Accessible Web Typography for the Visually Impaired

by

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Abstract

Background: Visual impairments affect millions of people worldwide. Accessible web typography is important in ensuring online legibility for this diverse group of users to help them maintain their independence. However, existing typographic guidelines are based heavily on best practices, with supported research based largely on printed typography, and rarely considers the needs of visually impaired users. The purpose of this research is to investigate which elements of typography have the most impact on visually impaired users in an effort to work towards more accessible typographic guidelines. **Method:** An in-depth analysis of existing online typography trends found that even with copious resources available web designers are often not adhering to typographic guidelines. This analysis helped build a solid foundation for experimental research with visually impaired users by providing insight into how typography is actually being used on the web. In response, both line height and font size were tested for their effects on simulated macular degeneration. A second experiment tested line height across three other simulated visual impairment types. **Results:** This study did not show significant effects on legibility for simulated macular degeneration based on font size, although error rate was nearly twice as high for smaller font sizes. Increased line height did significantly reduce the error rate for simulated macular degeneration. When increased line height was tested across other simulated visual impairments, the improvment was not statistically significant. However, this study should be repeated with a within-subjects design before these results are considered fully reliable. **Conclusions:** As past research has indicated, there may not be one solution for typography that fits in in regards to visually impaired users. Accomodations for the needs of one user may work against the needs of another user. With online access essential to daily tasks, though, it’s important to consider how visually impaired users interact with the web and continue to explore how enhancements to typography can benefit the distinct needs of these users.

Keywords: accessibility, visual impairment, low vision, typography, web design, readability, legibility, inclusive design

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Introduction

The increasing availability of open source fonts through services like Google Fonts, Typekit, and Font Squirrel give web designers access to more font choices than any one person could use in a lifetime. Access to these fonts continues to move us away from conventional approaches of relying on the so called “web-safe” fonts commonly available across operating systems, such as Verdana, Arial, Georgia, and Times New Roman (Santa Maria, 2014; Shaikh, 2011). Additionally, enhancements to Cascading Style Sheets (CSS) give web designers far more control over typography than ever before (Santa Maria, 2014). However, good typography is not about the ability to choose from the thousands of fonts available, nor is it about controlling every aspect of typography just because web designers now have that ability (Reichenstein, 2006). It is estimated that the web is 95% text, and textual content cannot be effectively communicated without the principles of good typography (Reichenstein, 2006). Typography communicates through the strokes, proportion, and visual weight that make up the grouping of individual characters into the content blocks that make up the grids, columns, bodies, lists, and headings found throughout the web (Lupton, 2014). To be effective, typography needs to be both legible and readable for all web users. This includes users with visual impairments, an estimated 285 million people worldwide, who are among some of those most affected by choices in web typography (Ratliff, 2016; WHO, 2014). The web is a powerful means of communication and connection, and for disabled users that is no exception (Saito, Saito & Saito, 2010). In fact, the web has the potential to improve the lives of visually impaired users perhaps more than any other technological development in history. The web allows those with even severe visual disabilities access to perform essential tasks of daily living, like personal correspondence, banking and personal finance, shopping, and accessing information, without the assistance of a sighted person (Arditi & Lu, 2008; WebAIM, 2013b). Yet, there are limited web accessibility guidelines ensuring that web typography is accessible to users with visual impairments. As of this writing, most web accessibility guidelines are aimed to better assist blind users, who make up 39 million, or just 13%, of the total low vision population (Arditi & Lu, 2008; WHO, 2014). Because those diagnosed with visual impairments prefer to rely on any remaining functional eyesight still available to them in order to perform and accomplish tasks, it's essential to understand the needs of users with visual impairments in relationship to web typography in order to better optimize web accessibility through this vital means of communication (Arditi & Lu, 2008; Richards & Hanson, 2004).

Why Visual Impairments Should be a Focus for Web Research

How the web is perceived is affected by a variety of factors: the type of device being used, lighting and environmental conditions, the quality of the website being viewed, and also the dynamics of an individual's vision (Marks, 2016). Though exact numbers differ depending on the definition being used, visual impairments affect an estimated 253 million people worldwide, and as many as 23.7 million Americans in particular (AFB, 2017; WHO, 2017). There are a large spectrum of disabilities that encompass visual impairments, including complete blindness. However, visual impairments also include congenital, or inherited, impairments such as albinism, amblyopia, retinitis pigmentosa, and color blindness; cognitive impairments such as dyslexia and autism; and degenerative diseases such as cataracts, macular degeneration, glaucoma, and diabetic retinopathy, to name just a few. Uncorrected refractive errors, such as nearsightedness, farsightedness, and astigmatism, also end up under the general umbrella of low vision (Prevent Blindness America, 2008). Though severity can vary widely, visual impairments are collectively defined as vision loss that cannot be fully corrected. This loss may be severe enough to impede a person's ability to carry out everyday activities, but there is often still enough functionally useful eyesight remaining to affect how the web is viewed and interacted with. This interaction can greatly benefit from careful consideration to typography and layout (AFB, nd; Bruggeman & Legge, 2002; Cheong, Lovie-Kitchin & Bowers, 2002; Kalbag, 2017).

A total lack of vision is the extreme and affects only a small portion of the population, an estimated 1.3 million Americans (NFB, 2017; WebAIM, 2013b). Complete blindness, defined as having no vision or perception of light, is rare. It is far more common to have some permanent loss of vision while still retaining a varying degree of visual acuity (Prevent Blindness America, 2008). Though the exact impact of visual impairments on the quality of life varies based on the extent of vision lost, visual impairments can reduce the ability to do common, everyday tasks such as manage personal accounts, drive a car, read, or watch television (CDC, 2011). Of those activities, it is argued that reading is one of the most highly-valued, and any visual impairment, such as reduced acuity, contrast sensitivity, and visual field loss, that deprives someone of the ability to read causes severe restrictions and makes vision loss a serious handicap (AFB, 2017; Arditi, 2006; Bruggeman & Legge, 2002; Cheong, Lovie-Kitchin & Bowers, 2002). The unknown degree of impact makes vision loss one of the most feared disabilities, a disability that all of us are likely to face to some extent. While visual impairments affect an estimated 93,600 school aged American children, the likelihood of experiencing vision loss increases as we age (NFB, 2017; Prevent Blindness America, 2008; Theofanos & Redish, 2005). Our eyes weaken as we age and the lens starts to lose elasticity, becoming increasingly yellow and less transparent. This results in a decreased ability to focus, especially during reading, along with a loss of visual acuity that often results in blurred vision, loss in depth perception, and an increased sensitivity to light (Arditi, 2005; Nini, 2006; Richards & Hanson, 2004). Together, these changes in vision affect legibility, reading speed, comprehension, navigation, and searching on the web. Visual design distractions, such as font size, font style and type, foreground and background colors, patterned background images, and animation, can cause additional eye fatigue and eye strain (Becker, 2014).

Common Types of Visual Impairments

The rate of visual impairments among adults is on the rise, due in large part to the aging baby boomer generation, and studies show that the number of Americans affected with visual impairments is projected to double over the next 30 years as the population ages (NFB, 2017; Prevent Blindness America, 2008). While the leading causes of visual impairments are primarily due to age-related eye diseases, such as cataracts, macular degeneration, diabetic retinopathy, and glaucoma, visual impairments are by no means restricted to the elderly (Prevent Blindness America, 2008). Loss in visual acuity and diagnosis of visual impairments can affect anyone at anytime, from birth throughout old age. The intent of this section is to provide a better understanding of the most common types of visual impairments in order to better determine how to adapt different elements of typography to encompass a variety of visual needs. The goal is not to address the aging population in particular. The following types of visual impairments are by no means inclusive, and only broad generalizations of each impairment are discussed.

Cataracts. Although cataracts can occur at any age, as of 2012, more than 24.4 million Americans aged 40 years or older have experienced at least one cataract, the result of the naturally clear lens of the eye becoming progressively cloudy or opaque (AFB, 2017; CDC, 2011; Prevent Blindness America, 2008). Because more than half of all Americans will have experienced a cataract in one or both eyes by the age of 80, cataracts are considered one of the most common visual impairments, however they are also one of the few that can be corrected (Prevent Blindness America, 2012). Cataracts lead to blurred or foggy vision, sensitivity to light, difficulty seeing at night, and a fading or yellowing of colors (AFB, nd; Mayo Clinic, 2016). As shown in Figure 1, cataracts, often described as looking through a fogged-up window, can make it difficult to read because text appears to fade into the background, making high contrast an especially important consideration for these users (Mayo Clinic, 2016; WebAIM, 2013b).

Figure 1. Simulated view of early to advanced cataracts. Retrieved from “EyeSimulator,” by CNIB, 2018, http://www.cnib.ca/en/your-eyes/eye-conditions/eye-connect/Pages/EyeSimulator.aspx#cataracts.

Macular degeneration. Macular degeneration is one of the leading causes of irreversible blindness and visual impairment in the world (BrightFocus Foundation, 2016). It is estimated that 13 million Americans have been diagnosed with some degree of macular degeneration, which is a destruction of the macula, or the middle area of the retina responsible for sharp, central, or straight ahead vision (NFB, 2017; AFB, nd; BrightFocus Foundation, 2016; Prevent Blindness America, 2008). Peripheral vision is generally not affected, though deterioration of the macula leads to blurred, distorted, or dim central vision, often described as a blind spot in the center of the visual field, which makes it difficult to see objects that a person is looking at directly. As shown in Figure 2, effects of macular degeneration interfere with reading by causing text to appear broken and unclear (AFB, 2017; AFB, nd; BrightFocus Foundation, 2016; WebAIM, 2013b). Central vision is critical for good reading; however, users with macular degeneration rely heavily on their peripheral vision to read, which invariably slows them down (Bruggeman & Legge, 2002).

Figure 2. Simulated view of early to advanced macular degeneration. Retrieved from "EyeSimulator," by CNIB, 2018, http://www.cnib.ca/en/your-eyes/eye-conditions/eye-connect/Pages/EyeSimulator.aspx#amd.

Diabetic retinopathy. An estimated 7.7 million Americans are affected by diabetic retinopathy, with the risk of developing the disease increasing the longer a person has been living with diabetes (Prevent Blindness America, 2012). Diabetic retinopathy is caused the by blood vessels in the retina breaking down or leaking. As shown in Figure 3, this leads to blurred or fluctuating vision, dark, empty spots in the field of vision, and impaired color vision (Mayo Clinic, 2015a; Prevent Blindness America, 2012; WebAIM, 2013b). Complications of diabetic retinopathy can lead to other forms of visual impairment, such as vitreous hemorrhage, retinal detachment, glaucoma, or complete blindness (Mayo Clinic, 2015a).

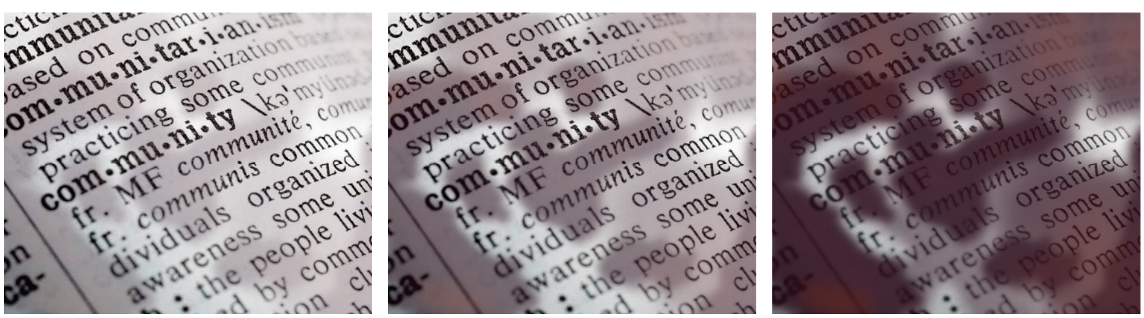

Figure 3. Simulated view of early to advanced diabetic retinopathy. Retrieved from "EyeSimulator," by CNIB, 2018, http://www.cnib.ca/en/your-eyes/eye-conditions/eye-connect/Pages/EyeSimulator.aspx#diabetic-retinopathy.

Glaucoma. Recent estimates indicate that more than 3 million Americans have been diagnosed with glaucoma, though the actual number is thought to be higher because some studies show that half the people living with glaucoma may not be aware of it (BrightFocus Foundation, 2017). Glaucoma can occur at any age, and causes damage to the optic nerve, a vital part of the eye that communicates visual information to the brain, due to increased pressure inside the eye (AFB, nd; BrightFocus Foundation, 2017; Mayo Clinic, 2015b; Prevent Blindness America, 2008; WebAIM, 2013b). Damage to the optic nerve is irreversible and, as shown in Figure 4, leads to a slow, patchy loss of peripheral vision, blurry central vision, sensitivity to light, and can result in tunnel vision or complete blindness (Mayo Clinic, 2015; Prevent Blindness America, 2012; WebAim, 2013b). Even with treatment, glaucoma is one of the leading causes of blindness in the world (BrightFocus Foundation, 2017; Mayo Clinic, 2015b). Glaucoma has been described by some as looking at everything through a straw, and users find it especially difficult to read as text can appear both faded and blurry (WebAIM, 2013b).

Figure 4. Simulated view of early to advanced glaucoma. Retrieved from "EyeSimulator," by CNIB, 2018, http://www.cnib.ca/en/your-eyes/eye-conditions/eye-connect/Pages/EyeSimulator.aspx#glaucoma.

Current State of Web Accessibility for Visually Impaired Users

While cognitive and motor impairments also impact how people interact with the web, it can be argued that visual impairments are one of the biggest barriers in web interaction because the web, in general, is very visual by nature (Kurniawan & Zaphiris, 2005). The web is making the world a smaller and more connected place, but there is still much work to be done to make the web a more inclusive place that everyone can use (Horton & Quesenbery, 2013). Web accessibility is defined as the degree to which a website is usable by as many people as possible, which includes, but isn't limited to, people with disabilities (Kalbag, 2017). Web accessibility is becoming a more common topic, and in turn the web is becoming increasingly more accessible. This is especially true for blind web users especially, though the web continues to remain less accessible for the 69.7% of visually impaired web users (Arditi & Lu, 2008; Saito, Saito & Saito, 2010). Even when low vision web accessibility is considered, it's often interpreted strictly as a requirement to make a website capable of being rendered by a screen reader (Hanson, 2004). A large reason for this is may be that most accessibility standards for visually impaired users inaccurately treat this diverse group the same as blind users, despite their different needs. This can be attributed to a lack in understanding of what visual impairments are and what they encompass (Arditi & Lu, 2008). It may also be that making accommodations for no vision is easier than supporting the wide range of needs experienced by visually impaired users (Theofanos & Redish, 2005). Limited visual acuity is an ever-increasing challenge for web accessibility; however, as most educational and employment opportunities are now, and will continue to be, dependent on an individual's ability to access and use a full range of computer and web technology, it's an important challenge to address (NFB, 2017).

Web Guidelines

The World Wide Web Consortium (W3C), an international community working to develop web standards, supports many efforts related to accessibility. This is not all that surprising given that the W3C founder, Tim Berners-Lee, inventor of the web, is most famously quoted for his belief that "The power of the web is in its universality. Access by everyone regardless of disability is an essential aspect," (Marks, 2016; Horton & Quesenbery, 2013). One of the more well-known approaches to web accessibility is the W3C's establishment of an international set of web standards known collectively as the Web Content Accessibility Guidelines (WCAG). In its current state, WCAG 2.0 focuses on web accessibility in terms of overarching principles, rather than on specific web technologies, so that these principles can be more easily applied to new technologies (Horton & Quesenbery, 2013). The four foundational principles of WCAG 2.0, making content perceivable, operable, understandable, and robust, take a human-centered approach to web design and development (Horton & Quesenbery, 2013; Kalbag, 2017). These four principles are made up of a set of 12 guidelines that have three levels of testable success criteria: level A, level AA, and level AAA. Most organizations invested in accessibility aim for Level AA conformance, with Level AAA being the hardest level to achieve and often requiring a lot of additional time and expense (Kalbag, 2017).

Principle 1 of WCAG 2.0 is aimed at users with visual impairments in particular, with a focus on presenting content in ways that users can recognize and understand (Horton & Quesenbery, 2013; Kalbag, 2017; WebAIM, 2013b). This includes, but is not limited to, providing text alternatives for non-text content, creating adaptable content that can be presented in different ways without losing information or structure, and ensuring content is distinguishable with sufficient color contrast (W3C, 2008). Additionally, the W3C has published a working draft targeted specifically at accessibility requirements for people with low vision. These requirements focus largely on user needs regarding typography, such as brightness, color, and contrast; tracking along lines of text, including rewrap, reflow, line length, and hyphenation; perceivable size, font, style, capitalization, and spacing; spacing for reading, such as leading, letter-spacing, word spacing, justification, and margins and borders; distinguishable heading and list elements; proximity of related information; and working with user settings, such as increases in font size, leading, or a change in other text display (W3C, 2016).

Adherence to WCAG and other accessibility guidelines does not guarantee a usable or satisfying experience. Not only do the needs of many users fall outside the guidelines for accessible content, but most websites are developed with the average user in mind first, followed by accessibility modifications for users with disabilities last (Hanson, 2004; Theofanos & Redish, 2005). To help fill these gaps, browser modifications and software applications provide a variety of ways in which the presentation of websites can be altered, though these tools are not without their own side-effects and unexpected consequences (Hanson, 2004).

Assistive Technology and Accommodations

Some websites include customization features that allow users to adjust the display directly within the website, such as enlarging text, changing color settings, and adjusting page width and number of columns. This is certainly helpful to some extent, though often the people who need these features will already have the necessary software, browser, and operating system configurations set to meet their needs and preferences (Horton & Quesenbery, 2013). Instead of predetermined customization features, it's far more important that everything within the website be configurable to adapt to individual low vision needs (WebAIM, 2013b). For example, if the text is real text and not an image of text, users can enlarge it, change its color, and change the background color it sits on. Additionally, if the layout is designed to be responsive, the screen can easily be widened, narrowed, or zoomed in on (WebAIM, 2013a; WebAIM 2013b).

There are a number of configurable options available to visually impaired users. Some of the most common, and most basic, are available right in the web browser and operating system. However, these configurable strategies only work if users know about them in the first place, and it can be argued that the users who most need to adjust their settings sometimes don't know how (Tennant, 2011; Theofanos & Redish, 2005). Other assistive technology hardware and software can give people access to the web who wouldn't otherwise have been able to engage. It should never be assumed that users are relying on assistive technology, however, because an individual's disability may not be severe enough for them to benefit from assistive-technology support, or they may not be aware these technologies exist, or the technologies that could help them may be too expensive, or they could have a secondary impairment and use technology that is more specific to a different need (Kalbag, 2017). Additionally, customizable adjustments and assistive technology can only help to a point because much of their success relies on the initial semantic coding or programming of websites with accessibility in mind. Content not coded for accessibility can prevent assistive technology, such as screen magnification, screen readers, or other accessibility customizations, from working.

Enlarging text and images. Text magnification is often essential for visually impaired users (Bruggeman & Legge, 2002; Legge et al, 1985). The most common technology used by those with visual impairments is screen magnification software. There are screen magnifiers that are already built into the operating system, typically accessed through the computer's system preferences, but full-feature screen magnifiers, such as ZoomText, MAGic, and LunarPlus, offer more robust options and higher levels of magnification than system defaults (AFB, 2017; Arch, Sutton & Henry, 2010; Kalbag, 2017; WebAIM, 2013b). Screen magnification software is designed to work like a physical magnifying glass, moving over a page and zooming in on a small area of the screen around the cursor, creating a "picture-in-picture" effect of the enlarged portion of the screen (AFB, 2017; Kalbag, 2017; WebAIM, 2013b).

These high levels of magnification are not without problems. Though screen magnification tools can be useful in enhancing the overall visual resolution of the screen, they tend to obscure or hide other content, reduce the field of view, limit readability, and make it difficult to skim text for specific information (Arditi & Lu, 2008; Bailey et al, 2003; Bruggeman & Legge, 2002; Horton & Quesenbery, 2013; Kalbag, 2017). Another shortcoming is the field constraints of the magnifier, often emphasized with color or shading, can also interfere with perceptual spans and eye-movement behaviors as users must continuously move the magnifier across the screen in order to bring text into the small field of readable sizes. Adding perceptual and motor complexities to a visual task makes using these tools a cumbersome process that decreases the number of letters in the reading field, reduces reading speed, efficiency, and comprehension (AFB, 2017; Arditi & Lu, 2008; Bailey et al, 2003).

Aside from magnification software, users can also zoom into and out of an entire webpage through the browser options menu, keyboard shortcuts, or through pinch and zoom gestures on touch devices (Arch, Sutton & Henry, 2010; Kalbag, 2017). However, enlarging text through these methods is often a tradeoff against the proportion of the screen visible at any given time. Unless the website has implemented a design that allows information within the webpage to easily adapt and reflow, most zooming ends up requiring both horizontal and vertical scrolling, which makes it difficult to comprehend the whole page and easy to miss key information (Bruggeman & Legge, 2002; Hanson, 2004; Horton & Quesenberry, 2017; Richards & Hanson, 2004; Theofanos & Redish, 2005; WebAIM, 2013b). These magnification changes are also temporary. In order to adjust the default font size each time the web browser is opened, users must modify font size through the browser settings, or, for increased font size across all applications, through the operating system (Arch, Sutton & Henry, 2010; W3C, 2010). It is also critical that font sizes within websites be set in relative units, as using absolute sizing or setting text in images does not allow visually impaired users to easily enlarge content (Hanson, 2004; Theofanos & Redish, 2005).

Listening rather than reading. For some, the use of sound as an output device for textual content can potentially resolve issues surrounding reduced visual acuity (Kurniawan & Zaphiris, 2005). In fact, screen readers, a piece of assistive technology that reads the contents of a screen, have become the symbol for web accessibility because they make text-based web pages accessible for those with visual impairments. Similar to screen magnification software, screen readers range from those already installed on the operating system to full feature software that provides more robust options (Arch, Sutton & Henry, 2010; Kalbag, 2017). The most well-known screen reader is Job Access with Speech (JAWS), a Windows-based screen reader that has been around since 1995 (Kalbag, 2017). However, the cost of software like JAWS can be prohibitively expensive for many people, especially for visually impaired users who still prefer to rely on their remaining visual acuity to perform and accomplish tasks. Free and open-source screen readers, such as NonVisual Desktop Access (NVDA), are becoming increasingly more common (Kalbag, 2017). Newer devices are also including screen readers as part of their default operating system, such as VoiceOver on Apple and Narrator on Windows, which can be enabled quickly and provide instant access to anyone requiring a screen reader (Kalbag, 2017). However, setting up and learning how to use screen readers effectively may require some initial guidance and training. For those visually impaired web users that are also hard of hearing, the benefits of audio output are lost entirely (Arch, Sutton & Henry, 2010; Kurniawan & Zaphiris, 2005). Screen readers are also not a substitution for the visual experience. They cannot describe images or scan the entirety of a webpage and zero in on the important content, as a visual user might (WebAIM, 2013b).

Other customizations. There are many custom adjustments visually impaired users can set through their web browser or operating system that change colors, increase contrast, and adjust overall screen resolution (Arch, Sutton & Henry, 2010; Horton & Quesenberry, 2017; WebAIM, 2013b). Low contrast and poor color combinations can be especially difficult for visually impaired users, and there are times when even the contrast requirements in WCAG 2.0 are not enough (Horton & Quesenberry, 2017; WebAIM, 2013b). For some visually impaired users, high-contrast modes, such as a white or yellow background with black text, or inverted color schemes, such as a black background with yellow text, are preferred (Horton & Quesenberry, 2017; WebAIM, 2013b). Customized stylesheets can be created through both the web browser and through the operating system as well, though this is becoming increasingly difficult as websites rely more and more on stylesheets in order to correctly display content. While this approach is quite powerful, it is not easy to set up and may require guidance or assistance by someone with more technical skills (Arch, Sutton & Henry, 2010; W3C, 2010). Even with these custom modifications, room lighting, a user's position in front of the screen, and the device's display settings must also all be optimal, something that can be harder to achieve when using technology such as laptops, tablets, e-readers, mobile phones, and wearable technology (Arch, Sutton & Henry, 2010).

Web Typography and its Effects on Visual Impairments

In addition to providing those with visual impairments a feeling of independence and self-control, reading itself creates an emotional connection. Typography sets the tone for content, giving it meaning, and impacting its overall appeal and readability. The effort web designers put into manipulating typography through considerations of font size, contrast, weight, color, rhythm, texture, and hierarchy is often considered a defining aspect of effective web design. Typography goes a long way toward creating pleasing and compelling online experiences, especially for websites with a content-heavy focus (Constantin, 2013; Lupton, 2014; Watzman, nd). It's really no wonder that implementation of typography can make or break how a user engages with a website. In fact, our ability to read content effectively depends largely on how that content is laid out typographically. Reading is comprised of many factors, from the series of quick back and forth eye movements, called saccades, to the fraction of a second our eyes stop, called fixations, to the processing that occurs between our eyes and brain (Santa Maria, 2014). Reading is further influenced by our environment, our attention, and our device (Lupton, 2014; Santa Maria, 2014). Choices made in typography, like size and spacing, can also impact how we read and influences the overall reading experience (Santa Maria, 2014). The role of typography in reading has roots in both legibility and readability.

Legibility and Readability

There is a difference between being able to distinguish individual letters (legibility), being able to effectively read and understand sentences (readability), and being able to sustain reading for an extended period of time (Allan, Kirkpatrick & Henry, 2016). Legibility, in particular, has been of great interest to typographers for more than two centuries not only because typography has a significant impact on the ability to easily read content, but also because illegible typography is a common complaint among visually impaired users (Arditi, 2005; Arditi & Cho, 2005; Rubin, 2013; Santa Maria, 2014; Sheedy, Subbaram, Zimmerman & Hayes, 2005; Watzman, nd). Legibility often refers to the individual characters of a font, the the thickness of the letters, the presence or absence of serifs, the distinguishability of the individual letterforms, the spacing between characters, and the overall impression created by the interaction of style, size, spacing, color, line length, white space, and the shapes those characters make when combined into words and sentences (Ali et al, 2013; Bonneville, 2011; Morrison & Noyes, 2003; Russell-Minda et al, 2007; Santa Maria, 2014; Watzman, nd).

Just because typography is legible doesn't mean it's readable. Readability combines the emotional aspect of the overall design with the amount of effort it takes to read, as well as the speed and comfort of reading and the understanding of what is being read, which are all, in part, dependent on the reader's own proficiency (Ali et al, 2013; Santa Maria, 2014). Focusing on readability and reducing reading fatigue also means relying on principles of good typographic design. A frequent complaint from visually impaired users is that it's difficult to sustain extended periods of reading, even with appropriate magnification (Rubin, 2013). Improving readability often means choosing fonts that were designed for the purpose of prolonged reading, using sufficient font size, color and contrast, line height, line spacing and white space, and writing shorter sentences (Bonneville, 2011; Horton & Quesenberry, 2013).

While accessible typography is both legible and readable, the focus of this research is on the elements of typography that encompass legibility.

Elements of Typography

Despite its prevailing importance, there are generally no hard rules in typography, only basic principles, overall best practices, and methods that work most, but not all of the time. This is a challenge that is further compounded by the constant change in devices and environments in which these devices are used to access the web (Santa Maria, 2014; Watzman, nd). Even with a foundation largely in intuition and experience, it's commonly agreed that good typography goes largely unnoticed while bad typography draws highly unwanted attention to itself. Good, accessible typography relies on keeping text as legible as possible, and font family, size, and line height all have an impact (Kalbag, 2017). The challenge of accessible typography for visually impaired users is compounded by the different visual impairment needs. Existing research into low vision and web typography has found that these differing needs depend on the visual acuity of each individual user, and that often one user's needs and accommodations conflict with or hinder those of another user (Allan, Kirkpatrick & Henry, 2016; Hallett et al, 2015). An outcome from a 2003 study conducted by Mary Frances Theofanos and Ginny Redish argued that the needs of visually impaired users are too diverse for simple solutions to web accessibility, and that usability and flexibility in design is ultimately the key in responding to customizations and configurations based on individual needs (Horton & Quesenbery, 2013). Still, other research has found there are many typographic details that impact the legibility of text on the web, and that attention to details such as font size, x-height, line height, line and word length, and attention to color all go a long way in helping to improve the legibility of text (Ali et al, 2013; Anayian, 2011; Morrison & Noyes, 2008). To help simplify the complex nature of typography, the typographic elements that appear to have the most impact on legibility have been divided into the following five groups for further discussion: (1) size; (2) color; (3) texture; (4) structure & form; and (5) weight. These groups are based in large part on those groups of typographic contrast established by world renowned typographer Carl Dair in 1952, though they are not used in quite the same way for the purpose of this research. It should be mentioned that not all of these elements have been thoroughly researched for the web, nor for visually impaired users specifically. In fact, research linked directly to low vision was difficult to find, as will become increasingly apparent in this section. In general, more research is needed to determine how typography can be leveraged in ways that enhance the online experience for visually impaired users.

Size. While web designers may be more concerned with getting as much information as possible on a single screen, it is well known that increasing font size increases legibility, especially for users with visual impairments (Arditi, 2005; Hanson, 2004; Sheedy, Subbaram, Zimmerman & Hayes, 2005). While users with normal vision can efficiently read a large range of type sizes, users with visual impairments are much more restricted (Arditi & Lu, 2008). Thus, accessibility guidelines tend to recommend sufficiently larger font sizes be used in order to better accommodate for visual impairments (Becker, 2004). A common argument, however, is that font size is no longer a usability issue given that users can resize text within their browser, an argument that is further compounded by the idea that there is no single font size that is ideal for all users and that font size can only be effectively increased up to a certain point before there is no additional benefit (Becker, 2004; Rubin et al, 2006; Tennant, 2011). In order for users to adequately resize text it needs to be set in relative units. There are generally four main units for setting type on the web: pixel, point, percentage, and em. Pixels and points are absolute units set by the browser, and though they provide web designers with the most control over font size, they make it difficult for users to increase font size through common zooming techniques without also interfering with the layout of the site (Catteneo et al, 2009). Fortunately, points aren't quite as commonly used on the web anymore, though pixels are still a very heavily used unit of measurement. Percentages and ems, on the other hand, are scalable, non-fixed, relative units, and are preferable because they allow users to adjust font sizes to better fit their individual preferences while also not breaking the design of the site (Horton & Quesenberry, 2013; Kurniawan & Zaphiris, 2005; Lupton, 2014; Theofanos & Redish, 2005; WebAIM, 2013a). As shown in Figure 5, a general rule of thumb is that 12pt = 16px = 1em = 100%.

font-size: 1em	The quick brown fox
font-size: 12pt	The quick brown fox
font-size: 16px	The quick brown fox
font-size: 100%	The quick brown fox

Figure 5. Relationship between em, point, pixel, and percent font sizing. Retrieved from "CSS Font-Size: em vs. px vs. pt vs. percent," by Kyle Shaeffer, 2008, https://kyleschaeffer.com/development/css-font-size-em-vs-px-vs-pt-vs/.

Browsers are set to display 1em (16px) font by default (Tennant, 2001). Recent trends in web typography have shown that common font sizes generally range from 0.875em (14px) to 1em (16px) (Constantin, 2013). However, typographic guidelines recommend a more inclusive font size of 1-1.2em (16-20px), while the Royal National Institute of the Blind (RNIB) recommends 1em (16px) or larger, and the American Printing House for the Blind (APH) favors 1.5em (24px) or larger (Arditi, 2005; Garnham, 2017b; Kalbag, 2017; Rubin et al, 2006; Santa Maria, 2014). Past research has found that among measurements of 0.7em (11px), 0.8em (12px), 1em (16px), and 1.2em (19px), 1.2em had the highest legibility while the remaining font sizes showed progressively lower legibility as they got smaller (Constantin, 2013; Sheedy, Subbaram, Zimmerman & Hayes, 2005).

Font size is more complex than recommending a single ideal number because there is no fixed or objective sizing. The numerical value of font size depends on the individual font, meaning that different fonts reportedly set to the same value can vary greatly in their legibility because they actually measure differently in terms of size (Arditi, 2005; Bix, 2002; Garnham, 2017b; Kalbag, 2017). Even though fonts are now created using computer programs, font size is still based on the antiquated system of setting metal type, a technique used when letterpress was the only means for printing text (Bix, 2002; Roethlein, 1912). To summarize, in letterpress printing, font size is based on the size of the block from which the letter is raised, which is not directly related to the height of the letter because different fonts utilize different areas of the same size block (Bix, 2002; Roethlein, 1912). No font ever utilized the full block, but even those that were much shorter were still referred to by the size of the block from which they were set (Bix, 2002). The takeaway is that it's important to consider the size of a font from a visual standpoint, and not by the numerical value alone (Santa Maria, 2014). The overall vertical space a letter takes up, its x-height, is better at conveying the visual impression of the font over its numerical size, as two different fonts set at the same font size can appear quite different in size, as shown in Figure 6 (Bix, 2002; Garnham, 2017a; Watzman, nd).

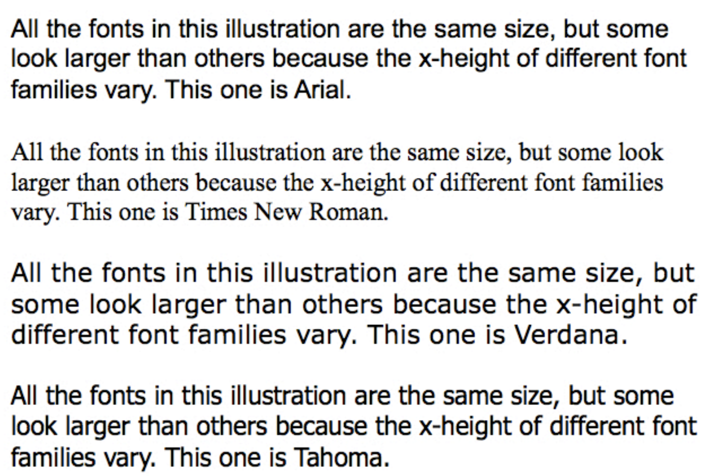

Figure 6. Fonts set in the same font size can still look different due to differences in x-height. Retrieved from "100 things you should know about people: #91 - size matters when it comes to fonts," by Susan Weinschenk, 2011, https://www.blog.theteamw.com/2011/03/26/100-things-you-should-know-about-people-91-size-matters-when-it-comes-to-fonts/.

Fonts with a larger x-height and more inter-letter spacing have also been found to increase legibility by increasing the overall size of the font and providing more distinct letter shapes that further aid in definition and clarity (Arditi, 2004; Bix, 2002; Garnham, 2017b; Horton & Quesenbery, 2013; Ratliff, 2016; Santa Maria, 2014). However, there is still a delicate balance. Too much x-height may diminish the recognizability of letters, making letters such as ‘a’ (ae) and ‘d’ (dee), or ‘n’ (en) and ‘h’ (aitch) difficult to distinguish, while too little x-height may have a negative impact on the legibility of letters, such as ‘c’ (cee) and ‘e’ (ee). (Bonneville, 2011; Santa Maria, 2014). Generally speaking, though, the smaller the x-height, the larger the font needs to be (Kalbag, 2015).

Color. Color is useful for attracting attention, expressing meaning, and highlighting relationships (Cattaneo et al, 2009). However, colors that are easily distinguishable to users with normal vision may not work at all for users with visual impairments (Horton & Quesenbery, 2013). When designing for accessibility, color is one of the easiest adjustments that can be made, largely because something either has sufficient foreground/background contrast or it doesn’t. Users with limited vision may need as much contrast as possible in order to read, and WCAG 2.0 recommends a minimum contrast ratio of 4.5:1, with a preferred contrast ratio of at least 7:1, to better aid users with impaired vision or color perception deficiencies (Hanson, 2004; Horton & Quesenbery, 2013; Kalbag, 2017; Marks, 2016). A majority of past research has consistently found that dark text on a light background, such as black on white, provides the best legibility and is the easiest to read (Arditi, 2005; Bix, 2002; Becker, 2004; WebAIM 2013a). Despite this, color contrast continues to be one of the biggest obstacles to text that is both legible and accessible (Marks, 2016). This is in part due to several trends on the web that cause contrast to be reduced, such as textures, gradients, or images instead of solid backgrounds, and a heavier implementation of grey body copy, which is thought to reduce eyestrain (Becker, 2004; Hanson, 2004; Horton & Quesenbery, 2013;

Marks, 2016; Richards & Hanson, 2004). While it's said that increasing contrast never decreases legibility, there is some debate over whether or not excessively high contrast, 21:1 being the highest level of achievable contrast, actually degrades visibility, which has led to some widespread belief that darker grey text or the use of a slightly off white background may actually be more comfortable for reading than pure black on white (Arditi, 1996; Cattaneo et al, 2009; Constantin, 2013; Kalbag, 2015; Kurniawan & Zaphiris, 2005; Saito, Saito & Saito, 2008; Santa Maria, 2014). However, grey text can be difficult to read if there isn't sufficient contrast or if the font weight is too light, and it's been argued that between ambient light, backlight, and brightness of screen, not even black text is truly perceived as pure black by the time it reaches the eye (Allan, Kirkpatrick & Henry, 2016; Garnham, 2017b; Marks, 2016).

Texture. There appears to be little research regarding the texture, or overall composition, of typography in relationship to low vision, yet the following typographic guidelines and recommendations are thought to be a good place to start. It's best to avoid long lines of text as a way to reduce fatigue and make it easier for users to easily move from one line of text down to the next. However, recommendations for line length vary wildly, and can range from 45 characters all the way up to 90 characters. The most widely accepted range for optimal readability appears to be 45-86 characters per line, though most websites are averaging about 75-90 characters per line across various displays (Cattaneo et al, 2009; Constantin, 2013; Lupton, 2014). There are some arguments that anything more than 66 characters forces users to have to turn their head from side to side, while existing research has found that line length ranging from 35-90 characters actually has little impact on reading speed and fluency for users without significant visual impairment (Kalbag, 2017; Rubin et al, 2006).

Line height is another factor that affects the accessibility of web typography in terms of texture. Also referred to as line spacing or leading, line height is the overall spacing between consecutive lines of text (Horton & Quesenbery, 2013). In addition to line length, the amount of space between individual lines of text influences how effectively users track from the end of one line to the beginning of the next, with too little space making the text appear to overlap and too much space making it hard for users to easily move to the next line (Bonneville, 2008; Garnham, 2017b; Horton & Quesenbery, 2013). An ideal line height doesn't exist because every font is different and optimal line height can depend on the visual layout of the design (Bix, 2002; Constantin, 2013; Santa Maria, 2014; Watzman, nd). However, the biggest problem with line height on the web is that it's often too tight (Sethfors, 2017). Browsers set a default line height of 1em, which is often not adequate for easily tracking across a line of text and staying on track if the lines above and below it are too close (Bonneville, 2011; Cattaneo et al, 2009; Sethfors, 2017). Best practice indicates that a good starting point for line height ranges from 1.2-1.8, with 1.5 being more widely accepted (Cattaneo et al, 2009; Constantin, 2013; Garnham, 2017b; Santa Maria, 2014). Another recommendation is to start with one and a half times the font size and refine from there (Ratliff, 2017; Sethfors, 2017).

Letter-spacing is the third area of typographic texture believed to impact legibility, especially for visually impaired users (Arditi, 2004; Rubin, 2013). Generally, negative adjustments to letter-spacing should be used cautiously, if it all, as it makes letterforms and words difficult to recognize (Bix, 2002; Bonneville, 2011; Horton & Quesenbery, 2013; Watzman, nd). Increasing letter-spacing, on the other hand, has been effectively shown to increase legibility and improve reading performance (Arditi, 2004; Rubin, 2013). As shown in Figure 7, the default letter-spacing can sometimes cause letters, such as 'r' (ar) and 'n' (en), to run together and appear to form a different letter, thereby changing the word in which they appear (Bohm, 2015; Bonneville, 2011; Garnham, 2017b; Ratliff, 2017; Russell-Minda et al, 2007; Watzman, nd). In these cases especially, additional letter-spacing can help break up the flow between the two letters to help differentiate them better.

clear or dear
burn or bum
skivvy or skiwy

Figure 7. Tight letter-spacing can cause individual letters to run together, forming entirely new words. Retrieved from "Letter and symbol mis-recognition in highly legible typefaces for general, children, dyslexic, visually impaired, and aging readers," by Thomas Bohm, 2015, https://typography.guru/journal/letters-symbols-misrecognition/.

Lastly, left-justified, right-ragged text has been determined to be more legible in regards to typographic texture because the consistent left margin creates a stable anchor for tracking through lines of text. Other types of justification often results in awkward spacing between text that may cause the user to lose the natural flow from one line to the next (Bonneville, 2011; Horton & Quesenbery, 2013). Centered text in particular is not considered to be accessible and is significantly more difficult to read because it creates different starting positions for each line of copy (Garnham, 2017a). It's also important that text reflows, or wraps when users zoom in, preventing horizontal scrollbars which disrupts reading flow and comprehension (Allan, Kirkpatrick & Henry, 2016).

Structure and form. There is reason to believe that visually impaired users may be particularly sensitive to typographic structure and form, or the overall choices made in selecting a font (Arditi & Cho, 2004; Mansfield, Legge & Bane, 1996). While arguably not the most essential aspect of typography, font selection still plays an important role in the typographic choices designers make. Additionally, designers no longer have to rely on the 15 web safe system fonts of the past, which despite being flexible, consistent, and designed specifically for screens in the early 1990's, worked better on the low resolution screens of the past than they do on today's high resolution, retina displays (Lupton, 2014). Designers have increasing access to a wide variety of fonts for use on the web, a trend that could be found on 60% of the Alexa Top 1 million websites in 2016 (Fink, 2016; Shaikh, 2011). Though designers now have thousands of fonts to implement across the web, it's important to step back and clarify that web fonts and typographic diversity are not new ideas (Lupton, 2014; Shaikh, 2011; Watzman, nd; WebAIM, 2013a). There has always been a desire for more control over typography on the web. The first implementation of the @font-face rule was drafted into CSS in 1998, allowing designers to download and use different fonts across the web (Lupton, 2014). The problem with this first attempt at web typography was the lack of piracy protections (Lupton, 2014). That changed in 2008 when font hosting services such as Font Squirrel, Google Fonts, and Adobe Typekit stepped in to fill the licensing and piracy void, adding to cross-browser support and making web fonts easier to implement (Constantin, 2013; Lupton, 2014; Shaikh, 2011). Google Fonts, in particular, is a popular service because web designers have free access to all of the available fonts, which was over 200 back in 2011, and is currently up to 877 at the time of this writing (Shaikh, 2011).

A common approach in many legibility studies has been to compare one font against another, the results of which often favor individual fonts and lead to broader claims of font legibility despite the underlying issue of contrasting elements, such as actual letter size, weight, and style, which makes it difficult to identify the specific elements that influenced those findings (Anayian, 2011; Beier & Larson, 2010; Rubin et al, 2006). Focusing on the differences between pairs of fonts is also a poor method of critique because font trends come and go, which makes specific font recommendations quickly outdated. While it can be argued that poor web typography has very little to do with choices in font, it's still important to choose a typeface that has strong character recognition, such that the individual letters are clear and distinct (Garnham, 2017b; Ratliff, 2017). While well-designed typefaces have a harmonious and unified appearance, it also means that many of the characters can end up sharing similar forms with other characters, resulting in visually similar letterforms that do not perform well when tested under single-letter recognition (Nini, 2006). As seen in Figure 8, one of the most common confusions can be found between the similarity of ‘I’ (uppercase eye), ‘i’ (lowercase eye), ‘l’ (lowercase el), and ‘1’ (numeral one) (Bohm, 2015; Garnham, 2017a; Garnham, 2017b; Ratliff, 2017). Similarly, some characters, such as ‘b’ (lowercase bee) and ‘d’ (lowercase dee), as well as ‘p’ (lowercase pee) and ‘q’ (lowercase cue), aren’t as easily distinguishable from one another for users who may perceive letters as flipped or mirrored (Ratliff, 2017).

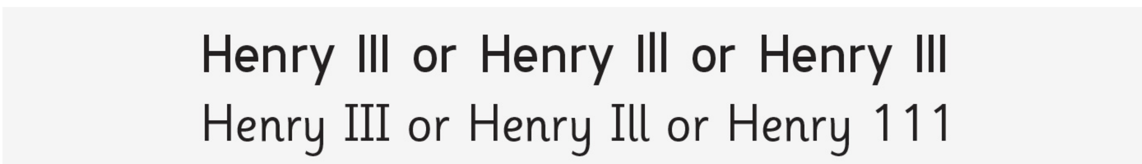

Figure 8. Confusion between individual letterforms. Retrieved from “Letter and symbol mis-recognition in highly legible typefaces for general, children, dyslexic, visually impaired, and aging readers,” by Thomas Bohm, 2015, https://typography.guru/journal/letters-symbols-misrecognition/.

In regards to serif vs sans serif fonts, there have been no concrete answers on the role serifs do, or do not, play in legibility, leaving designers divided and the debate ongoing, despite the seemingly insignificance of the issue (Bix, 2002; Poole, 2008). Web designers in favor of serif fonts argue that serifs contribute positively to improvements in legibility because serifs increase the spacing between letters and words to aid in legibility, which also contributes to the horizontal movement of the eye during reading (Bix, 2002; Poole, 2008; Watzman, nd). It’s also claimed that serifs increase contrast and irregularity between letters, making them more easily differentiated than letters without serifs (Arditi, 2005; Arditi & Cho, 2005; Bohm, 2015; Bix, 2002; Morrision & Noyes, 2003; Poole, 2008). That last advantage is said to be so small, though, as to have virtually no impact on the decision to choose a serif font over a sans serif font, and in fact, there has effectively been no significant difference in legibility studies between serif or sans serif fonts (Arditi, 2005; Morrision & Noyes, 2003; Perea, nd). Some studies have tried to prove that at smaller sizes serifs may interfere with legibility, though again there has been no strong determination of a definite difference in legibility between serif and sans serif fonts (Arditi & Cho, 2005; Perea, nd; Poole, 2008; Ratliff, 2017; Russell-Minda et al, 2007). Still, those web designers in favor of sans serif fonts argue that sans serif fonts are made up of simpler and more distinct letter shapes that are free of the detailing of serif letters, thus reducing visual distraction (Bix, 2002; Garnham, 2017b; Horton & Quesenbery, 2013; Morrision & Noyes, 2008; Poole, 2008). There are also claims that the x-heights of sans serif fonts are often greater than the x-heights of serif fonts of equal font size, thus creating more space and improving legibility (Bix, 2002; Garnham, 2017b; Horton & Quesenbery, 2013). Another widely held belief is that sans serif fonts render better on the web than serif fonts, a thought that may be left over from the past when computer displays had less rendering capability than they do now (Poole, 2008; WebAIM, 2013a). While existing research does not enable us to make strong conclusions about choosing one over the other, there appears to be a subjective preference among visually impaired users and advocates alike for the use of sans serif fonts, which may have more to do with the fact that sans serif fonts tend to be more common on the web, and common fonts usually outperform less common fonts despite the inconclusive research on the presence or absence of serifs (Bohm, 2015; Becker, 2004; Perea, nd; Russell-Minda et al, 2007; Sethfors, 2017; Theofanos & Redish, 2005; Watzman, nd). As of this writing, no definitive answers have been found to support serif or sans serif fonts either way, although many opinions continue to be expressed on the topic.

Many of the discrepancies among font choice may be a factor of legibility that do not actually hinder the overall readability of content, and may not be a large factor in typography for visually impaired users. A 1969 study found that that letter recognition is quicker and more accurate when letters are within words rather than when they are presented individually or within a random string of letters, a finding that has been held consistent across several more recent studies (Schwanenflugel & Flanagan, 2015). This may in part be because reading individual letters isn't as common as reading full words. However, it's still important to choose a font that has recognizable and distinct characters, especially with regards to visually impaired users, because the more unfamiliar and easily confused the individual characters are the more slowly the text is understood (Bohm, 2015; Santa Maria, 2014). While there is no perfect font, careful consideration needs to go into choosing common fonts with conventionally designed characters, generous spacing, and a tall x-height (Bonneville, 2011; Ratliff, 2017; Sethfors, 2017).

Weight. The final typographic element to consider for legibility for visually impaired users is the overall contrast, visual weight, or stroke width of the font. High contrast fonts can have a weight of hairline thin to very broad, while monoline fonts have a consistent weight throughout (Santa Maria, 2014). Even individual characters can be subject to weight variation; they may be consistently faint, heavy, or bold, or they may contain both thin and heavy lines (Roethlein, 1912). Serif fonts, in particular, are often made up of a combination of both thick and thin lines within each individual letter, which can create an uneven and distracting texture (Kalbag, 2015). Thin type has recently became more popular on the web, but it can be hard to read for visually impaired users specifically as the lower level of perceived contrast makes thin fonts appear to break apart (Arditi, 1996; Kalbag, 2017; Nini, 2006). Conversely, heavier strokes may cannibalize counter forms, which can make it more difficult to distinguish individual letters which also diminishes overall legibility (Arditi, 2005; Arditi, 1996; Bix, 2002; Kalbag, 2015; Roethlein, 1912). It's a delicate balance between too thick and too thin. Research indicates that the thinnest stroked letters are less legible than the thicker stroked letters, but the consistent use of intermediate, uniform strokes on letters have the best legibility overall (Arditi, 2005; Bohm, 2017; Nini, 2006; Roethlein, 1912; Sheedy, Subbaram, Zimmerman & Hayes, 2005).

Closing Thoughts on Typography

A thorough review of the different elements of typography reveals just how complex this area is. Additionally, it is difficult to determine where to begin, as each element of typography must be considered individually and as a sum of its parts for sufficient legibility to be achieved (Bix, 2002). While the rise of web fonts and font adjustment capabilities available through CSS give web designers far more control over typography than ever before, it also creates more opportunity to make poor typographic choices on a very important aspect of the web that heavily relies on legibility and readability for effective communication, especially among visually impaired users (Lupton, 2014; Shaikh, 2011). However, existing typographic research is dated, geared more toward print than web, and often compares the difference between individual fonts rather than the different typographic elements, which have more longevity given that font popularity is not a fixed variable. For example, Barbara Roethlein performed extensive research in regards to typography and legibility, but her research was specific to print and dates back to 1912 (Roethlein, 1912). The work of Miles Tinker, one of the more well-known contributors to readability and legibility of printed typography, dates back to pre-1960 (Sheedy, Subbaram, Zimmerman & Hayes, 2005). Research from both authors, among others, continues to be cited throughout typographic literature. The problem with relying on older research in typography is that type is not printed on paper anymore, but rather rasterized into pixels and rendered on the screen, which makes web typography vastly different and past research irrelevant. Most importantly, it's apparent that a lot of the existing research lacks in the understanding of visually impaired users and their specific needs, often making broad claims about typographic guidelines across all web users (Russell-Minda et al, 2007). Optimizing typography is optimizing legibility, readability, and accessibility among visually impaired users, and is an area of web technology that could greatly benefit from further research (Reichenstein, 2006).

Chapter 2: Evaluation of Current Typographic Trends

Overview

The first step in creating a better experimental design for accessible web typography for visually impaired users was to determine how web typography was actually being implemented in comparison with how guidelines and best practices recommend it to be implemented. An evaluation of current typographic trends was conducted on Alexa's top 100 visited websites from 2017 (Cawley, 2017). Data collected during the evaluation focused on current typographic trends in font size, line height, color, and font style. These specific elements of typography were selected largely because of the vast amount of discrepancy in existing research, but also because they are often the elements of typography perceived as being the easiest to implement in a way that provides a better online experience for visually impaired users.

Findings

The results of the evaluation of current typographic trends provided meaningful data on which typographic elements are being implemented in accordance to guidelines and best practices and which elements are not. Of Alexa's top 100 visited websites from 2017, 88 were carefully reviewed. Websites that were flagged as email, pornography, torrenting or illegal streaming, or as ad networks were excluded from the analysis. Included in the analysis was a wide variety of online international newspapers, social media and blog sites, and well-known, global organizations.

The evaluation had a high focus on the overall legibility of content. Each website was evaluated using Chrome DevTools as a way to thoroughly analyze stylesheets for the typographic settings applied to body copy. Because not all of the websites evaluated were text-heavy in nature, for purposes of evaluation body copy was considered to be the primary copy used for means of communication. Body copy was analyzed specifically for the stylesheet elements of font size, line height, font color, and font family being used. The following diagrams and discussions are a compilation of the detailed table of findings found in Appendix A.

Font Size

While specific font size was analyzed, the following results should be interpreted with a level of caution, as it has been previously mentioned that an exact numeric value for font size is not equal across fonts. Exploring how font size is being used on the web is still an important observation, however, because it provides a better understanding of current website trends and lays a better foundation with which to set recommendations.

In order to effectively compare font size across the different values implemented within the individual websites, all values needed to be converted to a standard format. Chrome DevTools was used to compute this automatically, providing a rendered font size, in pixels, through its Computed Styles feature. As shown in Figure 9, the most widely used font size was 14px, followed closely by 16px. Recall from the literature review that 16px is the minimum font size recommended in typography guidelines. It is also the default font size set across browsers. Results from the evaluation reveal that 54.5% of the top websites, including Google, YouTube, and Facebook, are setting font size below the recommended, default font size.

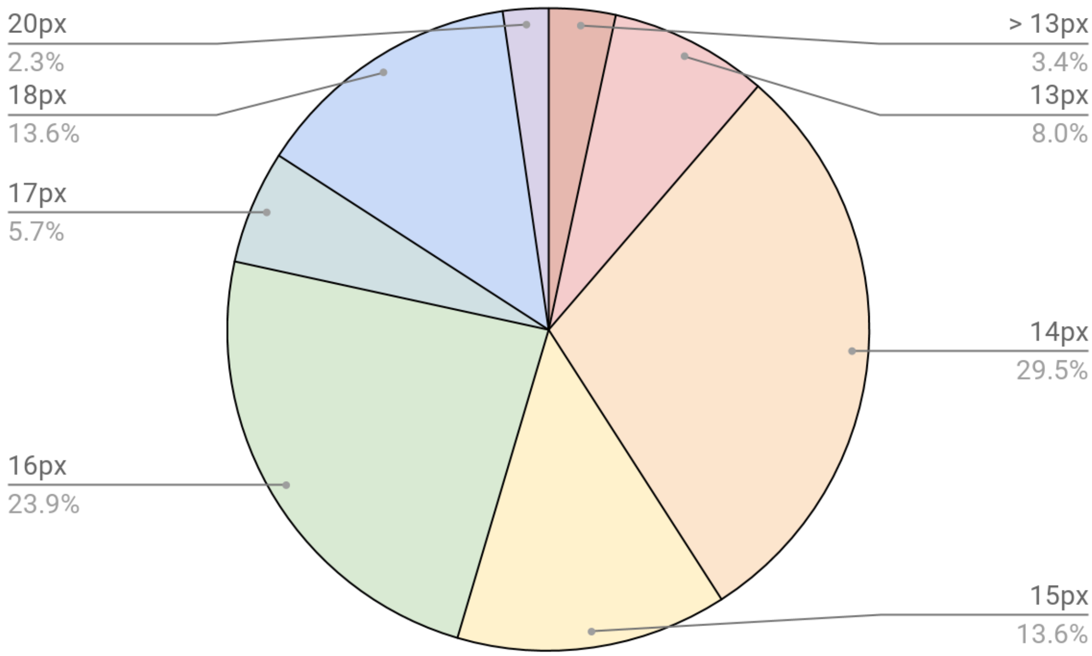

Figure 9. Overview of computed font sizes, in pixels, implemented across the websites analyzed.

Taking this analysis a step further, the evaluation indicates that 84.1% of websites are under the minimum 18px font size recommended by low vision advocacy groups for visually impaired users. Websites implementing font sizes at 18px or larger include popular sites like Diply, CNN, and Huffington Post.

In terms of actual units being used, both relative and absolute font sizing was implemented equally across the 88 websites analyzed. Recall from the literature review, however, that relative font sizing is preferred because it allows users to easily resize text to fit their needs. In accordance to existing guidelines, 50% of the most popularly visited websites, including sites like Facebook, Amazon, and Twitter, are not readily accessible for visually impaired users who rely on zooming techniques to enlarge text. Further usability verification indicated that zooming in on these sites results in horizontal scrolling, making it difficult for visually impaired users to effectively navigate and maintain context of their location within the website.

This analysis indicates that even with the multitude of resources and recommendations available, web designers are electing to ignore standards and guidelines in favor of smaller font sizes set in absolute units.

Line Height

Recommended line height was a bit more ambiguous in existing research, largely because line height depends on font size. General guidelines advocate for line height to be set at 1.5 times, or 150%, of the font size used. To calculate line height for this evaluation, rendered values were first converted to a shared value that was then divided by the rendered font size.

As shown in Figure 10, just over half of the websites analyzed, 52.3%, are implementing a line height of less than the recommended 1.5 times the font size. These include sites like Facebook, Netflix, and Instagram.

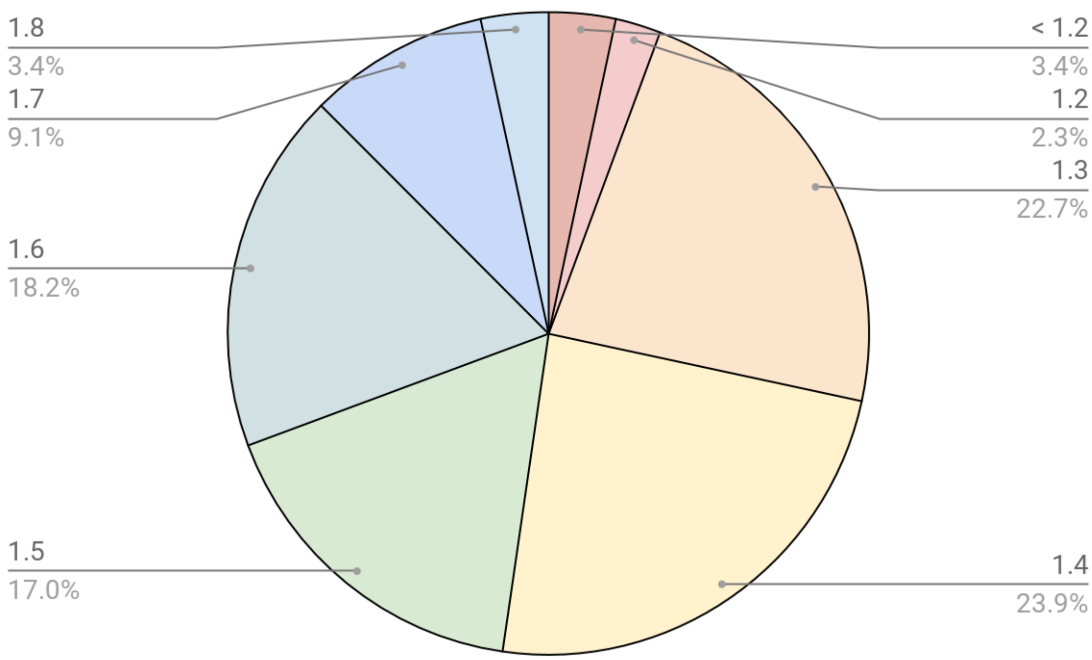

Figure 10. Overview of computed line height, in relationship to font size, implemented across the websites analyzed.

Recall that one of the biggest issues with line height is that it's often set too tight. Findings from the evaluation confirm this is an existing issue. With very little research done in regards to line height with visually impaired users, this area of web typography would be an interesting area to explore further.

Font Color

There has been a lot of recent debate on font color and whether or not the highest level of achieved contrast, black text on a white background, is adequate, even for visually impaired users. There is some thought that the use of pure black (#000) for body copy may be too harsh, and that shades of grey may therefore be more comfortable for reading. The following evaluation on font color was conducted to get a better idea of what colors are actually being implemented for body copy across the web, which may help drive future research and recommendations in this area.

As Figure 11 indicates, 63.6% of websites have body font color set in a shade of grey rather than pure black, which makes up only 19.3% of the websites analyzed.

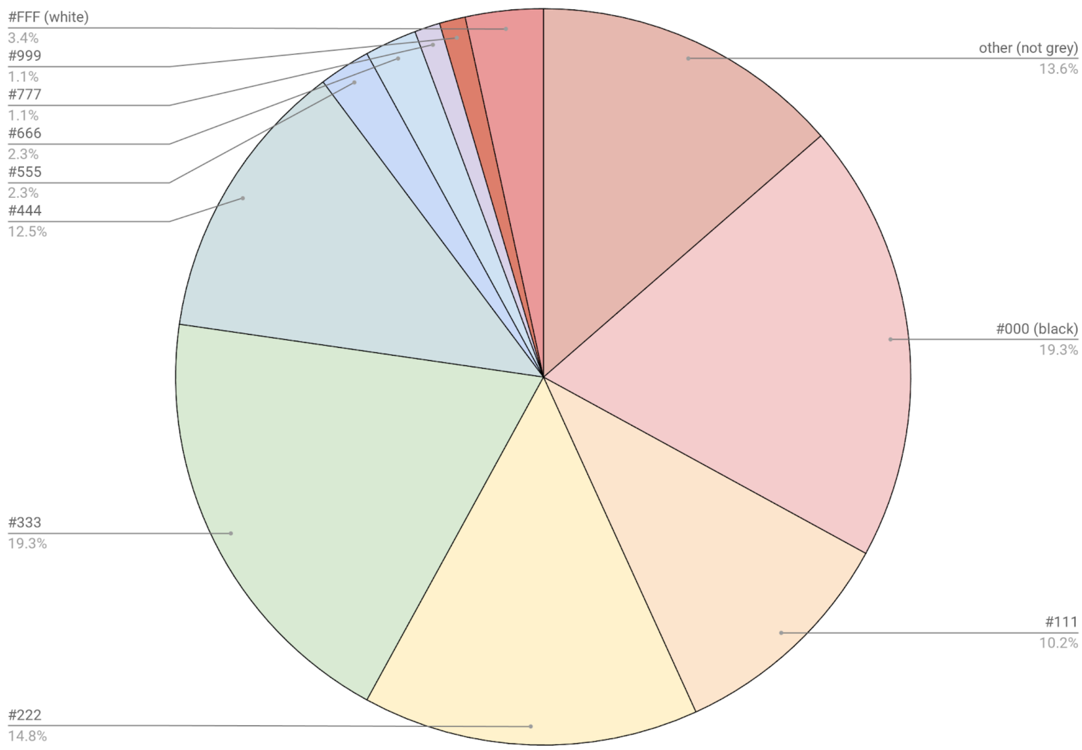

Figure 11. Overview of color used for body copy across the websites analyzed.

Far more web designers are following the trend of using grey font for body copy, which indicates more research needs to be done in this area to get a firmer understanding of the impact this may have on visually impaired users.

Note that adequate color contrast was not taken into consideration for this analysis, and background colors were not recorded in response to font color. However, #666 is the lightest shade of grey that can be used on a white background and still achieve a WCAG 2.0 Level AA color contrast ratio of 5.74:1.

Serif or Sans Serif

While the debate for either serif or sans serif fonts for body copy is inconclusive, research from the literature review indicated that users prefer fonts that are common, and tend to view common fonts as being easier to read. An analysis of the use of serif and sans serif fonts was conducted to gauge if there was a clear preference in the implementation of either serif or sans serif fonts in body copy.

As can be seen in Figure 12, the use of sans serif text in body copy makes up 87.5% of the font styles used across popular websites.

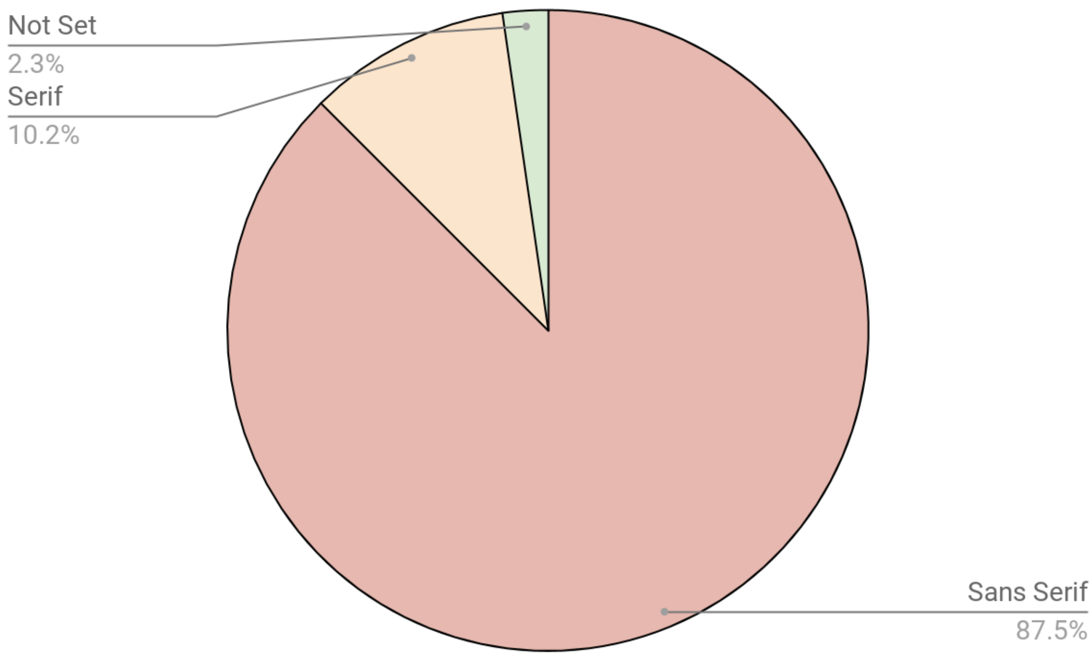

Figure 12. Overview of serif and sans serif font in body copy implemented across the websites analyzed.

To improve the overall legibility of a website, findings from the typographic evaluation, combined with the existing research presented in the literature review, indicate that sans serif fonts for body copy are the recommended choice. Further research into the use of the specific font choices being made may help provide additional recommendations, despite the growing typographic diversity and implementation of open source web fonts.

Discussion

Findings from the typographic evaluation show that there is a large disregard to typographic guidelines and best practices across the web. Web designers aren't fully embracing good typographic standards for normally sighted users, much less taking visually impaired users into consideration. Using this analysis of common website trends as a foundation for typographic research going forward may have a lot more impact on the future of web typography. This is because it may be more helpful for web designers to have a comparison of what is actually being put into practice versus what should be implemented. This typographic evaluation, along with guidelines for typography, accessibility, and visually impaired users, provide a good starting point for researching ways to enhance existing web typography for visually impaired users.

Chapter 3: Experimental Research

Methodology

In order to better understand meaningful ways in which web typography can be leveraged in order to increase usability for visually impaired users, two rounds of experimental research were conducted. Because no single typographic element is independent of another, it was first important to test if an individual element (font size) was affected by adjustments and changes in another element (line height) among one group of visually impaired users. Findings made from the first experiment then needed to be tested across different visual impairment types to verify which typographic adjustments successfully aided in contributing to a positive experience for visually impaired users.

Legibility Score

The behavior examined for both Experiment 1 and Experiment 2 was operationally defined as a legibility score. The following formula was used to calculate the legibility score across participants:

$$\text{Legibility Score} = \frac{\text{Total Words - Word Errors}}{\text{Total Words}} \times 100$$

where total words for Experiment 1 was equal to 166 and total words for Experiment 2 was equal to 168. Word errors was equal to the total number of mispronounced or skipped words made by the participant as he or she read the paragraph for each experiment out loud.

Experiment 1

The first experiment explored the relationship of font size, line height, and the interaction effect of font size and line height on simulated macular degeneration. Existing research indicates that increasing font size increases legibility for visually impaired users. However, it is commonly argued that there is no ideal font size for all users, which has lead to the implementation of smaller than recommended font sizes across the web. Line height, which is typically influenced by font size, was also explored because the recommendations for line height are often ignored, with half of the websites previously researched setting line height too tight. The following null hypotheses were tested: (1) an increase in font size will not have a positive effect on legibility for visually impaired users; (2) an increase in line height will not have a significant effect on legibility for visually impaired users; and (3) the interaction of font size and line height will not have a significant effect on legibility for visually impaired users.

Design and Materials

A 3x2 between-subjects design with 3 levels of font size (0.875em, 1.125em, or 1.375em) and two levels of line height (1.3 or 1.7) was used to explore the effect of font size and line height on legibility for visually impaired users.

Participants. The participants were 54 predominantly white, non-visually impaired, working professionals (35 men, 19 women, with an age range of 20-50 years old). Participants were recruited primarily from an internal information technology department within a student loan servicing organization based on their interest in accessibility. Additional participants were recruited from internal marketing and communications, business and operations, and management teams. All participants were given a selection of various candy bars and snacks as incentives.

Rapid Estimate of Adult Literacy in Medicine (REALM). Participants were first measured on their literacy level. While it was originally designed in 1993 to measure the literacy level of patients in a health care setting, the use of the REALM scale for the purposes of this study allowed for quick inferences to be made about the ability of participants to read and pronounce a series of 66 terms (Dumenci, Matsuyama, Kuhn, Perera & Siminoff, 2013). This relatively short task (typically less than 2 minutes) required administering and scoring on behalf of the moderator. REALM scores are calculated by the number of correctly pronounced words which are then converted into five reading levels as grade equivalencies: 3rd grade and below, 4th-6th grade, 7th-8th grade, and 9th grade or above (Dumenci, Matsuyama, Kuhn, Perera & Siminoff, 2013). Validity of REALM scores have been measured to be quiet high, ranging from .88 to .97 (Dumenci, Matsuyama, Kuhn, Perera & Siminoff, 2013). It was concluded, therefore, that participants with less than a 7th-8th grade level would not comprehend the subsequent reading task under normal circumstances, much less while wearing a pair of visual impairment simulation goggles. It was decided that participants who scored below 60 words would not be factored into the results of the study.

Visual impairment simulation goggles. Participants performed a short reading task while wearing a set of visual impairment simulation goggles representing age-related macular degeneration (central scotoma) with a visual acuity of 20/200 (6/60), as shown in Figure 13, in order to replicate some of the functional limitations and abilities that may be experienced with visual impairments. The simulation goggles were designed by Marshall Flax, a Certified Low Vision Therapist (CLVT) and a Certified Orientation and Mobility Specialist (COMS) who owns Fork in the Road Vision Rehabilitation Services LLC. The goggles were not meant to portray what it is like to have a permanent visual impairment, as that affects a person in ways beyond just their ability to read. However, use of the simulation goggles allowed for a larger sample of convenience while also giving fully-sighted persons interested in web accessibility a sense of some of the complexities involved for visually impaired users.

Figure 13. Visual impairment simulation goggles representing macular degeneration. Retrieved from "Low vision simulators," by Fork in the Road, 2018, https://www.lowvisionsimulators.com/product/macular-degeneration-simulators.

Reading task. A paragraph (166 words, 804 characters, 6 sentences) was selected from The Twelve Huntsmen, a short story by Grimm Brothers. The paragraph was given a Flesch reading ease score of 82.2 (easy to read) and a Flesch-Kincaid grade level of 7.8 (8th grade). Each participant was randomly assigned one version of the paragraph, which differed only in font size and line height: (a) 0.875em x 1.3; (b) 0.875em x 1.7; (c) 1.125em x 1.3; (d) 1.125em x 1.7; (e) 1.375em x 1.3; or (f) 1.375em x 1.7.

Procedure

Participants were briefed that the study was an investigation on which typographic traits, font size and line height in particular, factored into legibility for online users with visual impairments. Informed consent was obtained and sessions were conducted in a private conference room. Participants were first given a copy of the REALM word list. They were asked to read each word out loud, starting from the top of the list, and instructed that they could skip any words they were unable to pronounce. The moderator held the scoring sheet in a way that would prevent distracting the participant by the scoring the procedure.

Participants were then asked to put on a pair of visual impairment simulation goggles representing macular degeneration. They were instructed to wear the simulation goggles over any existing corrective eyewear (i.e., glasses). Participants were given a brief explanation of macular degeneration as context for what they were seeing through the simulation goggles. They were handed the iPad and asked to begin reading the text out loud, taking as much time as they needed. Participants were encouraged to read the paragraph without zooming in on the iPad screen and skipping any words they could not distinguish. However, if participants indicated that they could not make out any of the text they were given additional instruction to zoom in just enough for the words to become legible. Zooming in to any degree was considered a failed task and resulted in a 0% legibility score. All participants read an identical paragraph, except that font size and line height varied according to each of the six specific experimental conditions.

Participants were timed on how long it took them to read the paragraph, though they were not made aware of this and timing did not factor into the results. This ambiguity was done to reduce feelings of nervousness and avoid making participants feel as if they were being tested. Timing started as soon as participants began reading and stopped when participants concluded the paragraph. Because it can be informative to know how participants perceived the reading versus how they performed, participants were also asked to rate the ease of the paragraph they just read on a Likert Scale of 1 (difficult) to 5 (not at all difficult). This rating ended up not being factored into the overall results. Upon completion, individuals were thanked for their participation.

Control procedures. The following control procedures were used as a means to eliminate extraneous variables: (1) Font style was consistently set to Roboto Sans, the most popular font on Google Fonts at the time of this study, with a font color of #000 (black); (2) Participants read from a 9.7-inch iPad (5th Generation) with an IPS LED-backlit display at a resolution of 2048 by 1536 (264 ppi); (3) Brightness was set at 45% with no changes made to Text Size settings; (4) Sessions were conducted in a small conference room with standard office lighting; and (5) Participants were handed the iPad in a horizontal orientation and instructed to read from the screen as it was presented to them (i.e., without zooming in or changing any of the settings).

Data Collection

Individual sessions were screen and audio recorded and detailed note taking occurred during each participant task. Findings were transcribed into Google Sheets and later analyzed with a factorial analysis of variance (ANOVA) using the IBM Statistical Package for the Social Science (SPSS) software, version 23.

Experiment 1 Results

Participants unanimously achieved a high school reading level on the REALM task, with a range of 64-66 words pronounced correctly between participants. This indicated that all participants were adequately assessed for the reading and understanding of the 8th grade level reading task under normal conditions.

A 3x2 factorial ANOVA was performed to explore the effect of font size and line height on legibility for simulated macular degeneration. As previously mentioned, participants were randomly assigned one of six versions of a short reading task. Each version of the reading task was tested by nine participants, which were assumed to be normally distributed and of equal variance. These findings are outlined in Table 1, and the average legibility score, or percentage of words right, across users are outlined in Table 2.

Table 1

Tests of Between-subjects Effects of Font Size and Line Height on the Dependent Variable Legibility.

Source	*SS*	*df*	*MS*	*F*	*p*	Partial Eta²	Observed Power*
Font Size	7,691.878	2	3,845.939	2.142	0.129	0.082	0.418
Line Height	9043.766	1	9,043.766	5.036	0.029	0.095	0.595
Font Size * Line Height	2,717.064	2	1,358.532	0.757	0.475	0.031	0.171
Error	86,195.318	48	1,795.736				
Total	105,648.027	53					

Note. * Computed using alpha = 0.05.

As indicated by the results, there was insufficient evidence to reject the interaction effect null hypothesis at the 0.05 significance level ($F_{2,48} = 0.757$, $p = 0.475$, partial $\eta^2 = .031$). There was, however, a statistically significant main effect for line height on legibility for simulated macular degeneration ($F_{1,48} = 5.036$, $p = 0.031$). Post-hoc comparisons, outlined in Table 2, indicated a mean line height of 1.3 ($M = 58.346$, $SD = 49.329$, 95% CI [41.948, 74.743]) was significantly different than a mean line height of 1.7 ($M = 84.228$, $SD = 35.808$, 95% CI [67.831, 100.625]). Further, effect size value (partial $\eta^2 = 0.095$) suggested a high practical significance. A pairwise post-hoc comparison indicated that while a mean font size of 0.875em ($M = 54.687$, $SD = 50.36$, 95% CI [34.604, 74.769]) differed from a mean font size of 1.375em ($M = 82.231$, $SD = 37.868$, 95% CI [62.148, 102.313]), it was not enough to be considered statistically significant ($p = 0.057$). A font size of 1.125em ($M = 76.943$, $SD = 42.332$, 95% CI [56.861, 97.026]) did not differ significantly from either of the other two font sizes, which further indicated there was insufficient evidence to reject the font size null hypothesis at the 0.05 significance level ($F_{2,48} = 2.142$, $p = 0.129$, partial $\eta^2 = 0.082$).

Table 2

Descriptive Statistics for Dependent Variable Legibility by the Independent Variables Font Size and Line Height (N = 54).

	1.3			1.7			Total		
Font Size	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
0.875em	32.13	48.232	9	77.243	43.796	9	54.687	50.36	18
1.125em	66.333	49.752	9	87.553	32.856	9	76.943	42.332	18
1.375em	76.573	43.451	9	87.888	32.972	9	82.231	37.868	18
Total	58.346	49.329	27	84.228	35.808	27	71.287	44.647	54

General Discussion

The alternative hypothesis for line height was supported: an increase in line height had a significant effect on legibility for visually impaired users. Thus, when line height increases from 1.3 to 1.7, legibility for visually impaired users also increases from a score of 58% to a score of 84%, while when line height decreases the opposite is true. Both the null hypothesis for increased font size and the interaction effect of font size and line height were supported: an increase in font size did not have a significant positive effect on legibility for visually impaired users, although legibility increased from 55% to 77% to 82% (of the percentage of words read correctly), and the interaction of font size and line height did not have a significant effect on legibility for visually impaired users.

In terms of statistical significance, the results of Experiment 1 do not confirm past research, which has consistently indicated that an increase in font size does have a positive effect on legibility for visually impaired users. For example, research conducted by Chung et al. in 1998 measured the effect of print size on participants with normal vision, concluding that a minimum of 16-18px was needed to achieve maximum legibility. Aside from the flaws of broadly applying results from normal sighted users to low vision users, typography on the web is arguably much different than printed type (Russell-Minda et al, 2007). Additionally, research conducted by Sheedy, Subbaram, Zimmerman & Hayes in 2005, was done on a participant pool recruited specifically for a visual acuity of 20/20 or better, with no visually impaired individuals being included in the study. The researchers also mention in their results that even though a larger font size generally had a higher legibility, effect size was small and other factors may have contributed to this result (Sheedy, Subbaram, Zimmerman & Hayes, 2005). In fact, in a second experiment Sheedy, Subbaram, Zimmerman & Hayes found that at 9px there was enough detail for participants with 20/20 vision to correctly recognize letters and words and that there was no significant increase in recognition as font size went up. Finally, Rubin et al. conducted an experiment with visually impaired participants in 2006, that reports a significant effect of font size. However, the experiment tested font sizes in relationship to different typefaces. As previously discussed in the literature review, there are too many variables across individual font families that limit our ability to conclusively state that font size alone is a distinguishing cause. Differences in actual letter size, weight, and style all need to be considered. Taking these factors into account, it may be reasoned that increasing font size does result in only minor benefits for visually impaired users.

Conversely, while the overall results of this experiment were not statistically significant ($p = 0.129$), it is worth mentioning that in regards to font size, the mean legibility score for a font size of 0.875em (M = 82.231) was quite a bit lower than that of a font size of 1.375em (M = 54.687), where $p = 0.057$. The standard for scientific research indicates that there needs to be a 95% chance or more that the observed result was not a result of chance. In this case, there is only a 94% chance that the observed improvement in acuraccy, from 55% to 82% was not accidental. Designers may still choose to use larger font sizes for readers with visual impairments based on these inconclusive results. Additionally, text set at 0.875em took an average of 0:02:40 minutes to read while text set at 1.125em and 1.375em took an average of 0:01:40 minutes and 0:01:46 minutes to read, respectively. While adjusting the ANOVA calculations for the dependent variable to be time on task instead of legibility (Appendix C) did not result in statistical significance for font size ($p = 0.080$), these factors still indicate that a larger font size is better for most visually impaired users, and that increasing font size even slightly is more inclusive. Lastly, this experiment was only conducted on simulated macular degeneration. Because central vision is significantly lost, users with macular degeneration may be less sensitive to increases in font size and may benefit from other enhancements to typography instead. The use of the simulation goggles may have also biased the results, along with a high individual variation between participants. Because differences in font size did not reach the threshold of statistical significance, additional research among a larger study using a within-subjects design across different types of visual impairments should be considered for future research.

Interestingly, line height did have a direct positive effect on legibility for visually impaired users, especially at smaller font sizes. This finding suggests that line height may have a larger effect on web typography for visually impaired users than has been previously researched. While the interaction effect of font size and line height was not statistically significant ($p = 0.475$), the mean legibility scores for font size did consistently show an increase in legibility when line height is also increased, especially when font size was smaller: 0.875em * 1.3 ($M = 32.13$) compared to 0.875 * 1.7 ($M = 77.243$); 1.125 * 1.3 ($M = 66.333$) compared to 1.125 * 1.7 ($M = 87.553$); and 1.375em * 1.3 ($M = 76.573$) compared to 1.375em * 1.7 ($M = 87.888$). These results indicate that line height is more important for visually impaired users at smaller font sizes than at larger font sizes. Furthermore, adjusting the ANOVA calculations for the dependent variable to be time on task shows statistical significance in the interaction effect of font size and line height ($p = 0.49$), where a simultaneous increase in both font size and line height decreases the time it took for participants to complete the task.

Based on the statistical significance of line height for simulated macular degeneration, it is important to see if the same statistical significance holds true across different types of visual impairments. If it does, line height needs to be considered a more important factor in legibility for visually impaired users. Thus, further determining if there is significance of line height on legibility across different types of visual impairments was the foundation for Experiment 2.

Experiment 2

Because of the significance on the effect of line height on simulated macular degeneration, the second experiment further explored the relationship of line height on three additional types of simulated visual impairments. The goal of Experiment 2 was to determine if the significance in the results for line height in the first experiment with macular degeneration held true across different types of visual impairments. The following alternative hypothesis was tested: (1) increasing line height has no effect on visually impaired web users.

Design and Materials

A single factor between-subjects design with 2 levels of line height (1.3 or 1.7) was used to explore the effect of line height on legibility for three groups of participants randomly assigned a set of visual impairment simulation goggles (cataracts, diabetic retinopathy, or glaucoma).

Participants. The participants were 36 predominantly white, non-visually impaired, working professionals (26 men, 10 women, with an age range of 20-50 years old). Participants were recruited based on their participation in the first experiment because the widely used 66-item REALM reports a near perfect test-retest correlation (r = .99), which suggests REALM scores are stable over a short time-period (Dumenci, Matsuyama, Kuhn, Perera & Siminoff, 2013). All participants were given a gourmet cupcake as an incentive.

Visual impairment simulation goggles. Participants were randomly assigned to a set of visual impairment simulation goggles, as shown in Figure 14: (1) cataracts, with an impaired visual acuity of 20/80 (6/24); (2) diabetic retinopathy, with visual acuity of 20/100 (6/30); or (3) glaucoma, with a visual field of 10 degrees and visual acuity of 20/80 (6/24), meant to represent glaucoma. As in the first experiment, use of the simulation goggles allowed for a sample of convenience while also giving fully-sighted persons interested in web accessibility a sense of some of the complexities involved.

Figure 14. Visual impairment simulation goggles representing (from left to right) cataracts, diabetic retinopathy, and glaucoma. Retrieved from "Low vision simulators," by Fork in the Road, 2018, https://www.lowvisionsimulators.com/find-the-right-low-vision-simulator.

Reading task. A paragraph (168 words, 873 characters, 5 sentences) was selected from The Raven, a short story by Grimm Brothers. The paragraph was given a Flesch reading ease score of 80.6 (easy to read) and a Flesch-Kincaid grade level of 8.1 (8th grade). Each participant was randomly assigned one version of the paragraph, which differed only in line height: (a) 1.7 or (b) 1.3.

Procedure

Participants were told that the study was a further exploration on how line height factored into legibility for users with visual impairments. Sessions were conducted in a private conference room. Participants were asked to put on a pair of randomly assigned visual impairment simulation goggles and were instructed to wear the simulation goggles over any existing corrective eyewear (i.e., glasses). Participants were given a brief explanation of the randomly assigned visual impairment as context for what they were seeing through the simulation goggles. They were handed the iPad and asked to begin reading the text out loud, taking as much time as they needed. Participants were encouraged to read the paragraph without zooming in on the screen. All participants read an identical paragraph, except that line height varied according to each of the two specific experimental conditions.

As in the first experiment, participants were timed on how long it took them to read the paragraph, though they were not made aware of this and timing did not factor into the results. This ambiguity was done to reduce feelings of nervousness and avoid making participants feel as if they were being tested. Timing started as soon as participants began reading and stopped when participants concluded the paragraph. Because it can be informative to know how participants perceived the reading versus how they performed, participants were also asked to rate the ease of the paragraph they just read on a Likert Scale of 1 (difficult) to 5 (not at all difficult). This rating ended up not being factored into the overall results. Upon completion, individuals were thanked for their participation.

Control procedures. The following control procedures were used as a means to eliminate extraneous variables: (1) Font style was consistently set to Roboto Sans, the most popular font on Google Fonts at the time of this study, with a font color of #000 (black), and a font size of 1.125em; (2) Participants read from a 9.7-inch iPad (5th Generation) with an IPS LED-backlit display at a resolution of 2048 by 1536 (264 ppi); (3) Brightness was set at 45% with no changes made to Text Size settings; (4) Sessions were conducted in a small conference room with standard office lighting; and (5) Participants were handed the iPad in a horizontal orientation and instructed to read from the screen as it was presented to them (i.e., without zooming in or changing any of the settings).

Data Collection

Individual sessions were screen and audio recorded and detailed note taking occurred during each participant task. Findings were transcribed into Google Sheets and later analyzed with both an independent-samples t-test and also a factorial ANOVA using SPSS software, version 23.

Experiment 2 Results

First, an independent-samples t-test was performed to explore overall legibility for visually impaired participants, regardless of visual impairment type, on 1.3 and 1.7 line height. Participants were randomly assigned to one of two versions of a short reading task. Each version of the reading task was tested by 18 participants, which were assumed to be normally distributed and of equal variance. The results of the mean and standard deviations and the independent-samples t-test are outlined in Tables 3 and 4, respectively.

Table 3

Group Statistics for Dependent Variable Legibility by the Independent Variable Line Height (N = 36).

Line Height	*M*	*SD*	*n*
1.3	98.214	1.155	18
1.7	98.446	1.597	18

Table 4

Independent Samples Test for Equality of Means on 1.3 and 1.7 Line Height on the Dependent Variable Legibility.

t	*df*	Sig. (2-tailed)	Mean Difference
0.499	34	0.621	0.232

As indicated by the results, there was insufficient evidence to reject the null hypothesis at the 0.05 significance level, as there was not a significant difference in the legibility scores for 1.3 line height ($M = 98.214$, $SD = 1.155$) and 1.7 line height ($M = 98.446$, $SD = 1.597$) conditions ($t_{34} = 0.499$, $p = 0.621$). These results suggest that line height does not have an effect on legibility for visually impaired users.

Additionally, a 3x2 factorial ANOVA with 3 levels of visual impairment (cataracts, diabetic retinopathy, or glaucoma) and 2 levels of line height (1.3 or 1.7) was performed to explore the effect of different types of visual impairment and line height on legibility. Participants were randomly assigned one of three visual impairment simulation goggles and one of two reading tasks. Each version of the reading task was tested by a total of 18 participants, 6 participants for each visual impairment type, which are assumed to be normally distributed and of equal variance. These results are outlined in Table 5, and the average legibility score, or words correct, across participants are outlined in Table 6.

Table 5

Tests of Between-subjects Effects of Line Height and Visual Impairment Type on the Dependent Variable Legibility.

Source	*SS*	*df*	*MS*	*F*	*p*	Partial Eta^2	Observed Power*
Line Height	0.483	1	0.483	0.259	0.615	0.009	0.078
Type of Visual Impairment	9.348	2	4.674	2.507	0.098	0.143	0.464
Line Height * Type of Visual Impairment	0.728	2	0.364	0.195	0.824	0.013	0.078
Error	55.930	30	1.864				
Total	348,143.283	36					

Note. * Computed using alpha = 0.05.

As indicated by the results, there was insufficient evidence to reject the interaction effect null hypothesis at the 0.05 significance level ($F_{2,36}$ = 0.195, p = 0.824, partial η^2 = 0.013). Additionally, there was no statistically significant main effect for line height ($F_{1,36}$ = 0.259, p = 0.615). The magnitude of the difference in the means and the effect size was very small (partial η^2 = 0.009). Post-hoc comparisons, shown in Table 6, indicated a mean line height of 1.3 (M = 98.214, SD = 1.155, 95% CI [41.948, 74.743]) was minimally different than a mean line height of 1.7 (M = 98.446, SD = 1.597, 95% CI [67.831, 100.625]). Lastly, there was no statistically significant effect on the different types of simulated low vision ($F_{2,36}$ = 2.507, p = 0.098, partial η^2 = 0.143).

Table 6

Descriptive Statistics for Dependent Variable Legibility by the Independent Variables Line Height and Visual Impairment Type (N = 36).

	1.3			1.7			Total		
Visual Impairment Type	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
Cataracts	98.611	1.34	6	99.206	1.042	6	98.909	1.186	12
Diabetic Retinopathy	97.718	1.478	6	97.619	1.992	6	97.669	1.673	12
Glaucoma	98.313	0.243	6	98.512	1.446	6	98.413	0.994	12
Total	98.214	1.155	18	98.446	1.597	18	98.33	1.378	36

General Discussion

In terms of consistency of the provided information, the null hypothesis for increasing line height was supported: an increase in line height will probably not have a positive effect on legibility for visually impaired users. The results of this experiment indicate that there was not a significant difference in the effect of line height on simulated visual impairments, either calculated together or individually.

A few participants mentioned that they sometimes lost their place on the line changes, or noted that it was hard to tell if they were skipping a line or not which slowed them down. However, of the 101 total errors made across participants, only 14 of them were made directly before or after a line break on either version of the test. The majority of the errors made, then, may arguably have nothing to do with line height but may have more to do with chance. Further analysis of the results of this experiment with time as the dependent variable (Appendix D) showed that a smaller line height of 1.3 resulted in a faster time on task, 0:01:21 minutes compared to 0:01:42 minutes when line height was increased to 1.7. Though there was still no statistical significance on the effect of line height ($p = 0.529$) on visual impairments, this is an important indication that to effectively explore line height further, alternative methods of measuring legibility in relationship to line height must first be investigated.

Discussion

The results of Experiment 1 indicated that an increase in font size will not have a positive effect on legibility for visually impaired users and also that the interaction of font size and line height will not have a significant effect on legibility for visually impaired users. There has been more recent discussion that there is no ideal font size for every user, and the results of Experiment 1 do help to prove that theory. What works well for one user will not always work for another user. In fact, the legibility score for individual results in Experiment 1 found that 8 participants failed the reading task at the 0.875em font size while 10 participants were effectively able to read at that same font size. The same can be found when looking at the font sizes for both 1.125em and 1.375em, where a combined total of 7 participants failed the reading task at either of these font sizes while 29 participants were able to read these same font sizes effectively. This non-normal distribution of the dependent variable likely accounts for the lack of statistical significance in font size for visually impaired users. Additionally, an interesting observation from Experiment 2 was that font size was held constant at 1.125em, and none of the participants needed to zoom in on the iPad screen to make the text easier to read. This may be a good indication that the recommended 18px font size is an adequate starting point for visually impaired users. Repeating Experiment 1 across the different types of visual impairments studied in Experiment 2 is recommended.

A single legibility score alone also cannot be used to determine the actual level of difficulty among the participants across the various font sizes and line heights, nor can it determine whether or not these same font sizes and line heights could be read for an extended period of time. Recall from the literature review that sustained reading is a frequent complaint from visually impaired users. While the individual REALM score can provide the assumption that all participants would have been able to understand and comprehend the reading task under normal conditions, the legibility score itself cannot give insight into how well the participants were able to understand and comprehend what they read while wearing the macular degeneration simulation goggles. Participants may have been more focused on trying to read the individual words of the task and less focused on what the words and overall paragraph meant. In fact, a few participants admitted that they weren't sure what they just read while others mentioned that context made it easier to determine some of the words. Future research should consider longer passages of text followed by verification of participant comprehension.

While the results of Experiment 1 indicated that there was a statistically significant effect of line height on simulated macular degeneration, the results of Experiment 2 indicated no statistical significance of line height when tested across additional types of simulated visual impairments. The underlying assumption of both experiments was that legibility, in terms of word errors, was a realistic way to test differences in line height. The difference in results for independently analyzing both legibility and time on task indicate that there is more than one way to measure the effect of font size and line height on visually impaired users. Ultimately, it is up to the discretion of the researcher, in conjunction with the end user, to determine the appropriate measure of success in moving forward. Is it more important for users to read faster or make fewer errors while reading? Determining the answer that question will help research into accessible web typography for the visually impaired move forward more advantageously.

Chapter 4: Conclusion and Future Research

Closing Remarks

Results from both experiments show no statistically significant effect of font size on simulated macular degeneration nor do they indicate a statistically significant effect of line height across simulated cataracts, diabetic retinopathy, or glaucoma. These findings may be a combination of experimental error not accounted for during the planning and implementation of either experiment, as well as some additional experimental limitations of the study overall.

Experimental Error

The first experimental error was that participants were allowed to hold the iPad at any distance that was comfortable for them. Some participants held the iPad a few inches from their face while other participants left the iPad resting on the table in front of them. This accounts for a vast discrepancy in the total viewing distance, nose distance to arm distance, from which participants read the short paragraph of text, and may factor heavily into the number of errors made. The reason viewing distance was not thought to be a significant factor during the design of this study was because web users do not sit at a fixed distance from their viewing device. It was thought that by allowing participants to view the iPad from a distance of their choosing that the replication of the experiment would be more accurate to real life. However, this decision introduced a third independent variable into both experiments that was not accounted for in the statistical analysis.

The second experimental error was based in large part on assumption. It was assumed that by having each participant wear the visual impairment simulation goggles that each person would then have the same level of visual acuity. However, upon conclusion of Experiment 1 in particular, this is not believed to be the case. Each participant brought their own level of visual acuity to the study, such as a decline in visual acuity due to age or perhaps uncorrected refractive errors. These pre-existing conditions were then compounded by the use of the visual impairment simulation goggles, which were deliberately designed with limited visual acuity. Thus, these participants had even more loss in visual acuity than the participants who could see 20/20 prior to the introduction of the simulation goggles. One valid argument for this discrepancy would be that even across visual impairments, no one person experiences the exact same loss in visual acuity as another person. In that regard, the individual visual acuity of each participant may actually be a more accurate representation of the limitations visually impaired users face. Instead of testing between-subjects, then, results may be more inclusive if the experiments had been conducted within-subjects.

Experimental Limitations

One of the biggest limitations of this study was the inability to test with actual users diagnosed with these visual impairments. While the use of the simulation goggles allowed for a larger sample of convenience, assumptions had to be made in several areas regarding the limitations of the goggles themselves. The goggles were designed to give normally sighted users an understanding of some of the abilities and limitations brought on by different visual impairments. However, the goggles were designed for average facial measurements, particularly the average distance between pupils but also the average distance between the inner and outer corners of the eyes. Even slight deviations from these averages may have provided a slightly different visual experience between participants. Another limitation of the goggles was the ability for participants to look around inside the goggles and find a better vantage point from which to read. For instance, in macular degeneration the central scotomas would always be at the center of the field of vision, no matter which direction the eyes moved. With the goggles, however, participants could freely move their eyes away from the central scotoma and read without looking straight through the scotoma. The final disadvantage to the visual impairment simulation goggles is the short duration in which the participants were asked to wear the goggles to perform the reading task. Actual visual impairments do not happen overnight. Instead, the slow progression of visual decline happens over an extended period of time, giving those who are faced with a visual impairment time to make adjustments and better accommodate for their loss in vision. For example, users diagnosed with macular degeneration learn to read from their peripheral vision over time. In contrast, the simulation goggles gave participants little to no time to adapt and make these accommodations, and and instead participants were more likely to have found the best area within the goggles to read from rather than reading as someone who was actually diagnosed with the disease may have read.

Another limitation to this study may have been the decision to conduct between-subjects testing. Though normal distribution between participants was assumed and the decision to use between-subjects testing helped to minimize task learning, individual variability between participants suggests that a within-subjects test may have helped to further minimize random noise. Had each participant interacted with all variables within each experiment they would have helped to counteract any effects of experimental error.

Future Research

Access to the web is a part of daily life and it's realistic to assume that technology will work, at least most of the time. This expectation is as true for people with disabilities as for anyone else (Horton & Quesenbery, 2013). Users are seeking more control over not just what they read but how, when, where, and in what medium, and reading on the web is becoming more and more routine, especially for visually impaired users reluctant to give up their independence despite their reduced ability to read (Arditi, 2004). The way users read and understand text from a computer screen is different than reading from printed material. Research in low vision typography needs to keep up with this shift to ensure an accessible online experience and empower visually impaired users (Ali et al, 2013; Arditi & Lu, 2008; Lupton, 2014). A review of existing research confirms that the individual elements of typography do not determine legibility by themselves. Rather, sufficient legibility is the outcome of all the typographic elements working together (Bix, 2002). Additionally, the actual characteristics of the user must also be taken into consideration, such as age, computer experience, personal preferences, and especially their visual acuity (Morrison & Noyes, 2003). Because of these factors, it is recommended that future research begin by focusing on each type of visual impairment individually and determine where adjustments in typography for each type of visual impairment overlap. Findings can then be used as a foundation for establishing guidelines for accessible web typography moving forward. We should be able to build a baseline structure of web typography in a way that works for most users, regardless of their visual acuity, and it seems clear that there is an opportunity for progress in this area (Marks, 2016; Nini, 2006). Improving accessibility for one group of users generally improves usability for all of us. By focusing on how to make the web more usable for those with visual impairments, we are really making a better web for everyone.

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Appendix A: Evaluation of Current Typographic Trends

Table 7

Typographic Analysis of Alexa's Top 100 Websites from 2017.

Website	CSS Font Size	Rendered Font Size*	CSS Line Height	Rendered Line Height**	Calculated Line Height***	Font Color	Serif / Sans Serif
google.com	small	13px	1.4	18.2px	1.4	#545454	Sans
youtube.com	1.4rem	14px	2.1rem	21px	1.5	#111	Sans
facebook.com	14px	14px	1.38	19.32px	1.38	#1D2129	Sans
amazon.com	14px	14px	1.6em	22.4px	1.6	#333	Sans
yahoo.com	1.55rem	15.5px	1.5	23.25px	1.5	#000	Sans
wikipedia.org	0.875em	14px	1.6	22.4px	1.6	#222	Sans
reddit.com	1em	14px	1.43	20px	1.43	#222	Sans
ebay.com	100%	13px	22px	22px	1.69	#333	Sans
twitter.com	14px	14px	20px	20px	1.43	#14171A	Sans
netflix.com	1.125vw	17.56px	1.3	22.83px	1.3	#999	Sans
linkedin.com	14px	14px	20px	20px	1.43	#404040	
imgur.com	14px	14px	20px	20px	1.43	#F2F2F2	Sans
instagram.com	14px	14px	18px	18px	1.29	#000	
live.com	*Not analyzed due to website type classification of 'Email'*						
craigslist.com	100%	16px	default	NA	1.15	#222	Serif
diply.com	1.125rem	18px	1.44	25.875px	1.6	#222	Sans
bing.com	13px	13px	17px	17px	1.31	#666	Sans
pinterest.com	18px	18px	20px	20px	1.11	#555	Sans
tumblr.com	100%	14px	1.4	21px	1.4	#444	Sans
espn.com	16px	16px	1.6	25.6px	1.6	#48494A	Serif
walmart.com	0.875rem	14px	1.5	21px	1.5	#444	Sans

cnn.com	1.2rem	18px	1.67	30px	1.67	#262626	Sans
office.com	*Not analyzed due to website type classification of 'Email'*						
microsoftonline.com	*Not analyzed due to website type classification of 'Email'*						
t.co	*Not analyzed due to website type classification of 'NA'; t.co is Twitter's link-shortening service and is not an actual website that users navigate to.*						
paypal.com	1rem	15px	1.6	24px	1.6	#2C2E2F	Sans
blogspot.com	1rem	16px	1.66	26.56px	1.66	#FFF	Sans
chase.com	1em	16px	1.5em	24px	1.5	#414042	Sans
imdb.com	13px	13px	140%	18.2px	1.4	#333	Sans
apple.com	17px	17px	1.47	25px	1.47	#111	Sans
nytimes.com	1rem	16px	21px	21px	1.31	#333	Serif
weather.com	16px	16px	21px	21px	1.31	#393939	Sans
pornhub.com	*Not analyzed due to website type classification of 'Porn'*						
wikia.com	18px	18px	1.6	28.8px	1.6	#002A32	Sans
bankofamerica.com	14px	14px	18px	18px	1.29	#524940	Sans
wordpress.com	15px	15px	1.6em	24px	1.6	#444	Serifs
msn.com	1.8rem	18px	1.44	25.99px	1.44	#333	Sans
wellsfargo.com	75%	12px	1.5em	18px	1.5	#434343	Sans
bestbuy.com	15px	15px	1.3	19.5px	1.3	#474747	Sans
twitch.tv	100%	14px	20.8px	20.8px	1.49	#333	Sans
microsoft.com	15px	15px	20px	20px	1.33	#000	Sans
etsy.com	14px	14px	1.71	24px	1.71	#444	Sans
target.com	14px	14px	1.43	20px	1.43	#333	Sans
pandora.com	1.5rem	15px	2.6rem	26px	1.73	#FFF	Sans
breitbart.com	16px/1.4	16px	1.4	22.4px	1.4	#111	Serif
googleusercontent.com	*Not analyzed due to website type classification of 'NA'; googleusercontent.com is used by Google for much of their hosted content and is not an actual website that users navigate to.*						

yelp.com	14px	14px	1.29em	18px	1.29	#333	Sans
salesforce.com	15px	15px	24px	24px	1.6	#222	Sans
huffingtonpost.com	1.125rem	18px	1.75rem	28px	1.56	#000	Sans
foxnews.com	16px	16px	22px	22px	1.38	#222	Sans
instructure.com	17px	17px	1.25	33.18px	1.25	#000	Sans
dropbox.com	16px	16px	1.65	26.4px	1.65	#1B2733	Sans
stackoverflow.com	100%	15px	1.3	19.5px	1.3	#343729	Sans
washingtonpost.com	18px	18px	1.8em	32.4px	1.8	#111	Serif
zillow.com	93.75%	15px	1.5	22.5px	1.5	#444	Sans
spotify.com	100%	14px	20px	20px	1.43	#FFF	Sans
gyfcat.com	1.5em	15px	1.6	24px	1.6	#222	Sans
github.com	14px	14px	1.5	21px	1.5	#24292E	Sans
aol.com	17px	17px	30px	30px	1.76	#333	Sans
soundcloud.com	12px	12px	1.4	16.8px	1.4	#333	Sans
reddituploads.com	*Not analyzed due to website type classification of 'NA'; i.reddituploads.com is an upload service for the reddit mobile platform and is not an actual website that users navigate to.*						
buzzfeed.com	17px	17px	1.5	25.5px	1.5	#222	Sans
vice.com	1.06rem	17px	1.6	27.2px	1.6		Sans
usps.com	1.3rem	13px	1.6rem	16px	1.23	#202020	Sans
xfinity.com	1rem	16px	1.25	20px	1.25	#191919	Sans
indeed.com	10pt	13.33px	1.3	17.33	1.3		Sans
weebly.com	1em	18px	1.5	27px	1.5	#9BA0A3	Sans
amazonaws.com	1em	14px	1.6	22.4px	1.6	#333	Sans
quora.com	15px	15px	1.6	24px	1.6	#333	Serif
ups.com	14px	14px	18px	18px	1.29	#242424	Sans
adobe.com	1rem	16px	1.31	21px	1.31	#000	Sans

force.com	16px	16px	24px	24px	1.5	#4A4A4A	Sans
homedepot.com	1.4rem	14px	1.8	25.2px	1.8	#333	Sans
thesaurus.com	14px/ 17px	14px	17px	17px	1.21	#333	Sans
macys.com	100%	16px	1.3	20.8px	1.3	#333	Sans
txxx.com	*Not analyzed due to website type classification of 'Porn'*						
capitalone.com	1em	16px	1.4	22.4px	1.4	#021829	Sans
thepiratebay.org	*Not analyzed due to website type classification of 'Torrenting / Illegal Streaming'*						
groupon.com	1.4rem	14px	1.5	21px	1.5	#75787B	Sans
roblox.com	16px	16px	1.3em	20.8px	1.3	#191919	Sans
bbc.com	1rem	16px	1.38em	20.8px	1.38	#404040	Sans
deviantart.com	9pt	12px	default	NA	1.15	#000	Sans
forbes.com	17.6px	17.6px	1.4em	24.64px	1.4		Serif
nfl.com	14px	14px	18px	18px	1.29	#222221	Sans
godaddy.com	1rem	16px	1.5	24px	1.5	#2B2B2B	Sans
patch.com	18px	18px	30px	30px	1.67	#111	Serif
dailymail.co.uk	16px	16px	23px	23px	1.44	#000	Sans
baidu.com	13px	13px	1.54	20.02px	1.54	#666	Sans
123movies.is	*Not analyzed due to website type classification of 'Torrenting / Illegal Streaming'*						
kohls.com	14px	14px	1.4	18px	1.4	#000	Sans
vimeo.com	0.875em	14px	1.43	20px	1.43	#1A2E3B	Sans
quizlet.com	1rem	16px	1.63	26px	1.63	#455358	Sans
conservativetribune.com	18px	18px	1.6	28.8	1.6	#000	Sans
cnet.com	1.18em	20px	1.5em	30px	1.5	#000	Sans
go.com	0.96em	14.75px	1.6em	23.59px	1.6	#000	Sans
stackexchange.com	15px	15px	1.3	19.5px	1.3	#242729	Sans

onclkds.com	*Not analyzed due to website type classification of 'Ad Network'*						
citi.com	1rem	16px	1.5rem	24px	1.5	#000	Sans

*Note. Websites considered pornographic or illegal in nature (i.e., torrenting and illegal streaming) were not included in this analysis, nor were email websites, though all examples can be found in the top 100 list provided by Alexa. * Rendered font size is the computed value of the CSS font size in pixels. This was captured from Chrome DevTools Computed Styles feature for easier comparison across font sizes. ** Rendered line height is the computed value of the CSS line height translated to pixels. This was captured from Chrome DevTools Computed Styles feature for easier comparison across line height.*
**** Calculated line height is the unit-less value of line height in relationship to font size, which was determined by dividing the rendered line height by the rendered font size.*

Appendix B: Participant Consent Form

Whom to Contact about this study

Principal Investigator: Erica McCoy

Department: Interaction Design and Information Architecture

Telephone number: 262-443-9713

CONSENT FORM FOR PARTICIPATION IN RESEARCH ACTIVITIES

Accessible Web Typography for the Visually Impaired

INTRODUCTION/PURPOSE:

I am being asked to participate in a research study, the purpose of which is to better understand how typography can impact the overall legibility for online users with visual impairments. I am being asked to volunteer because of my interest with accessible online best practices. My involvement in this study will begin when I agree to participate and will continue through April, 2018.

PROCEDURES:

As a participant in this study, I will be asked to participate in the verbal reading of tasks, of which I will be timed and my accuracy noted. Upon completion of each set of tasks, I will be allowed to provide my opinion and feedback. My participation in this study will last for approximately 15 minutes, and audio recording, screen recording, and detailed note taking will occur. However, no personal identifying information will be written with responses to the questions or tasks.

RISKS AND BENEFITS:

My participation in this study does not involve any significant risks and I have been informed that my participation in this research may not benefit me personally, but will provide guidance in how web accessibility can be improved for visually impaired users through the choices made in typography.

CONFIDENTIALITY:

All information collected in this study will be stored in a secure, password protected server online. Only the investigator and members of the research team will have access to these records. If information learned from this study is published, I will not be identified by name. By signing this form, however, I allow the research study investigator to make my records available to the University of Baltimore Institutional Review Board (IRB) and regulatory agencies as required to do so by law.

Consenting to participate in this research also indicates my agreement that all information collected from me individually may be used by current and future researchers in such a fashion that my personal identity will be protected. Such use will include sharing anonymous information with other researchers for checking the accuracy of study findings and for future approved research that has the potential for improving human knowledge.

Check if voice recordings are used during the research study:

- ☐ Yes, I give permission to use my voice in scientific publications or presentations.
- ☐ No, I do not give permission to use my voice in scientific publications or presentations

Although your confidentiality in this study is protected, confidentiality may not be absolute or perfect. There are some circumstances where research staff might be required by law to share information I have provided.

SPONSOR OF THE RESEARCH:

This research study is for a master's thesis in Interaction Design and Information Architecture at the University of Baltimore, Maryland.

CONTACTS AND QUESTIONS:

The principal investigator(s), Erica McCoy (researcher) and Kathryn Summers (faculty advisor) have offered to and have answered any and all questions regarding my participation in this research study. If I have any further questions, I can contact

Erica McCoy (researcher): 262-443-9713; erica.mccoy@ubalt.edu.
Kathryn Summers (faculty advisor): 410-837-6202; ksummers@ubalt.edu.

For questions about rights as a participant in this research study, I can contact the UB IRB Coordinator: 410-837-6199; irb@ubalt.edu.

VOLUNTARY PARTICIPATION

I have been informed that my participation in this research study is voluntary and that I am free to withdraw or discontinue participation at any time.

I will be given a copy of this consent form to keep.

SIGNATURE FOR CONSENT

The above-named investigator has answered my questions and I agree to be a research participant in this study. By signing this consent form, I am acknowledging that I am at least 18 years of age.

Participant’s Name: ________________________________ Date: ___________

Participant’s Signature: ____

Investigator's Signature: ____________________________ Date: ____________

Appendix C: Experiment 1

Moderator Script

Hi, thank you for taking the time to participate in this study. I am reading from a script to ensure all participants receive the same information, so you'll understand if I sound a bit formal at times.

My name is Erica McCoy and I am currently a graduate student in the University of Baltimore's Interaction Design & Information Architecture program. As part of this program of study, I am required to complete a thesis project that not only demonstrates what I have learned but also gives me the opportunity to contribute to ongoing research that ensures usable and accessible websites. My area of focus is to identify the online needs of users with visual impairments. Specifically, how typography factors into legibility for this group of users. My goal is to find which typographic traits should be considered in order to enhance the user experience for those who are visually impaired.

Today I am testing how line height relates to font size, which I have derived from a combination of current website trends, typographic guidelines, and suggestions from low vision advocacy groups. I'm interested in seeing what actually works; putting science behind these recommendations. This session is pretty straightforward--I'll be giving you specific tasks to complete and I'll ask you a few questions as we go along. Before you begin each task, I'll provide a little bit of context behind it, such as why you might be doing it and what you may hope to achieve. We will be doing one task with your normal, or corrected to normal, vision and a second task with a set of visual impairment simulation goggles. I anticipate this entire session to last about 15 minutes.

It's really important to know that I am only testing the site, not you. You can't do or say anything wrong here and there are no right or wrong answers. I'm interested in learning about what works and what doesn't work. Do I have your permission to continue with the study? Also, to ensure I don't miss any details, I will be audio and screen recording this session to review later. Do I have your permission to record?

[have participant read and sign consent form]

If at any point you have questions, please don't hesitate to ask. Know that I may respond to your questions with a question, because I really want to understand what you think. If there are any unanswered questions, I'll be sure to address them at the end of today's session.

If you become uncomfortable at any time and wish to stop the session, please let me know and I will do so. Do you have any questions before we get started?

[pause for questions]

Great, let's begin!

1. For the first task I want to give you an idea of how this study will work to help you get comfortable. I'm going to give you a short list of common medical terms. Starting at the top of the list, say each word for me. If you don't recognize a word, you can say 'pass' and move on to the next word. You are not being timed, so take as long as you need. When you are ready, you may begin.

2. For this second task, I will have you put on a pair of visual impairment simulation goggles representing macular degeneration. When you put on the goggles you may notice that your vision has become blurred, distorted, dim, and you may have a blind spot near the center of your visual field, which can make it difficult to see

objects you are looking at directly. Macular degeneration affects the middle area of the retina responsible for sharp central vision. In its advanced stages, macular degeneration is the leading cause of irreversible blindness and visual impairment in the world, and is the leading cause of vision loss in Americans over the age of 60. I have chosen to simulate macular degeneration because it is a very serious disease that an estimated 11 million Americans are living with to some degree.
I will now have you read a short story by the Brothers Grimm. Looking directly at the screen, read me as much of the story as you can, taking as much time as you need. I'd like you to read from the iPad as it is, without zooming, but do let me know if you can't make out any of the text. When you are ready, tap the button to begin.

3. How would you rate the ease of this task (1 being difficult and 5 being not at all difficult).

That concludes our study. Thank you again for taking the time to participate today. Do you have any final questions for me before we conclude?

[pause for questions]

Would you be interested in participating in the next round of testing?

Rapid Estimate of Adult Literacy in Medicine - REALM

List 1	List 2	List 3
fat	fatigue	allergic
flu	pelvic	menstrual
pill	jaundice	testicle
dose	infection	colitis
eye	exercise	emergency
stress	behavior	medication
smear	prescription	occupation
nerves	notify	sexually
germs	gallbladder	alcoholism
meals	calories	irritation
disease	depression	constipation
cancer	miscarriage	gonorrhea
caffeine	pregnancy	inflammatory
attack	arthritis	diabetes
kidney	nutrition	hepatitis
hormones	menopause	antibiotics
herpes	appendix	diagnosis
seizure	abnormal	potassium
bowel	syphilis	anemia
asthma	hemorrhoids	obesity
rectal	nausea	osteoporosis
incest	directed	impetigo

Figure 15. Copy of REALM word list given to participants during Experiment 1. Retrieved from "Rapid Estimate of Adult Literacy in Medicine - REALM," by Health Literacy Tool Shed, 2018, http://healthliteracy.bu.edu/realm.

REALM Health Literacy Test
(Rapid Estimate of Adult Literacy in Medicine)

How many of these words can you read aloud and pronounce correctly, each within five seconds? Start with the first column, reading down. Skip those you cannot read.

Fat	Fatigue	Allergic
Flu	Pelvic	Menstrual
Pill	Jaundice	Testicle
Dose	Infection	Colitis
Eye	Exercise	Emergency
Stress	Behavior	Medication
Smear	Prescription	Occupation
Nerves	Notify	Sexually
Germs	Gallbladder	Alcoholism
Meals	Calories	Irritation
Disease	Depression	Constipation
Cancer	Miscarriage	Gonorrhea
Caffeine	Pregnancy	Inflammatory
Attack	Arthritis	Diabetes
Kidney	Nutrition	Hepatitis
Hormones	Menopause	Antibiotics
Herpes	Appendix	Diagnosis
Seizure	Abnormal	Potassium
Bowel	Syphilis	Anemia
Asthma	Hemorrhoids	Obesity
Rectal	Nausea	Osteoporosis
Incest	Directed	Impetigo

SCORE

Add up the number of words pronounced correctly.

0—18 words ***Third grade or below*** You will not be able to read easy materials. You will need repeated oral instructions, materials composed primarily of illustrations, or audio or videotapes,

19—44 words ***Fourth to sixth grade*** You will need easy materials. You will not be able to read prescription labels.

45—60 words ***Seventh to eighth grade*** You will struggle with most patient education materials and will not be offended by low-literacy materials.

61—66 words ***High school*** You will be able to read most patient-education materials

Source: Rapid Estimate.of Adult Literacy in Medicine
The New York Times

Figure 16. Copy of REALM score sheet used by moderator during Experiment 1. Retrieved from "Plain Language at Work Newsletter," by Impact Information, 2012, http://www.impact-information.com/impactinfo/newsletter/plwork53.htm.

Reading Task

Excerpt from *The Twelve Huntsmen*. 166 words, 804 characters, 6 sentences; 7-8th grade reading level. Flesch reading ease score of 82.2 (easy to read); Flesch-Kincaid grade level of 7.8.

> There was once a king's son who had a bride whom he loved very much. And when he was sitting beside her and very happy, news came that his father lay sick unto death, and desired to see him once again before his end. Then he said to his beloved: 'I must now go and leave you, I give you a ring as a remembrance of me. When I am king, I will return and fetch you.' So he rode away, and when he reached his father, the latter was dangerously ill, and near his death. He said to him: 'Dear son, I wished to see you once again before my end, promise me to marry as I wish,' and he named a certain king's daughter who was to be his wife. The son was in such trouble that he did not think what he was doing, and said: 'Yes, dear father, your will shall be done,' and thereupon the king shut his eyes, and died.

Grimm, J. & Grimm, W. (1905). *Grimm's fairy tales* (E. Taylor & M. Edwardes, Trans.). New York: Maynard, Merrill, & Co. (Original work published 1812). Retrieved from http://www.gutenberg.org/files/2591/2591-h/2591-h.htm.

Task Screenshots

When participants were initially handed the iPad for the reading task, the screen looked similar to that shown in Figure 17, the only difference being the task letter, which was randomly assigned to each participant prior to launching the study. Participants were instructed that the reading task would appear approximately where the existing line of text was on the screen as soon as they tapped the button labeled “Begin”. They were told they may tap the button and begin reading whenever they were ready.

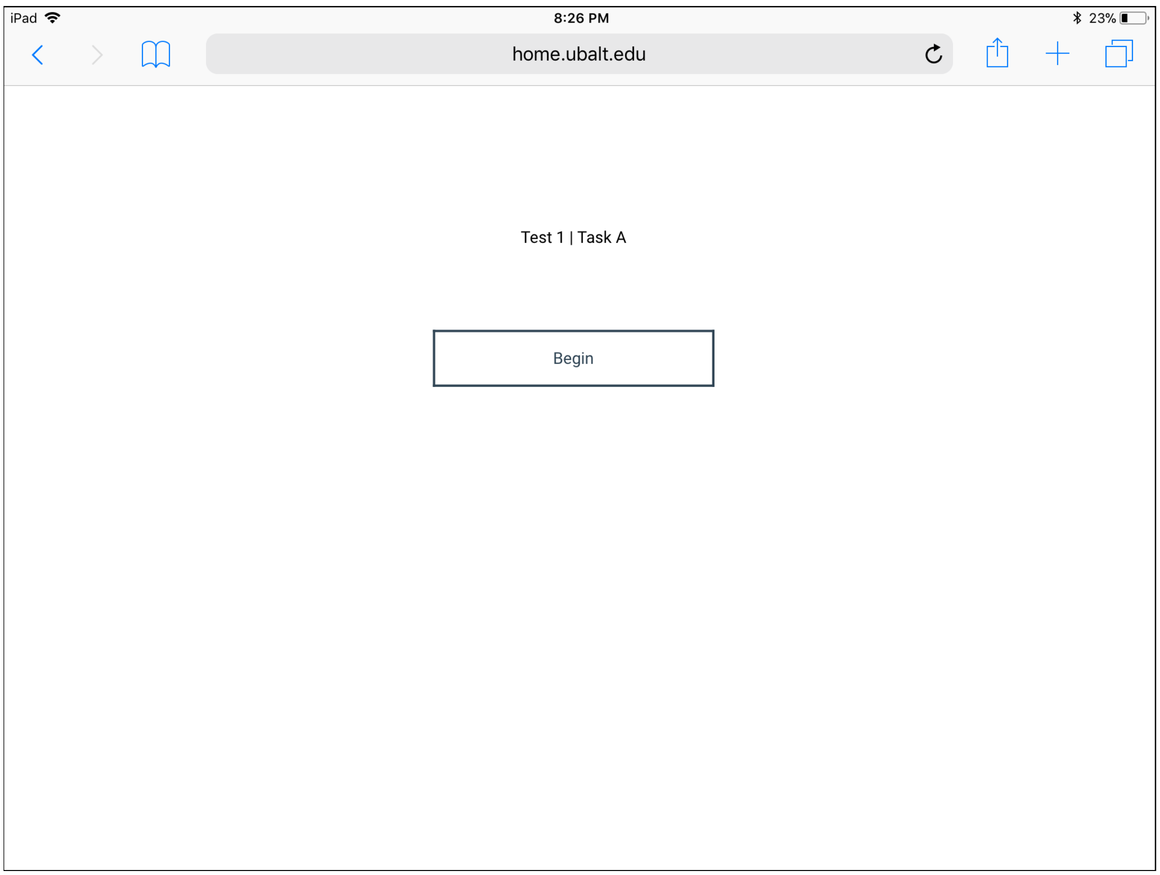

Figure 17. Initial view of the iPad screen prior to the participant beginning the reading task for Experiment 1.

The following figures depict what each version ((a) 0.875em x 1.3; (b) 0.875em x 1.7; (c) 1.125em x 1.3; (d) 1.125em x 1.7; (e) 1.375em x 1.3; or (f) 1.375em x 1.7) of the task looked like as it initially loaded onto the screen just after participants tapped the button.

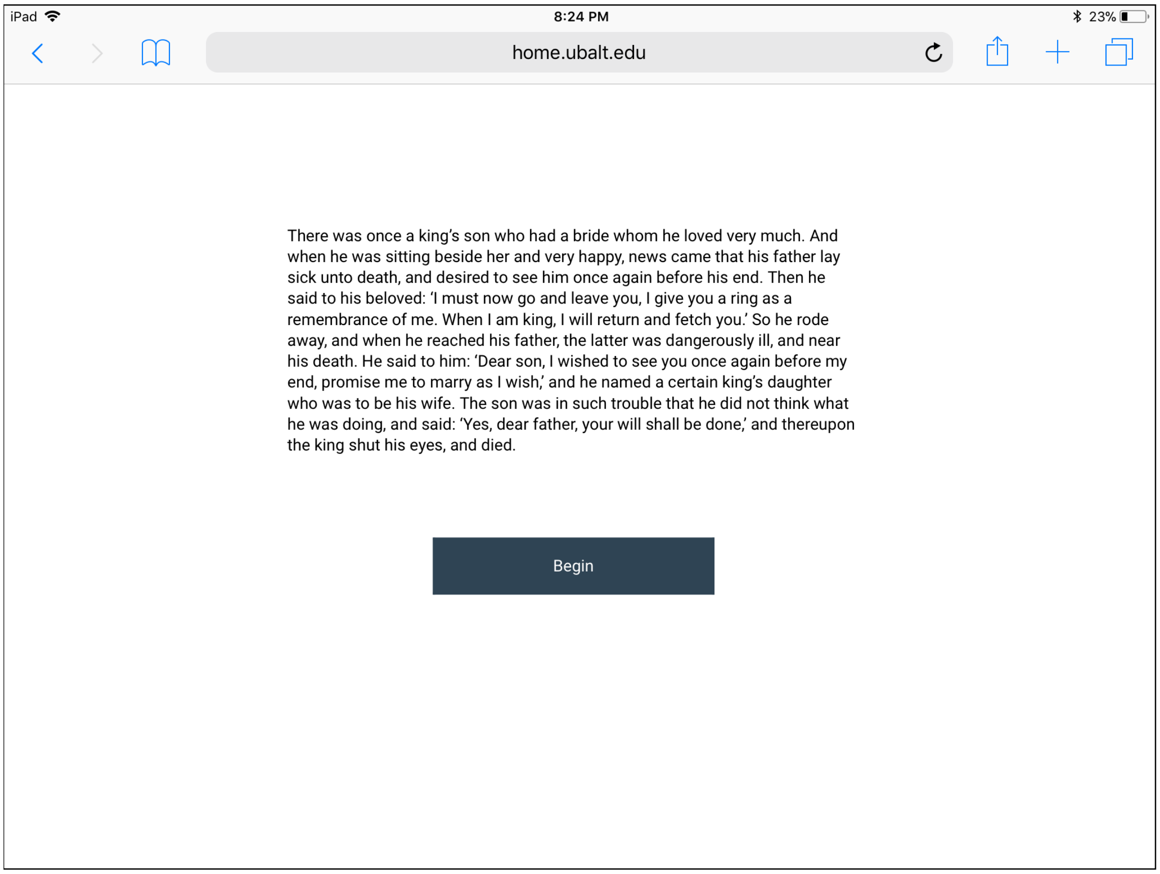

Figure 18. Experiment 1, Task A: Font Size 0.875em; Line Height 1.3.

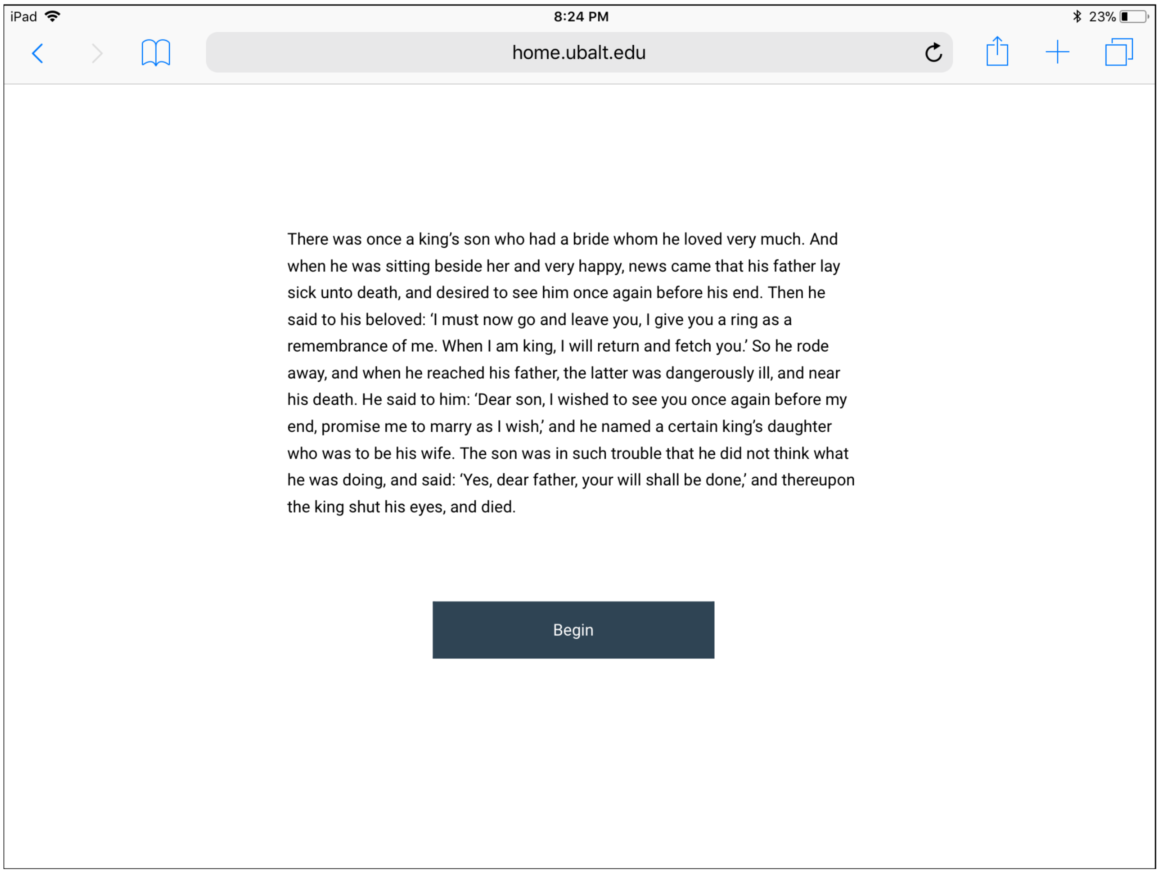

Figure 19. Experiment 1, Task B: Font Size 0.875em; Line Height 1.7.

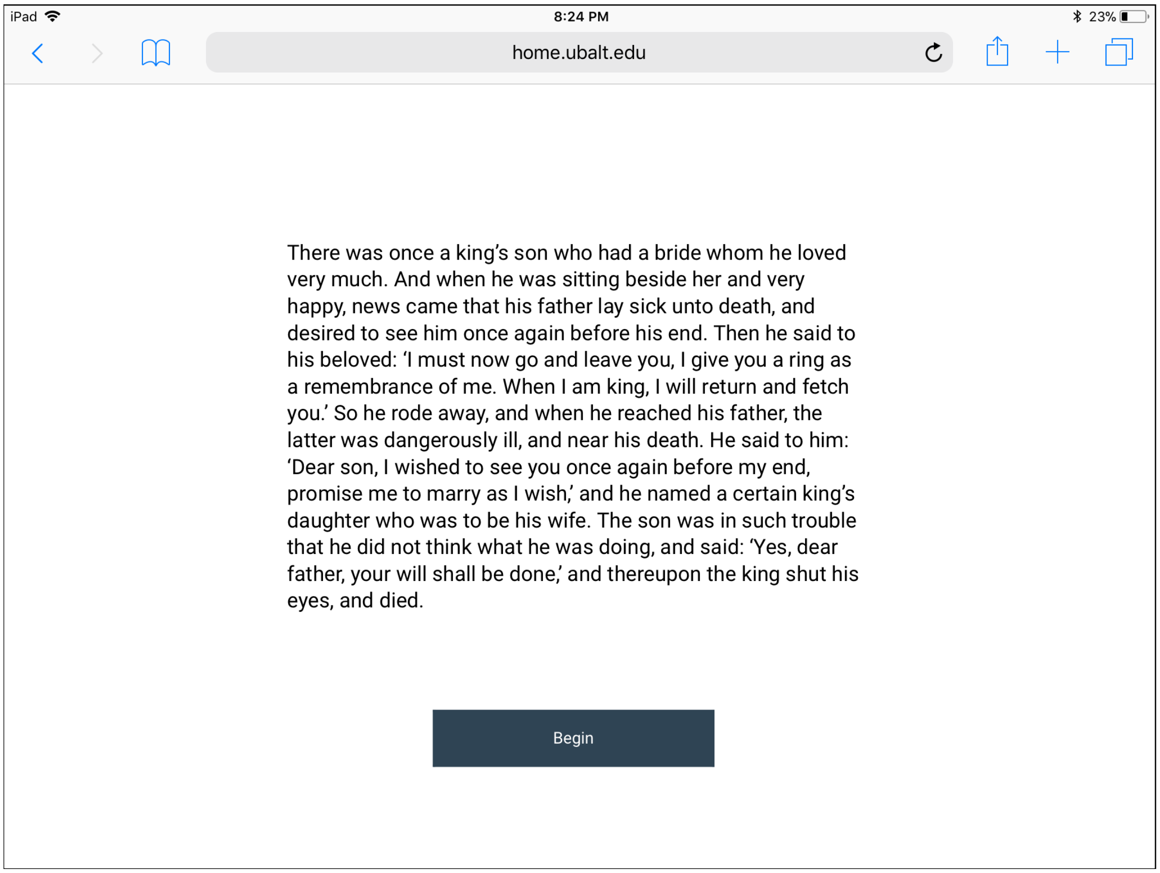

Figure 20. Experiment 1, Task C: Font Size 1.125em; Line Height 1.3.

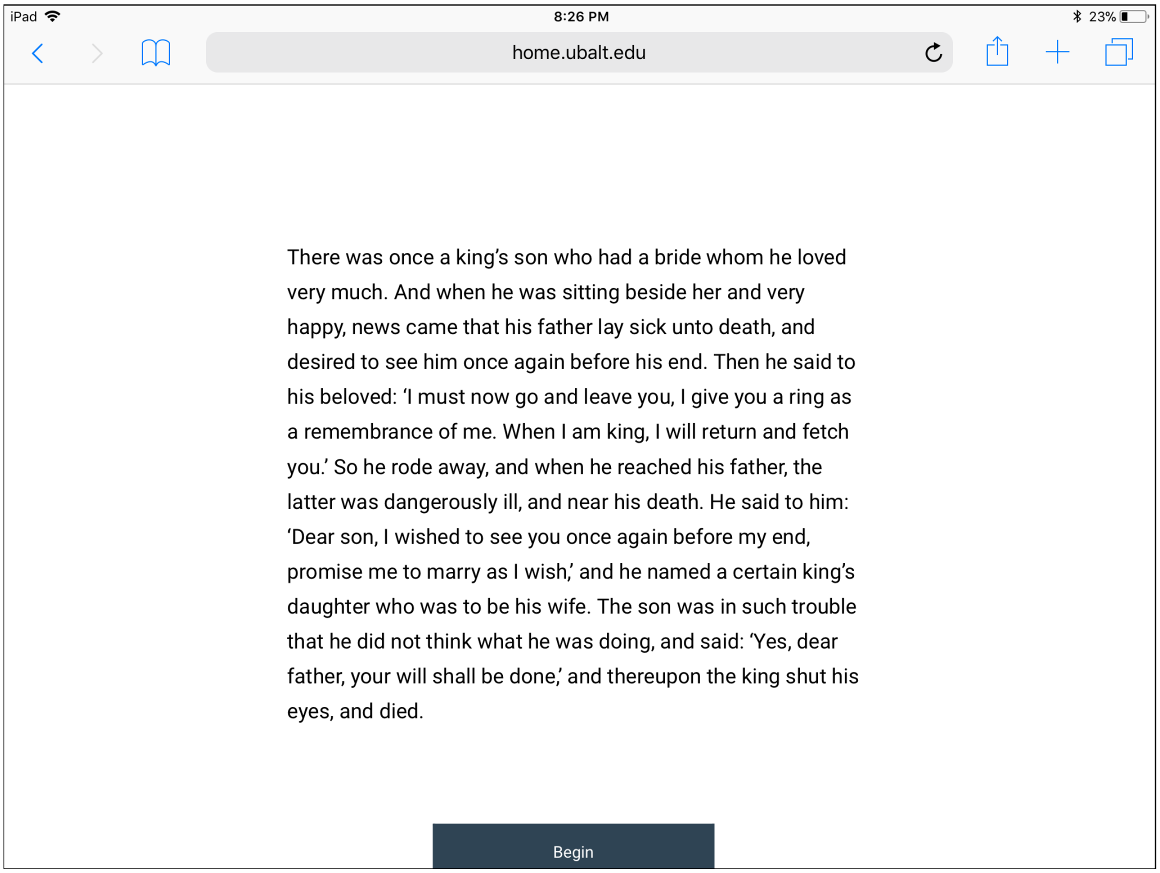

Figure 21. Experiment 1, Task D: Font Size 1.125em; Line Height 1.7.

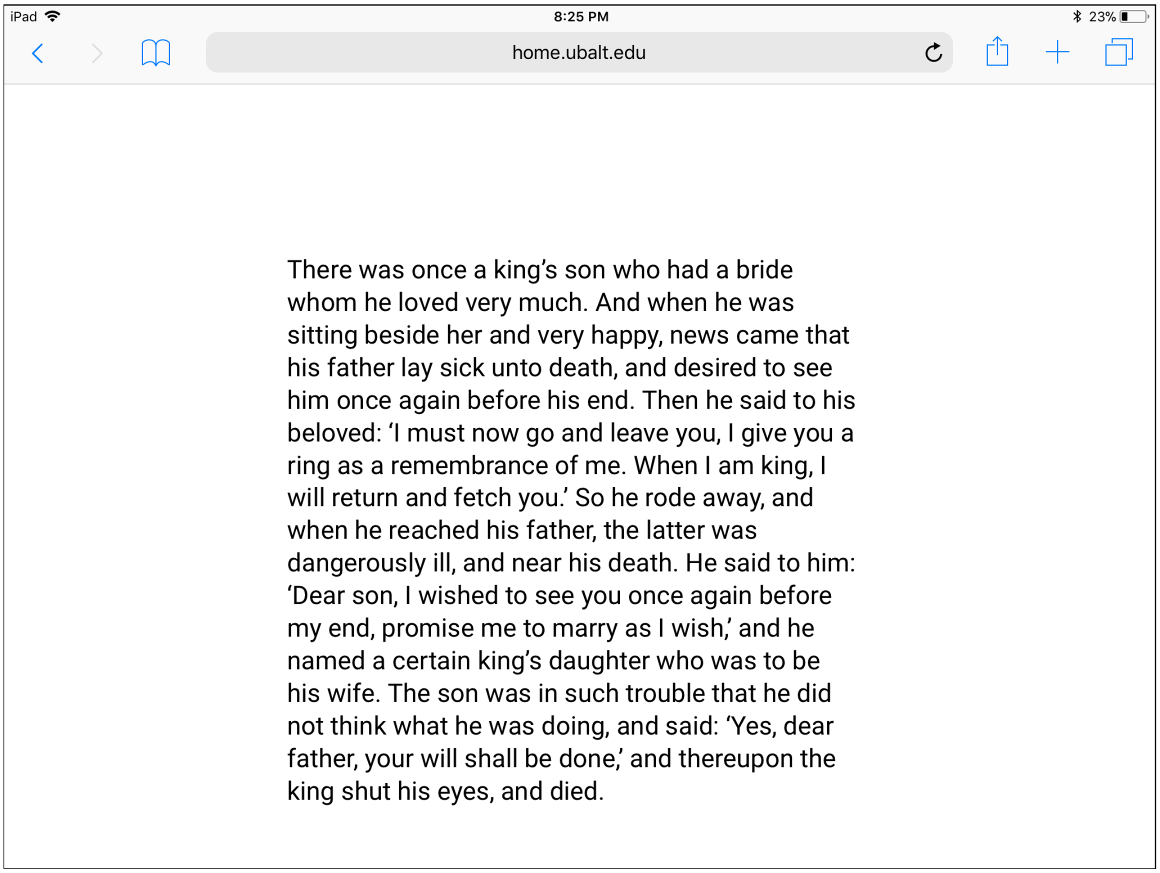

Figure 22. Experiment 1, Task E: Font Size 1.375em; Line Height 1.3.

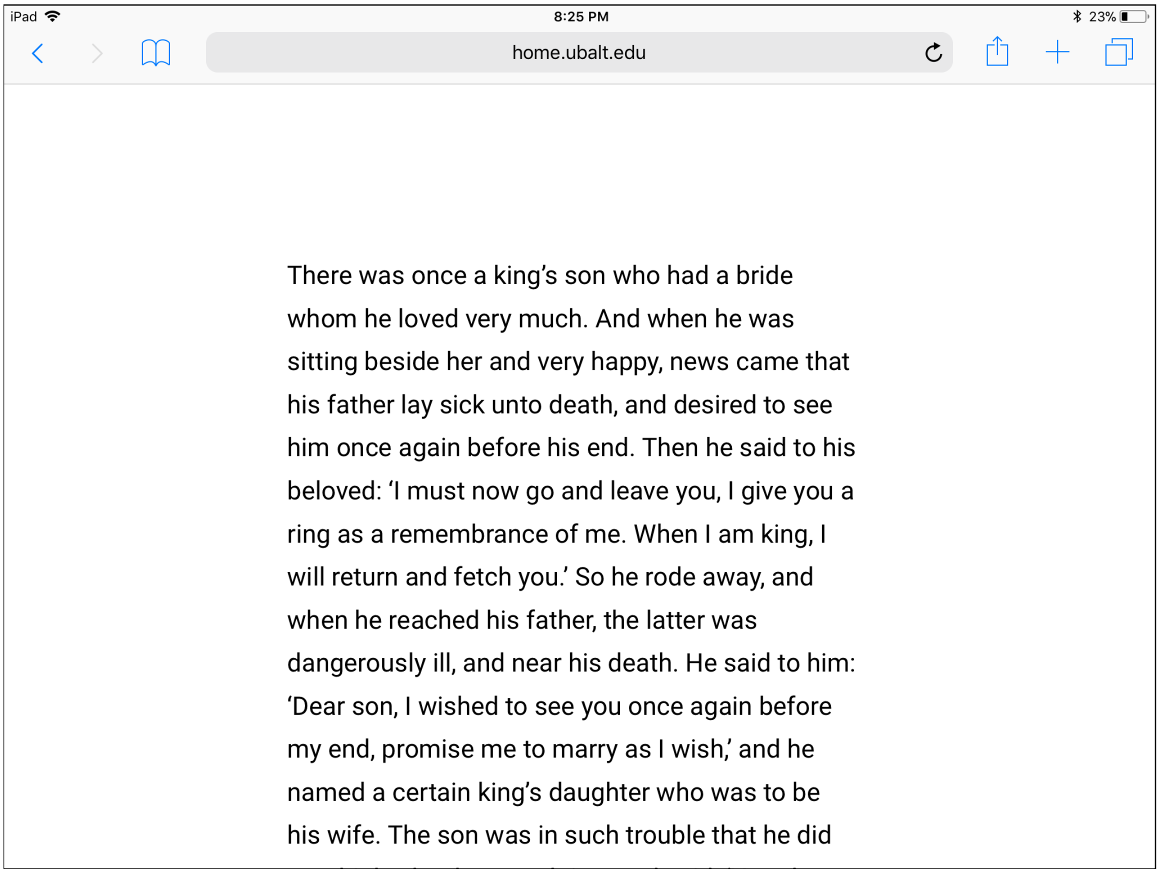

Figure 23. Experiment 1, Task F: Font Size 1.375em; Line Height 1.7.

Time on Task Results

Because the difference of 0.875em and 1.375em font size was close to reaching the statistical significance with the operationally defined dependent variable of legibility, a 3x2 factorial ANOVA was performed to explore the effect of line height and font size on time on task for simulated macular degeneration. Using the same null hypotheses: (1) an increase in font size will not have a positive effect on time on task for visually impaired users; (2) an increase in line height will not have a significant effect on time on task for visually impaired users; and (3) the interaction of font size and line height will not have a significant effect on time on task for visually impaired users, the results of the factorial ANOVA are listed in Table 8.

Table 8

Tests of Between-subjects Effects of Font Size and Line Height on the Dependent Variable Time on Task.

Source	*SS*	*df*	*MS*	*F*	*p*	Partial Eta^2	Observed Power*
Font Size	4,045.035	2	2,022.518	2.732	0.080	0.142	0.503
Line Height	2,627.521	1	2,627.521	3.550	0.068	0.097	0.448
Font Size * Line Height	4,905.823	2	2,452.912	3.314	0.049	0.167	0.588
Error	24,428.179	33	740.248				
Total	373,338.000	39					

Note. * Computed using alpha = 0.05.

As indicated by the results, there was sufficient evidence to reject the interaction effect null hypothesis at the 0.05 significance level ($F_{2,33}$ = 3.314, p = 0.475, partial η^2 = 0.167). There was, however, no statistically significant main effect for line height on time on task for simulated macular degeneration ($F_{1,33} = 3.550$, $p = 0.068$). Post-hoc comparisons, shown in Table 9, indicated a mean line height of 1.3 (*M* = 0:01:39, *SD* = 0:00:34, 95% CI [91.952, 121.540]) was not significantly different than a mean line height of 1.7 (*M* = 0:01:29, *SD* = 0:00:24, 95% CI [77.792, 100.922]). Additionally, a pairwise post-hoc comparison indicated that while a mean font size of 0.875em (*M* = 0:01:43, *SD* = 0:00:29, 95% CI [95.353, 133.551]) differed the most from a mean font size of 1.125em (*M* = 0:01:27, *SD* = 0:00:22, 95% CI [72.567, 102.551]), it was not enough to be considered statistically significant, $p = 0.353$. A font size of 1.375em (*M* = 0:01:32, *SD* = 0:00:34, 95% CI [77.774, 106.422]) also did not differ with enough statistical significance from either of the other two font sizes, which further indicated there was insufficient evidence to reject the font size null hypothesis at the 0.05 significance level ($F_{2,33} = 2.732$, $p = 0.080$, partial $\eta^2 = 0.142$).

Table 9

Descriptive Statistics for Dependent Time on Task by the Independent Variables Line Height and Visual Impairment Type (N = 33).

	1.3			1.7			Total		
Font Size	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
0.875em	0:02:21	0:00:11	3	0:01:27	0:00:14	7	0:01:43	0:00:29	10
1.125em	0:01:25	0:00:19	6	0:01:29	0:00:26	8	0:01:27	0:00:22	14
1.375em	0:01:33	0:00:37	7	0:01:30	0:00:33	8	0:01:32	0:00:34	15
Total	0:01:39	0:00:34	16	0:01:29	0:00:24	23	0:01:33	0:00:29	39

The alternative hypothesis for the interaction effect was supported: an interaction of font size and line height will have a significant effect on time on task for visually impaired users. Thus, when both font size and line height increase simultaneously, time on task for visually impaired users also increases, while when font size and line height decrease simultaneously the opposite is true. Both the null hypothesis for increased font size and increased line height were supported: an increase in just font size will not have a positive effect on time on task for visually impaired users and an increase in just line height will also not have a significant effect on time on task for visually impaired users.

Appendix D: Experiment 2

Moderator Script

Thank you for taking the time to participate in this study. I anticipate this entire session to last approximately 10 minutes. I am reading from a script to ensure all participants receive the same information, so you'll understand if I sound a bit formal at times.

I am testing how line height relates to various types of low vision. I have derived the format of the tasks from my previous study, of which you were a part of, and I'd be happy to share the results of that study when we finish today. I'm interested in seeing if the results of my first study hold true across different types of visual impairments. This session is much the same as the last--I'll be giving you a specific task and I'll conclude with a few questions. As before, I'll provide some context before the task begins, such as why you might be doing it and what you may hope to achieve. The task will be conducted with a set of randomly assigned visual impairment simulation goggles.

It's really important to know that I am only testing the site, not you. You can't do or say anything wrong here and there are no right or wrong answers. I'm interested in learning about what works and what doesn't work.

I have your consent documented from our last session together, but I would like to audio and screen recording this session to review later. Do I have your permission to record?

[*pause for response*]

If at any point you have questions, please don't hesitate to ask. Know that I may respond to your questions with a question, because I really want to understand what you think. If you become uncomfortable at any time and wish to stop the session, please let me know and I will do so. Do you have any questions before we get started?

[*pause for questions*]

Great, let's begin!

1. For this task I will have you put on a pair of visual impairment simulation goggles representing [visual impairment; read corresponding summary].

   [Cataracts: When you put on the goggles you may notice that your vision has become blurred, foggy, and you may be more sensitive to light or struggle with how dark the room is, depending on the available light. Cataracts are the result of the naturally clear lens of the eye becoming progressively cloudy or opaque. I have chosen to simulate cataracts because they are considered one of the most common visual impairments, with more than 24 million Americans over the age of 40 having experienced at least one cataract. This particular simulator also offers a general understanding of visual abilities and limitations those with congenital impairments face, such as optic nerve hypoplasia, albinism, and achromatopsia to name a few.]

   [Diabetic Retinopathy: When you put on the goggles you may notice blurred or fluctuating vision with dark empty spots. Diabetic retinopathy breaks down the blood vessels in the retina. I have chosen to simulate diabetic retinopathy because an estimated 7.7 million Americans are affected by the disease, with the risk of developing diabetic retinopathy increasing the longer a person has been diagnosed with diabetes.]

[Glaucoma: When you put on the goggles you may notice a patchy loss of peripheral vision, blurry central vision, and perhaps some tunnel vision, which can be described as looking at everything through a straw. Glaucoma causes damage to the optic nerve, a vital part of the eye that communicates information to the brain. Damage to the optic nerve is irreversible, and can lead to complete blindness over time. In the early stages, visual acuity is not affected, only the visual field. I have chosen to simulate glaucoma because an estimated 3 million Americans are living with this disease. This particular simulator also offers a general understanding of what it is like for individuals living with retinitis pigmentosa, which is characterized by progressive visual field loss and night blindness.]

I will now have you read a short story by the Brothers Grimm. Looking directly at the screen, read me as much of the story as you can, taking as much time as you need. I'd like you to read from the iPad as it is, without zooming, but do let me know if you can't make out any of the text. When you are ready, tap the button to begin.

2. How would you rate the ease of this task (1 being difficult and 5 being not at all difficult).

That concludes our study. Thank you again for taking the time to participate today. Do you have any final questions for me as we wrap up?

[*pause for questions*]

Reading Task

Excerpt from *The Raven*. 168 words, 873 characters, 5 sentences; 7-8th grade reading level. Flesch reading ease score of 80.6 (easy to read); Flesch-Kincaid grade level: 8.1.

> So they went indoors together and sat down, and the man brought out the bread, meat, and wine, which although he had eaten and drunk of them, were still unconsumed. The giant was pleased with the good cheer, and ate and drank to his heart's content. When he had finished his supper the man asked him if he could direct him to the castle of Stromberg. The giant said, 'I will look on my map; on it are marked all the towns, villages, and houses.' So he fetched his map, and looked for the castle, but could not find it. 'Never mind,' he said, 'I have larger maps upstairs in the cupboard, we will look on those,' but they searched in vain, for the castle was not marked even on these. The man now thought he should like to continue his journey, but the giant begged him to remain for a day or two longer until the return of his brother, who was away in search of provisions.

Grimm, J. & Grimm, W. (1905). *Grimm's fairy tales* (E. Taylor & M. Edwardes, Trans.). New York: Maynard, Merrill, & Co. (Original work published 1812). Retrieved from http://www.gutenberg.org/files/2591/2591-h/2591-h.htm

Task Screenshots

Just as in the first experiment, when participants were initially handed the iPad for the reading task, the screen looked similar to that shown in Figure 24, the only difference being the task letter, which was randomly assigned to each participant prior to launching the study. Participants were instructed that the reading task would appear approximately where the existing line of text was on the screen as soon as they tapped the button labeled 'Begin'. They were told they may tap the button and begin reading whenever they were ready.

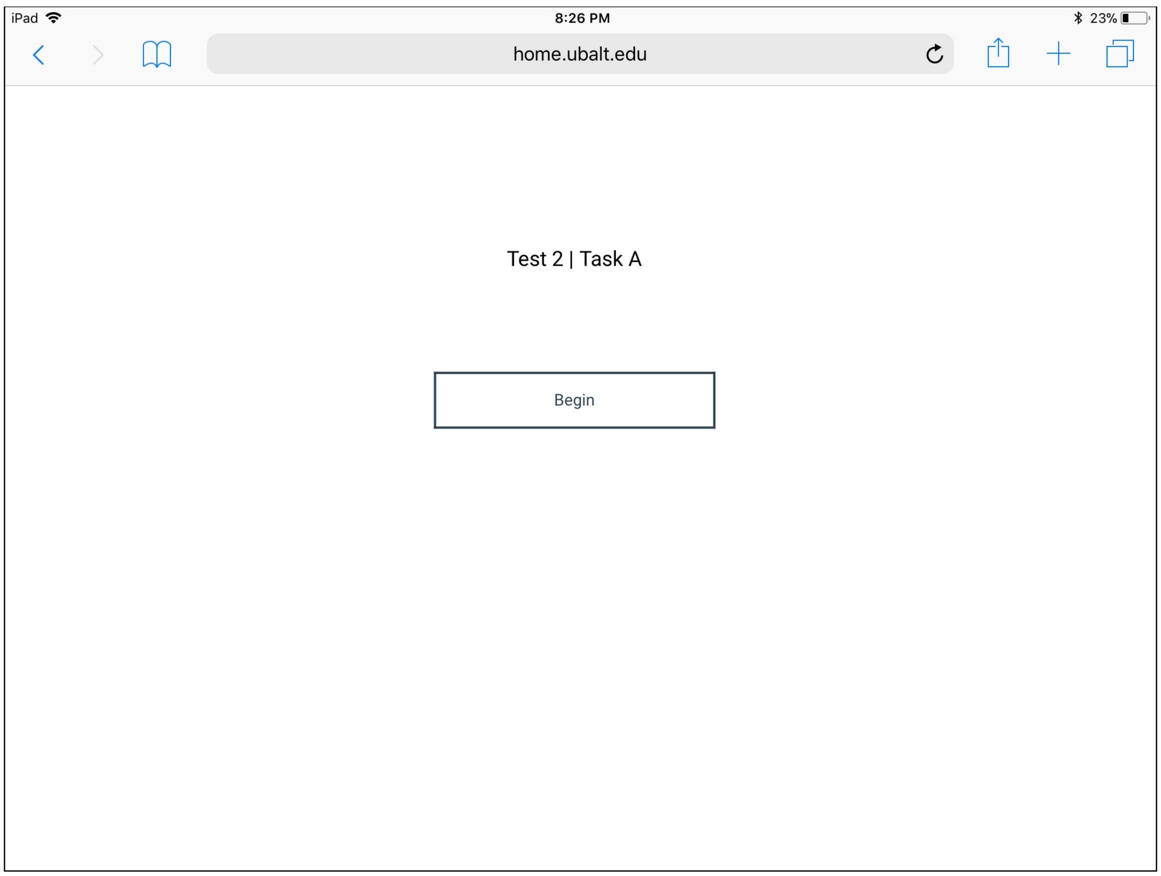

Figure 24. Initial view of the iPad screen prior to the participant beginning the reading task for Experiment 2.

The following images depict what each version ((a) 1.7 or (b) 1.3) of the task looked like as it initially loaded onto the screen just after participants tapped the button.

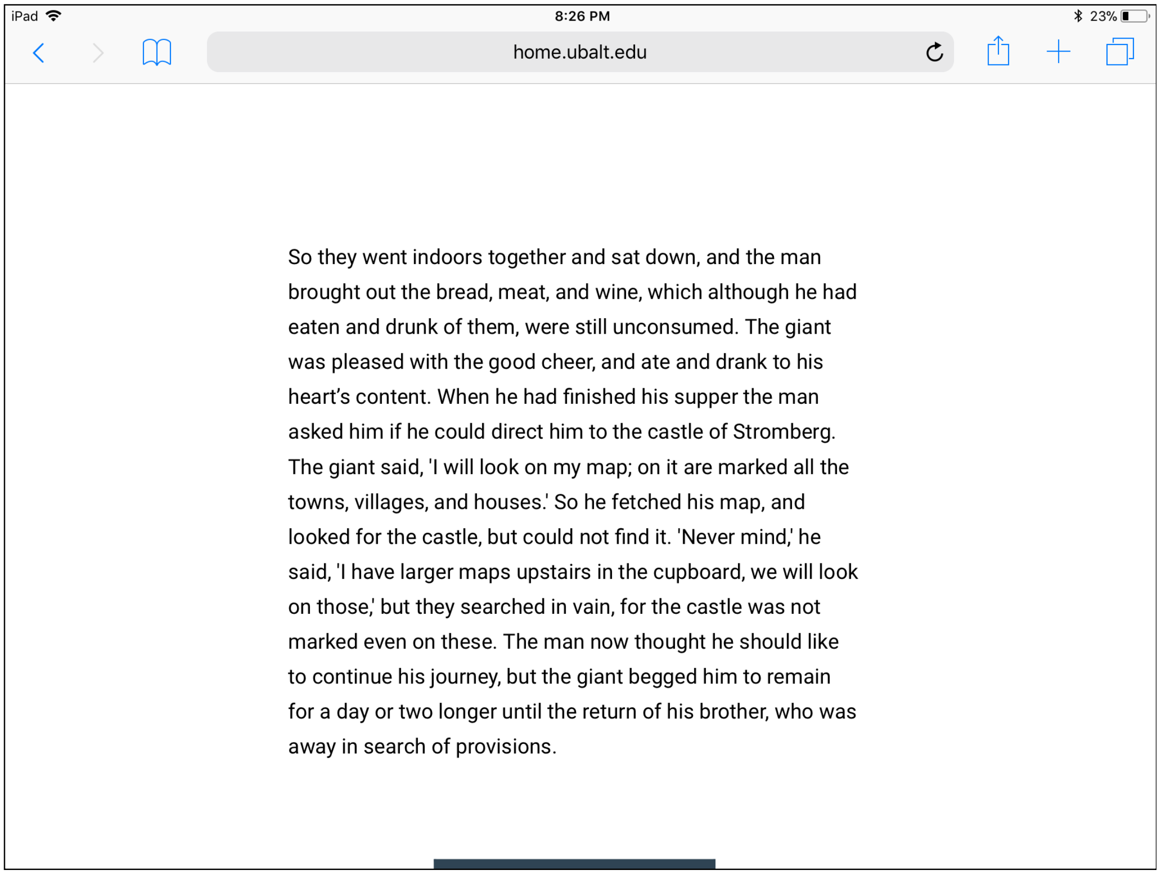

Figure 25. Experiment 2, Task A: Font Size 1.125em; Line Height 1.7.

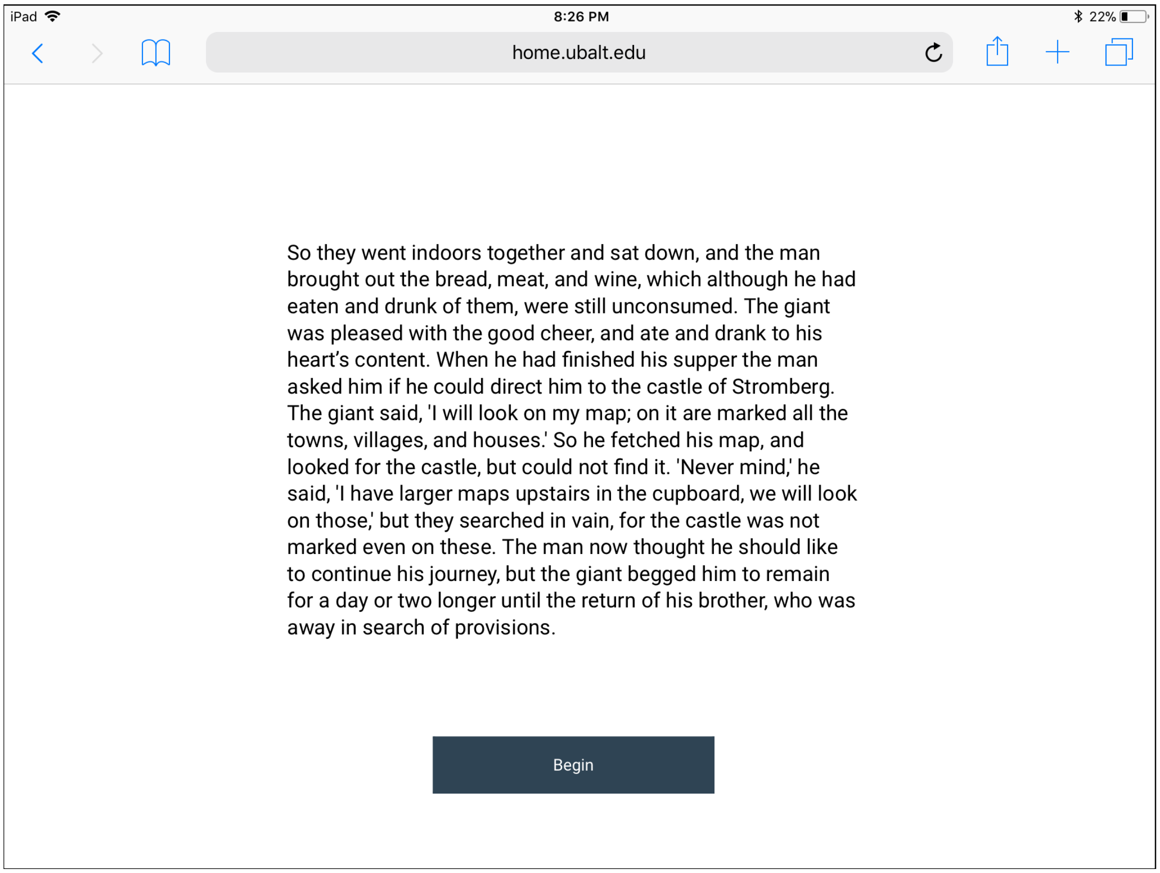

Figure 21. Experiment 2, Task B: Font Size 1.125em; Line Height 1.3.

Time on Task Results

Because the operationally defined legibility score may not have been the most accurate way to measure differences between line height, an independent-samples t-test and a 3x2 factorial ANOVA were performed to explore the effect of line height on time on task for simulated visual impairments. Using the same null hypotheses: (1) increasing line height has no effect on visually impaired web users. First, an independent-samples t-test was performed to explore overall time on task for visually impaired participants, regardless of visual impairment type, on 1.3 and 1.7 line height. The results of the mean and standard deviations and the independent-samples t-test are listed in Tables 10 and 11, respectively.

Table 10

Group Statistics for Dependent Variable Time on Task by the Independent Variable Line Height (N = 32).

Line Height	*M*	*SD*	*n*
1.3	0:01:21	0:00:25	16
1.7	0:01:41	0:01:02	18

Table 11

Independent Samples Test for Equality of Means on 1.3 and 1.7 Line Height on the Dependent Variable Time on Task.

t	*df*	Sig. (2-tailed)	Mean Difference
-1.186	32	0.245	-0:00:19

As indicated by the results, there was insufficient evidence to reject the null hypothesis at the 0.05 significance level, as there was not a significant difference in the time on task for 1.3 line height (*M* = 0:01:21, *SD* = 0:00:25) and 1.7 line height (*M* = 0:01:41, *SD* = 0:01:02) conditions (t_{32} = -1.186, *p* = 0.245). These results suggest that an increase in line height does not have a positive effect on time on task for visually impaired users.

Additionally, a 3x2 factorial ANOVA with 3 levels of visual impairment (cataracts, diabetic retinopathy, or glaucoma) and 2 levels of line height (1.3 or 1.7) was performed to explore the effect of visual impairment type and line height on time on task. The results of the factorial ANOVA are listed in Table 12.

Table 12

Tests of Between-subjects Effects of Line Height and Visual Impairment Type on the Dependent Variable Time on Task.

Source	*SS*	*df*	*MS*	*F*	*p*	Partial Eta^2	Observed Power*
Line Height	3,322.704	1	3,322.704	1.757	0.196	0.059	0.249
Visual Impairment Type	19,276.901	2	9,638.450	5.095	0.013	0.267	0.777
Line Height * Visual Impairment Type	2,466.901	2	1,233.450	0.652	0.529	0.045	0.148
Error	52,964.733	28	1,891.598				
Total	68,855.000	34					

Note. * Computed using alpha = 0.05.

As indicated by the results, there was insufficient evidence to reject the interaction effect null hypothesis at the 0.05 significance level ($F_{2,34}$ = 0.652, *p* = 0.529, partial η^2 = 0.045). Additionally, there was no statistically significant main effect for line height

($F_{1,34}$ = 0.1.757, p = 0.196). Post-hoc comparisons, shown in Table 13, indicated a mean line height of 1.3 (M = 0:01:21, SD = 0:00:25, 95% CI [59.412, 104.122]) was minimally different than a mean line height of 1.7 (M = 0:01:41, SD = 0:01:02, 95% CI [80.612, 122.610]). However, there was a statistically significant effect on the different types of simulated low vision ($F_{2,34}$ = 5.095, p = 0.013, partial η^2 = 0.267).