Modification of a Head-Mounted Tablet Device for Reading in Low Vision

Thesis

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By

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Abstract

Although many low vision aids are commercially available, reading with vision impairment remains a difficult task. The goal of this study was to modify the RealWear HMT-1, a head-mounted tablet with a camera and micro-display that is currently used primarily in industry settings, and evaluate this modified version for the purpose of reading with low vision. A custom Android application, the Industrial Badger App, was used to modify the HMT-1 to provide increased magnification capability and text-to-speech conversion of printed material. Fourteen subjects with low vision were recruited to evaluate the HMT-1 with a previously validated 300-word passage reading and comprehension test. Mean better eye visual acuity improved significantly from 51 ± 10 with habitual correction to 80 ± 8 when using the HMT-1 camera for magnification ($p < .001$). However, contrast sensitivity decreased from 1.47 ± 0.25 with habitual correction to 1.31 ± 0.27 with the HMT-1 camera ($p=0.001$) and mean passage reading time increased from 162 ± 64 seconds with habitual correction to 290 ± 139 seconds with the HMT-1 camera ($p=0.001$). Comprehension scores were worse with the HMT-1 camera compared to habitual and text-to-speech conditions. We found that 79% of subjects reported the device to be useful, and 57% of subjects reported they would use the HMT-1 in real life. The RealWear HMT-1 has the potential to be a useful low vision device that is hands-free and preserves peripheral vision, especially for short spot reading tasks.

Dedication

This document is dedicated to my family, especially my sister.

Acknowledgments

I would like to acknowledge my advisor, Bradley Dougherty OD, PhD, and committee members Roanne Flom OD and Deyue Yu PhD. I would also like to acknowledge Rebecca Deffler OD, MS, San-San Cooley OD, MS, and Gregory Hopkins OD, MS, for their help with study design, recruiting, and data collection, as well as Brad Henry and Chip McCullough of EduTechnologic for their work on modifications of the study device. This work was funded by NIH T35EY007151 and Research to Prevent Blindness.

Vita

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Presentations

Deffler RA, Srikantan P, Cooley SL, Hopkins GH, Henry B, McCullough HD, Dougherty BE. Modification of a Head-Mounted Tablet Device for Reading in Low Vision. Poster presented to the American Academy of Optometry, November 2021, Boston, MA.

Srikantan P, Deffler RA, Cooley SL, Hopkins GH, McCullough HD, Henry B, Dougherty BE. Head-mounted Tablet Device for Reading and Navigation in Low Vision. Abstract for The Association for Research in Vision and Ophthalmology, May 2021, San Francisco, CA (virtual).

Fields of Study

Major Field: Vision Science, Optometry

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Chapter 1. Introduction

What is low vision?

Low vision is chronic, uncorrectable visual impairment that hinders a person from participating in daily activities. Such a disability affects 3.2 million Americans. There is a strong relationship between age and visual impairment, so this number will continue to grow as the population ages, resulting in 6.95 million people with vision impairment by 2050.[1] Common diseases that result in low vision include age-related macular degeneration, glaucoma, and diabetic retinopathy, which primarily affect older adults.[2] As the number of people in this age group rises in the future, so will the number of individuals with low vision.

While many studies define low vision as a best-corrected visual acuity of 20/40 or worse in the better eye or the inability to read newsprint at a normal reading distance with the best optical correction, visual field loss and contrast sensitivity reduction also significantly affect those with low vision.[3,4] Additionally, low vision may be better defined as a disruption in a person's functional ability, rather than only by vision measures. Vision related quality of life and health related quality of life are significantly reduced in individuals with low vision compared to healthy people with normal vision, and worse visual impairment is correlated with higher levels of depression and anxiety.[5-8] Furthermore, the population most affected by low vision is also more frequently affected by other functional difficulties including loss of mobility, hearing, and agility.[9] Loss of independence due to vision loss can be distressing and challenging. Vision rehabilitation and visual aids can play an important role in helping people regain the ability to complete meaningful activities.[10]

How does low vision affect reading?

One of the highest priorities of patients with low vision is regaining the ability to read text that they could comfortably see prior to vision loss.[9,11] Ramulu et al.[12] examined the correlation between visual impairment and reading difficulty. Out-loud and silent reading in glaucoma patients with bilateral visual field loss was studied. The authors hypothesized that visual field loss would not affect out-loud reading but would affect sustained silent reading. Subjects were tested for out-loud reading speed using the MNRead acuity chart and an IReST passage. Then, they read a long passage for 30 minutes silently and answered accompanying comprehension questions. Reading speeds were calculated in words per minute. Reading speed was slower for subjects with glaucoma with bilateral visual field loss during out-loud reading, and especially during sustained silent reading, compared to that of normally sighted subjects. Slower reading speed was associated with more extensive field loss. Lastly, those with visual field loss exhibited lower reading comprehension scores. This was an important finding, as decreased ability to read and understand has been shown to negatively impact patients' quality of life.[13]

Reading speed is often used as the outcome measure for baseline measurements or rehabilitation success. However, comprehension should also be measured since the two are different and comprehension is important for sustained reading. Therefore, a reading test that better reflects real-life applications of reading was created and validated.[14] Rudolf et al. aimed to create a reading test that used natural reading, tested comprehension, and could be used at low vision exams or in research as a relatively brief but more accurate reading test. That study created 12 passages at a 6th grade level containing common words from the English language with 300 words each. Each passage was science related and was accompanied by four multiple choice questions with four possible answers for each question. The passages were standardized using the Flesch-Kincaid grade level and reading measures and the answers to the questions were evenly spaced throughout the passages. The questions had a low guess rate and a low error rate. Passages were printed at 12 point font, or 1.3M.

The passages and questions were tested with normally-sighted subjects first, wearing habitual correction. This passage reading test was compared to performance on the MNRead test, using performance metrics of visual acuity, maximum reading speed, critical print size, and the reading accessibility index[15]. Subjects were told to read each of the newly created passages silently and as quickly as possible without rereading or backtracking. Each passage was taken away after the subject completed reading the text. The questions and answer choices were read aloud for the subject. Subjects read six passages answering the associated comprehension questions after reading each passage.

For the remaining six passages, subjects answered the associated questions without having read the text.

Most questions met the criteria for correct guess rate and error rate. The six passages with the worst questions were discarded. The worst performing question for the six remaining passages was also discarded. This left six passages with the best questions and the three best questions per passage to be administered to the low vision subjects.

Next, the study was conducted with low vision subjects. Participants wore their habitual correction during the study visit. The Ruby, a handheld electronic magnifier, was used to achieve the magnification necessary for the subjects to read the passages based on data collected through MNRead testing. Low vision subjects read six passages total and answered 3 comprehension questions with each passage.

There were 16 low vision subjects between the ages of 20 and 84 with an average of 60. Ten of those subjects claimed difficulty with reading. They had a range of ocular conditions and 12 had previous surgery. Fifteen subjects had previous experience with low vision devices while two had experience with a handheld video magnifier. Visual acuity ranged from 0.36 to 0.88 logMAR with an average of 0.62. Contrast sensitivity ranged from 1.00 to 1.84 with an average of 1.55.

The study found that MNRead maximum reading speed, critical print size, and reading accessibility index were positively correlated with this new test's silent reading speed and comprehension. There was also a positive correlation between silent reading speed and correct guess rate. Reading speed of the 1.3M size on MNRead with the Ruby was positively correlated with silent reading speed and reading acuity. Contrast sensitivity and reading speed were also positively correlated. Normally sighted subjects had higher reading speed, better reading acuity, smaller critical print size, higher reading accessibility scores, and better contrast sensitivity compared to low vision subjects. However, the two groups did not differ in comprehension. Both groups showed higher reading speed predicted better comprehension. The lack of performance difference in comprehension between the two groups suggests that with enough magnification, low vision patients can achieve good comprehension.

This new standardized passage test stimulated a more organic approach to reading. It was sensitive to differences between normally-sighted and low vision subjects. Regardless of the variety of ocular conditions among the low vision subjects, all were able to complete the test. Although the results were somewhat consistent with MNRead results, they were not the same, showing that out loud and silent reading are different, so should be evaluated differently.

Reading with low vision is difficult because print size is small and reading speed is reduced. Magnification alone does not always allow low vision readers to reach normal reading speeds, as one study showed.[4] Out of 141 subjects, only 30% reached reading speeds considered to be in the normal range, even with magnification. Although magnification is not a perfect solution to reading with low vision, it often allows low vision readers to reach functionally useful reading speeds, even if this speed is not as fast as in normally-sighted people. However, high levels of magnification can actually be detrimental and decrease reading speed due to a reduced field of view.[16]

Granquist et al.[17] conducted an online survey of low vision reading to better understand how variables affect low vision reading in the natural world. One goal of this study was to gain an understanding of the visual reading behavior of low vision patients who use technological aids. The authors wanted to estimate the required magnification of text in relation to acuity and see how viewing distance and print size were manipulated to obtain that magnification. Participants were given a passage to read on their chosen device and were instructed to adjust the display magnification as desired. Subjects answered questions about the device used, viewing distance, screen parameters, and number of characters visible on the screen without scrolling the text. The authors found that low vision subjects generally preferred larger displays; most used a computer instead of a tablet or smartphone. Those who did use a tablet or smartphone had slightly better mean visual acuity compared to computer users. Furthermore, viewing distance for low vision subjects was shorter than for normally sighted subjects. The authors found that low vision subjects tended to magnify the text on the screen rather than move closer to the device. On average, low vision subjects magnified the text six times by reducing viewing distance or increasing angular print size compared to normally sighted subjects. Preferred physical print size increased as visual acuity decreased and the preferred amount of magnification increased as logMAR visual acuity increased. Since subjects with worse visual acuity used higher levels of magnification, they had fewer characters per line displayed on the device. This study demonstrates the challenge of reading with low vision. There is a careful balance between sufficiently large print size, the corresponding reduction in characters per line, and the viewing distance. The authors established that small devices and short viewing distance often allow for better spot reading, but are not always desirable for extended reading. For low vision subjects with worse acuity, a large display, short viewing distance, and large font size proved to be helpful.

One study by Latham et al.[18] investigated the effects of low vision aids (LVA) on the reading accessibility index (ACC). The ACC represents the mean reading speed across the ten largest passages on the MNRead chart normalized by 200 words per minute, which is the average reading speed for normally-sighted young adults. Values for the ACC range from 0 to 1 with 0 signifying the patient is unable to read print at these sizes and 1 signifying the patient can read print at these sizes at a speed of 200 words per minute. The ACC value reveals the array of print sizes that is fluently accessible to the patient without needing an accurate critical print size measurement and is calculated by taking the mean reading speed for the ten largest MNRead passages and dividing by 200. The aided ACC is calculated in the same manner but uses reading speeds obtained with the assistance of LVA. Participants brought their habitual LVA to the study, which included illuminated stand magnifiers, non-illuminated hand magnifiers, relative distance magnification (high add, removing glasses for myopes, bringing print closer for young subjects), illuminated flat-field magnifiers, telescopes, domes, and bar magnifiers. The study noted 88% of participants used their LVA "often" or "very often." This study showed that LVA are valuable in low vision rehabilitation, as they provided significant improvement in reading accessibility regardless of the cause of vision loss. Twenty five out of 100 participants had almost no accessibility to print with an ACC value less than or equal to 0.05, but with LVA, only 5 participants demonstrated a lack of accessibility.

LVA yielded an improved ACC in 92% of participants. The subjects with a decreased ACC using a LVA had relatively good acuity to begin with. Although all these subjects could read smaller print with their LVA, they sacrificed reading speed to do so, resulting in a reduced ACC value. One of the subjects demonstrated a reduced ACC value with LVA due to poor manipulation technique with their illuminated hand-held magnifier resulting in slower reading speed.

For many individuals who are visually impaired, decreased reading ability is their predominant complaint. Out of those who enjoyed reading prior to visual impairment, far fewer reported enjoying reading after vision loss.[19]

Electronic magnifiers

With improving technology, electronic magnifiers have become more commonly used. One study by Morrice et. al.[19] examined the effectiveness of portable electronic visual aids, like the Apple iPad, compared to more traditional magnification methods, like CCTV video magnifiers. CCTVs are generally capable of greater magnification than many handheld optical magnifiers. Magnification of text displayed on a large screen can result in greater reading speeds.[20,21] iPads combine the higher resolution and magnification of CCTVs with better portability and other functionality. Morrice et. al. compared out-loud reading speed on IRest passages[23] using an iPad, CCTV, and habitual reading device. The authors found that any magnification improved reading speed. The study also found that there was not a significant difference in reading speed among the three devices, but those with previous experience with the CCTV did not show increased reading speed compared to those without experience, while those with previous experience with the iPad did show increased reading speed compared to those without experience. Also, none of those with previous CCTV experience used the CCTV as a primary means of magnification, while those with previous iPad experience generally did use the iPad as a primary means of magnification. The takeaways from this study were that the iPad and CCTV are comparable in terms of improving reading speeds, but more experience with the iPad can potentially increase reading speed even more. The portability of the iPad could help patients enjoy reading again and improve reading ability.

Head-mounted electronic low vision devices are available and typically use a camera that captures live video, which is processed and may be displayed to the user with image enhancements. There are electronic head mounted systems that use optical character recognition and other types can be used for magnification. Wittich et al.[23] examined the changes in visual ability and functional vision after three months of using the second generation of eSight Eyewear. That system provides variable magnification, autofocus, contrast enhancement, hands-free use, portability, digital image processing that allows user scanning, freeze frames for OCR, and text-to-speech conversion. It can magnify up to 12.3 times. Users may manipulate the device with a handheld controller connected by a wire to the headset. Distance visual acuity, reading acuity, reading speed, critical print size, and contrast sensitivity were measured in the study. These measurements were obtained at baseline without the device, a few weeks later with the device, and then again three months later, after participants had been using the device at home. An eSight manual, training modules, and regular follow up phone calls for the first month of use were provided to all participants. The study found that distance visual acuity, contrast sensitivity, CPS, and reading speed improved immediately upon using the eSight, but there was no further improvement after three months. Also, the device was not suited for mobility and some participants (10 of 74) discontinued participation in the study due to discomfort, insufficient perceived benefit, and difficulty operating the device.

Another study investigated portable electronic vision enhancement systems (p-EVES).[24] P-EVES are hand-held electronic devices used as low vision reading aids. These devices can be used for more natural binocular viewing at habitual working distance since they can provide varying levels of magnification, contrast enhancement, and have freeze frame ability. This study compared the acceptability and effectiveness of p-EVES when used in addition to optical low vision aids (LVA) versus when just using optical LVA. The hypothesis was that p-EVES would allow for faster reading and be used more often compared to optical LVA. One group used a p-EVES and their LVA for 2 months and then used only their LVA for 2 months. The other group did the same, but in the opposite order. P-EVES devices used included Optelec Compact+, Optelec Compact 4HD, Schweizer eMAG 43, and Eschenbach Mobilux Digital. Participants were allowed to choose the p-EVES best suited for their needs and were provided usage instructions. Maximum reading speed was not significantly different when using the p-EVES versus the optical LVA in normal contrast conditions. Critical print size and threshold print size measured with MNRead showed significant improvement with a p-EVES compared to an optical LVA. At the end of 2 months of using the p-EVES, 64% of participants preferred to use the p-EVES for the MNRead test. However, in reduced contrast conditions, maximum reading speed was significantly worse with a p-EVES compared to an optical LVA. LVA were used more frequently and for a larger variety of tasks than p-EVES. LVA were preferred for spot reading. However, for leisure reading or extended near tasks, subjects preferred p-EVES. Although LVA were used more, p-EVES were used for different tasks that cannot be done as well with LVA alone, like reading a book. There was no difference in reading speed between the optical LVA and p-EVES when p-EVES was preferred. However, for those who preferred optical LVA over p-EVES, there was a decrease in reading speed with the p-EVES. In terms of tested daily activities, participants preferred the optical LVA or the p-EVES depending on the task, but performances of the tasks and the time it took to complete them did not differ significantly regardless of the device used. According to the difficulties questionnaire, least difficulty was reported when participants could use p-EVES and optical LVA in combination as needed.

Overview of the Realwear HMT-1

The RealWear HMT-1 was originally developed for industry applications (see figure 1) because it is durable and hands-free. The HMT-1 is a head-mounted electronic tablet device with a camera and video display. The device consists of a 854x480 pixel display that is mounted on an adjustable arm so it can be placed in front of either eye and adjusted for optimal visualization. There is space between the eyes and the video display allowing the user to wear spectacles comfortably. The display is reported to provide a 20-

degree field of view. A 16MP camera with autofocus and 4-axis optical image stabilization provides the video feed to the display. The device uses an Android 6.0 Qualcomm Snapdragon 625 platform with 2GB RAM. Four digital microphones allow voice activation and speech recognition to navigate menus and functions. Audible functions are made possible through an integrated 91 dB speaker and a 3.5 mm audio jack. Wi-Fi and Bluetooth 4.1 LE capabilities are included as well. The HMT-1 contains a GPS unit and gyroscopes and has the capability to detect Bluetooth beacons. Lastly, the device is highly durable with a long battery life of up to ten hours. A user with visual impairment may place the display before the better-seeing eye using the adjustable arm. Users may make voice commands to navigate through the device's features using the microphones.

Figure 1. The RealWear HMT-1

How the HMT-1 could be advantageous

There are potential advantages of the HMT-1 design, making the device beneficial in ways optical low vision aids may not be. One study[18] found that even with the optical LVA, the ACC of patients with low vision was still lower than what would be typical for a fully-sighted person of the same age. This could be due to the distraction of having to physically manipulate a magnifier while completing a reading task, reduced illumination provided by non-illuminated magnifiers, or magnification causing a smaller field of view. Since the HMT-1 is head-mounted and can be operated with voice commands, the device does not require manipulation or the use of steady hands. Also, the tablet provides illumination itself. Unlike optical low vision aids which must be held at certain distances to obtain focus, the HMT-1 can auto-focus on objects at various distances. The user may complete distance and near tasks without switching devices or low vision aids. Although low vision patients primarily use magnification to read, enlarging print does not always achieve the desired goal due to decreased field of view. OCR may compensate for what magnification cannot accomplish. People with low vision sacrifice reading speed with increased magnification, but by utilizing OCR, users may obtain the same information from reading material as with magnification without drastically slowing reading speed. Lastly, the HMT-1 is lightweight, offering better comfort for the user and is conveniently portable and durable.

In another study[9], 97 optometrists, ophthalmologists, and Canadian National Institute for the Blind rehabilitation worker teams reported on low vision exams conducted over three years. In addition to demographic information, ocular diagnoses, patient objectives, visual field loss, and visual aids used, data were gathered on functional limitations. Mobility, hearing, and agility were found to be the most common additional disabilities among older adults with low vision. People with visual impairment affecting central vision rely more heavily on peripheral vision, especially while walking. The HMT-1 does not affect peripheral vision of the user by its design so users may still navigate through their space and use their mobility aids. For those with hearing difficulties, the volume may be increased on the device. Also, since the HMT-1 aids users with magnification and OCR, patients may rely on one more than the other based on their particular level and type of disability. Lastly, unlike many optical low vision aids, as mentioned previously, the HMT-1 is relatively hands-free. This could prove beneficial for those with decreased dexterity.

Purpose of this study

Many optical and technological low vision devices are available to people with low vision. However, extended reading with vision impairment remains a challenge. One purpose of this study was to modify the RealWear HMT-1 for people with low vision. As mentioned in the literature, helpful features of electronic low vision devices include magnification and text-to-speech conversion, so one of the main goals was incorporating these functionalities. The other purpose of this study was to determine if the HMT-1 is useful and effective as a prolonged reading aid. In order to assess improvement in vision and reading with the HMT-1, a previously validated passage reading and comprehension test was used to measure reading performance. The hypothesis was that the HMT-1 would enable users to read smaller print, increase passage reading speed, and retain reading comprehension compared to habitual low vision aids.

Chapter 2. Methods

The Biomedical Sciences Institutional Review Board at the Ohio State University approved all study procedures, and all participants provided informed consent prior to the performance of any study procedures.

Modification of the Realwear HMT-1

To conduct this study, first the Realwear HMT-1 was adapted for improving functionality of people with vision impairment. A custom Android application—Industrial Badger App—was used to implement modifications to the HMT-1. This application was designed for use on Android-based devices like the HMT-1 or Google Glass. It allows for the custom addition of various features and provides easily accessible menus for the user to select functions. Alterations incorporated into the HMT-1 included increasing its magnification capabilities, adding a reverse contrast feature, and enabling text-to-speech functionality using optical character recognition. Magnification in the modified device ranged from 2x to 5x, and incorporated eight zoom levels in approximately tenth of a log unit steps. Reverse contrast capabilities enabled black-on-white text or white-on-black text. OCR was incorporated using the Google Cloud Text-to-Speech engine. Reading passages to be tested were stored on the device to be converted to speech for the study, though this function was also available by capturing an image of text. Menus and messages within the device were also enlarged and simplified to allow for easier browsing and location of desired applications and functions. Irrelevant items were removed to decrease clutter and confusion.

During study visits, the HMT-1 was connected to a laptop to allow the researcher to see the subjects' view through the camera. The device's video display was mirrored on the laptop. This allowed the researcher to troubleshoot positioning of the device and manage subjects' technical difficulties. The researcher could control the device via the laptop, and subjects could also control the device through simple voice commands.

Reading passages

A previously validated passage reading test by Rudolf et al.[14] was used to assess speed and comprehension in our study. Subjects read passages from this newly validated reading test under three conditions: using magnification with the HMT-1, using OCR with the HMT-1, and using their habitual low vision reading aid.

Participants

Fourteen participants with low vision were recruited to evaluate the utility and effectiveness of the Realwear HMT-1. Subjects were recruited from The Ohio State University College of Optometry Low Vision Rehabilitation Service and through phone calls to previous College of Optometry low vision study participants. Inclusion criteria were as follow: at or over the age of 18 years, best corrected better eye visual acuity in the 20/40 to 20/200 range, and passage of the the Mini-Mental State Examination[25] with a score of at least 27. Exclusion criteria included pediatric patients, best corrected better eye visual acuity better than 20/40 or worse than 20/200, failure on the MMSE, and illiteracy.

Clinical testing of Realwear HMT-1 in low vision subjects

Subjects were verbally queried on head and neck mobility issues, age, education level, cause of vision impairment, previous ocular surgeries, preferred eye, level of difficulty with reading, habitual low vision reading aid, and previous experience with electronic low vision devices. Subjects were asked, "In the past month, how much has your eyesight interfered with reading ordinary sized print?" This question was obtained from the Impact of Vision Impairment (IVI) Questionnaire.[26] The MMSE was also administered.

Participants wore their habitual distance correction for distance acuity testing. If they did not have spectacles, an auto-refractor was used and spectacles were made for them using trial lenses and a trial frame. Monocular visual acuity was measured with an ETDRS[27] chart at 4m using letter-by-letter scoring and a stopping rule of three or more errors in a line. Subjects were asked to guess letters that were difficult to see. Monocular contrast sensitivity was measured using a Mars contrast sensitivity chart[28] at 50cm and letter-by-letter scoring until two consecutive letters were missed. Appropriate near correction was used along with lighting at 2ft. Subjects were asked to guess letters that were difficult to see. Critical print size and reading acuity were measured with an MNRead card at 40cm. Appropriate near correction was used along with overhead lighting at 2ft. Subjects were asked to read each sentence aloud as quickly and accurately as possible without backtracking. Each sentence was uncovered one at a time using white poster paper for guidance. The critical print size was recorded as the smallest print observed to be read at the subject's maximum reading speed. It was noted if a participant chose to read monocularly and which eye was preferred. Lastly, if the subject did not report an obviously dominant eye, the eye with the better visual acuity was used to perform further testing.

Vision tests were then repeated with the Realwear HMT-1 over distance refractive correction. The device was placed on the subject's head with the video display positioned in front of the dominant eye. The subject was allowed to arrange the head band and adjustable arm to best suit their comfort and ensure the video display was located properly in front of their eye.

Binocular visual acuity was measured using the same method described previously. The subject was instructed to use the voice activation feature of the HMT-1 to zoom the camera into the chart when the letters became too small to read. The subject was permitted to zoom in to the maximum capability of the device or until they could read the 20/20 line. Subjects were asked to guess letters that were difficult to see. Binocular contrast sensitivity was measured using the method described previously. Contrast sensitivity was tested using zoom level 1 for all subjects. This zoom level was equivalent to viewing objects without any magnification. Subjects were asked to guess letters that were difficult to see.

The smallest print size read at maximum speed was divided by 1.3M to estimate the magnification level that would be used for reading the 1.3M sized passages. The subjects were then allowed to adjust the HMT-1 zoom level while viewing 1.3M print on an MNRead card to further adjust and optimize magnification. Once the subject was comfortable with the magnification level, a sample passage from the validated passage reading test was provided to allow them to become better acquainted with the task. It was noted if the subject preferred to read monocularly, winking an eye shut, using only the eye looking at the video display. Subjects were offered the option to read black-on-white text or white-on-black text. Once the participant felt comfortable reading the sample passage, we began the silent reading portion of the study visit.

Six passages were presented in a randomized order for each subject through the use of a random number generator. After each of these six passages, three comprehension questions were read aloud by the researcher, along with four answer choices for each question. Questions and answer choices were allowed to be repeated as many times as the subjects desired. The first two passages were read using magnification on the HMT-1. Subjects were asked to silently read each passage as quickly and accurately as possible without backtracking. Subjects were instructed to say, “done”, upon passage completion, and they were prompted to do so by a printed message at the bottom of each passage. Subjects were timed on each passage using the stopwatch application on an iPhone. Subjects listened to the next two passages using the OCR feature on downloaded passages on the HMT-1. Subjects voice activated the HMT-1 to begin reading the passages aloud. Each passage was aloud at a fixed, constant speed. The last two passages were read with the subjects' habitual low vision device. Subjects were again asked to silently read each passage as quickly and accurately as possible without backtracking and say, "done" upon completion.

To conclude the study visit, subjects were asked the following yes or no survey questions: Was the device simple to understand? Was the device easy to use? Was the device a useful tool? Would you recommend the device to others? Would you use the device in real life?

Analyses

Descriptive statistics were calculated to describe various subject characteristics. Relationships among patient characteristics, vision measures, reading measures, and survey results were evaluated using Spearman correlation and non-parametric analysis of variance. SPSS (IBM) was used to perform all statistical analyses.

Chapter 3. Results

The average age of participants was 53.6 ± 15.9, with a range of 34 to 74. Seventy-one percent of subjects were male and 29% of subjects were female (Table 1). Education level ranged from completion of some high school to completion of a master's degree (Table 2). Subject answers to the question from the IVI questionnaire, "In the past month, how much has your eyesight interfered with reading ordinary sized print?"[26] are given in Table 3. Participants presented with various ocular conditions causing vision impairment. Most participants used optical low vision aids; technological low vision devices included the Ruby and Humanware Explore 8 (see Table 4).

The average better eye visual acuity with habitual correction was 51 ± 10 letters with a range of 31 to 74. The average log contrast sensitivity with appropriate near correction was 1.47 ± 0.25 with a range of 0.8 to 1.8. The average smallest print size read at maximum speed at 40 cm with appropriate near add was 3.14 ± 1.15 M.

Table 1. Subject Sex

	Frequency	Percent (%)
Male	10	71.4
Female	4	28.6
Total	14	100

Table 2. Subject Education Level

	Frequency	Percent (%)
Some High School	1	7.1
Some College	2	14.3
Associate's Degree	1	7.1
Bachelor's Degree	7	50.0
Master's Degree	3	21.4
Total	14	100.0

Table 3. IVI Question: In the past month, how much has your eyesight interfered with reading ordinary sized print?

	Frequency	Percent (%)
A little	2	14.3
A fair amount	3	21.4
A lot	8	57.1
Don't do this for other reasons	1	7.1
Total	14	100

Table 4. Subject Cause of Vision Impairment and Habitual Low Vision Device

Age	Cause of Vision Impairment	Habitual Low Vision Device
69	Histoplasmosis and AMD	+12.00 reading glasses
61	Myopic degeneration	Portable electronic Ruby magnifier
61	Dominant optic atrophy	Humanware Explore 8
46	Stargardt macular degeneration	+10.00 prism half eye
51	Macular dystrophy	+4.00 prism half eye
68	Oculocutaneous albinism	+7.00 round bifocal
63	Diabetic retinopathy	+2.50 progressive lenses
75	Dry AMD	6x illuminated stand magnifier
18	Bilateral optic nerve colobomas	Prescription reading glasses
57	Congenital vision loss	+6.00 add
39	Congenital nystagmus	Prescription reading glasses
65	Diabetic retinopathy	Prescription reading glasses
69	Congenital vision loss	none
61	Stargardt macular degeneration	+5.00 add

Habitual low vision aid reading results

The average ± SD smallest print read at maximum reading speed at 40cm with the subjects' appropriate near correction was 3.14 ± 1.15. Participants completed the reading portion of the study using previously validated silent reading passages. The average passage reading time with the subjects' habitual low vision aid was 162 ± 64 seconds. Overall passage reading time ranged from 76 seconds to 296 seconds.

Subjects answered 98% ± 9% of comprehension questions correctly on average. Comprehension scores were perfect for all but one subject when using their habitual low vision device, despite a wide range of passage reading times. All participants answered all the comprehension questions with 100% accuracy except for one subject who had an average of 67% correct answers (Figure 2).

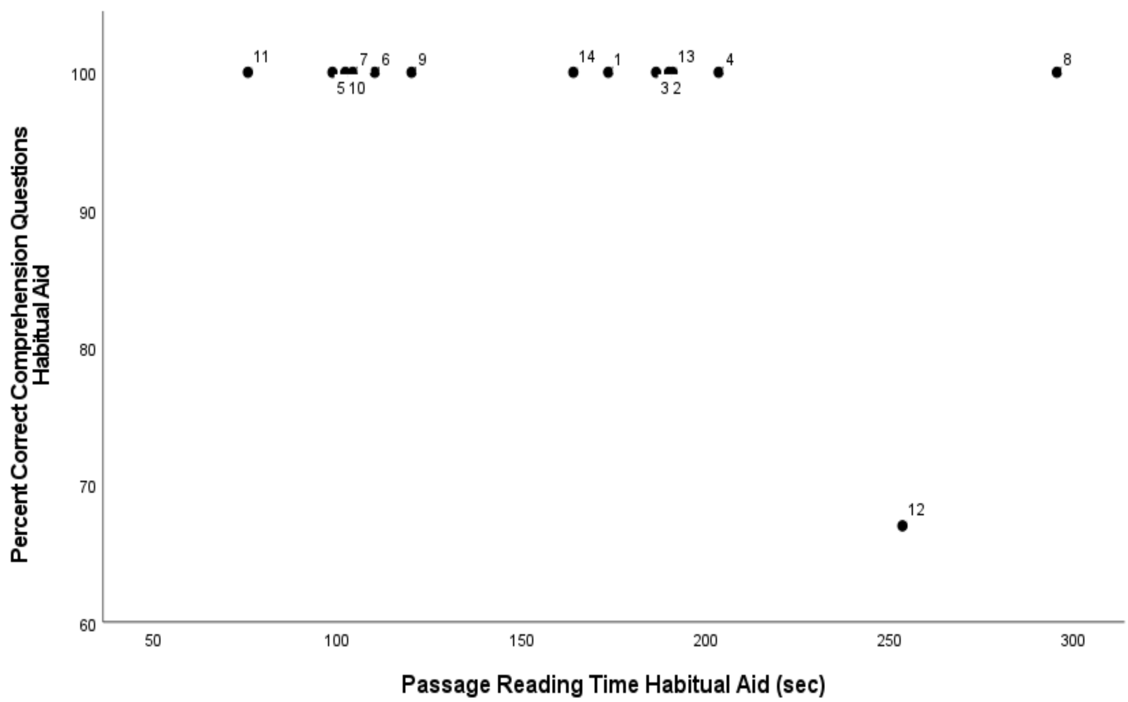

Figure 2. Relationship between percent correct comprehension questions using the habitual low vision aid versus mean passage reading time

RealWear HMT-1 camera results

The average visual acuity using the HMT-1 camera was 80 ± 8. The mean better eye visual acuity was 51 ± 10 with habitual correction. This was a significant improvement ($p < .001$) compared with habitual correction. There was no significant correlation between visual acuity with the HMT-1 camera and better eye visual acuity with habitual correction ($p=0.209$) (Figure 3).

The average log contrast sensitivity with the HMT-1 camera was 1.31 ± 0.27 and 1.47 ± 0.25 with habitual correction. Contrast sensitivity decreased significantly when using the HMT-1 camera ($p=0.001$). There was a positive correlation between log contrast sensitivity with the HMT-1 camera and log contrast sensitivity with habitual correction (Spearman's rho=0.789, $p<.001$) (Figure 4).

The average smallest print read at maximum speed at 40 cm with the HMT-1 camera was 1.8 ± 0.7 M while the average smallest print read at maximum speed at 40 cm with the subjects' appropriate near add was 3.1 ± 1.2 M, which was a significant improvement ($p < .001$). There was a positive correlation between smallest print read at maximum speed with the HMT-1 and smallest print read at maximum speed with near add for 40 cm (Spearman's rho=0.537, $p<0.05$) (Figure 5).

All participants preferred black-on-white text over white-on-black text and none preferred to shut the non-dominant eye while reading. The average passage reading time with the HMT-1 camera was 290 ± 139 seconds. Overall passage reading time ranged from 119 to 624 seconds. Compared to the mean passage reading time of 162 ± 64 seconds with habitual low vision aids, passage reading time was significantly increased with the HMT-1 camera ($p = 0.001$). Subjects answered 78% ± 17% of comprehension questions correctly on average with the HMT-1 camera. Comprehension scores were worse with the HMT-1 camera compared to habitual and text-to-speech conditions. One of the subjects was unable to complete reading passages using the HMT-1 camera, so was unable to answer comprehension questions.

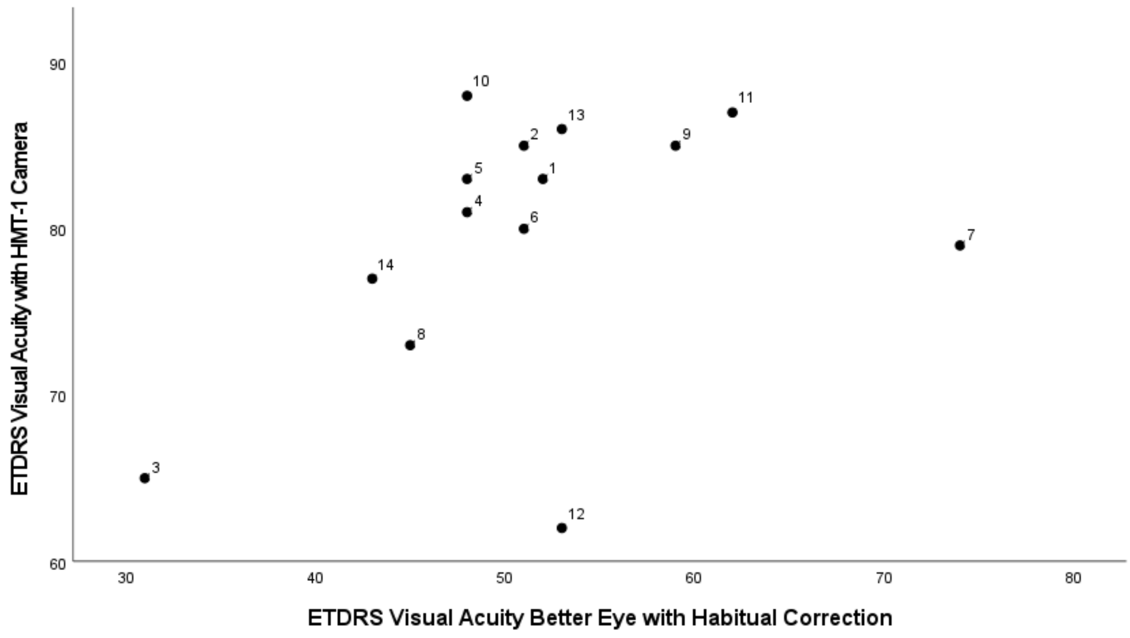

Figure 3. Relationship between ETDRS visual acuity with the HMT-1 versus ETDRS better eye visual acuity with habitual correction

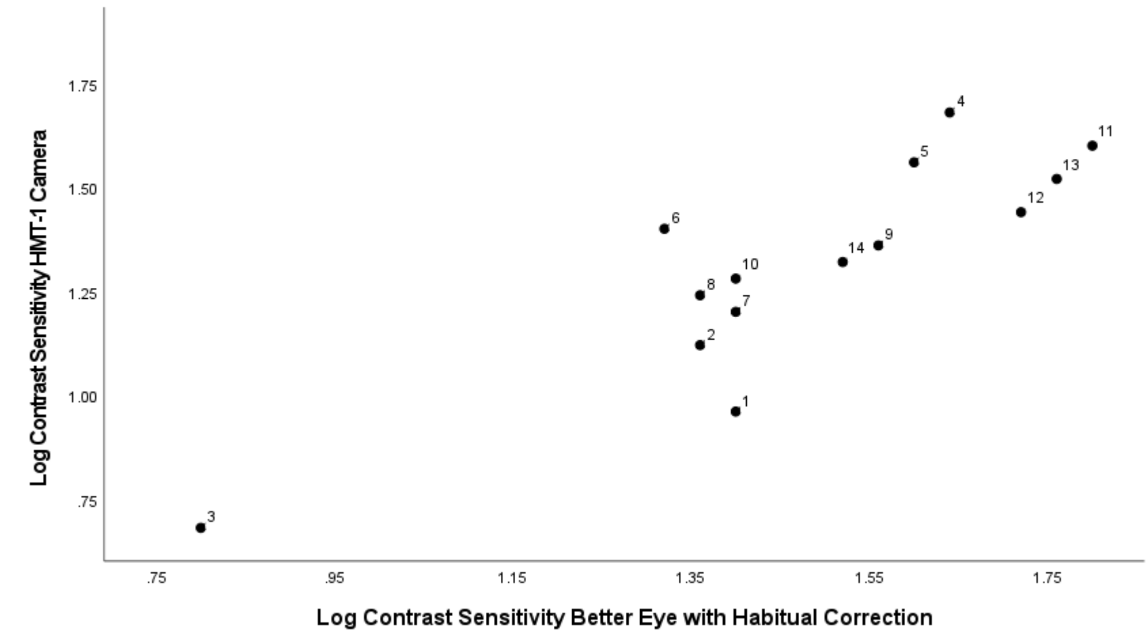

Figure 4. Positive correlation between log contrast sensitivity with the HMT-1 camera versus log contrast sensitivity with habitual correction and appropriate near add (Spearman’s rho=0.789, p<.001)

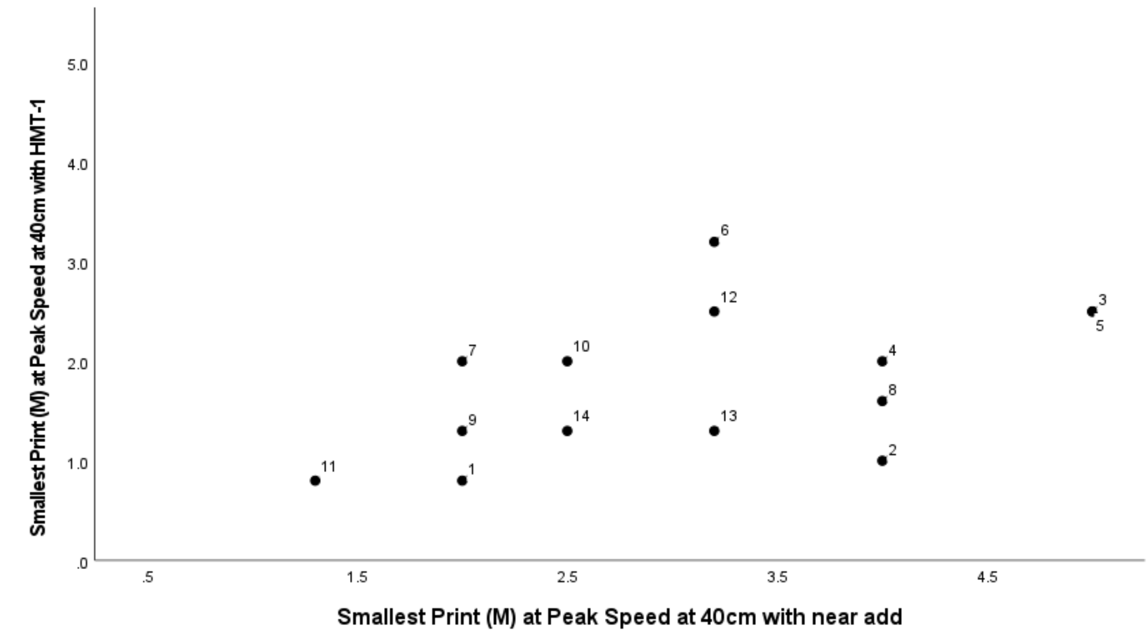

Figure 5. Positive correlation between smallest print size (in M units) read at maximum speed with the HMT-1 versus with appropriate near add (Spearman's rho=0.537, p<0.05)

Realwear HMT-1 optical character recognition text-to-speech results

The average passage reading time using the built-in OCR in the HMT-1 107 ± 3 seconds. Overall reading time ranged from 102 seconds to 113 seconds (though the text-to-speech function always read at a constant speed, there were minor variations in passage length accounting for slightly different times for each passage). Subjects answered 88% ± 18% of comprehension questions correctly on average after using the OCR function for the passages.

Table 5. Summary of Results

	Minimum	Maximum	Mean	Std. Deviation
ETDRS Better Eye Visual Acuity Habitual Correction	31	74	51.29	9.801
Log Contrast Sensitivity Habitual Correction	0.80	1.80	1.47	0.251
CPS with +2.50D	1.3	5.0	3.14	1.152
ETDRS Visual Acuity HMT-1 Camera	62	88	79.57	7.959
Log Contrast Sensitivity HMT-1 Camera	0.68	1.68	1.31	0.267
CPS with HMT-1 Camera	0.8	3.2	1.77	0.732
Reading Time Habitual Low Vision Aid (sec)	76	296	161.96	63.986
Reading Comprehension Habitual Low Vision Aid (percent)	67	100	97.64	8.820
Reading Time HMT-1 Camera (sec)	119	624	290.00	139.150
Reading Comprehension HMT-1 Camera (percent)	50	100	78.15	17.097
Reading Time HMT-1 OCR (sec)	102	113	106.86	3.416
Reading Comprehension HMT-1 OCR (percent)	50	100	88.00	17.845

Satisfaction survey results

Twelve of fourteen subjects reported the HMT-1 RealWear was simple to understand, while 57% of subjects reported HMT-1 was easy to use. There was no statistical difference between those who reported the device easy to use and those who did not with respect to passage reading time, but there was more variation in reading times among those reporting that the device was not easy to use (Figure 6). We found that 79% of subjects reported the HMT-1 was a useful tool, 79% of subjects reported they would recommend the HMT-1 to others, and 57% of subjects reported they would use the device in real life.

Subjects who expressed greater reading difficulty in response to the question from the IVI, “In the past month, how much has your eyesight interfered with reading ordinary sized print?” demonstrated a trend toward longer average passage reading time with habitual aid than those who reported their eyesight only interferes a little with reading ordinary print (Figure 7), with a similar trend for the HMT-1 camera reading times (Figure 8).

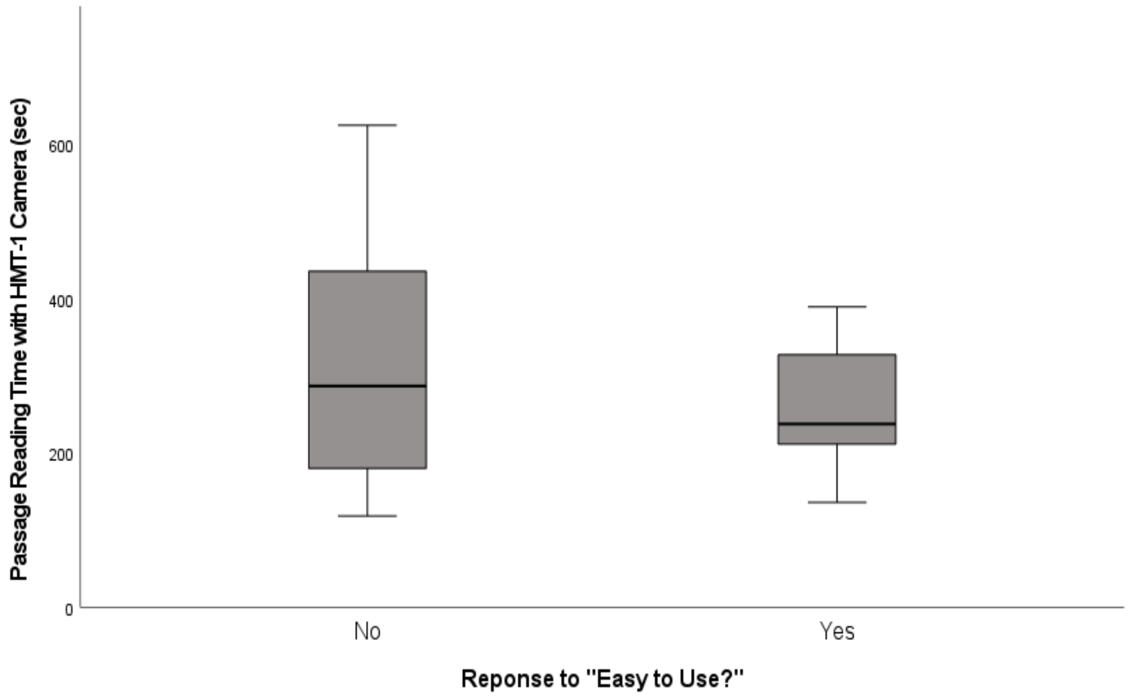

Figure 6. Mean passage reading time with the HMT-1 camera (sec) versus response to the question, "Was the device easy to use?"

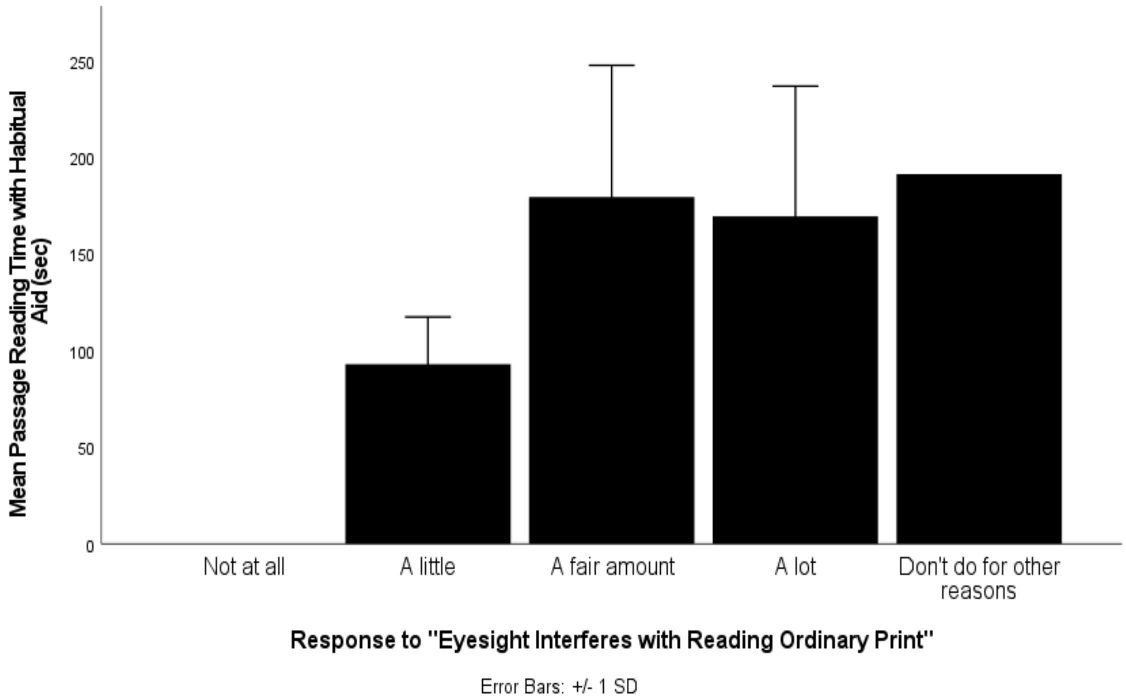

Figure 7. Mean passage reading time with habitual low vision aid (sec) versus response to "In the past month, how much has your eyesight interfered with reading ordinary sized print?"[26]

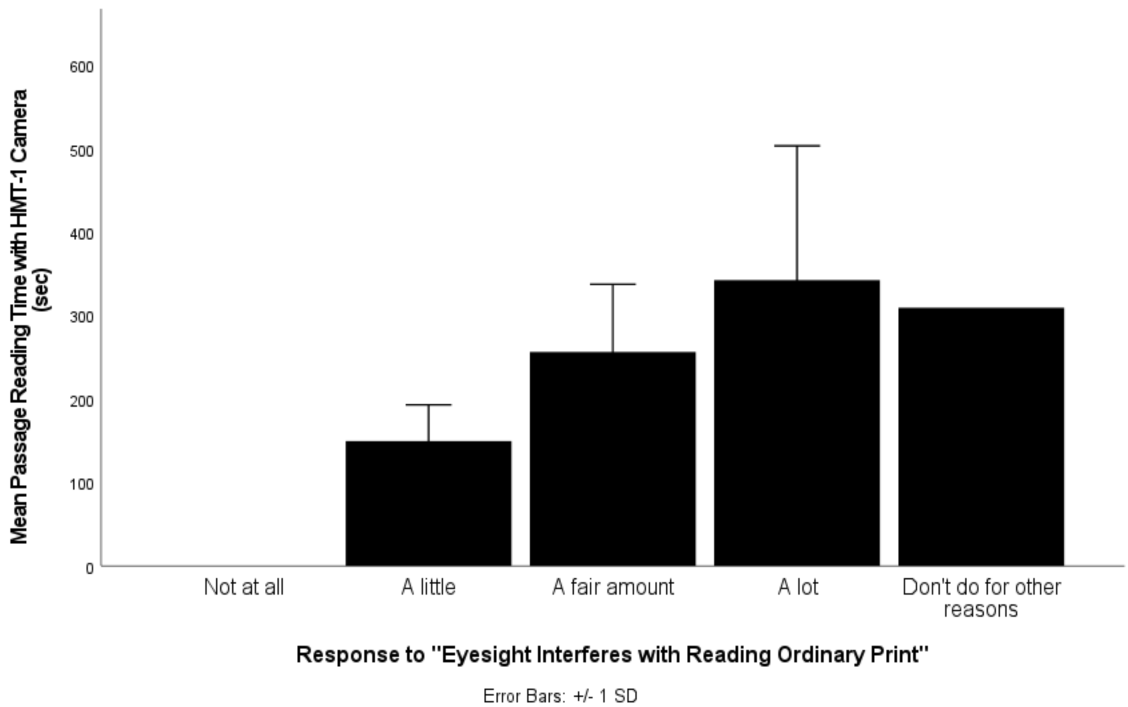

Figure 8. Mean passage reading time with the HMT-1 camera (sec) versus response to, "In the past month, how much has your eyesight interfered with reading ordinary sized print?"[26]

Correlations among patient characteristics, visual factors, and reading measures

Age was not significantly correlated with passage reading time with the HMT-1 camera (p=0.511) (Figure 9). There was a negative correlation between age and log contrast sensitivity with habitual correction (Spearman's rho=-0.621, $p<0.05$). Better eye visual acuity with habitual correction was not significantly correlated with passage reading time with the HMT-1 camera (p=0.46) (Figure 10), though there was a trend toward increased time for those with worse vision.

Passage reading time with the HMT-1 camera was not significantly correlated with comprehension (Figure 11). Since the OCR function has a fixed speed for each passage, passage reading time did not vary from subject to subject and there was no significant correlation between passage reading time with the HMT-1 OCR and comprehension (Figure 12). Better eye visual acuity with habitual correction was not significantly correlated with comprehension after reading with the HMT-1 camera (p=0.391). It should be noted that in the case of comprehension with the habitual aid, there was a ceiling effect, which may have obscured any correlation, as most subjects answered all questions correctly (Figure 2). Lastly, there was not a significant correlation between log contrast sensitivity with habitual correction and passage reading time (p=0.298) (Figure 13), though there was a trend toward longer reading times with worse contrast sensitivity.

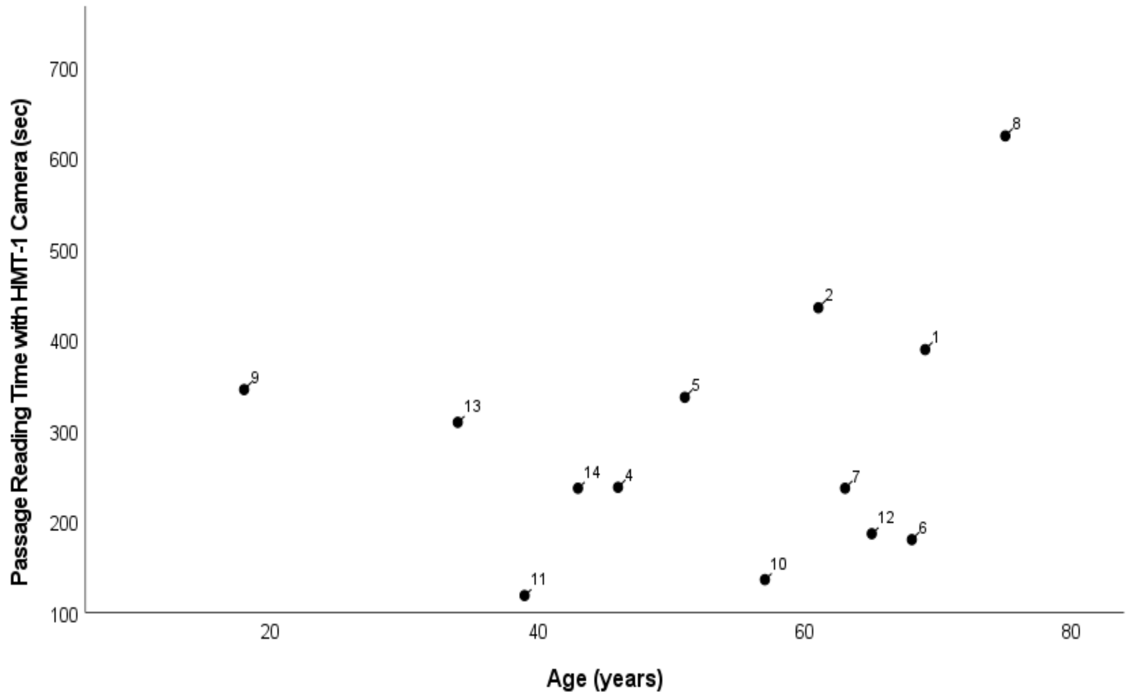

Figure 9. Relationship between mean passage reading time with the HMT-1 camera (sec) versus subject age (years)

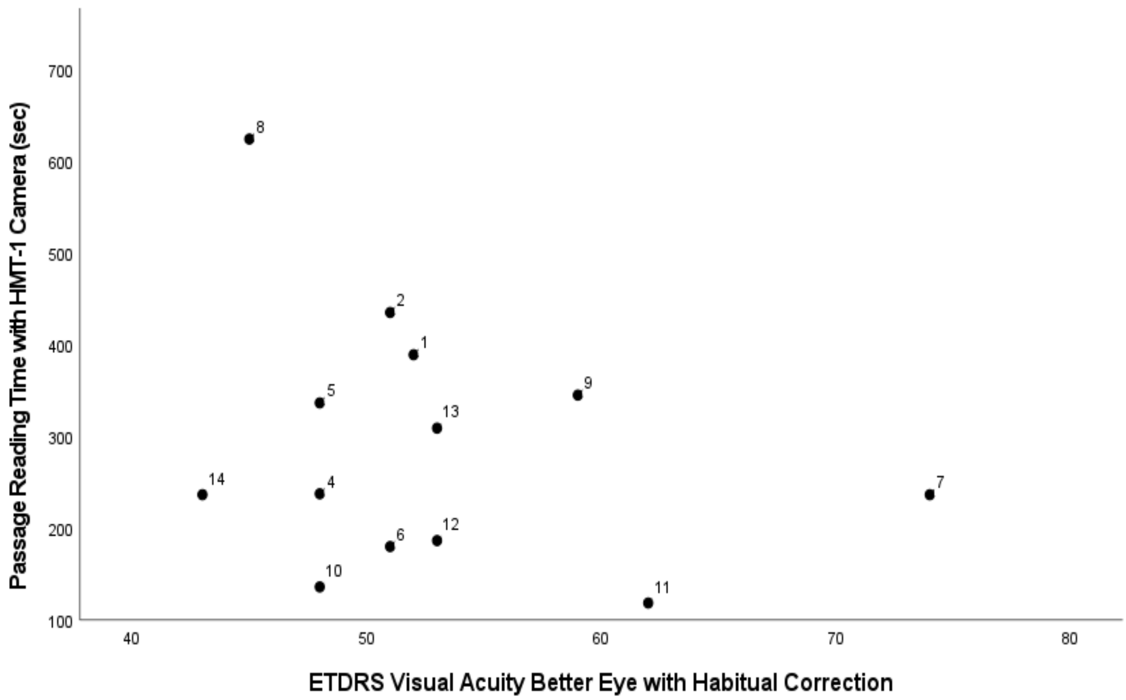

Figure 10. Relationship between mean passage reading time (sec) with the HMT-1 camera versus ETDRS better eye visual acuity with habitual correction

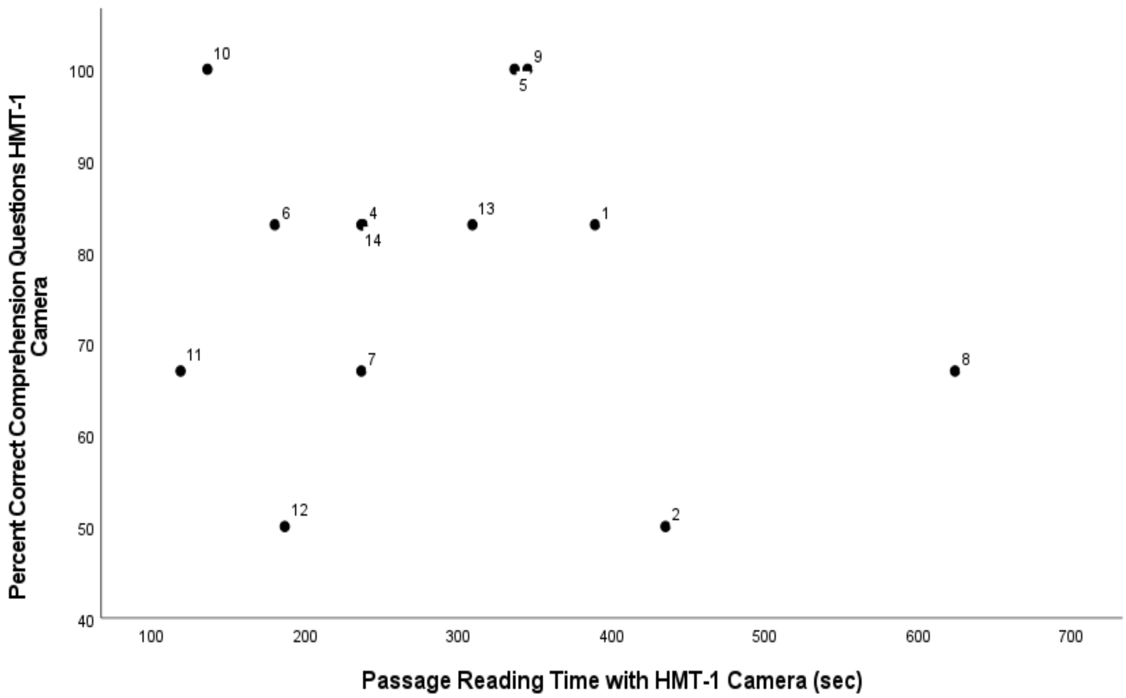

Figure 11. Relationship between percent correct comprehension questions with the HMT-1 camera versus mean passage reading time with the HMT-1 camera (sec)

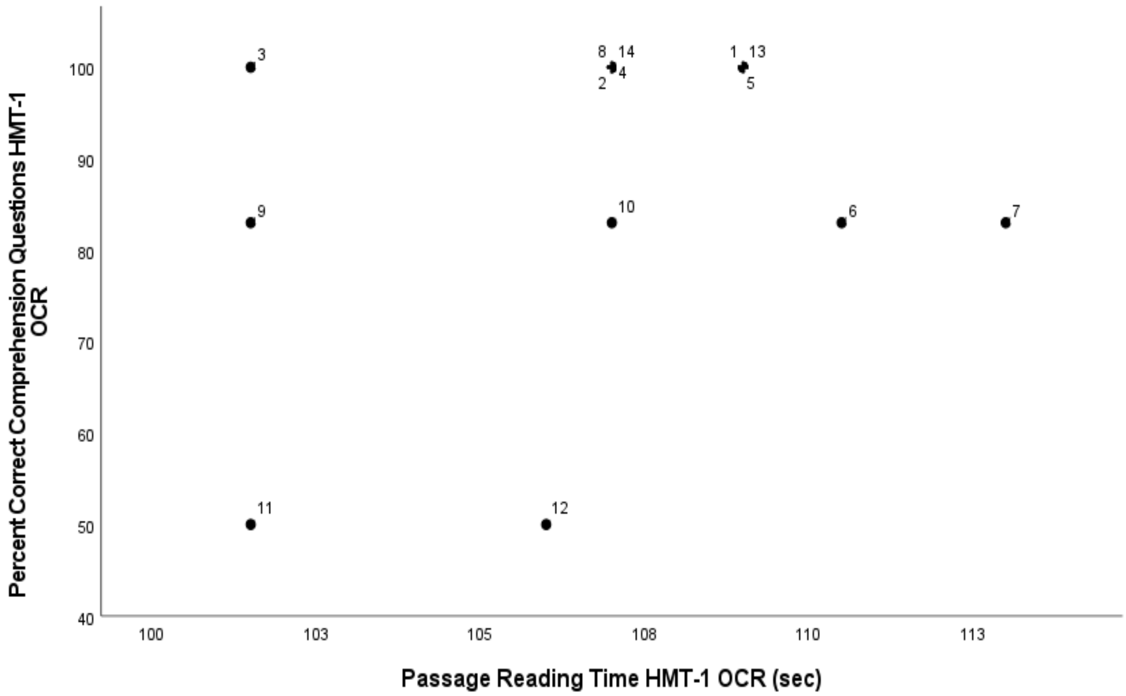

Figure 12. Relationship between percent correct comprehension questions with the HMT-1 OCR mean versus passage reading time with the HMT-1 OCR (sec)

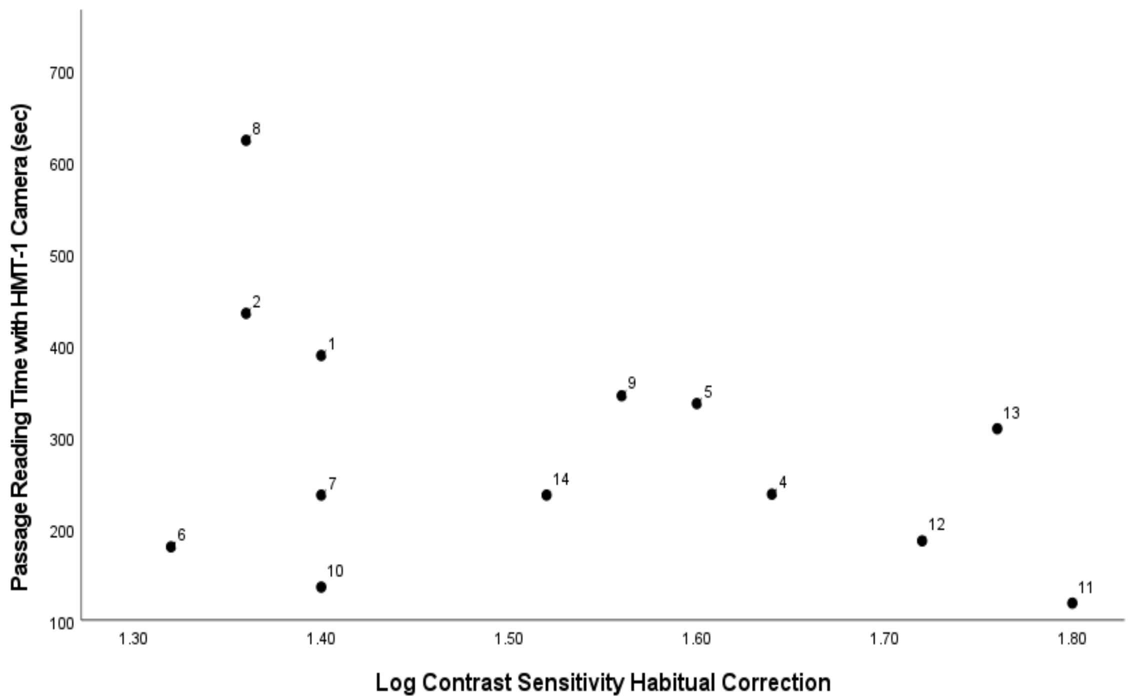

Figure 13. Relationship between mean passage reading time with the HMT-1 camera (sec) versus log contrast sensitivity with habitual correction

Chapter 4. Discussion

The goal of this study was to modify certain features of the RealWear HMT-1 head-mounted tablet device and evaluate its usefulness for reading with low vision. Visual acuity improved for all subjects with use of the device, and most subjects reported the device simple to understand, a useful tool, and that they would use it in real life and recommend it to others. Also, the optical character recognition feature to convert text to speech was reported as especially useful. We found improvement in critical print size with the device but also increased reading times for long passages. Contrast sensitivity and reading comprehension for longer passages were also reduced when using the HMT-1 compared with correction or low vision device.

RealWear HMT-1 camera

Considering that low vision is frequently defined by a reduction in visual acuity, a device that increases the patient's ability to see smaller print would be expected to be beneficial. Compared to habitual correction, the HMT-1 camera improved distance visual acuity in all subjects. The Industrial Badger App incorporated into the HMT-1 enabled magnification up to five times. The camera can be focused on distance and near targets allowing the user to switch viewing distances for various targets efficiently. However, magnified text results in fewer characters shown at once on the display compared with non-magnified text (reduced field of view), and navigating through a magnified passage can increase reading time.[29] Additionally, the video display on the HMT-1 is relatively small, resulting in the common complaint of difficulty with orientation on the page and locating letters on the visual acuity chart or words in passages. Subjects frequently lost their place with small head movements when using the higher magnification levels despite the built-in image stabilization.

Contrast sensitivity was slightly reduced with the HMT-1 camera, which can be detrimental for users with low vision considering many diseases that cause vision impairment also adversely affect contrast sensitivity. As the contrast of text decreases, reading speed declines at a faster rate for low vision patients than for normally sighted individuals.[30] In people with low vision, small reductions in contrast can cause reading speeds to decline more rapidly in those who have slower reading speeds with high contrast text compared with those who have faster reading speeds with high contrast text. It has been shown that contrast had to be reduced by 20 times to cut reading speed in half for normally sighted subjects, but contrast only had to be reduced by 4 times to result in half the reading speed in subjects with low vision. The fact that the HMT-1 reduces contrast in a population already affected by reduced contrast sensitivity is likely to reduce reading speed and patient satisfaction. It should be noted that there are methods for contrast enhancement in electronic devices that could be implemented in the HMT-1, and this is an area for future study.

With the exception of one subject, participants were able to read through both passages using the HMT-1 camera with magnification. However, passage reading with the HMT-1 camera yielded slower reading speeds. Study subjects only used about half as much time to read a passage with their habitual reading aid as with the HMT-1 camera magnification.

This study revealed there may be a subset of people with low vision for whom the HMT-1 would be most useful. Those with mild or moderate levels of vision loss experience the most benefit with the magnification capabilities of the modified HMT-1 in passage reading. One subject with a better eye visual acuity of only 31 was unable to read any passage in its entirety using the HMT-1 camera due to unstable fixation paired with high magnification level. The combination of the small physical display size and magnification likely prevents the HMT-1 from being particularly useful for those with more than moderate levels of vision impairment.

RealWear HMT-1 optical character recognition (OCR)

The original RealWear HMT-1 did not have OCR capabilities, but we incorporated it into the device through the Industrial Badger App in order to convert text to speech that is read aloud to the user. Reading speed with OCR in the HMT-1 was faster than with habitual reading aids and the HMT-1 camera. Subjects who reported the device as useful often cited the OCR as the most helpful feature. Comprehension was comparable to habitual spectacles or reading aids. As Legge et al.[4] found, magnification alone is often insufficient for people with vision impairment to reach normal reading speeds. In addition, high levels of magnification may reduce reading speed and comprehension.[16] OCR may compensate for these drawbacks.

Subject survey

The survey questions highlighted the subjective opinions of participants on the practicality and usefulness of the RealWear HMT-1 for people with low vision. Most participants found the HMT-1 useful, easy to use, and would recommend it to others. Subjects who reported they would use the HMT-1 in real life if it were available tended to be those with only moderate levels of vision impairment. As mentioned previously, subjects with more reduced acuity need higher levels of magnification to achieve the same level of visual acuity as those with better visual acuity. Higher levels of magnification can result in unstable images in a small video display, contributing to slower reading speeds. Unsurprisingly, slowed reading speeds in visually impaired people who already struggle with reduced reading speed led to diminished subject satisfaction with the device. Those with better visual acuity could manage reading with habitual spectacles and habitual low vision aids at greater speeds compared with the HMT-1 camera. Therefore, they generally felt they would not use the device in real life since there was little benefit associated with it.

Of the subjects who reported the HMT-1 would not be a useful tool, two had better eye visual acuity of 62 or better and simply used their habitual spectacles for distance tasks and reading. One subject who reported the device would not be useful had better eye visual acuity of 48 and had reading speeds reduced by nearly a third with the HMT-1 camera compared to their habitual reading device (+4.00 prism half eyes). Although this subject's visual acuity improved almost two-fold, the significantly reduced reading speed was enough to declare the device not useful.

Of subjects who reported that their eyesight interferes with reading “a lot”, most reported that, although the HMT-1 was a useful tool, they would not use it in real life. Interestingly, of subjects who answered that their eyesight interferes with reading “a little or a fair amount,” only one subject reported that the device was not a useful tool, not easy to use, that they would not recommend it to others, or that they would not use it in real life.

Strengths of the RealWear HMT-1

Although the HMT-1 is unlikely to be useful for long periods of reading, it has the potential to be beneficial for spot reading in environments where other devices would be a hinderance. Reading speed is not as consequential for spot reading tasks as for lengthy reading material.[31]

A desirable feature of the HMT-1 includes that people may wear their habitual correction while using the HMT-1, so they are at their best corrected visual acuity even before utilizing the device’s features. Furthermore, peripheral vision is not obstructed, enabling people to navigate their environments more easily than with some other head-mounted devices. Hands-free technology can be especially useful for certain jobs, hobbies, or environments. Examples include playing in concerts where the patient has to utilize distance vision and near vision for reading sheet music or art classes where the patient may want to view the subject matter and the medium. In terms of jobs, teachers may find such a device helpful to watch students and view paperwork or warehouse workers may perform their duties while accessing the HMT-1’s features with voice commands. One device that serves multiple purposes could be quite convenient. Unlike optical low vision aids, the HMT-1 provides text-to-speech functionality, which users may utilize for passage reading without sacrificing reading speed or comprehension. In addition, the HMT-1 is voice activated, so features are quickly and easily accessible to users with low vision without the need to visually search menus. Because the device was built for use in industrial settings, it is very durable and can be worn with safety glasses. Of course, optical low vision aids will likely continue to be of great use for people with low vision. However, access to both optical and electronic aids like the HMT-1 might help maximize quality of life for people with low vision.

Improving RealWear HMT-1

Subjects with more severe levels of visual impairment and who need high levels of magnification with the RealWear HMT-1 might especially benefit from addition of image stabilizing software that functions when using high magnification levels. This is another software feature that could be added. As mentioned previously, because contrast sensitivity was reduced with the HMT-1 camera compared with participants' habitual spectacles, future improvements to the device could also include contrast enhancing software.

Although not the focus of this study, this device could also be useful as a navigation aid. A potentially useful application for the HMT-1 is the capability to interact with Bluetooth beacons. This feature could allow users with low vision to obtain navigational guide points indoors similar to GPS. Indoor navigation using Bluetooth beacons is technology that has been tested in a limited capacity in other devices. Hands-free indoor navigation that does not obstruct peripheral vision could lend the user independence and confidence in maneuvering through unfamiliar environments. Our lab has explored Bluetooth beacons paired with the HMT-1, but thus far beacon location accuracy has been insufficient for utility in navigation indoors. Current work on technological upgrades to the Bluetooth beacons is ongoing. If successful, the HMT-1 could be a unique device that fulfills the dual purposes of a reading aid and navigational aid.

Limitations and future studies

It should be noted that the RealWear HMT-1 is a relatively new technological approach to addressing the challenges of low vision, and no study participants were currently using similar devices when enrolled. Subjects were given only a brief introduction and one practice reading passage to become acquainted with device. Comparatively, the participants have been using their habitual reading devices for much longer periods of time, from months to years. A future study could incorporate a training period prior to testing passage reading speed and comprehension. Subjects may gain experience by practicing reading with the HMT-1 camera at home and keeping a log of practice time and reading material prior to returning for testing with the standardized passages. This approach could yield better reading ability than found in this study. However, reading speed with the camera is still unlikely to improve to levels comparable to those reached with habitual reading aids, particularly in people with more severe visual impairments.

Another future study could examine other potential uses for the HMT-1 and conduct more formal satisfaction surveys covering a broader range of activities. Indeed, such a device may be useful in certain jobs or for specific hobbies, not only for reading. Although reading and navigation are significant hurdles for low vision patients, a device that may enhance quality of life in other ways would serve an important purpose. Satisfaction surveys conducted after using the HMT-1 for various tasks could then be compared to determine for which activities the device is most useful.

Research could be conducted to compare the RealWear HMT-1 to popular low vision technology currently on the market, including data collection on visual acuity, contrast sensitivity, reading speed, reading comprehension, and subject satisfaction. Such a study could reveal gaps in technology that need improvement and the most helpful aspects of devices. Various low vision aids have useful characteristics as well as drawbacks. For example, although a stand magnifier provides quick and easy magnification for spot reading, it is not useful for viewing distant objects. Hand-held magnifiers can pose difficulties for patients with poor dexterity. A CCTV can provide significant magnification for reading lengthy text, but is not portable and requires a significant amount of space in the patient's working environment to store and use. Devices such as the eSight, IrisVision, or Jordy may provide adequate magnification for reading and are hands-free, but can obstruct peripheral vision so as to prevent safe mobility. Small e-readers such as the Ruby, are portable and provide magnification, and other features but require manipulation with hands, are not useful for distant objects, and lack OCR capabilities. The Realwear HMT-1, like these other devices, has strengths and weaknesses.

Lastly, a future study could re-evaluate the RealWear HMT-1 after the improvements have been implemented. With image stabilization and contrast enhancement, results from passage reading tests are likely to improve along with increased positive responses to satisfaction survey questions. A separate study could be dedicated to testing navigation using Bluetooth beacons paired with the HMT-1. Such a study could examine navigational accuracy, speed, and subjective ease.

Conclusion

In this study, the RealWear HMT-1, with modifications made through the Industrial Badger App, demonstrated its potential to be a beneficial technologic low vision aid, but would likely require further modification to address contrast enhancement and image stabilization, and is unlikely to be of use for people with more than moderate vision impairment. It could be particularly useful for spot reading tasks in specific environments where hands-free use, durability, and the ability to wear dress spectacles are desirable. Overall, subjects showed improvement in visual acuity and a majority reported a positive impression of the device.

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