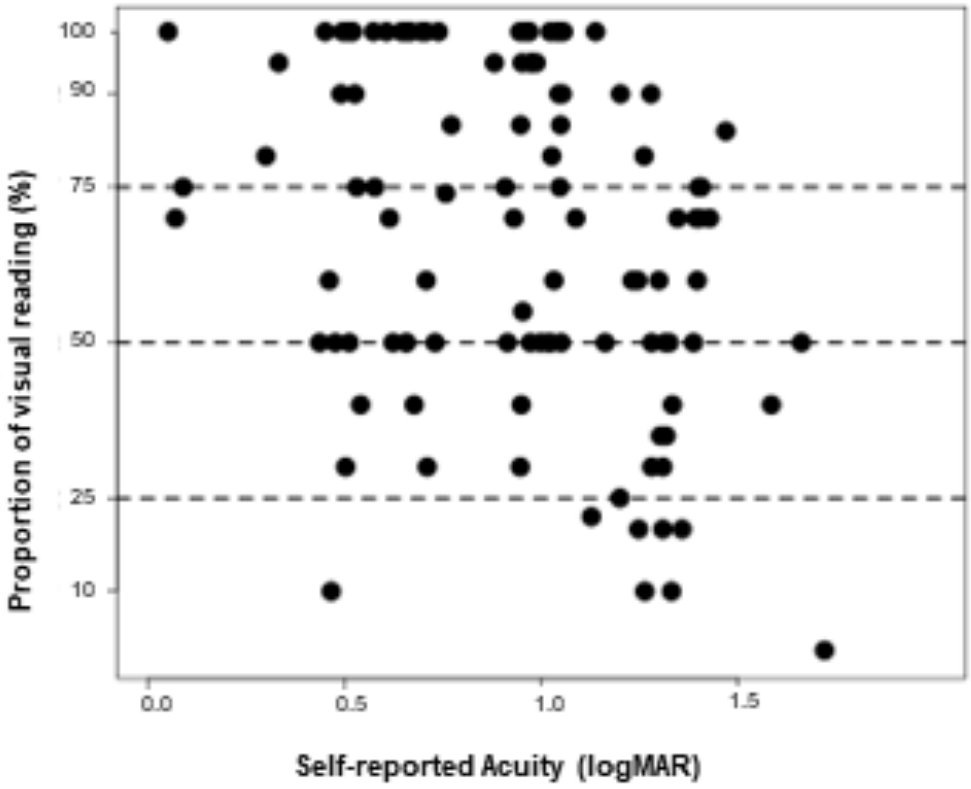

Figure 3-2 Proportion of visual reading and VA

The scatterplot shows the proportion of visual reading as a function of self-reported acuity for 106 participants. The three dashed horizontal lines represent 75%, 50%, and 25% of time spent on visual reading.

A multi-variate logistic regression model revealed that acuity (but not age or education level) was a predictor of whether a participant would spend more than 75% of reading time on visual reading (Vision Primary Group, coef: -2.12, $\boldsymbol{P} < .01$, Appendix Table A3-1). The negative coefficient of acuity means that better acuity was associated with a greater probability of 75% or more visual reading. Thirty-seven participants in the Vision Primary Group had an acuity better than 1.0 logMAR, and 5 had an acuity worse than 1.0 logMAR.

In Section 5 of the survey, we were interested in both the overall amount of visual reading and the differences between hard-copy and digital reading. For four of the five activities, more than half of our

participants reported that they used digital reading on a daily basis (ratings 4 or 5)—work/education (65%), news reading (50%), spot reading (59%) and social networking (77%). Fewer (44%) reported using digital reading for pleasure on a daily basis (ratings 4 or 5). Clearly, this group of low-vision participants engages in extensive daily use of digital reading. Figure 3-3 shows the proportion of ratings on each activity.

Wilcoxon signed-rank tests showed that our participants spent significantly more time on digital reading than hard-copy reading across all four reading activities—Work/Educational reading ($Z = -5.44$, $\boldsymbol{P} < .001$, effect size (r) $= 0.47$), News reading ($Z = 6.5$, $\boldsymbol{P} < .001$, effect size (r) $= 0.57$), Pleasure reading ($Z = -4.44$, $\boldsymbol{P} < .001$, effect size (r) $= 0.38$), and Spot reading ($Z = -5.16$, $\boldsymbol{P} < .001$, effect size (r) $= 0.45$).

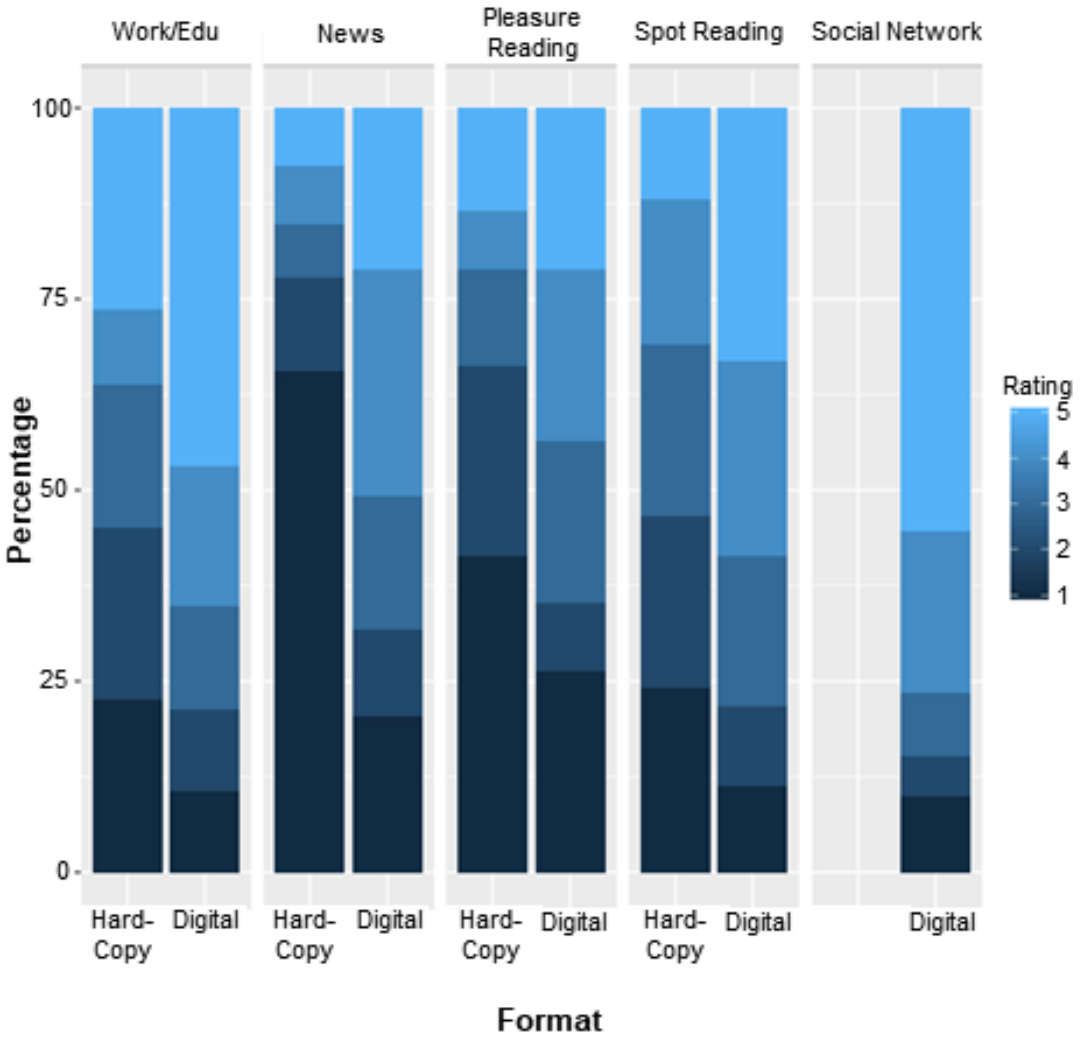

Figure 3-3 Digital reading and Hard-copy reading

The stacked bar plot shows the percentage of participants providing each of the ratings from 1 to 5 on the y-axis. The x-axis represents the five activities listed in the survey with separate bars for Hard-Copy and Digital reading. The darker color represents lower rating, which refers to less time spent on a specific activity.

Assistive Devices

In Section 3 of our survey, participants reported the devices they used for visual reading (Table 3-2). The devices can be categorized into two groups: Digital Content Magnifiers and Hard-Copy Magnifiers. Most of our participants (98%) used two or more devices for visual reading. Ninety-four percent of them reported using at least one type of Digital Content Magnifier, and 95% used at least one Hard-Copy Magnifier. Eighty-nine percent of our participants used devices from both categories. The three most frequently reported devices all came from the Digital Content Magnifier category: smartphones (69%), screen magnification software (62%), and tablets (59%). The two least used devices were in the Hard-Copy Magnifier category: stand magnifiers (10%) and magnifiers mounted on glasses (16%). Additional analysis revealed that 87% of our participants used either laptop or desktop computers for visual reading. For this group of laptop and desktop users, 68% of them used magnification software on their computers. Eighty percent of our participants used either a smartphone or tablet, and 44% of these smartphone or tablet users used magnification apps.

Digital Content Magnifiers	
Smartphone	69%
Screen magnification software	62%
Tablet	59%
Desktop Computer	58%
Laptop	56%
E-book reader	35%
Use at least one device in the category	94%
Hard-Copy Content Magnifiers	

Handheld magnifier	55%
CCTV	47%
Portable Handheld Electronic Magnifier	44%
Telescope	42%
Magnification apps	41%
Magnifier mounted on glasses	16%
Stand magnifier	10%
Use at least one device in the category	95%

Table 3-2 Usage of assistive technology
The table lists Percentage of participants using various types of devices

We used logistic regression to explore the use of acuity, education and age in predicting device usage. The only significant relationship occurred for acuity and whether a participant used a CCTV (Appendix Table A3-2). The coefficient of the logistic model was statistically significant (coef. = 2.45, $P < .001$).

Preferred text characteristics

We asked our participants about their preferences for contrast polarity and font. Thirty-nine percent reported that they preferred black text on a white background. A larger group of participants (46%) preferred reversed contrast (white text on a black background), and 14% of participants had no preference for contrast setting. On average, the group that preferred reversed contrast had significantly worse acuity (1.03 logMAR, SD = 0.35) than the group who preferred black-on-white (0.82 logMAR, SD = 0.33) ($t(85.86) = 2.86$, $\boldsymbol{P} < .01$). For the three largest diagnostic categories in our survey (Table 3-1), the number of participants preferring standard contrast (black-on-white) and reversed contrast (white-on-black) were—albinism (16 and 15), RP (5 and 13), and glaucoma (3 and 8), respectively. Although there were only 6 participants with AMD in our group, 5 of them preferred black-on-white contrast.

We also asked our participants to report their preferred font type, if any. Only 51 participants expressed a preference for one or more fonts. The most frequent fonts reported were Arial (n = 37), Times New Roman (n = 16), and Verdana (n = 7) (Table 3-3).

Contrast Polarity Preference	**n = 133**
Black Text on White Background	39%
White Text on Black Background	46%
No Preference	14%
Not Answered	1%
Font Preferences	**n = 51**
Sans Serif font types	
Arial	37
Verdana	7
Any Sans Serif font	6
Helvetica	4
APHont	3
Comic Sans	3
Calibri	3
Serif font	
Times New Roman	16

Table 3-3 Preferred text characteristics

Discussion

Our goal in the current study was to learn about visual-reading activities by people with low vision and the devices they use. Given the growing availability of text in audio formats and technology for text-to-speech and text-to-braille, we wondered if our participants might show diminished reliance on visual reading as a whole. To the contrary, four of our findings indicate the continuing importance of visual reading to low-vision individuals. First, for all five categories of digital reading activities in our survey, our participants reported substantial visual reading. For four of the five categories (pleasure reading excepted), they read daily.

Second, there was a high rate of adoption of multiple visual-reading devices (by more than 90% of our participants), and 89% had at least one aid from our two main categories (digital-content devices and hard-copy reading devices.) Third, vision was the primary reading modality for most of our participants, even for many with moderate to severe acuity loss. Presumably, those with low acuity who continue to read visually make use of high magnification.

Fourth, we found that our participants spent significantly more time reading digital text than hard-copy text across the different activities listed in our survey. This result is similar to the trend found in the normally sighted population (White et al., 2010). The growing range of digital materials enhances text accessibility for visually impaired people. The expansion of built-in features, such as screen magnification, the ability to adjust print size and contrast polarity, makes digital reading more accessible than hard-copy reading.

These findings reinforce our view of the importance of continued research on low-vision reading in the digital era and ongoing efforts to enhance the visual accessibility of text.

Devices and Technologies Used

Our findings on everyday reading activities indicated that more time was devoted to digital reading than hard-copy reading. The overall most used devices (Table 3-2) were from the Digital Content Magnifier category: smartphones (used by 69% of our participants), screen magnification software (62%), and tablets (59%). By comparison, the two least used devices were from the Hard-Copy Magnifier category: stand magnifiers (10%), and magnifiers mounted on glasses (16%).

Despite a smaller screen size, smartphones were the reading devices used most frequently by our participants. The popularity of smart devices, like smartphones and tablets, among both normally sighted and visually impaired individuals may indicate that the features of accessibility built in those devices facilitate their use for reading despite their small displays. Crossland et al., (2014) found an even higher adoption of smartphones in a survey of visually impaired users (81%), but their survey focused on general use and not specifically on visual reading. For our participants, it is likely that smartphones were used for spot reading tasks, and not for continuous reading. In support of this conjecture, in the portion of our survey described by Granquist et al., (2018) we asked our participants to report on the device used for reading a sample passage

from *Alice in Wonderland.* For the 75 participants who completed this portion of the survey, 60 used a desktop or laptop computer, 10 a tablet, two a CCTV and only three a smartphone. Moreover, Crossland et al., (2014) found that most of their visually impaired participants used smartphones for text messaging (90%) and internet browsing (80%), which are spot reading tasks.

Despite the shift to digital reading, our participants continue to read hard copy materials. Ninety-five percent of our participants reported using at least one type of Hard-Copy Magnifier for visual reading. Additionally, almost half of our participants reported using CCTVs, which are designed for reading hard-copy materials. Our analysis showed that participants with worse acuities were more likely to use a CCTV for visual reading.

Preferred Text Characteristics

Our participants included a surprisingly large number (46%) who preferred reversed-contrast text (white letters on a black background) compared with 39% who preferred standard black-on-white text. It has long been known that some people with low vision read better with reversed-contrast text.(Legge et al., 1985; Silver, 1978). Legge (2007b) reviewed research indicating that participants with cloudy ocular media (from cataract, corneal damage or vitreous debris) sometimes have better reading performance with reversed-contrast. In the current study, nine of fifteen participants with cataract or other disorders with cloudy ocular media reported a preference for reversed contrast. Many in our largest categories—albinism, RP and glaucoma— also reported a preference for white-on-black text. The preference of reversed contrast could be the result of photophobia, which is a common symptom shared by people with albinism (Pérez-Carpinell et al., 1992) and retinitis pigmentosa (Gawande et al., 1989). Ehrlich (1987) has reported that 21 of 23 patients with severe retinitis pigmentosa read better with reversed-contrast text. We note that our participants who preferred reversed contrast had overall poorer acuity than the remaining participants. We also note that five of our six AMD participants preferred regular black-on-white text. Further study would be required to determine if preferences correlate highly with measurable properties of reading performance such as reading speed or critical print size.

Although only 51 participants expressed font preferences, the Arial font family was the most cited font style (Table 3-3). This finding coincides with the guideline for large-print documents recommended by

the American Council of the Blind (American Council of the Blind, 2011) which suggests using sans-serif fonts such as Arial. Only 3 of our participants mentioned the APHont font, which was designed for low vision by the American Printing House for the Blind (American Printing House for the Blind, 2001). None of our participants mentioned Tiresias, a font designed by the Royal National Institute of Blind People in London. Previous studies have been unable to demonstrate a consistent benefit of specially-designed fonts for low vision or for specific mainstream fonts (Legge, 2007a; Woods & Satgunam, 2011; Xiong et al., 2018) There is some evidence, however, that fonts with increased between-letter spacing, such as courier, can be helpful (Pelli et al., 1985; Tarita-Nistor et al., 2013; Xiong et al., 2018).

Study Limitations

We address three significant limitations of our study.

First, we acknowledge that our low-vision sample is not representative of the low-vision population as a whole. In contrast to patients visiting low-vision clinics, many of whom are older and have macular degeneration (Goldstein et al., 2012), a majority of our participants had early-onset low vision, more had peripheral-field loss than central-field loss, and most of them had a college degree or higher. Our online survey targeted a group of people who are familiar and comfortable with computer technology and who make regular use of digital reading in their daily lives, and as such the current study provides information about visual reading among a technologically savvy group of people with low vision. The characteristics of our sample were similar to the sample composition of other online survey studies aiming for understanding the technology usage among people with low vision (Crossland et al., 2014; Web Accessibility In Mind (WebAIM), 2018). One advantage of an online survey over a clinic-based survey is the possibility of reaching people who do not have easy geographical access to a low-vision clinic. It is certainly possible that access to low-vision aids and also access to digital content might depend on rural vs. urban residency or other geographical variables. Our study shares with most clinical studies the difficulty in recruiting a truly representative sample of low-vision participants.

Second, in some cases, we have related our findings to the visual acuities of our participants. In so doing, we have relied on self-reports rather than direct clinical data, an inherent limitation of a survey study. It is known that self-reported subjective ratings of vision status are influenced by non-visual factors such as

race and socioeconomic status (El-Gasim et al., 2012; Quandt et al., 2016; Whillans & Nazroo, 2014). These studies asked participants to rate the quality of their vision on a numerical scale (1-10) or using descriptors such as Excellent, Fair and Poor. We did not ask our participants to make subjective ratings of their vision, but to report acuity scores, presumably obtained from their eye doctors. Our sample of low-vision participants tended to be fairly young and well-educated. Most (81%) reported an eye exam within the past year, and our eligibility criteria included stable vision over the past year. Furthermore, we encouraged our participants to check their clinical records or check with their eye doctor to acquire their visual acuity if they did not know it. These are factors which contribute to reliable self-reporting of eye conditions. Compared to the findings of Kiser et al., (2005), on repeat reliability which reported that the criterion for a significant change in low-vision acuity should be two to three lines (0.2 – 0.3 logMAR), our data shown in Figure 3-1 from a sample of 20 low-vision participants from whom we have both self-reported and lab measurements showed a mean absolute difference of only 0.13 logMAR. Nevertheless, we acknowledge that the self-reported clinical information is likely to be noisier than corresponding clinical or laboratory data. The 95% limit of agreement (LoA) in our 20-participant data was 0.35 logMAR, which is larger than the range of 0.2 to 0.3 logMAR found in the Kiser et al., (2005). Factors contributing to inaccuracy in reported acuity would include changes since the last clinic visit, inaccuracies in the clinical measurements themselves, and faulty memory. In addition, we converted visual acuities, reported as Snellen ratios, into logMAR units for the purpose of calculation and for the journal's international readership. It is likely that the acuities reported by our participants may have often been measured with Snellen charts rather than logMAR charts, contributing noise to our data.

Finally, given the rapid progress in the digital distribution of information and the continuing development of assistive technology, we recognize that our findings provide only a fleeting snapshot of the ecology of low vision reading. It will be valuable to compare our results with similar data in future years.

Despite these limitations, our study sheds light on the reading behavior of an online group of people with low vision in the current digital era. Given the increasing number of low-vision individuals and the popularity of digital content, our findings reinforce our view of the importance of continued research on low-vision reading and ongoing efforts to enhance the visual accessibility of text at the design stage.

Chapter 4: The early impact of the COVID-19 pandemic on social isolation in older adults with vision loss or hearing loss

Introduction

In 2020, the global COVID-19 pandemic resulted in drastic changes to our lives. In an effort to mitigate the transmission of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2 virus), public health officials recommended social distancing, wearing masks, cleaning, disinfecting, and isolating infected people. During different of the year, shelter-at-home orders were implemented to prevent overwhelming local health care systems. The coronavirus disease of 2019 (COVID-19) disproportionately affected the older population. Older individuals had to take more precautions to avoid severe illness and fatalities. These precautions may have resulted in greater social isolation and loneliness in older adults. Prior to the pandemic, older adults with sensory loss, especially vision loss or hearing loss, have been shown to experience higher social isolation and loneliness (Choi et al., 2018; Hajek et al., 2020; La Grow et al., 2009; Loh & Ogle, 2004; Mick et al., 2014; Sand et al., 2013; Shukla et al., 2020; Tetteh et al., 2020; Weinstein & Ventry, 1982). Our study was designed to determine the impact of the pandemic on social isolation in older adults with sensory loss.

Visual impairment and hearing loss are more prevalent in the older population. It is estimated that the prevalence rate of binocular visual acuity worse than 20/40 or blindness is less than 1% between 18 and 54 years in the United States (U.S.), but the prevalence rises to approximately 6% in the population older than 65 years (Chan et al., 2018; Flaxman et al., 2021). Similarly, the estimated prevalence of bilateral hearing loss (worse than 25 decibels (dB HL)) is less than 6% in younger people between 20 and 40 years in the U.S. and rises to at least 45% in older adults over 60 years (Lin et al., 2011). The estimated prevalence rate of both visual and hearing impairment (or dual sensory loss) in people older than 70 years is about 2.2% in the U.S. (Swenor et al., 2013).

Visual impairment and hearing loss can result in social isolation and loneliness. Social isolation is often measured by the frequency of social interactions and the complexity of social networks. Although people who are socially isolated do not necessarily feel lonely, social isolation is often closely associated with loneliness. The behavioral causes of social isolation in older people with sensory impairments are

complicated and differ between vision and hearing loss. Visual impairment can lead to difficulties in mobility, limiting opportunities for employment and education, commerce, recreation, and other types of social interaction. For people with hearing loss, difficulties with speech understanding can cause withdrawal from noisy social gatherings. Social isolation and loneliness are also two risk factors associated with higher mortality (Eng et al., 2002; Steptoe et al., 2013), cardiovascular disease (Barth et al., 2010), and cognitive decline (Bassuk et al., 1999) in the older population. Greater social isolation and loneliness are more prevalent in older adults with vision loss (Choi et al., 2018; Hajek et al., 2020; La Grow et al., 2009; Loh & Ogle, 2004; Sand et al., 2013; Tetteh et al., 2020) or hearing loss (Mick et al., 2014; Shukla et al., 2020; Weinstein & Ventry, 1982) compared to older adults without sensory loss. Greater social isolation and loneliness are also associated with depression and anxiety among older adults with sensory loss (Andrade et al., 2018; Brunes & Heir, 2020; Dawes et al., 2015; O'Donnell, 2005; Shukla et al., 2020; Tetteh et al., 2020).

Although past studies have indicated that social isolation and loneliness are more prevalent in older people with vision or hearing loss, it is unclear how these problems have interacted with the public health measures associated with the COVID-19 pandemic, such as the stay-at-home orders or mandatory face coverings. A few studies have tried to determine the impact of the pandemic on people with vision or hearing loss. A national survey led by the American Foundation for the Blind, conducted early in the pandemic, demonstrated that older participants with vision loss worried more about the psychological impact of social distancing than younger participants (Rosenblum et al., 2020). However, Dunn et al., (2020) showed that cochlear implant participants reported less social isolation during listening situations and less anxiety related to their hearing loss in the early pandemic compared to pre-pandemic times. A possible explanation is that the auditory environments were less noisy during the pandemic when large social gatherings were limited.

Although the above studies have shown the impact of the pandemic on adults with sensory loss, no studies have been done to demonstrate how older people with hearing or vision loss adapted to the early months of the pandemic. We designed this study to determine the impact of the COVID-19 pandemic on older adults with vision and hearing loss from March to October 2020. Our three major research questions were:

1. Were older adults with vision and hearing loss more socially isolated during the pandemic, as compared with before the pandemic?

2. What were the immediate and longitudinal impacts of the pandemic on daily activities for older adults with vision or hearing loss?
3. For older adults with sensory loss, did mental health ratings decline during the pandemic compared to before the pandemic?

We hypothesized that older adults with and without sensory loss would experience higher social isolation and poorer mental health after the pandemic started, but the magnitude would be more pronounced for individuals with vision and hearing loss compared to individuals without sensory loss. We also anticipated that individuals with vision loss would become less independent in their daily lives during the pandemic.

Methods

Participants

Our research protocol was approved by the University of Minnesota Institutional Review Board and followed the tenets of the Declaration of Helsinki. All participants provided written consent electronically before participating in the study. Three groups of older participants, fifty-five in total, were recruited from lists of past participants in several labs at the University of Minnesota, referrals from collaborative audiologists, and the local community. Participants were residents in the Twin Cities area in Minnesota, United States. The range of age was 57 to 80, with a mean age of 68.2 years (Table 4-2). The participants were categorized into three groups by their major types of sensory loss -- (1) vision loss (VL, N = 13), (2) hearing loss (HL, N = 24), and (3) control group (CTL, N = 18). The vision loss (VL) group participants were legally blind (visual acuity worse than 20/200). Five of the VL participants (38%) were totally blind or had only light perception. Half of the hearing loss (HL) group used hearing aids, and the other half had cochlear implants. All the hearing aid participants had bilateral hearing aids, and seven of the cochlear implant users (58%) had bilateral cochlear implants. The participants in the control (CTL) group did not have significant hearing or vision loss, based on self-reports.

Procedure

Participants were interviewed over phone or video conferencing by the research team every 5 to 7 weeks between the end of April and the end of October in 2020 (Pandemic session 3 to Pandemic session 6, See Table 4-1). The average time between sessions was 41.83 days (SD: 7.53). During the first interview

session in late April or early May, participants responded to the surveys based on their recollection of their living conditions in the first week of March (Pre-pandemic session) and the first week of April (pandemic session 2, PAN2). Some context information was given to help participants recall their daily lives during those periods, such as that the first case reported in Minnesota was on March 6th and the statewide shelter-in-place order began on March 28th, 2020. The PAN1 and PAN2 sessions were conducted during the stay-at-home order.

Session number	**Testing Period**	**Notes**
PRE (retrospective)	March 1st, 2020, to March 7th, 2020	Pre-Pandemic session
PAN1 (retrospective)	April 1st, 2020, to April 7th, 2020	Early Pandemic session
PAN2	M = May 12th, 2020 April 28th, 2020, to June 10th, 2020	During-Pandemic session
PAN3	M = June 17th, 2020 June 4th, 2020, to July 21st, 2020	During-Pandemic session
PAN4	M = July 30th, 2020 July 20th, 2020, to September 10th, 2020	During-Pandemic session
PAN5	M = September 10th, 2020 September 26th, 2020, to October 29th, 2020	During-Pandemic session
PAN6	M = October 21st, 2020 October 1st, 2020, to November 12th, 2020	During-Pandemic session

Table 4-1 Testing timestamps for each session.

The Pre and PAN1 sessions were retrospective sessions in which participants were asked to recall their daily lives within the same interview. M represents the median date of each non-retrospective session.

Materials

We designed two surveys -- (1) intake and (2) main survey. All participants completed the intake survey during their first interview. During the same interview, all participants completed the main survey for the PRE time period (Table 4-2). The main survey was repeated in all subsequent sessions (PAN1 through PAN6). The two surveys and the data are available at the Data Repository of the University of Minnesota (https://doi.org/10.13020/vmd2-pa76).

The intake survey covered basic demographic information about our participants including age, gender, race, types of sensory loss, extent of sensory loss, and underlying medical conditions. In the intake survey, participants' cognitive function was evaluated with the Mini Montreal Cognitive Assessment without visual elements (Mini-MoCA) to ensure that they had normal cognitive functioning to recall their daily activities. Every participant had a score higher than 11 out of 15 (Nasreddine et al., 2005).

The main survey consisted of 6 sections --

(a) Demographic information: Participants reported their living situation, employment status, and known COVID infections among their family, friends, or neighbors since their last interview.

(b) Social contacts and isolation: Participants reported the number of in-person and electronic contacts in the past week, referring to the number of separate individuals contacted. In-person interactions were limited to interactions within 6 feet, and only video/voice calls (not emails/text messages) were considered as electronic interactions. Participants rated their satisfaction level with the two types of interactions on a five-point scale. Participants were also asked to report the average hours they spent alone in the past week and rate their sense of loneliness on a five-point scale.

(c) Access to daily needs and services: Five different daily activities were listed in this section-- (1) access to pandemic information, (2) access to medical services, (3) access to essential needs and groceries, (4) transportation methods, and (5) access to support groups and services. For each activity, participants were asked to report what methods they relied on and rate how accessible those methods were.

(d) Worry Questionnaire: Participants rated their worry levels about five conditions related to the changes during the pandemic on a five-point scale. The five conditions were -- (1) I worry that I will contract the virus, (2) I worry that I won't be able to get my essential needs, (3) I worry that it's hard to keep social distance, (4) I worry that it's hard for me not to touch things, and (5) I worry that it can be difficult to understand someone talking to me when they are wearing a face mask.

(e) Mental Health Assessment: We used the Patient Health Questionnaire-9 (PHQ-9) to evaluate each participant's mental health (Löwe et al., 2004).

Two Generalized Estimating Equation (GEE) models were used to evaluate the immediate and longitudinal impact of the pandemic on the four main dependent variables (DVs): the number of in-person social contacts, the number of electronic social contacts, the PHQ-9 scores, and the self-reported sense of loneliness. The first GEE model was applied to the pre-pandemic session (PRE) and the first pandemic session (PAN1) in order to determine the immediate impact of the pandemic on the four DVs. The second GEE model included all pandemic sessions (PAN1 to PAN6) to evaluate the longitudinal impact of the pandemic on the four DVs. Types of sensory loss, time, and the interaction between time and types of sensory loss were the three main predictors included in the two models for our main research questions. The two models were adjusted for demographic variables--gender, age, education level, living alone or not, employed or not, and if the participant had COVID-related health risk factors. The results of the GEE models can be found in the appendix (Appendix Table A4-1 to A4-4). In addition to the GEE models, Kruskal-Wallis tests were used to determine the baseline differences between the three groups in the pre-pandemic session.

Results

Characteristics of the sample

Table 4-2 lists the breakdown of the three groups by gender, education, living alone or not, MoCA score, and COVID-related underlying health conditions.

	All	Vision Loss (VL)	Hearing Loss (HL)	Control (CTL)
N	55	13	24	18

	All	Vision Loss (VL)	Hearing Loss (HL)	Control (CTL)
Age - Mean (SD)	68.18 (6.71)	62.92 (6.1)	71.38 (5.79)	67.72 (5.98)
Gender – N (%)				
Male	22 (40%)	8 (62%)	7 (29%)	7 (39%)
Female	33 (60%)	5 (38%)	17 (71%)	11 (61%)
Mini MoCA[1] score – mean (SD)	13.56 (1.42)	14 (1.47)	13.42 (1.41)	13.44 (1.42)
Living Situation (Alone)	18 (33%)	7 (54%)	5 (21%)	6 (33%)
Education Level				
High School	3 (6%)	2 (15%)	1 (4%)	0 (0%)
University/College	26 (47%)	7 (47%)	14 (58%)	5 (28%)
Graduate/Professional Degree	26 (47%)	4 (38%)	9 (38%)	13 (72%)
Underlying Health Conditions				
Diabetes	6 (11%)	4 (31%)	2 (8%)	0
Chronic lung disease	1 (2%)	0	0	1 (6%)
Cardiovascular disease	7 (13%)	2 (15%)	2 (8%)	3 (17%)
Immunocompromised condition	1 (2%)	0	0	1 (6%)
Chronic renal disease	1 (2%)	0	0	1 (6%)

	All	Vision Loss (VL)	Hearing Loss (HL)	Control (CTL)
Other health conditions	25 (45%)	6 (46%)	13 (61%)	6 (33%)
Chose not to answer	1 (2%)	1 (8%)	0	0

Table 4-2 The sample characteristics.

[1]Mini MoCA: Mini Montreal Cognitive Assessment

Social isolation

In the survey, a participant's level of social isolation was quantified by the reported number of in-person contacts in the week before each interview (See Figure 4-1A). The medians for the pre-pandemic period were VL = 15, HL = 22, and CTL = 20 contacts. There were no significant differences between the groups (Kruskal-Wallis tests, $X^2(2) = 2.51$, $p > .05$), although the CTL group showed a larger variance. After the pandemic started, an overall significant reduction of in-person social contacts was observed across our three groups (Estimate B = -14.86, 95% Confidence Interval (95% CI) = -22.40 – -7.31, $p < .001$, See model 1 in Appendix Table A4-1). The medians in the PAN1 session were VL = 1, HL = 3.5, and CTL = 3 in-person contacts in a week. On average, the numbers of in-person contacts were reduced to 13% in the VL, 38% in the HL, and 24% in the CTL group relative to the weekly pre-pandemic contacts.

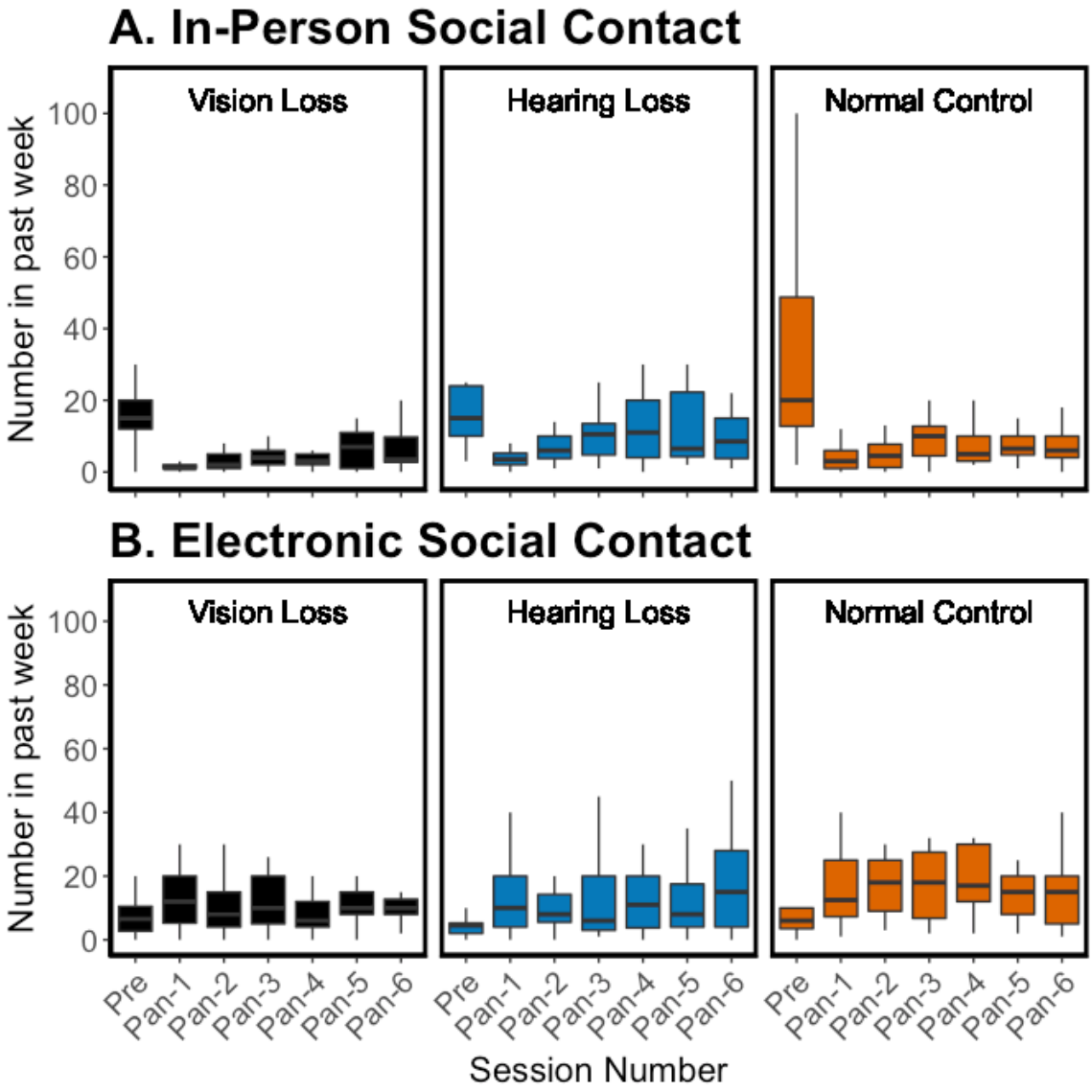

Figure 4-1 In-person and electronic social contacts.

The two rows of boxplots show the reported number of in-person (A) and electronic social contacts (B) in the preceding week for all 7 sessions. The middle line of each box represents the median of the number in each group. The upper boundary and lower boundary of each box show the 25% and 75% quantile values. The length of the whiskers represents 1.5 times the interquartile range (IQR). The PAN1 to PAN6 sessions represent the 6 pandemic sessions, and the PRE represents the pre-pandemic session.

Throughout the duration of the pandemic, the number of weekly in-person contacts significantly increased (B = 1.05, 95% CI = 0.25 – 1.85, $p < .001$, see model 2 in Appendix Table A4-1). The slopes of the recovery trends across the pandemic sessions between the three groups were not significantly different. However, the average number of weekly in-person contacts during the pandemic was significantly lower in the VL group than for the two other groups (HL vs VL: B = 5.86, 95% CI = 2.88 – 8.78, $p < .001$; CTL vs

VL: B = 4, 95% CI = 1.28 – 6.72, $p < .01$, see Appendix Table A4-1). The median numbers of social contacts for the three groups ranged from 1 to 7 in the VL group, from 3.5 to 11 in the HL group, and from 3 to 10 in the CTL group across the 6 pandemic sessions.

Besides the effect of groups and time, participants who were still employed during the pandemic reported significantly more in-person social contacts than the others who were retired or unemployed (B = 3.77, 95% CI = 0.74 – 6.8, $p < .05$). No other control variables were significantly associated with the number of in-person social contacts.

Participants were also asked to report the number of electronic contacts, including phone calls or video calls, in the week before the interview (Figure 4-1B). The medians for the PRE period were VL = 7, HL = 4.5, and CTL = 6 contacts. There was no significant difference between the groups (Kruskal-Wallis tests, $X^2(2) = 3.97$, $p > .05$). The average number of electronic contacts did not significantly change immediately after the pandemic started (See model 1 In Appendix Table A4-2). Throughout the six pandemic sessions, the number of electronic contacts did not significantly change (see model 2 in Appendix Table A4-2). The number of electronic contacts was not significantly different between the three groups during the pandemic. There was no correlation between the reported number of in-person and electronic contacts (r_τ = -0.02, $p > .05$).

Daily activities

In the survey, participants were asked how they completed five types of daily activities during the pandemic--(1) how they accessed pandemic information, (2) obtained essential needs, (3) accessed support groups, (4) how they accessed medical services, and (5) what their daily transportation methods were. Participants were also asked how they completed in these activities in the pre-pandemic period, with the exception of the question about accessing pandemic information.

For each category, they were given a list of Yes/No options. Among the five activities, daily transportation and getting essential needs were most affected by the pandemic in the VL group.

Public transportation was the most-cited mobility method in the VL group before the pandemic, but the percentage of VL participants using public transportation dropped from 85% in the PRE session to 30% in the PAN1 session (Figure 4-2). The participants with visual impairment replaced public transportation

with rides with family members or friends during the first three pandemic sessions. Public transportation became the most cited mobility method again for the VL group starting from the fourth pandemic session. In the last pandemic session, 91% of the VL group chose public transportation as one of their mobility methods. In contrast to the impact on mobility in the VL group, over 90% of both the HL and the CTL group relied on driving themselves both before and during the pandemic.

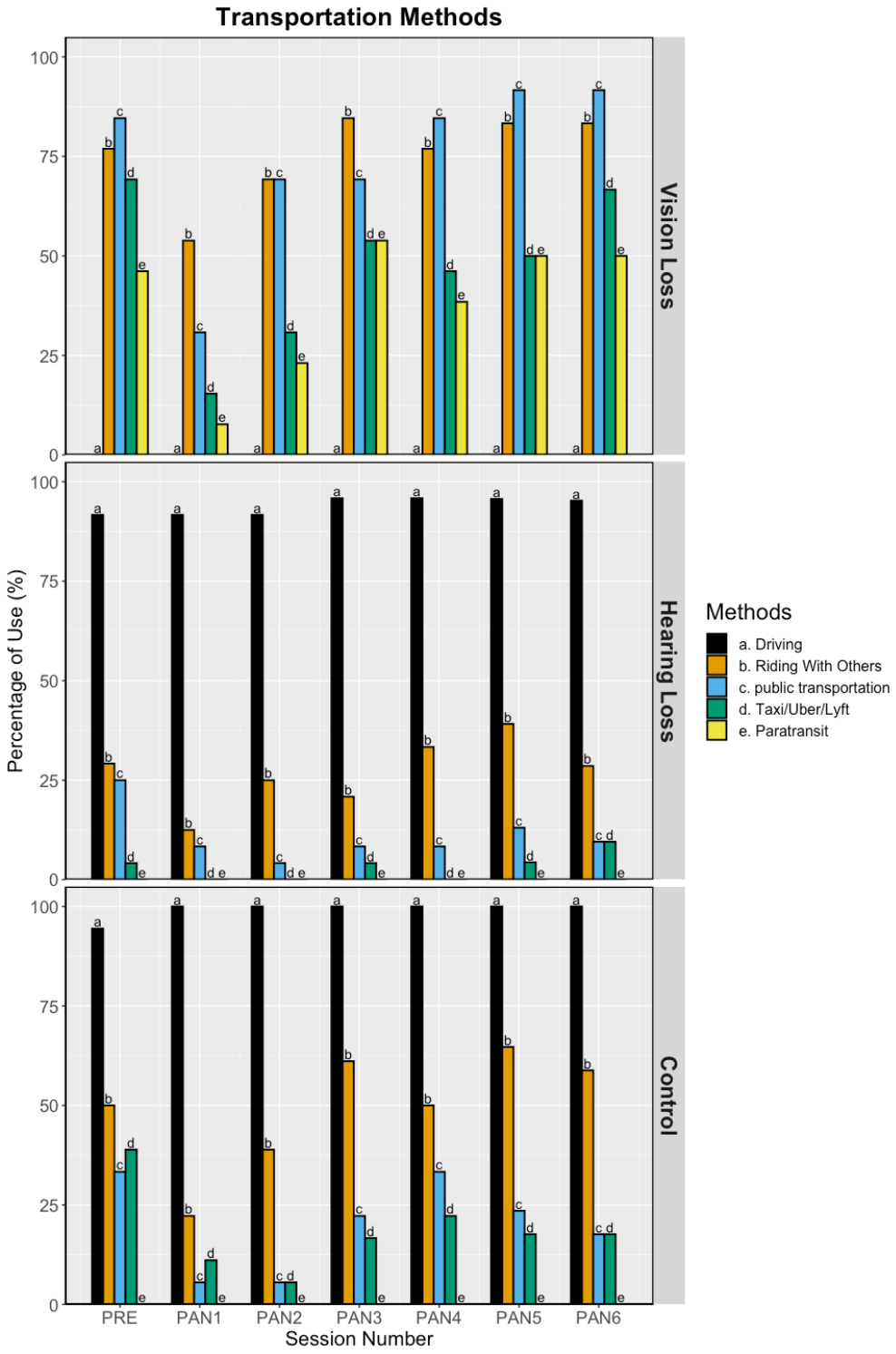

Figure 4-2 Transportation methods.

The figure shows the percentage of usage of each transportation method in the three groups in all 7 sessions. Participants were asked to choose one or more transportation methods they used to get to desired locations in each session.

Methods for obtaining essential needs were also greatly affected by the pandemic in the VL group (Figure 4-3). Before the pandemic, in-store shopping was the most cited method for getting essential needs in the VL group, but the percentage of usage of in-store shopping dropped from 92% in the pre-pandemic session to 53% in the first pandemic session. The percentage remained low in most of the pandemic sessions. Online shopping or relying on others' help became the most cited method for getting essential needs during the pandemic. In contrast to the behavior of the VL group, in-store shopping was the most cited method for obtaining essential needs in both the HL and CTL groups both before and during the pandemic.

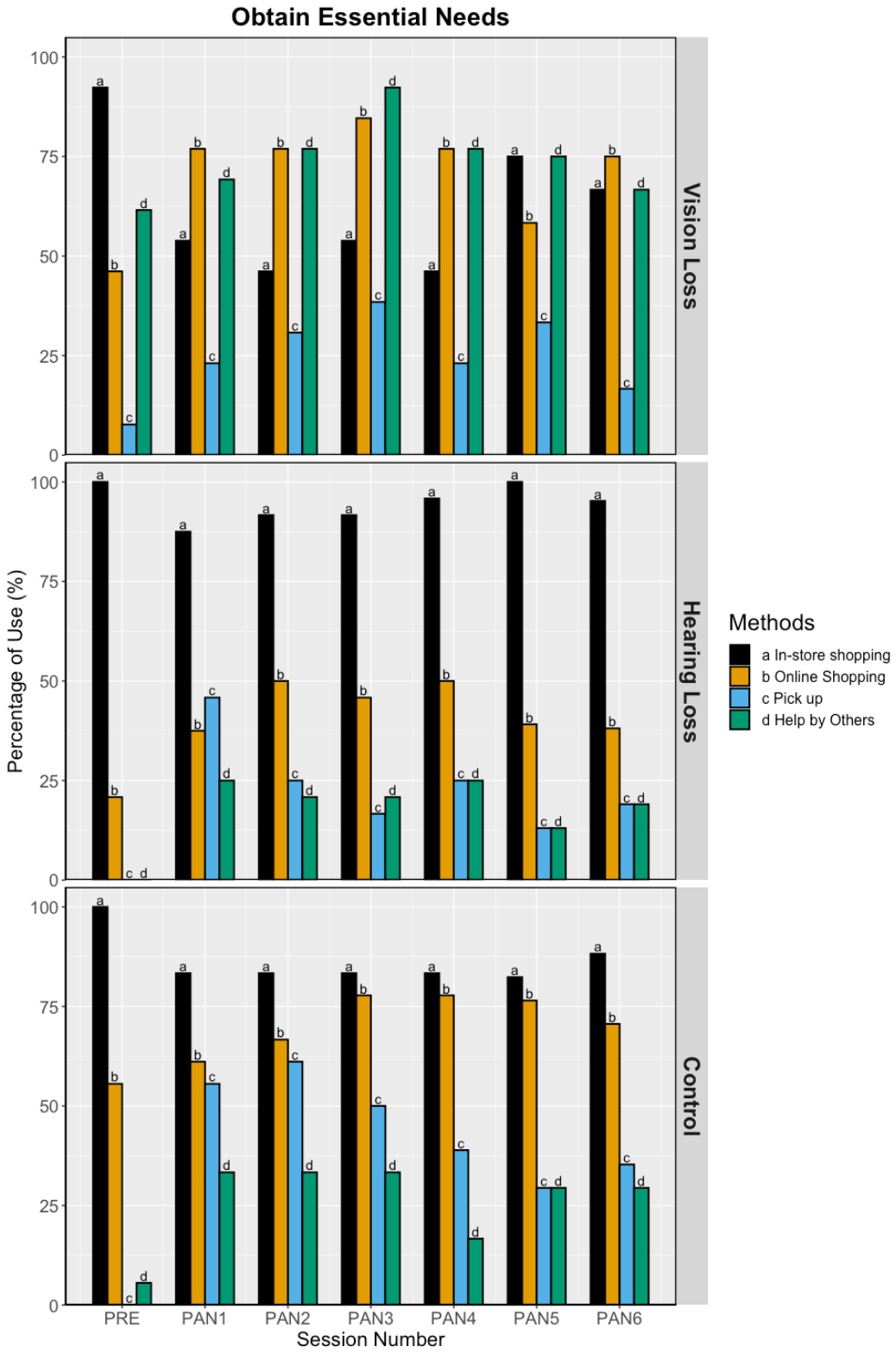

Figure 4-3 Obtaining essential needs.

The figure shows the percentage use of methods to obtain essential needs by each group in all 7 sessions. Participants were asked to choose one or more methods to obtain groceries, medicine, and other essential needs.

COVID-related concerns and mental health

We also asked our participants about their worry levels concerning contracting the virus, getting essential needs, keeping social distance, touching things, and understanding the speech of mask wearers. Participants were asked to rate their worry levels on a five-point scale from 1 = do not worry at all to 5 = worry a lot.

The VL group worried more about the risk of touching things (potential sources of infection) during the pandemic than the HL group (Wilcoxon sign rank test, $Z = 2.13$, $p < .05$) and CTL group (Wilcoxon sign rank test, $Z = 2.07$, $p < .05$) (Figure 4-4A). The mean worry rating in the VL group ranged from 3.3 to 3.5 throughout the pandemic sessions, while the mean worry ratings were consistently lower than 2 in the HL and CTL groups. The worry level for the VL group about touching things remained high through all pandemic sessions and did not decrease over time.

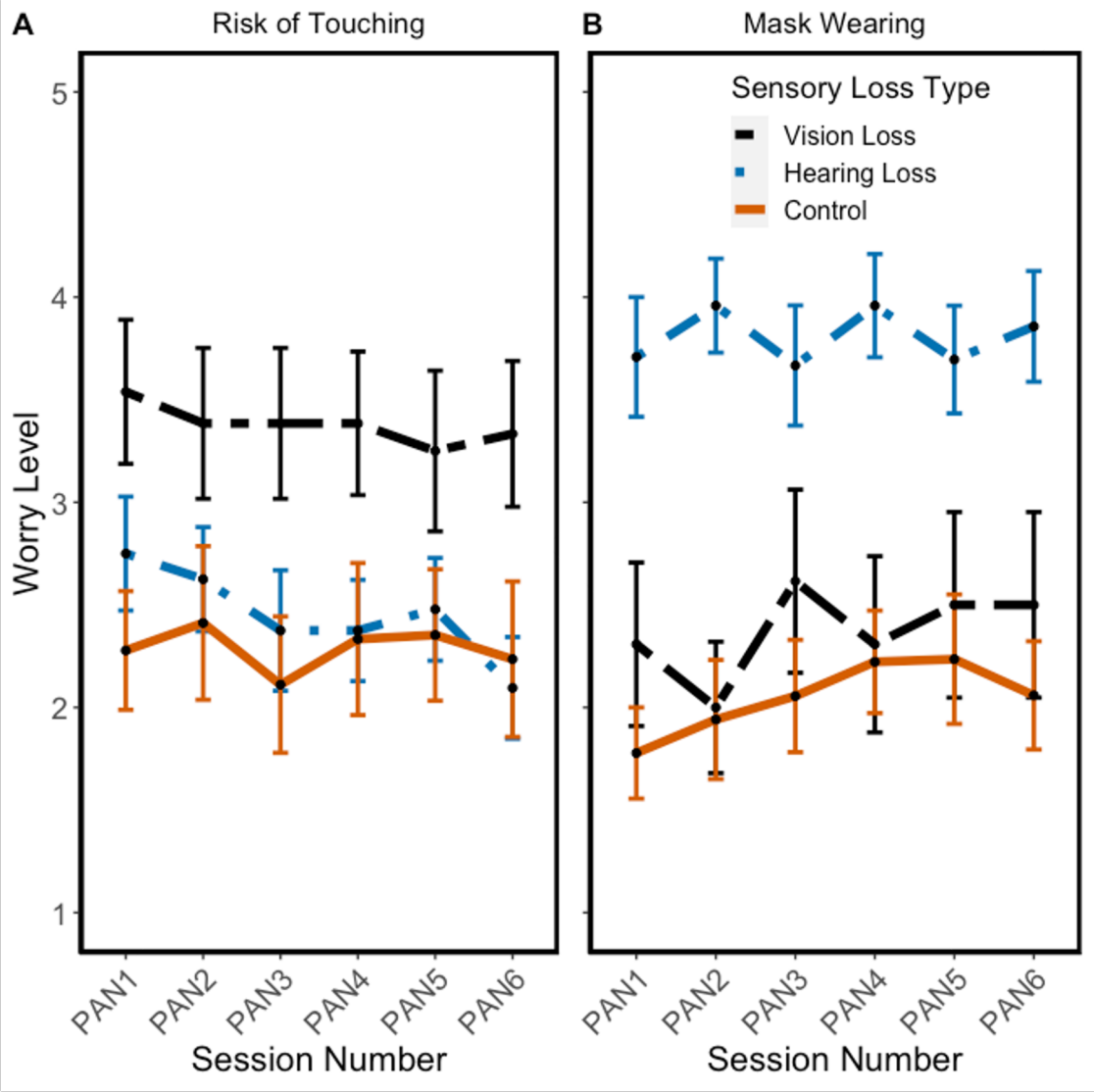

Figure 4-4 COVID-related concerns.

The figure shows the average worry levels about (A) the risk of touching things and (B) the difficulty of speech comprehension when people wear masks. Participants rated their worry levels on a 5-point scale (1= not at all, 5 = strong). The error bars represent 1 SE of mean ratings in each group.

The HL group worried more about the difficulty of speech comprehension when conversing with mask wearers during the pandemic than the VL group (Wilcoxon sign rank test, $Z = 2.89$, $p < .01$) and CTL group (Wilcoxon sign rank test, $Z = 4.13$, $p < .001$) (Figure 4-4B). The mean worry levels of listening to mask wearers in the HL group ranged from 3.7 to 4, while the mean ratings in the VL and CTL groups were lower than 2.5 in all pandemic sessions. The worry rating of conversing with mask wearers in the HL group remained high in all pandemic sessions and did not decrease over time.

The three groups did not demonstrate significant differences on worries about contracting the virus, getting essential needs, or keeping social distance.

In the survey, participants' mental health was assessed by the Patient Health Questionnaire-9 (PHQ-9) in all sessions. A total score ranging from 0 to 27 was the summation of all 9 questions in the PHQ-9 questionnaire. The higher the score, the more likely a participant was to experience depression.

Before the pandemic started, the mean PHQ-9 scores in each group were 2 in the VL group, 1.96 in the HL group, and 2.39 in the CTL group. (Figure 4-5A). No significant difference was found between the three groups (Kruskal-Wallis test, $X^2(2) = 1.16$, $p > .05$). After the pandemic started, a significant increase was found across the three groups (B = 2.12, 95% CI = 0.58 – 3.67. $p < .01$, see model 1 in Appendix Table A4-3). The average PHQ-9 scores increased to 4.23 in the VL, 2.9 in the HL, and 3.22 in the CTL group in the first pandemic session. The PHQ-9 scores remained stable in the following 6 pandemic sessions across all three groups.

Although the average PHQ-9 scores remained stable in the following pandemic sessions, we found that younger participants and the participants who lived alone reported worse mental health than others (age: B = -0.12, 95% CI = -0.2 – -0.05, $p < .001$; live alone: B = 1.65, 95% CI = 0.79 – 2.52, $p < 0.001$). there was a significant relationship between the number of weekly in-person social contacts and mental health (B = 0.001, 95% CI = 0.0007 – 0.002, $p < .001$) during the pandemic.

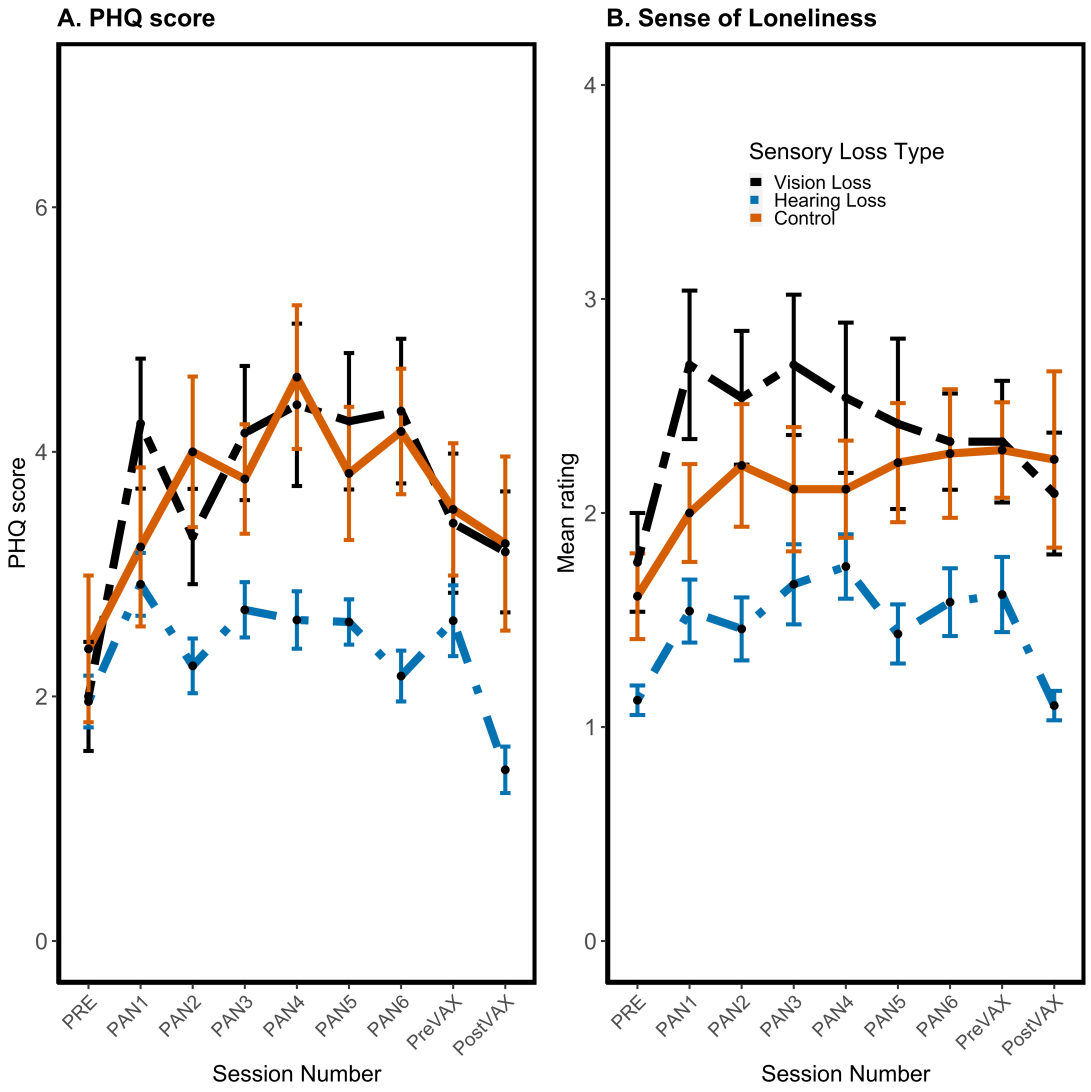

Figure 4-5 Mental health and loneliness.

The figure shows (A) the average PHQ-9 scores and (B) the average ratings of sense of loneliness in all three groups. (A) The higher the PHQ-9 score, the greater the likelihood that a participant was experiencing depression. (B) The average rating of sense of loneliness on a 5-point scale. Higher ratings represent stronger sense of loneliness. The error bars represent 1 SE of mean scores and ratings in each group.

Participants were also asked to rate their sense of loneliness on a 5-point scale (5 = strong, 1 = not at all) before and during the pandemic (Figure 4-5B). Before the pandemic, the VL and CTL group reported higher average ratings (VL: 1.77 and CTL: 1.61) than the HL group (HL: 1.12, Wilcoxon sign rank test, VL vs HL: $Z = 2.8$, $p < .01$, CTL vs HL: $Z = 2.13$, $p < .05$, see Appendix Table A4-4). After the pandemic started, a significant increase of self-reported loneliness was observed across the three groups ($B = 1.07$, 95% CI = 0.42 – 1.72, $p < .001$). The average ratings of loneliness in the first pandemic session were VL = 2.69, HL =

1.54, and CTL = 2. The sense of loneliness remained stable in the 6 pandemic sessions in all three groups, but the average rating of loneliness was significantly higher in the VL group than the HL group (B = -1.05, 95% CI = -1.86 – -0.25, $p < .05$). The difference between the VL group and the CTL group was nearly significant (B = -0.79, 95% CI = -1.66 – 0.08, $p = .07$).

Besides the group differences, the female participants (B = -0.29, 95% CI = -0.49 – -0.09, $p < .01$), the participants who lived alone (B = 0.65, 95% CI = 0.41 – 0.89, $p < .001$), the participants who had a college or higher degree (B = 0.58, 95% CI = 0.11 – 1.05, $p < .05$), and the participants who had fewer in-person social contacts (B = -0.0002, 95% CI = -0.0003 – -0.00006, $p < .01$) were more likely to report a higher sense of loneliness during the pandemic. There was a significant correlation between the sense of loneliness and PHQ-9 scores ($r_\tau = .42$, $p < .001$).

Discussion

The goal of our study was to understand the impact of the COVID-19 pandemic on older adults with vision or hearing loss. We found a widespread psychosocial impact of the pandemic on our sample of older adults. Our sample experienced a significant loss of in-person social interactions, poorer mental health, and a greater sense of loneliness after the pandemic started. Moreover, the effect of the pandemic remained unchanged during the 6 months of the study in 2020. However, the impact of the pandemic on the VL group was different from the other two groups. The VL group reported fewer weekly in-person social contacts and a higher sense of loneliness during the pandemic, compared with the HL and CTL groups.

The COVID-19 pandemic also affected different aspects of life and raised different concerns for our participants with vision loss and hearing loss. The VL group experienced a decrease in independence because of reduced access to transportation for shopping for groceries and other essential needs. The VL group reported switching from public transportation to riding with others during the early pandemic sessions, while the HL and CTL groups continued to rely on driving themselves. The VL group avoided in-store shopping and relied heavily on online shopping and help from others to get their essential needs during the pandemic, while in-store shopping was the main method for the HL and CTL groups both before and after the onset of the pandemic.

The pandemic also created distinctive challenges for people with sensory impairment Our VL group was more concerned with the risk of touching things, while the HL group worried more about the difficulty of understanding speech when people wore masks. These worries persisted across all our pandemic sessions.

Our results from the PHQ-9 and self-report sense of loneliness questions also demonstrated the widespread impact of the pandemic on mental health. All three groups showed higher worry levels, greater loneliness, and poorer depression and anxiety scores once the pandemic began, and these measures remained stable across all pandemic sessions.

Similar psychosocial impacts of the pandemic have been demonstrated in the general older population in other studies in other areas in the U.S, Austria, Netherlands, Ireland, and the U.K. (Emerson, 2020; Hyland et al., 2020; Kotwal et al., 2021; Krendl & Perry, 2021; Robb et al., 2020; Stolz et al., 2021; Van der Roest et al., 2020). Most of these studies were conducted during the lockdown period in each region and found that older adults experienced higher levels of depression, anxiety, loneliness, and social isolation.

Some studies have also found a significant impact of the pandemic on mobility and independence in people with visual impairment. In the nationwide survey led by the American Foundation for the Blind in the U.S in early April 2020, 68% of the 1921 participants were concerned with transportation accessibility and safety (Rosenblum et al., 2020). Bernard et al., (2021) surveyed three groups of participants with visual impairment (N = 112), hearing loss (N = 108) and no sensory loss (N = 155), ages > 50 years, to understand the impact of the pandemic. The survey was conducted in Michigan, U.S.A. from early May to early July in 2020. Similar to our findings of reduced independence in our participants with visual impairment, they found that participants with visual impairment relied more on families for assistance compared to the hearing loss and control groups. Labrum et al., (2021) surveyed 46 participants aged 18 or older with visual impairments in Oregon, U.S.A. in September 2020. Eighty-five percent of their participants reported difficulties with mobility. Forty-four percent of the participants also reported that they were less willing to run essential errands themselves. Gombas and Csakvari (2021) found that participants with visual impairment in Hungary replaced independent in-store shopping with online delivery and help from others.

Although our study shares some similar findings with other studies regarding the immediate impact of the pandemic on people with vision loss and advanced age, our study also demonstrates the persisting effect of the pandemic on social isolation and mental health.

In our study, the HL group did not show the same level of social isolation as the VL group after the onset of the pandemic. The levels of depression and reported loneliness in the HL group were also lower than in the VL and the CTL group. Other recent studies have also demonstrated similar differences. Dunn et al., (2020) assessed the impact of the pandemic in a group of 48 cochlear implant recipients, who lived in the Midwestern U.S ranging in age from 27 to 78 years old. The pandemic assessment was done between April and May in 2020 with a retrospective pre-pandemic assessment. Although they found that the CI participants had fewer people to interact with and less types of different listening environments during the pandemic, they did not experience greater levels of depression during the pandemic compared to the pre-pandemic reports. The less severe psychosocial impact of the pandemic might have been due to better speech understanding in indoor contexts during the lockdown period. The same study also showed that the CI participants reported less listening effort when they spent more time indoors. Naylor et al., (2020) also found that their participants who struggled to hear reported relief at not being obliged to attend social gatherings in difficult listening environments. These results suggest that the reduction of listening difficulties during the pandemic may have contributed to better adaptation in people with moderate or severe hearing loss.

Although the auditory environment may have been easier indoors and with smaller gatherings, our HL participants worried about the difficulty of speech comprehension when people wore face coverings. Concerns about speech intelligibility with masks shown in our HL group have also been reported in other studies (Naylor et al., 2020). Recent studies have demonstrated that face masks can impair speech comprehension in people with normal hearing (Brown et al., 2021; Cohn et al., 2021) as well.

Limitations

Our study had two major limitations: (1) a limited sample and (2) relying on retrospective data for the pre-pandemic and 1st pandemic sessions. We acknowledge that our small convenience sample, drawn from previous research participants and local community contacts, did not represent the overall visually impaired or hearing-loss population in the country. The estimated prevalence of visual acuity worse than 20/200 in people aged over 45 in the U.S. is 1% (Chan et al., 2018). Hearing-aid and cochlear implant users do not represent the majority of people with hearing loss. Chien and Lin (2012) estimated that only 14% of adults older than 50 years with hearing loss adopted hearing aids in the U.S.

Although we did not have a representative and large sample, we did conduct 375 interview sessions, including 110 retrospective sessions, at equally spaced intervals to determine the immediate and longitudinal effect of the pandemic. Moreover, all our participants were from the metro or suburban area of the Twin Cities in Minnesota. The limited geographical sample offers the advantage that participants had a more homogeneous experience of the pandemic, with all participants exposed to a similar pattern of community exposure and local media information.

The second limitation is our reliance on retrospective data for pre-pandemic and initial pandemic reports. We acknowledge the possibility of false memories in our retrospective data. Past studies have shown that the quality of retrospective data may depend on many factors, such as the length of reference period and recall period, the characteristics of the event to recall, the structure of the questions asked (Müggenburg, 2021). We took three steps to improve the quality of the retrospective data. First, all participants passed the cognitive screening test before participating in the study, guarding against dementia or other forms of significant memory deficits. None of our participants reported any type of cognitive disorders. Second, we provided context for retrieving memories during the retrospective session. For example, to help our participants recall their daily lives during the first week of March, the interviewers reminded our participants that the first week of March occurred after the first COVID death reported in the US (February 28th, 2020) and before the first COVID case reported in Minnesota on March 6. We also reminded our subjects of other pivotal time points, including when the COVID-19 state of emergency and the first shelter-in-place order were announced in Minnesota. These events were salient for our participants and had occurred within five to seven weeks of the retrospective testing. Third, we relied primarily on quantitative, factual data, such as numbers of social contacts, the methods to do daily activities, and the frequency of psychological problems. The participants were also encouraged to check their calendars, emails, or text messages to help them recall their daily routines. We judge that our participants had no difficulty in recalling their levels of social engagement and attitudes prior to and immediately after the onset of the pandemic.

Conclusion

The COVID-19 pandemic had a widespread psychosocial effect on older people with and without sensory impairment. Older people with visual impairment were especially vulnerable to the changes during

the pandemic. Loss of independence and long-lasting social isolation were accompanied by higher loneliness in older people with visual impairment. Although mask-wearing impaired speech intelligibility for older people with hearing loss, the quieter acoustic environment due to restrictions of gatherings may have helped them adapt to the pandemic. Additional studies will help us understand whether any of these effects are long lasting, as well as the influence of those adaptations on post-pandemic life for older people with sensory impairment.

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Appendix A1: Study 1: Visual Acuity Survey questions and IRT estimates

item number	item text	estimated difficulty	SE of estimated difficulty	estimated discriminability	SE of estimated discriminability	estimated VA threshold (logMAR)
Q1	Are you able to see any texture on the surface of the moon on a clear dark night?	0.92	0.11	1.84	0.21	0.28
Q2	If you are standing on a sidewalk, would you be able to see an ant that you are about to step on?	0.87	0.10	2.15	0.24	0.29
Q3	Would you be able to see if the person sitting directly across the table from you has freckles on their face?	0.23	0.07	3.60	0.41	0.51
Q4	When standing an arm's length away from a screen door, are you able to see the individual holes in the screen?	0.25	0.07	2.64	0.29	0.50
Q5	When looking at a pen on a table in front of you, are you able to see if the tip is retracted or exposed?	-0.01	0.06	2.99	0.33	0.59
Q6	Would you be able to see the eye of a needle, if you hold it at arm's length?	1.29	0.12	2.17	0.28	0.15
Q7	On a clear dark night, are you able to see the stars composing the Big Dipper?	0.11	0.07	2.18	0.24	0.55
Q8	When looking at an aspirin pill on the table in front of you, are you	0.21	0.06	3.91	0.46	0.51

	able to see the groove that allows you to cut the pill in half?					
Q9	When looking at a salt shaker on the table in front of you, are you able to count the number of holes in the cap of the shaker?	0.14	0.07	2.69	0.29	0.54
Q10	When seated at a desk with an open notebook, are you able to see the horizontal lines in the notebook that guide your writing?	-0.54	0.05	3.31	0.41	0.76
Q11	When looking at a ruler on the table in front of you, are you able to see the marks that indicate inches?	-0.21	0.06	3.25	0.37	0.65
Q12	When stopped at a crosswalk in a residential area, are you able to read the street sign of the road you are about to cross?	0.22	0.08	2.30	0.25	0.51
Q13	When standing at a sink looking into a mirror, are you able to see the whites of your eyes?	-0.73	0.06	2.84	0.36	0.83
Q14	When standing at a sink looking into a mirror, are you able to see your individual teeth?	-0.67	0.06	2.82	0.36	0.81
Q15	When holding a newspaper at a regular viewing distance of about 16 inches (40 centimeters), are	0.80	0.09	2.82	0.33	0.32

	you able to read the printed text in the articles?					
Q16	Would you be able to tell if your neighbor is smiling or frowning if you are standing directly across a residential street from her?	0.76	0.08	3.37	0.42	0.33
Q17	If you are wearing an average sized wrist watch (the kind with hands and numbers), would you be able to read the time with your wrist at arm's length?	0.23	0.07	2.59	0.28	0.51
Q18	If you have a bowl of rice on the table in front of you, would you be able to see the individual grains of rice?	-0.30	0.05	3.44	0.40	0.69
Q19	If a single Cheerio from your cereal is on the counter in front of you, would you be able to see the hole in the center of the Cheerio?	-0.62	0.06	2.90	0.36	0.79
Q20	Can you see the difference between a full moon and a half moon on a clear dark night?	-1.23	0.11	2.11	0.32	0.99
Q21	When looking at a traditional credit card (the kind with raised numbers), are you able to read the numbers on the card when it	0.49	0.08	2.69	0.30	0.42

	is on the table in front of you?					
Q22	If you are seated directly across a table from someone, would you be able to see if they have a wedding ring on their finger?	-0.57	0.06	2.68	0.33	0.78
Q23	When you are at a check-out counter, are you able to see the slot where you need to swipe your credit card?	-0.62	0.06	2.66	0.33	0.79
Q24	When standing, would you be able to see the difference between a golf ball and a ping pong ball on the floor, if they were the same color?	0.26	0.08	2.23	0.24	0.50
Q25	If you are holding a golf ball at arm's length, would you be able to see the individual dimples in the ball?	-0.07	0.06	4.01	0.47	0.61
Q26	When you are standing, can you tell whether the trousers you are wearing are solid in color or have pin stripes?	-1.25	0.13	1.86	0.29	1.00
Q27	If you are standing on the sidewalk next to a residential street, would you be able to recognize a friend by their face across the street?	0.54	0.08	3.22	0.37	0.40
Q28	When sitting directly across	-0.67	0.05	3.62	0.46	0.81

	the dinner table from a friend, would you be able to see if they have buttons on their shirt?					
Q29	When you are at a checkout counter, are you able to tell the value of the paper money bills on the counter in front of you (such as $1, $5, $10, etc)?	-0.67	0.06	2.59	0.32	0.81
Q30	When seated in front of a computer, are you able to read the letters on the keyboard keys?	-0.37	0.06	2.97	0.35	0.71
Q31	When sitting in a car, can you see the slot in the buckle where you secure your seatbelt.	-0.80	0.06	2.92	0.38	0.85
Q32	When looking at standard playing cards on a table in front of you, are you able to read the numbers on the corners of the cards?	-0.25	0.06	3.07	0.35	0.67
Q33	When you are seated at a table set for dinner, are you able to tell where the water line is in a clear drinking glass?	-0.66	0.06	2.85	0.36	0.81
Q34	Are you able to count the individual tines on a fork that is sitting on the table in front of you?	-0.76	0.06	3.15	0.41	0.84
Q35	Are you able to tell the difference between the	-1.39	0.10	3.65	0.63	1.05

	writing end and the eraser end of a pencil that is sitting on the desk in front of you?					
Q36	If a piece of watermelon is placed on the table in front of you, are you able to see if it contains seeds?	-1.27	0.12	2.07	0.32	1.01
Q37	Are you able to read the numbers on a microwave key pad at arm's length?	0.04	0.07	2.63	0.29	0.57
Q38	When you are standing barefoot, are you able to see your toenails (if they are unpainted)?	-0.37	0.05	3.43	0.41	0.71
Q39	If you are standing an arm's length away from a bicycle, would you be able to see the individual spokes on the wheels?	-0.85	0.07	2.88	0.38	0.87
Q40	If you are looking at a can of soda pop on the counter in front of you, are you able to see if the tab is open?	-1.23	0.10	2.86	0.44	0.99
Q41	When you hold your arm straight out forward from your body, are you able to see your fingernails (assuming they are unpainted)?	-0.81	0.06	3.01	0.40	0.85
Q42	When standing at a check-out counter, are you able to see the difference between the	-0.48	0.05	3.54	0.43	0.75

	coins--dimes, nickels, and quarters, on the counter?					
Q43	When looking at a key ring at arm's length, are you able to visually tell the difference between the keys?	-0.51	0.06	2.72	0.33	0.76
Q44	If you are looking at a pair of dice on a table in front of you, are you able to tell what numbers are on the dice?	-0.16	0.06	2.93	0.33	0.64
Q45	When looking at standard playing cards on the table in front of you, are you able to distinguish between a clubs card and a spades card?	-0.38	0.06	2.76	0.32	0.71
Q46	When you are sitting in the passenger seat of a car, are you able to read the license plate of the car in front of you while waiting at a stop light?	0.29	0.07	2.99	0.33	0.49
Q47	When you are an arm's length away from an electrical socket, are you able to see the individual holes where the plug would fit?	-0.63	0.06	3.05	0.38	0.80
Q48	At a restaurant, are you able to see if your water glass contains a straw when the	-1.32	0.11	2.58	0.41	1.03

	glass is placed in front of you?					
Q49	Can you see if the person eating dinner directly across the table from you is wearing glasses?	-1.36	0.09	4.35	0.79	1.04
Q50	If you are looking at standard playing cards on the table in front of you, would you be able to count the number of symbols (clubs, spades, hearts or diamonds) on the face of the cards?	-0.59	0.06	2.91	0.36	0.78
Q51	If you are wearing white sneakers with white shoelaces, would you be able to see the individual laces while standing?	-0.33	0.05	3.32	0.39	0.70
Q52	If you are looking at a key ring sitting on a table in front of you, would you be able to count the number of keys?	-0.74	0.07	2.37	0.30	0.83
Q53	When you are sitting directly across the table from a friend, are you able to see if they are smiling or frowning?	-0.80	0.05	4.77	0.67	0.85
Q54	When you are sitting in an unfamiliar car, are you able to see where the door handle is located?	-0.96	0.08	2.52	0.35	0.90
Q55	When you are walking down a sidewalk, are you able to see the	-1.39	0.13	2.44	0.40	1.05

	cracks that separate the large square cement slabs that make up the sidewalk?					
Q56	If you are holding a guitar in your lap, would you be able to see the individual guitar strings?	-0.89	0.07	3.04	0.41	0.88
Q57	When you are looking at a CD on a table in front of you, are you able to see the hole in the center of the CD?	-1.57	0.17	2.01	0.35	1.11
Q58	When you are looking at a chess board sitting on the table in front of you, are you able to see the individual squares on the board?	-1.54	0.13	3.37	0.63	1.10
Q59	At a bowling alley, are you able to see the individual pins at the end of the lane when you are standing at the line ready to bowl?	-0.47	0.06	2.75	0.33	0.74
Q60	When you are in the passenger seat of a moving car, are you able to see the broken white line that is the lane divider?	-1.33	0.12	2.52	0.41	1.03
Q61	If you are standing in front of a bathroom sink facing a mirror and holding your fingers up over your shoulder, would you be	-1.05	0.09	2.45	0.35	0.94

	able to count your fingers in the mirror?					
Q62	When you are standing an arm's length away from a standard light switch, are you able to see whether the switch is flipped up or down?	-0.67	0.05	4.18	0.55	0.81
Q63	When you are frying an egg on a stovetop, are you able to see the contrast between the egg white and the egg yolk?	-1.70	0.16	3.34	0.69	1.15
Q64	If you are looking at a medium sized apple sitting on the table in front of you, are you able to see where the white produce sticker on the apple is located?	-1.27	0.09	3.28	0.53	1.01
Q65	If you are looking at a white envelope on the table in front of you, would you be able to see if it had a dark colored stamp in its corner?	-1.82	0.19	3.17	0.70	1.19
Q66	If you are looking at a can of Coca-Cola classic on the table in front of you, would you be able to read the word Coca-Cola, in white letters on the red can?	-1.28	0.11	2.51	0.39	1.01

Q67	If you are sitting at a table set for dinner, would you be able to see the difference between your fork, knife and spoon?	-1.75	0.14	5.21	1.37	1.17
Q68	Would you be able to recognize a friend's face if they were sitting directly across a dinner table from you?	-0.91	0.05	4.68	0.68	0.89
Q69	When standing at a white board writing with a black marker, are you able to read what you have written?	-1.68	0.19	1.98	0.37	1.15
Q70	When standing an arm's length away from a red brick building, are you able to make out the individual bricks?	-1.26	0.11	2.46	0.38	1.00
Q71	When you are in an elevator, ready to press a button, are you able to read the numbers on the buttons for the different floors.	-0.62	0.05	3.37	0.42	0.79
Q72	If you are standing at a bus stop, would you be able to read the number on your bus when it arrives?	-0.51	0.06	2.67	0.32	0.76
Q73	If you are sitting directly across the table from a person who is wearing a white shirt and a dark neck tie, would you be able to see that they are	-2.17	0.30	2.80	0.76	1.31

	wearing a neck tie?					
Q74	If you are looking at an open carton of eggs on the table in front of you, would you be able to count the individual eggs?	-1.41	0.09	4.74	0.90	1.06
Q75	When you are holding a standard black bowling ball in your lap, are you able to see the three holes where your fingers should fit?	-0.94	0.08	2.61	0.36	0.90
Q76	If you are sitting in front of a piano, would you be able to see the individual black keys?	-1.91	0.23	2.48	0.54	1.22
Q77	When sitting in the passenger seat of a car, are you able to see where the rear-view mirror is located?	-2.31	0.38	1.90	0.49	1.36
Q78	When using a public restroom, are you able to visually identify where the roll of toilet paper is located?	-1.83	0.18	3.49	0.80	1.20
Q79	When standing an arm's length away from a chest height dresser, are you able to count the number of drawers that the dresser contains?	-1.48	0.12	3.40	0.61	1.08
Q80	When looking at a CD on a table, are you able to see the outline of the CD?	-2.03	0.30	1.55	0.33	1.26

Q81	If you accidentally drop a credit card on the floor, would you be able to see where it is to pick it up?	-1.22	0.13	1.81	0.28	0.99
Q82	When looking at a bunch of bananas on a table in front of you, are you able to count the individual bananas?	-1.24	0.09	3.29	0.52	1.00
Q83	When holding a soccer ball an arm's length away, are you able to see the individual black hexagons among the white hexagons that make up the ball?	-2.22	0.36	1.43	0.32	1.33
Q84	In daylight, when waiting to cross at an intersection, are you able to see whether the stoplight is red, green or yellow?	-1.02	0.07	3.22	0.46	0.93
Q85	If you are standing in the middle of a parking space in a parking lot, would you be able to see the white lines that border the spot you are standing in?	-2.65	0.54	1.53	0.43	1.47
Q86	On a bus, subway or airplane, can you see which seats are occupied by people?	-1.95	0.25	2.05	0.44	1.24
Q87	When you are standing at a curb preparing to cross a street at a	-2.11	0.28	2.65	0.68	1.29

	crosswalk, are you able to see the white stripes that make up the crosswalk?					
Q88	When walking down a sidewalk, are you able to see the outline of the sidewalk path if it is bordered by green grass?	-2.42	0.43	1.61	0.42	1.40
Q89	If a toothbrush is sitting on the counter in front of you, can you see which end has the bristles?	-1.31	0.08	5.45	1.02	1.02
Q90	If a match is sitting on the counter in front of you, can you see which end to light?	-0.75	0.06	3.50	0.46	0.83
Q91	When you shake hands with someone, would you be able to see if they are wearing a wrist watch?	-1.37	0.11	2.98	0.50	1.04
Q92	If you pass a seated person in a waiting room, can you usually tell if they are a man or a woman?	-1.15	0.08	3.46	0.53	0.97
Q93	If you are in a car on the highway, are you able to see if there are power lines beside the road?	-0.96	0.08	2.53	0.35	0.90
Q94	If a teacup or coffee cup is on the table in front of you, are you able to see the handle?	-1.57	0.12	4.02	0.81	1.11
Q95	In a public bathroom, can you usually see the location of	-1.97	0.26	2.01	0.43	1.24

	the paper-towel dispenser?					
Q96	If you are walking down the corridor of a public building, can you see the symbols for men's and women's bathrooms?	-0.74	0.08	2.07	0.27	0.83
Q97	In a fast-food restaurant, can you usually read the posted menus?	0.69	0.08	2.89	0.33	0.36
Q98	If you are near a flagpole with a flag flying, can you tell if the flag is the U.S. stars and stripes?	-1.28	0.09	3.32	0.54	1.01
Q99	When approaching a closed door, are you able to see whether the handle is on the left or right?	-1.49	0.13	2.76	0.48	1.08
Q100	In a large grocery store, are you able to read the large numbers that indicate the different isles?	-0.77	0.08	2.22	0.29	0.84

Table A1-1 Visual Acuity Survey

The table lists item difficulty estimates, standard error of item difficulty estimates, item discriminability estimates, and standard errors of item discriminability for each item from the IRT 2PL model. The last column lists the estimated VA threshold for each item in logMAR.

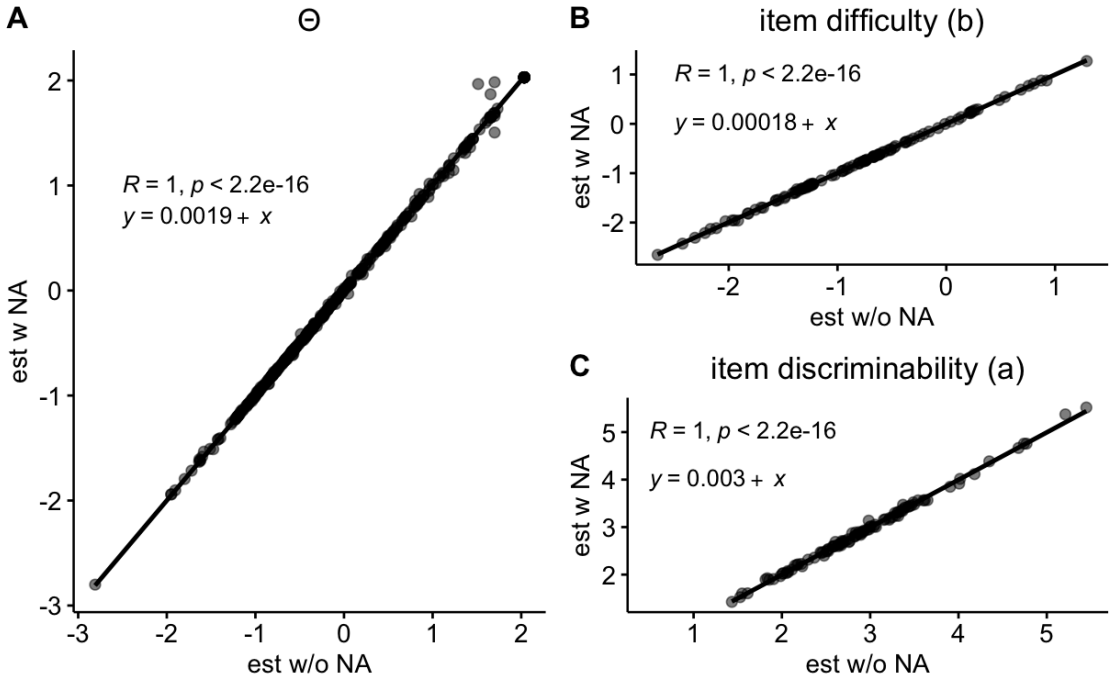

Figure A1-1 Comparisons of the two 2PL models

The figure shows the difference between the 2PL model built with N/A values in the participants' responses and another 2PL model built without N/A values. (A) Differences in theta estimates between the two 2PL models. (**B**) Differences in estimates of item difficulty between the two 2PL models. (**C**) Differences in estimates of item discriminability between the two 2PL models.

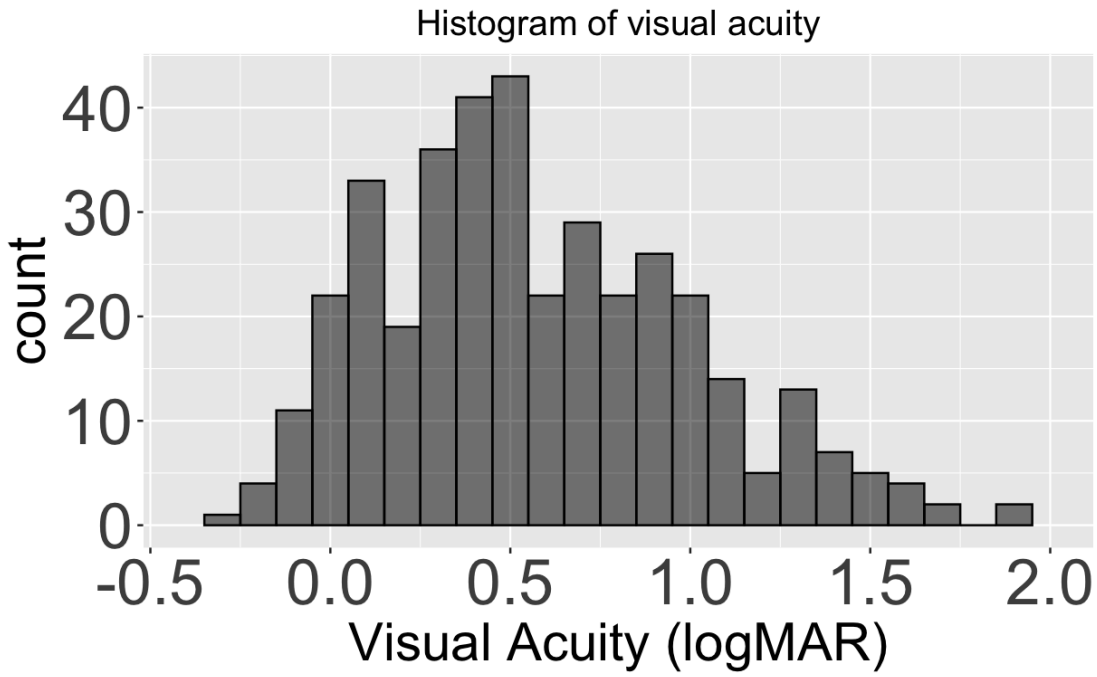

Figure A1-2 Study 1 VA distribution

Appendix A2: Study 2 Online Reading Questionnaire

Section 0. Eligibility

In order to establish your eligibility for this survey, please answer the following questions:

Q0.1
Are you a person with low vision?
(Low vision is defined as acuity less than 20/60 with best prescribed glasses or contacts, or a visual field less than 20 deg in extent.
Low vision does not refer to people who can achieve normal vision with the aid of glasses or contacts.
Low vision does not refer to people who have normal vision in one eye and reduced vision in the other eye.)

- ☐ Yes
- ☐ No

Q0.2
Has your vision remained fairly stable during the past year?

- ☐ Yes
- ☐ No

Q0.3
Do you read visually at least for some purposes?

- ☐ Yes
- ☐ No

Q0.4
Are you 18 years old or older?

- ☐ Yes
- ☐ No

Section 1. Demographics

Q1.1
What is your name? _____

Q1.2
What is today's date? _____

Q1.3
What is your date of birth?
Month: _____
Day (DD): ____
Year (YYYY): _____

Q1.4
What is your gender?

- ☐ Male
- ☐ Female
- ☐ I'd prefer not to say

Q1.5
What city, state, and country do you live in?

City: _____
State: _____
Country: _____

Q1.6

What is your email address? _____

Q1.7

What is your highest level of education?

- Primary School
- High School
- University/College Degree
- Advanced Graduate or Professional Degree

Q1.8

What is your employment status?

- Full time
- Part time
- Unemployed
- Retired

Q1.9

Are you currently a student?

- Yes, a full-time student
- Yes, a part-time student
- No, not a student

Section 2: Nature and History of Your Low Vision

Q2.1

What is the cause(s) of your low vision? _____

Q2.2

At what age did your low vision begin (age in years; enter 0 if visually impaired since birth)? _____

Q2.3

When did you last have an eye exam of any kind?

- Within the past month
- Within the past year
- Within the past 5 years
- More than 5 years ago

Q2.4

If you wear reading glasses, when were you last prescribed them?

- Within the past month
- Within the past year
- Within the past 5 years
- More than 5 years ago

Q2.5

People with good vision are often said to have 20/20 visual acuity. If you know your visual acuity, please enter it here: _____

Q2.6
Do you have visual-field loss?
- ☐ Yes
- ☐ No

[Q2.7 should only appear if 'yes' is selected for Q2.6]

Q2.7
Is your field loss in Central vision or Peripheral vision?
- ☐ Central vision
- ☐ Peripheral vision

Some people with low vision use audio and/or Braille in addition to vision for reading. Thinking about all of your reading, please estimate the percentages of reading you do with vision, with audio and with Braille. For instance, if you read about equal amounts with vision and with audio, but none with Braille, you would enter 50% for Vision, 50% for Audio, and 0 for Braille.

Q2.8
Your percentage of reading by (the total should equal 100%):
Vision: _____
Audio: _____
Braille: _____

Q2.9
Do you have any physical disabilities (such as arthritis or neuropathy of the fingers) that affect your ability to operate mobile reading devices or a computer?
- ☐ Yes
- ☐ No

Q2.10
Do you experience nystagmus (rapid, involuntary eye movements) that affects your ability to read?
- ☐ Yes
- ☐ No

Q2.11
Do you have a hearing impairment that affects your ability to use audio for reading?
- ☐ Yes
- ☐ No

Section 3: Usage of assistive devices/technologies

In this section, we will ask you about the devices you use for reading. Some people use more than one device. Please respond concerning all devices you use. Digital devices refer to smartphones, tablets (such as iPads), electronic books (such as Kindles) and computers. In the following questions that ask about different digital devices, please indicate the model type (e.g., iPhone 5S, Mac Mini, etc.) that you use. Some digital devices can be used for auditory and/or Braille reading, as well as visual reading, but please respond concerning your use of these digital devices for visual reading only.

Q3.1a
Do you use a smartphone for visual reading?
- ☐ Yes, please specify below.
- ☐ No

Q3.1b

If yes, please specify smart phone model: _____

Q3.2a
Do you use a tablet for visual reading?
- ☐ Yes, please specify below.
- ☐ No

Q3.2b
If yes, please specify tablet model: _____

Q3.3a
Do you use an E-book reader for visual reading?
- ☐ Yes, please specify below.
- ☐ No

Q3.3b
If yes, please specify E-book reader model: _____

Q3.4a
Do you use a laptop computer for visual reading?
- ☐ Yes, please specify below.
- ☐ No

Q3.4b
If yes, please specify laptop computer model: _____

Q3.5a
Do you use a desktop computer for visual reading?
- ☐ Yes, please specify below.
- ☐ No

Q3.5b
If yes, please specify desktop computer model: _____

Video Magnifiers
This category of reading aid refers to closed-circuit television (CCTV) magnifiers, portable handheld electronic magnifiers, screen-magnification software (such as ZoomText or Magic) and magnifying apps on smartphones or tablets. In the following questions please indicate which of the following types of video magnification you use for visual reading:

Q3.6a
Do you use a closed-circuit TV?
- ☐ Yes, please specify below.
- ☐ No

Q3.6b
If yes, please specify closed-circuit TV model: _____

Q3.7a
Do you use a portable electronic handheld magnifier?
- ☐ Yes, please specify below.
- ☐ No

Q3.7b

If yes, please specify portable electronic handheld magnifier model: _____

Q3.8a
Do you use computer screen magnifying software?
- ☐ Yes, please specify below.
- ☐ No

Q3.8b
If yes, please specify computer screen magnifying software type: _____

Q3.9a
Do you use any smartphone or tablet apps for magnification?
- ☐ Yes, please specify below.
- ☐ No

Q3.9b
If yes, please name the app(s): _____

Please indicate which of the following types of optical magnifiers you use:

Q3.10a
Do you use a handheld optical magnifier?
- ☐ Yes, please specify below.
- ☐ No

Q3.10b
If yes, please specify power or magnification: _____

Q3.11a
Do you use a stand magnifier?
- ☐ Yes, please specify below.
- ☐ No

Q3.11b
If yes, please specify power or magnification: _____

Q3.12a
Do you use a magnifier mounted on glasses?
- ☐ Yes, please specify below.
- ☐ No

Q3.12b
If yes, please specify power or magnification: _____

Q3.13a
Do you use a telescope for reading street signs or other types of distant text?
- ☐ Yes, please specify below.
- ☐ No

Q3.13b
If yes, please specify power or magnification: _____

Unaided Reading

Q3.14
Please indicate if you use any of the following methods to read without any reading aids: Select all that apply.

- ☐ Regular reading glasses without additional magnifier.
- ☐ Strong reading glasses that require text to be positioned close to the eyes.
- ☐ Reading with unaided vision by positioning text very close to the eyes.
- ☐ Reading large print materials.

Q3.15
If you use a visual reading method not captured by the list above, please describe it in a few words below: _____

Q3.16
Do you require a bright source of light for reading hard-copy text such as a lamp, flash light or other source of bright light?

- ☐ Yes
- ☐ No

Q3.17
Please briefly describe the source of illumination you prefer to use: _____

Q3.18
Do you prefer reading text composed of:

- ☐ black letters on a white background
- ☐ white letters on a black background
- ☐ no preference

Q3.19
If you have one or more preferred fonts, please list them in order of your preference. Otherwise, please enter "No Preference": _____

Section 4. Assessment of Magnification:

A short sample of text from *Alice in Wonderland* is included on the next page. If you use a digital device (such as an iPad or computer) or video magnifier for reading, we would like to know how you would configure your display for reading this sample. If possible, please adjust your display for your best reading of this sample and answer the questions that follow. If your preference is to read with a video magnifier, you will need to print the sample before answering the questions.

Text Sample:

Alice was beginning to get very tired of sitting by her sister on the bank, and of having nothing to do: once or twice she had peeped into the book her sister was reading, but it had no pictures or conversations in it, 'and what is the use of a book,' thought Alice 'without pictures or conversation?' So she was considering in her own mind (as well as she could, for the hot day made her feel very sleepy and stupid), whether the pleasure of making a daisy-chain would be worth the trouble of getting up and picking the daisies, when suddenly a White Rabbit with pink eyes ran close by her. There was nothing so very remarkable in that; nor did Alice think it so very much out of the way to hear the Rabbit say to itself, 'Oh dear! Oh dear! I shall be late!' (When she thought it over afterwards, it occurred to her that she ought to have wondered at this, but at the time it all seemed quite natural); but when the Rabbit actually took a watch out of its waistcoat-pocket, and looked at it, and then hurried on, Alice started to her feet, for it flashed across her mind that she had never before seen a rabbit with either a waistcoat-pocket, or a watch to take out of it, and

burning with curiosity, she ran across the field after it, and fortunately was just in time to see it pop down a large rabbit-hole under the hedge.

If you prefer reading text with a CCTV or portable electronic magnifier, please print this page and use it to answer the questions on the following screens.

Please answer the following questions about the conditions you use for reading the sample of text from *Alice in Wonderland.* The sample of text is displayed again below:

Alice was beginning to get very tired of sitting by her sister on the bank, and of having nothing to do: once or twice she had peeped into the book her sister was reading, but it had no pictures or conversations in it, 'and what is the use of a book,' thought Alice 'without pictures or conversation?' So she was considering in her own mind (as well as she could, for the hot day made her feel very sleepy and stupid), whether the pleasure of making a daisy-chain would be worth the trouble of getting up and picking the daisies, when suddenly a White Rabbit with pink eyes ran close by her. There was nothing so very remarkable in that; nor did Alice think it so very much out of the way to hear the Rabbit say to itself, 'Oh dear! Oh dear! I shall be late!' (When she thought it over afterwards, it occurred to her that she ought to have wondered at this, but at the time it all seemed quite natural); but when the Rabbit actually took a watch out of its waistcoat-pocket, and looked at it, and then hurried on, Alice started to her feet, for it flashed across her mind that she had never before seen a rabbit with either a waistcoat-pocket, or a watch to take out of it, and burning with curiosity, she ran across the field after it, and fortunately was just in time to see it pop down a large rabbit-hole under the hedge.

Q4.1

What device are you using to read this text? _____

Q4.2

If you are using a mobile device, please indicate whether you are reading in:

- ☐ Landscape mode
- ☐ Portrait mode

Q4.3a

What is your approximate viewing distance from the display screen? Please select the unit of measurement you would like to use:

- ☐ inches
- ☐ centimeters

Q4.3b

Please estimate the distance: _____

Q4.4a

What is the size of the screen you are using? Please select the unit of measurement you would like to use:

- ☐ inches
- ☐ centimeters

Q4.4b

Please estimate (or measure) the size of the screen by including its width and height dimensions. (You can skip this step if you have listed a device and model number above because we can look up the screen dimensions.)

Width: _____

Height: _____

Now we would like to know how many characters appear in a line of text from the Alice in Wonderland passage, from the left edge to the right edge on your display. Many people with low vision adjust magnification so that their display shows only a portion of each line at one time. Please count the number of

characters visible on a line of the passage on your display including all letters, punctuations, and spaces. If your viewing conditions permit you to view the full width of the passage at one time, please enter "All".

Q4.5
How many characters are there in a line of text, from the left edge to the right edge on your display, including spaces? (The number of characters may vary slightly from line to line, so a typical value is fine.)

Number of characters per line: _____

Here is the sample of Alice in Wonderland text again. Please answer the question below.

Alice was beginning to get very tired of sitting by her sister on the bank, and of having nothing to do: once or twice she had peeped into the book her sister was reading, but it had no pictures or conversations in it, 'and what is the use of a book,' thought Alice 'without pictures or conversation?' So she was considering in her own mind (as well as she could, for the hot day made her feel very sleepy and stupid), whether the pleasure of making a daisy-chain would be worth the trouble of getting up and picking the daisies, when suddenly a White Rabbit with pink eyes ran close by her. There was nothing so very remarkable in that; nor did Alice think it so very much out of the way to hear the Rabbit say to itself, 'Oh dear! Oh dear! I shall be late!' (When she thought it over afterwards, it occurred to her that she ought to have wondered at this, but at the time it all seemed quite natural); but when the Rabbit actually took a watch out of its waistcoat-pocket, and looked at it, and then hurried on, Alice started to her feet, for it flashed across her mind that she had never before seen a rabbit with either a waistcoat-pocket, or a watch to take out of it, and burning with curiosity, she ran across the field after it, and fortunately was just in time to see it pop down a large rabbit-hole under the hedge.

Please click “Next” to review the Alice in Wonderland sample of text again and answer the question.

Q4.6
How many lines of text are displayed on the screen at one time, when the screen is filled with text?

Number of lines on the display: _____

Q4.7
Are you using black letters on a white background or white letters on a black background?

- ☐ Black letters
- ☐ White letters

Q4.9
If you configure your display to use a color other than white for background or text, please indicate here:

Text color: _____

Background color: _____

Q4.10
If you know the font used for displaying this text sample, please indicate it here:

_____

Section 5: Past and current reading habits

Q5.1
Did you learn to read before the onset of your low vision?

- ☐ Yes
- ☐ No

[If participants respond Yes in Q5.1, they will continue to answer questions to Q5.2. If they respond No, to this part will be skipped and they will go directly to Q5.13.

Q5.2
Before the onset of your low vision, were you diagnosed with any form of reading or learning disability?

- ☐ Yes
- ☐ No

Q5.3
If yes, please describe briefly: _____

For the year before the onset of your low vision, please rate the amount of visual reading you did in the following activities, using a scale from 1 to 5 as follows:
1 - Rarely or never.
2 - Occasionally, once a week or less.
3 - Frequently, at least a few days per week.
4 - Almost every day, at least once.
5 - Daily heavy use.

Q5.4
Work or educational reading from hard-copy text.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q5.5
Work or educational reading from computer or other digital device.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q5.6
Newspaper reading from hard copy.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q5.7
News reading on computer or digital device.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q5.8
Social networking (email communication, social media, etc.).

- ☐ 1
- ☐ 2

- 3
- 4
- 5

Q5.9
Pleasure reading of books or articles from hard copy.

- 1
- 2
- 3
- 4
- 5

Q5.10
Pleasure reading of books or articles from computer or digital device.

- 1
- 2
- 3
- 4
- 5

Q5.11
Brief information look-up from hard copy (recipes, food labels, restaurant menus, phone numbers, TV listings, etc).

- 1
- 2
- 3
- 4
- 5

Q5.12
Brief information look-up from computer or digital devices (recipes, food labels, restaurant menus, phone numbers, TV listings, etc).

- 1
- 2
- 3
- 4
- 5

[If Q5.1's answer is No, then skip to Q5.13]

Current Reading Habits
For the past year, please rate the amount of visual reading you did in the following activities, using a scale from 1 to 5 as follows:
1 - Rarely or never.
2 - Occasionally, once a week or less.
3 - Frequently, at least a few days per week.
4 - Almost every day, at least once.
5 - Daily heavy use.

Q5.13
Work or educational reading from hard-copy text.

- 1
- 2
- 3
- 4

- 5

Q5.14
Work or educational reading from computer or other digital device.

- 1
- 2
- 3
- 4
- 5

Q5.15
Newspaper reading from hard copy.

- 1
- 2
- 3
- 4
- 5

Q5.16
News reading on computer or digital device.

- 1
- 2
- 3
- 4
- 5

Q5.17
Social networking (email communication, social media, etc.).

- 1
- 2
- 3
- 4
- 5

Q5.18
Pleasure reading of books or articles from hard copy.

- 1
- 2
- 3
- 4
- 5

Q5.19
Pleasure reading of books or articles from computer or digital device.

- 1
- 2
- 3
- 4
- 5

Q5.20
Brief information look-up from hard copy (recipes, food labels, restaurant menus, phone numbers, TV listings, etc).

- 1
- 2

- 3
- 4
- 5

Q5.21
Brief information look-up from computer or digital devices (recipes, food labels, restaurant menus, phone numbers, TV listings, etc).

- 1
- 2
- 3
- 4
- 5

[End of the survey]

Appendix A3: Study 2: Tables of Regression Results on reading habits

Predictor	β	SE β	Z	***P***	Odds ratio (95% CI)
(Intercept)	3.35	1.27	2.64	< .01**	N/A
Age	-0.02	0.02	-1.1	0.27	0.98 (0.95 – 1.02)
Education Level - 0 = primary school - 1 = High school - 2 = University/College degree - 3 = Advanced Graduate or Professional Degree	0.42	0.36	1.13	0.26	1.51 (1.74 – 3.17)
Self-reported Visual Acuity (logMAR)	-2.05	0.61	-2.53	< .05**	0.13 (0.02 – 0.58)

Table A3-1 Proportion of visual reading

The table shows the results of multiple logistic regression model for the association between visual reading (visual reading time < 75% or visual reading time >= 75%) and other predictors, including Age, Educational level, and Self-reported acuity (logMAR).

Predictor	β	SE β	Z	***P***	Odds ratio (95% CI)
(Intercept)	-2.69	1.02	-2.63	< .01 **	NA
Age	0.02	0.01	1.59	0.11	1.02 (1 — 1.05)
Education Level -0 = primary school -1 = High school -2 = University/College degree -3= Advanced Graduate or Professional Degree	-0.38	0.31	-1.22	0.22	0.68 (0.37 — 1.25)
Self-reported Visual Acuity (logMAR)	2.45	0.69	3.58	< .001 ***	11.63 (3.24—48.49)

Table A3-2 CCTV usage

The table shows the results of the multiple logistic regression model for the association between the usage of CCTV (0 = not used, 1 = used) and other predictors, including Age, Educational level, and Self-reported acuity (logMAR).

Appendix A4: Study 3: Tables of GEE model analysis

Weekly In-person social contacts							
		Model 1 (PRE vs PAN1)			Model 2 (PAN1 to PAN6)		
Predictors	levels	B	95% CI	p	B	95% CI	p
(Intercept)		31.53	(-4.61, 67.67)	0.09	-8.93	(-22.66, 4.81)	0.203
Session Number		-14.86	(-22.40, -7.31)	<.001	1.05	(0.25, 1.85)	p<.001
Sensory Loss							
	VL	ref			ref		
	HL	4.57	(-25.55, 34.68)	0.77	5.86	(2.88,8.78)	p<.001
	CTL	28.74	(0.34, 57.13)	0.05	4.00	(1.28,6.72)	p<.01
Session Number * Sensory Loss							
	Session * VL	ref			ref		
	Session * HL	-1.17	(-15.93, 13.59)	0.88	0.32	(-1.01, 1.65)	0.64
	Session * CTL	-13.63	(-28.29, 1.02)	0.07	-0.26	(-1.31, 0.78)	0.62
Living Alone							
	No	ref			Ref		
	Yes	0.58	(-7.96, 9.12)	0.89	1.63	(-0.76, 4.02)	0.18
Age		0.05	(-0.42, 0.51)	0.94	0.09	(-0.11, 0.29)	0.37
Gender							
	Female	ref			ref		
	Male	-2.30	(-8.82, 4.22)	0.49	0.82	(-1.31, 2.94)	0.45
Heath-risk factors for COVID-19							
	No	ref			ref		
	Yes	-5.56	(-12.14, 1.03)	0.1	1.58	(-1.27, 4.43)	0.28
Know anyone got infected							
	Yes	ref			ref		
	No	-1.51	(-7.43, 4.40)	0.62	-0.56	(-2.94, 1.83)	0.65
Employed							
	Retired/Unemployed	ref			ref		
	Employed	8.43	(-0.85, 17.70)	0.08	3.77	(0.74, 6.80)	p<.05
Education							
	No College Degree	ref			ref		

College Degree	-0.52	(-8.99, 7.95)	0.90	0.54	(-3.25, 4.34)	0.78

Table A4-1 GEE model results for in-person contacts

Weekly Electronic social contacts

		Model 1 (PRE vs PAN1)			Model 2 (PAN1 to PAN6)		
Predictors	levels	B	95% CI	p	B	95% CI	p
(Intercept)		4.90	(-116.63, 126.42)	0.94	-11.05	(-53.51, 31.42)	0.61
Session Number		-7.30	(-59.31, 44.72)	0.08	-1.97	(-5.33, 1.39)	0.25
Sensory Loss							
	VL	ref			ref		
	HL	-42.77	(-141.03, 55.48)	0.39	-9.62	(-33.25, 14)	0.42
	CTL	-46.85	(-143.77, 50.06)	0.34	2.81	(-22.39, 28.01)	0.83
Session Number * Sensory Loss							
	Session * VL	Ref			ref		
	Session * HL	16.89	(-34.76, 68.54)	0.52	1.81	(-1.94, 5.57)	0.34
	Session * CTL	20.25	(-32.49, 72.98)	0.45	2.05	(-2.58, 6.68)	0.39
Living Alone							
	No	ref			ref		
	Yes	9.49	(-6.33, 25.32)	0.24	3.78	(-8.32, 15.89)	0.54
Age		0.27	(-0.62, 1.15)	0.55	0.30	(-0.06, 0.65)	0.10
Gender							
	Female	ref			ref		
	Male	-4.75	(-18.60 ,9.10)	0.50	1.22	(-10.04, 12.48)	0.83
Heath-risk factors for COVID-19							
	No	ref			ref		
	Yes	-1.00	(-18.29, 16.29)	0.91	2.94	(-8.93, 14.82)	0.63
Know anyone got infected							
	Yes	ref			ref		
	No	-4.48	(-17.33, 8.37)	0.49	0.85	(-4.29, 6.00)	0.74
Employed							
	Retired/Unemployed	ref			ref		
	Employed	20.21	(-4.05, 44.47)	0.10	5.02	(-1.17, 11.21)	0.11
Education							
	No College Degree	ref			ref		

College Degree	17.03	(-2.14, 36.20)	0.08	10.88	(-1.37, 23.13)	0.08

Table A4-2 GEE model results for electronic contacts

PHQ-9 score

		Model 1 (PRE vs PAN1)			Model 2 (PAN1 to PAN6)		
Predictors	levels	B	95% CI	p	B	95% CI	p
(Intercept)		6.44	(-5.07, 17.96)	0.27	9.48	(3.69, 15.27)	p<.01
Session Number		2.12	(0.58, 3.67)	p<.01	0.14	(-0.32, 0.60)	0.55
Sensory Loss							
	VL	ref			ref		
	HL	3.10	(-0.77, 6.97)	0.12	0.78	(-1.79, 3.36)	0.55
	CTL	2.46	(-1.66, 6.58)	0.24	0.42	(-2.92, 3.77)	0.80
Session Number * Sensory Loss							
	Session * VL	ref			ref		
	Session * HL	-1.48	(-3.15, 0.19)	0.08	-0.24	(-0.76, 0.28)	0.36
	Session * CTL	-1.41	(-3.26, 0.45)	0.14	-0.01	(-0.66, 0.64)	0.98
Weekly in-person contacts		-0.0001	(-0.00015, -0.000112)	P<.001	-0.0013	(-0.002, -0.0007)	p< .001
Living Alone							
	No	ref			ref		
	Yes	1.47	(-0.41, 3.35)	0.12	1.65	(0.79, 2.52)	p<.001
Age		-0.12	(-0.29, 0.04)	0.14	-0.12	(-0.2, -0.05)	p<.001
Gender							
	Female	ref			ref		
	Male	1.47	(-0.41, 3.35)	0.12	-0.72	(-1.44,0)	0.05
Heath-risk factors for COVID-19							
	No	ref			ref		
	Yes	1.23	(-1.77, 4.22)	0.42	0.83	(-0.19, 1.85)	0.11
Know anyone got infected							
	Yes	ref			ref		
	No	0.94	(-0.59, 2.47)	0.23	0.15	(-0.59, 0.9)	0.69
Employed							
	Retired/Unemployed	ref			ref		
	Employed	-0.89	(-2.58, 0.80)	0.30	-0.65	(-1.6, 0.3)	0.18
Education							
	No College Degree	ref			ref		

College Degree	-0.34	(-5.69, 5.02)	0.90	1.36	(-0.59, 3.31)	0.17

Table A 4-3 GEE model results for PHQ-9 scores

Loneliness rating

		Model 1 (PRE vs PAN1)			Model 2 (PAN1 to PAN6)		
Predictors	levels	B	95% CI	p	B	95% CI	p
(Intercept)		0.47	(-2.47, 3.41)	0.75	2.24	(0.70, 3.77)	p<.01
Session Number		1.07	(0.42, 1.72)	p<.01	-0.03	(-0.16, 0.10)	0.67
Sensory Loss							
	VL	ref			ref		
	HL	0.11	(-0.97, 1.18)	0.85	-1.05	(-1.86, -0.25)	p<.05
	CTL	0.58	(-0.50, 1.65)	0.29	-0.79	(-1.66, 0.07)	0.07
Session Number * Sensory Loss							
	Session * VL	ref			ref		
	Session * HL	-0.60	(-1.34, 0.13)	0.11	0.04	(-0.12, 0.19)	0.65
	Session * CTL	-0.62	(-1.35, 0.10)	0.09	0.09	(-0.08, 0.26)	0.31
Weekly in-person contacts		0.00002	(0.00001, 0.00003)	p<.001	-0.0002	(-0.00003, -0.00005)	p<.01
Living Alone							
	No	ref			ref		
	Yes	0.39	(0.00, 0.79)	0.05	0.65	(0.41, 0.89)	p<.001
Age		-0.01	(-0.04, 0.03)	0.70	-0.01	(-0.02, 0.01)	0.60
Gender							
	Female	Ref			ref		
	Male	-0.07	(-0.40, 0.26)	0.68	-0.29	(-0.49, -0.09)	p<.01
Heath-risk factors for COVID-19							
	No	ref			ref		
	Yes	-0.17	(-0.58, 0.25)	0.43	-0.02	(-0.26, 0.22)	0.86
Know anyone got infected							
	Yes	ref			ref		
	No	0.33	(-0.33, 0.99)	0.33	0.21	(-0.01, 0.42)	0.06
Employed							
	Retired/Unemployed	ref			ref		
	Employed	-0.03	(-0.40, 0.34)	0.88	-0.1	(-0.33, 0.13)	0.39
Education							

No College Degree	ref			ref		
College Degree	0.23	(-0.35, 0.80)	0.44	0.58	(0.11, 1.05)	p<.05

Table A 4-4 GEE model results for self-reported loneliness