Spatial Reading System for Individuals with Blindness

Yasmine N. El-Glaly

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Computer Science

Francis Quek, Chair
Tonya Smith-Jackson
Roger Ehrich
Denis Gracanin
Mohamed Rizk

March 26, 2013
Blacksburg, Virginia

Keywords: Active reading, Audio rendering, Spatial cognition, Multimodal interaction, Blindness, Touch devices, Assistive technology

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(ABSTRACT)

In this research we introduce a novel reading system that enables Individuals with Blindness or Severe Visual Impairment (IBSVI) to have equivalent spatial reading experience to their sighted counterparts, in terms of being able to engage in different reading strategies e.g. scanning, skimming, and active reading. IBSVI are enabled to read in a self-paced manner with spatial access to the original layout of any electronic text document. This system renders text on iPad-type devices, and reads aloud each word touched by the user's finger. The user could move her finger smoothly along the lines to read continuously with the support of tactile landmarks. A tactile overlay on the iPad screen helps IBSVI to navigate a page, furnishing a framework of tactile landmarks to give IBSVI a sense of place on the page. As the user moves her finger along the tangible pattern of the overlay, the text on the screen that is touched is rendered audibly to speech. The system supports IBSVI to develop and maintain a cognitive map of the structure and the layout of the page. IBSVI are enabled to fuse audio, tactile landmarks, and spatial information in order to read.

The system's initial design is founded on a theoretical hypothesis. A participatory design approach with IBSVI consultants was then applied to refine the initial design. The refined design was tested in a usability study, which revealed two major issues with the tested design. These issues are related to the lack of instant feedback from the system (psycho-motorical problem), and the lack of conveying the semantic level of the page structure. We adapted the reader design to solve the usability problems. The improved design was tested in an experience sampling study. The results showed a leap in the system usability. IBSVI participants successfully self-paced read spatial text. Further reading support was then added to the system to improve the user experience while reading and interacting with the system. We tested the latest design of the reader system with respect to its featured function of enabling self-paced reading and re-finding information. A decomposition study was conducted to evaluate the main components of the system; the tactile overlay, and the intelligent active reading support. The results showed that both components are required to achieve the best performance in terms of efficiency, effectiveness, and spatial perception. We conducted an evaluation study to compare our reader system to the state-of-the-art iBook with VoiceOver. The results show that our reader system is more effective than iBook with VoiceOver in finding previously read information and in estimating the layout of the page, implying that IBSVI were able to construct a cognitive map for the pages they read, and perform advanced reading strategies. Our goal is to to enable IBSVI to access digital reading materials effectively, so that they may have equal learning opportunities as their sighted counterparts.

GRANT INFORMATION

This research has been supported by:

NSF CRI Program: II-EN: Device and display ecologies IIS 1059389,

NSF HCC: STAAR: Spatial Touch Audio Annotator and Reader for Individuals with Blindness or Severe Visual Impairment IISI-1117854.

Dedication

To my beloved parents, Nader and Samia

To my sincere husband, Samir

To the joy of my life, my sons, Adham and Aser

To my dear siblings, Nadreen and Basem

To the soul of my grandma, Zainat

Acknowledgments

I would like to thank very much my advisor Prof. Francis Quek. He helped me tremendously through my research. His discussions and arguments added a lot to my knowledge. His advisory extended to topics beyond my research point, which was really helpful and interesting. Many thanks to Prof. Tonya Smith-Jackson. She provided me with a lot of her unique expertise in industrial and systems engineering. She added a valuable perspective to my research. Prof. Denis Gracanin, Roger Ehrich, Mohamed Rizk, I want to thank you for helping me further formulating my research argument, and leveraging the quality of my dissertation.

On weekly basis, I had meetings with the wonderful VISLab research group directed by Prof. Quek: Chreston Miller, Sharon Chu, Seung In Park, Blake Sawyer, Yonca Haciahmetoglu, Rongrong Wang, Xiao Lin, Ji-Sun Kim, and Manpreet Hora. Thank you so much all my friends for your discussions that broadened my horizon and engaged me in thinking in various research problems. Also, your suggestions and ideas contributed to my research. The time I spent with you was really very-well invested, thank you!

I want to thank Gurjot Dhillon and Zerrin Ondin who extensively participated in the STAAR project. Thank you for all the time you dedicated for the project, and your effort. I also want to thank Shreya Kothaneth, Yang Yushi, and Stephanie Alpert for volunteering and helping with the studies.

I was so lucky meeting my Blacksburg friends: Randa Abdelmagid, Samah Gad, Hussein

Ahmed, Niveen Tayel, Leelian Quek, Sarah Quek, Mustafa ElNainay, and Shaimaa Lazem. I can never express my gratefulness towards them. They made me feel Blacksburg is my home.

I will never forget the Computer Science faculty Sharon Kinder-Potter, Matt Moore , Emily Simpson, and Ginger Clayton. Thank you so much for all your help.

Many thanks to the Assistive Technology lab at Virginia Tech. Specifically, I want to thank William Holback, Hal Brackett, and Jennifer Sparrow. I benefited a lot from their wide and deep expertise. They gave me ideas, information, and assistance.

This research was never been feasible without the help of RAVE and Voice of Blue Ridge directors and members. I want to thank all the amazing people I met in RAVE and Voice of Blue Ridge, and all who participated in my studies.

Saving the last for the best. Thank you VT-MENA program and on the head of the program, Prof. Sedki Riad. You were outstanding support to me. I deeply appreciate all your sincere effort. May Allah bless you always.

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Chapter 1

Introduction

1.1 Introduction

Reading and writing are two complimentary activities. Authors write with the assumption that readers have sight capabilities. Readers use their visual-spatial capabilities to consume written information. The resulting product of this tacit mutual agreement between the writer and the reader is an embodied book. A book, or any other reading material, has all its characteristics built with one unique identifying characteristic, which is embodiment. The book shape, size, dimensions, and weight are designed to be used by humans. Not only the external features, but also, and more importantly, the internal features are designed to make use of the humans mind and body capacities. Information laid out on pages is presented in words, and the position of the words. Groupings of words into sentences, paragraphs, and columns, are all various means for delivering messages to the reader. Punctuations, symbols, and formatting words, are also examples of writing-reading reasoning. Modern learning and psychology research shows that visual-spatial access is critical to reading of typographical information [38,40,58,101]. Moreover, the layout and visual spatial cues make it easy to find information and to compare data content [103]. While the whole body of literature across the different cultures among the years of printing are formulated based on the human capabilities of visual and spatial processing, Individuals with Blindness or Severe Visual Impairment (IBSVI) face various difficulties trying to access reading materials. The main reason behind that is the current way text is transcribed. In general, text is accessed by IBSVI by either tactile medium (e.g. Braille), or audio medium (e.g. Talking books). Both media have problems that eliminate fluent spatial reading. Braille is spatial in its nature; however, Braille books are non-portable because of their size and weight, and digital Braille displays highly reduce the sense of spatiality because Braille displays are typically composed of only one refreshable line of Braille at most. Moreover, 90% of IBSVI in USA are Braille illiterate according to the American Federation for the Blind [5, 88]. Electronic audio books provide IBSVI with portability but they are sequential and lack spatial indexing. Screen readers such as JAWS or VoiceOver don't provide IBSVI with enough spatial information [73, 74].

Moreover, the reading process requires reading word by word [79], and that can explain why reading Braille activates IBSVIs visual cortex [85]. Further discussion of the available reading technologies for IBSVI is presented in Chapter 2.2.

1.2 Overview of Reading Theories

This section is divided into two parts. The first part explains the definition of *Reading*, and the different strategies of reading. Then a discussion on the importance of *Spatial Reading* and how it contributes to comprehension of the reading materials is presented. The second part of the section is dedicated to show that IBSVI do have spatial capabilities and that lack of visual access does not mean lack of spatial awareness or spatial cognition.

1.2.1 Importance of Spatial Reading

Before investigating the importance of spatial reading, we need to accurately define what *Reading* really is, and how it can be performed to reach the reader's goal. According to the modern learning and psychology research, *Reading* is the process of decoding a set of written symbols that have been assigned linguistic meaning, for the purpose of communicating ideas [80, 98]. There are five reading strategies [30, 62, 77, 81] that one may use according to her purpose of reading:

1. *Scanning*: is the process of extracting specific information from the reading material. The reader's goal in this case is to locate the word or phrase she is looking for without necessarily making meaning from the text.

2. *Search Reading*: meaning that the reader is trying to find information about a topic. In this case, the reader does not have a specific text to look for.

3. *Skimming*: is about obtaining the general idea about the topic the one reads. It helps

the reader to know how the author structured her ideas, and to decide whether to engage in active reading or not.

4. *Receptive Reading*: is the process of reading the whole text without stopping to think about the reading material. This type of reading resembles receptive listening, and is usually used for leisure reading.

5. *Active Reading*: is reading to learn about the text you are reading in details. When details matter for the reader, she intensively read with paying attention and probably taking notes. This is the strategy of reading that students usually follow while reading for studying.

Reading is a highly cognitive process requiring simultaneous access to both words and the construction of entire sentential units [79]. Typography is a self-contained mode that interacts with all other textual signing modes. Page layout, spacing, and paragraph structure are designed to help readers to keep place while reading [69], and to revisit critical pieces [40]. The layout and visual spatial cues make it easy to find information and to compare data content [103]. The research literature in Reading shows the effects of *text layout* on reading and comprehension [58].

When readers are engaged in reading some material, they can recall the position of information with a marginal error within these reading materials [59,82], that is, they can recall that a certain piece of information was positioned at a specific location in the page. This memory appears to be incidental with the reading process, and not developed intentionally [68]. Spatial locations include the position of letters in words, words in sentences and sentences or words in the page. This spatial indexing process occurred in the spatial sketchpad and the phonological loop of working memory [14]. Analysis of readers' eye movements has shown that readers can reposition their gaze by making a single and accurate regression [12,67,78]. Spatial location awareness is important for readers because it supports search and re-finding of information. Moreover, research shows that spatial awareness increases comprehension while reading by understanding the document's organizational structure [42]. While readers engaged in the reading process, they construct cognitive maps, i.e. unconsciously link ideas to their physical locations in the reading material [40]. It becomes difficult for readers to construct cognitive maps if the location of the content is dynamically changing [41,68]. For example, readers of digital material can better comprehend the information if the text is presented in page format as in a book (as opposed to a continuous text scroll) [76] due to their greater reliance on regressions and spatial memory [87], and their use of the spatial features of the text [99].

1.2.2 Spatial Abilities of IBSVI

The National Health Interview Survey (NHIS) reported that there are 21.5 million adults in the US who are experiencing vision loss [7]. This vision loss applies to individuals who could not see after wearing glasses or lenses and includes individuals with complete vision loss. In the U.S., an individual becomes blind every seven minutes [66]. The worldwide population of blind is approximately 45 million which increases every year by 1-2 million each year [7,100]. As IBSVI are the target population of our research, we need to explore brain and cognitive sciences literature to find out the effect of blindness on the human brain, and whether there is a difference in the way the brain works between people who are born blind and who acquired blindness. Answers to these questions will help us understand blindness and then we can build our system based on realistic needs and capabilities for the unsighted people.

An interesting research in [61] tried to figure out whether the brain reacts the same for blind and sighted people, when it comes to manipulating objects. The authors conducted an experiment, where participants are late-blind, and congenitally blind and sighted volunteers. Each person laid in an MRI scanner while they heard a set of words from a category, either tools, like saw, scissors, and fork; animals, like butterfly, turtle, and cat; and objects you don't manipulate, like bed, fence, and table. Functional MRI scanning showed which parts of the brain are active when the volunteer heard each word. By analyzing the fMRI scan results, the authors showed that blind people think about manipulating tools in the same regions of the brain as do people who can see. Moreover, like visual people, a non-tool like a cat or a fence generally did not activate those same regions of the brain.

Another study [37] was conducted in Canada to examine wayfinding in the blind. Wayfinding encompasses all the ways in which people orient themselves in physical space and navigate from place to place. Wayfinding requires the proper encoding, processing and retrieval of spatial information. Successful spatial navigation also requires the activation of a network of brain regions that are essential for the processing of space. The hippocampus, in particular, plays an important role for navigation in large-scale environments. The contribution of this structure to the processing of spatial information has been demonstrated in several human studies. It has also been shown that hippocampal (a brain region well known to be involved in spatial processing) volume varies as a function of experience: the more spatial memory is important or essential for the survival, the larger is the structure. In the absence of visual input, the question arises as to how complex spatial abilities develop and how the brain adapts to the absence of this modality. The authors in [37] explored navigational skills in both early and late blind individuals and structural differences in the hippocampus. Thirty-eight participants were divided into three groups: early blind individuals (n= 12; loss of vision before 5 years of age), late blind individuals (n= 7; loss of vision after 14 years of age) and 19 sighted, blindfolded matched controls. Subjects undertook route learning and pointing tasks in a maze and a spatial layout task. Anatomical data was collected by MRI. Remarkably, it was shown that blind individuals possess superior navigational skills than controls on the route learning task, also for the first time a significant volume increase of the hippocampus in blind individuals was reported, irrespective of whether their blindness was congenital or acquired.

In summary, individuals who lack visual-spatial attention can have reading disabilities [32, 38]. This is not the case in IBSVI who have reading abilities, as they do have spatial capabilities [20]. Brain research shows with fMRI studies that IBSVI's visual cortex is activated when they read Braille [24, 85], or perform tactile discrimination tasks [84].

1.3 Research Problem

In this research, we aim to provide IBSVI with a reading tool that enables them to self-paced read in a spatial domain, so that they may be enabled to follow various reading strategies, e.g scanning, skimming, and active reading. Our hypothesis is that IBSVI may benefit from their spatial capabilities in their active reading activities if they have access to a well-designed system that enables them to read in a spatial domain. Our approach is to design and develop a multimodal system that allows IBSVI to read digital books in their original format by fusing spatial information, touch, and audio together. We used the iPad to render text on its surface, and as the user touches the words, a speech module will speak them aloud. We claim that augmenting the iPad with a tactile overlay may help IBSVI to locate their place on the screen and help them move horizontally to follow the lines of text. The interaction design should support continuous touch, multi-touch, and avoid finger lifting as much as possible, to help IBSVI keep place.

1.4 Research Questions

The main research question that we investigate is: how to transform reading materials in its spatial format to a medium that is accessible for IBSVI? Our goal is to render text audibly as it is touched on the iPad surface, and we hypothesize that with the appropriate design, the user will be able to fuse the textual information (what is on the page) with the location of touch (where the information resides on the page). This overall hypothesis leads us to several categories of sub-questions that relate to:

1. *The text format on the screen, the structure of the tactile overlay, and the inter-relationship between them.* How to render the text? What is the unit of rendering that can provide smooth reading? How much text can be rendered on the touch screen? Also, we need to investigate the pattern of the overlay and the landmarks that

can facilitate page navigation for IBSVI. What is the relationship between the overlay pattern and the text beneath? Must they be aligned? Can IBSVI find text that is not coincident with the tactile lines?

2. *The underlying architecture of the system.* Our hypothesis is that the spatial information that should be conveyed to IBSVI is the document structure on both the macro and micro level (i.e. lines within a page, and pages within a chapter). After defining the spatial information, we need to know how to convey them. If audio feedback is to be used, how to design it? And how would it interact with the audible speech?

3. *Technology support for reading itself.* How can the system help the user to keep her finger on the reading line? How the system should respond to accidental position shifting from the reading line?

4. *Interaction issues relating to reading.* What kinds of interaction IBSVI can use effectively to read on a spatial touch surface? How can IBSVI read using a touch screen for reading at her own pace? What interaction can be used to navigate in the document?

1.5 Dissertation Organization

The rest of this dissertation is organized in the following chapters:

- Chapter 2 Related Work

  In this chapter, we review the various reading technologies available for IBSVI. Then, we review the design challenges of enabling IBSVI to use touch devices.

- Chapter 3 Approach

  In this chapter, we explain the approach we follow in this research. We illustrated the iterative design-test-refine approach that we used to reach our research goals. The initial design of the system and the first iteration of the participatory design sessions are presented in this chapter. The page rendering subsystem, and the typography model we developed are explained in this chapter.

- Chapter 4 The Reader System

  This chapter includes the design enhancements we applied to the initial prototype of the reader system, and the usability and the experience sampling studies we conducted. The multi-interaction model, the overlay model, and the page sonifications model are explained in this chapter.

- Chapter 5 Active Reading Support

  In this chapter, we address two interaction problems that are related to further improves the user experience, and supports IBSVI to read on the line without straying. Then, we presented the participatory design sessions we conducted to evaluate the system's new features. The audio dynamics model, and the self-controlled reading speed technique are presented in this chapter.

- Chapter 6 Reader System Evaluation

  This chapter presents an evaluation of the reader system. It consists of two parts, a decomposition study, and a comparative study. The studies' results and discussions are then explained.

- Chapter 7 Conclusions and Future Work

  This chapter summarizes the research work and the results we obtained. It encompasses the research contributions of the whole dissertation, and possible future extensions of this work. Finally, we present a list of the publications that were published from this research work.

Chapter 2

Related Work

2.1 Introduction

As the goal of our research is to enable IBSVI to read on a spatial medium using modern touch devices, we divide the related work of our research into two main areas: available reading technologies for IBSVI, and the accessibility of touch devices.

In Section 2.2, we review the available reading technologies for IBSVI, such as Braille, digital Braille, audio-based books, and screen readers. Then, we discuss the cons and pros of these reading technologies.

In Section 2.3, we discuss the various research efforts to enable IBSVI to use touch devices. We review different multimodal systems that make use of other channels to carry information instead of the visual channel. Single modal systems such as audio-based and haptic-based systems are also reviewed in this section.

2.2 Reading Technologies for IBSVI

In this section, we review the main streams of reading technologies for IBSVI. We categorize them into 4 groups:

- *Embossed Braille*
- *Digital Braille*
- *Audio books*
- *Screen readers*

2.2.1 Embossed Braille

Spatial tactile reading is not new. Braille, invented in 1824, transforms text into raised dot patterns laid out spatially on paper just as printed material does [47]. Braille, referred by

Grade 1, transcribes each letter into a cell of 6 dots. For more advanced reading, Braille can be transcribed in which a single cell is a group of letters or a whole word. This is known as Braille Grade 2 (see Figure 2.1). Braille gives IBSVI the opportunity for self-paced reading and rereading of information on a page. The layout and spatial cues make it easy to find information and to compare data content [103]. Braille readers engage in an active process, pausing and thinking as they read, however reading Braille requires continuous practice [29]. The problem with Braille code is that only 10% of people with blindness in the USA can read Braille [88]. There are numerous causes for the decline in Braille usage, including school budget constraints, technology advancement, and different philosophical views over how blind children should be educated [83]. A key turning point for Braille literacy was the passage by the United States Congress of the Rehabilitation Act of 1973 [27], which moved thousands of children from specialized schools for the blind into mainstream public schools [23]. Because only a small percentage of public schools could afford to train and hire Braille-qualified teachers, Braille literacy has declined since the law took effect [102]. University training programs for teachers of visually handicapped students have given lip service to teaching Braille and have, over the years, graduated less-than-proficient Braille instructors as teachers [92]. In addition, Braille code is difficult to learn especially among people with multiple disabilities [93].

Braille illiteracy affects the IBSVI capability to continue their high education, or even participate in the workforce. Only 45% of IBSVI complete high school compared to 80% among their sighted colleagues [9], and only 35.9% of IBSVI between the age of 16 and 64 are employed according to the U.S. Department of Labor's Bureau of Labor Statistics report [4]. Even IBSVI Braille literate cannot read Braille with the same speed as the sighted can read printed materials [56]. This is because IBSVI read Braille one character at a time, while sighted people read one word at a time. Another problem with Braille is its size. Braille books are large in size and cumbersome to handle. A standard textbook of 300 pages could be translated to Braille in 1800 pages [96]. Advances in audio books technology and their cheap prices lead to more unwillingness for IBSVI to learn Braille [11, 19, 91]. All these fac-

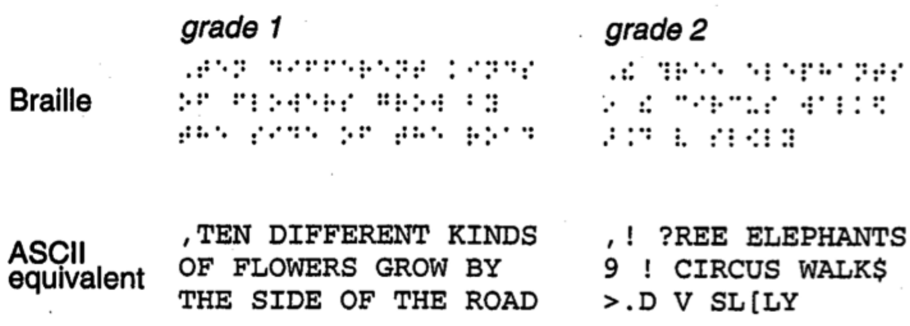


Figure 2.1: Illustration for Braille Grade 1, and Grade 2 [56]

tors lead to 90% Braille illiteracy among IBSVI in USA [88]. Moreover, access to up-to-date information and recent published literature is more convenient for ISBVI using audio readers than waiting these materials to be republished in Braille format [18, 25, 46].

2.2.2 Digital Braille

Transforming Braille to digital form has been done by refreshable Braille display [22, 44], and by display of virtual Braille dots [55]. However, most computer-based Braille translators cannot produce Grade 2 Braille transcription [96]. These high cost technologies solved the digitalization, portability and mobility problems of Braille books, however they eliminated the capability of Braille to provide spatial referencing because the size of the displays is relatively small. They consist of one-line display, where Braille text is generated in blocks of 20, 40, or 80 characters. While reading one line at a time is not passive as in listening to audible text, the information is represented in temporal sequential format. The reader cannot develop a mental map for the page she reads, and face text-locating problems [70].

2.2.3 Audio Books

Converting textbooks to audio books was the goal of various projects that aimed to offer a Braille alternative for IBSVI. Examples of these audio books are Talking Book [94] and DAISY books [1]. These popular audio readers are different from active reading. Audio readers cannot address the spatial bias we have identified. Audio format provides IBSVI with information in the form of linear stream with no spatial reference, which overloads IBSVI's working memory. Interviews with IBSVI who feel comfortable using audio and Braille, pointed out that audio is ideal for recreational reading, while Braille is mandatory for active reading [70]. Converting Braille to Audio for IBSVI is like converting print to audio for sighted population, leads to virtual illiteracy [70]. Auditory learners must read and write, in either print or Braille, to meet the competitive employment needs [29].

2.2.4 Screen Readers

Most computer interfaces highly depend on graphics and visual access. For IBSVI, to interact with GUI systems, they may use the screen reader. The screen reader is a part of the universal access technology of various computer systems, such as Windows Microsoft Narrator and Mac VoiceOver. There also exist popular commercial screen readers such as JAWS. This assistive technology is even extended to the touch tablets, such as the iOS VoiceOver for iPad, and the Ice Cream Sandwich Talk Back for Android tablets. These different types of screen readers have two main functions: reading the screen content, and navigating the screen. Screen readers have usability problems [71, 74], especially when the content of the screen is designed with the assumption that it will be visually read [19]. Browsing web pages by IBSVI, for example, using screen readers leads to more probing and takes longer than for sighted users [17]. Screen readers process pages sequentially, which leads to information overload [60]. The navigation function on desktop screens is achieved by keyboard shortcuts, which are typically different combinations of two keys. On touchscreens, IBSVI can navigate the screen by touch, or alternatively connect the touch device to a keyboard. Screen readers do not provide IBSVI with feedback regarding their location on the screen of both desktop and touch devices. In touch devices, the spatial awareness problem is reduced, however much more accuracy is needed in locating place because any unintended touch could lead to undesired interaction. Finally, screen readers are not built to support active reading, and they do not provide IBSVI with the needed mental model of the page.

2.3 Accessibility of Touch Devices

In this subsection, we review the research efforts that are dedicated to enable IBSVI to use touch devices. Also, we describe the design ideas in previous work that inspired our initial overlay design. Leveraging accessibility of touch devices is usually achieved by introducing sonifications and auditory feedback, or haptic feedback. Some systems tried to combine both the auditory and haptic feedback in their design.

2.3.1 Audio-based Interfaces

Examples of systems that use auditory feedback on touch screens are [50,65,90], which have the purposes of accessing menus, maps and relational diagrams, respectively. Another study in [33] showed that earcons and speech synthesis could be used in video annotating for IBSVI. For mobile phones, an interaction technique to increase the efficiency of accessing icons and advanced functions for IBSVI is proposed in [57]. Accessing large screens using auditory overlays was investigated in [51]. The overlays they used are software-based techniques that provide auditory feedback for spatial navigation and interaction. The studies they conducted showed that their overlays are better than Apple's VoiceOver. Their results, also, show the need for supporting spatial awareness for IBSVI especially on large touch screens. We can see from the literature that different kinds of information cannot be accessed using only one auditory structure. This need is obvious when we consider the varied visual formats used for different kinds of information. For example, geographical information or tabular financial

Figure 2.2: Left: Tactile keyboard [8]. Right: Tactile grid [3]. Bottom: Overlay for MP3 player [63].

information employ significantly different visual presentation and cues.

2.3.2 Tactile and Haptic Interactions

Another body of literature is devoted to provide accessibility for touch devices using haptic feedback. Trying to find the best characteristics of the haptic feedback on touch screens, for example, the authors of [52] tested different tactile clicks produced by piezo actuators and a standard vibration motor. A recent study targeted the design of tactile stimuli using variable-reluctance actuators to give feedback for tapping soft buttons on touch screen [72]. Another study used the haptic feedback to acknowledge the user's navigation and locating on the touch screen before starting interacting [104]. Turunen et al. conducted a series of studies to achieve a usable multimodal design to make media centers more accessible to both IBSVI and low vision users [95]. They combined gestures, speech, and haptic feedback as models of interactions. The authors in [49] provide a good discussion of the main existing techniques used by blind users to have graphical access and communication. Their contribution was to describe a grid-based model that gives blind users feedback for relocating important points, determining angles and lines length. Their study highly affected assistive technology literature, as their model is the basis for various systems and applications for unsighted users. This paper influenced our design to use a modified grid-based interface that is more suited to reading standard text layout. This interface will help IBSVI relocate lines they previously read or notes they had taken.

Examples of tactile surfaces are shown in Figure 2.2. The top-left of Figure 2.2 shows a tactile keyboard design for iPhone to enable better and faster typing on the iPhone [8]. The top-right of Figure 2.2 shows a tactile grid for an iPad application that explores relationships between musical pitches [3]. These tactile overlays were developed for personal and commercial reasons. To the best of our knowledge, no research studies are reported for their usability or rationale. The picture shown at the bottom of Figure 2.2 is a raised paper that covers an MP3 player touch screen [63]. The overlay was evaluated by 2 studies, the first one was with blindfolded participants, and the second was with one blind participant. The authors discussed the problems with touch screens accessibility for IBSVI, and suggested a set of design rules to solve the lack of accessibility of touch devices. In order to help researchers and developers with their work in the field of accessibility, the authors of [10] proposed an accessibility toolkit. The toolkit can be used for creating various accessible mobile applications.

Chapter 3

Approach

3.1 Introduction

We follow an iterative design-test-refine approach in our investigation. The research is planned to be of four iterations:

- We started with developing an informed design of the reader system and the overlay. We tested the preliminary system and the overlay with IBSVI from the local community in a series of participatory design sessions. This is described in the rest of Chapter 3.
- We employed the lessons learned from these studies to develop the second iteration of our design. However, our experiments showed us that usability issues prohibited IBSVI from using our system adequately. The design and the experiment are discussed in Chapter 4.
- In the third iteration of our research, we addressed the usability issues and tested the system in an experience sampling study. We then analyzed the data we collected in this study to discover the weaknesses of the system and to gain insight on how to increase the system effectiveness. The improved design and the study are explained in Section 4.5.
- At the fourth iteration, we embedded reading prediction model in our reading system to empower its supportive interaction for IBSVI. Adequate audio feedback was designed for the IBSVI. A usability study was then conducted to test the system at its latest design. Details are in Chapter 5.

3.2 Preliminary Theory-Based Design

The proposed solution for our research problem is to use a static embossed overlay on an iPad device. The IBSVI user would be able to move her finger along the lines of text on the iPad, and when she touches a word, the reader system will speak it aloud. The purpose of

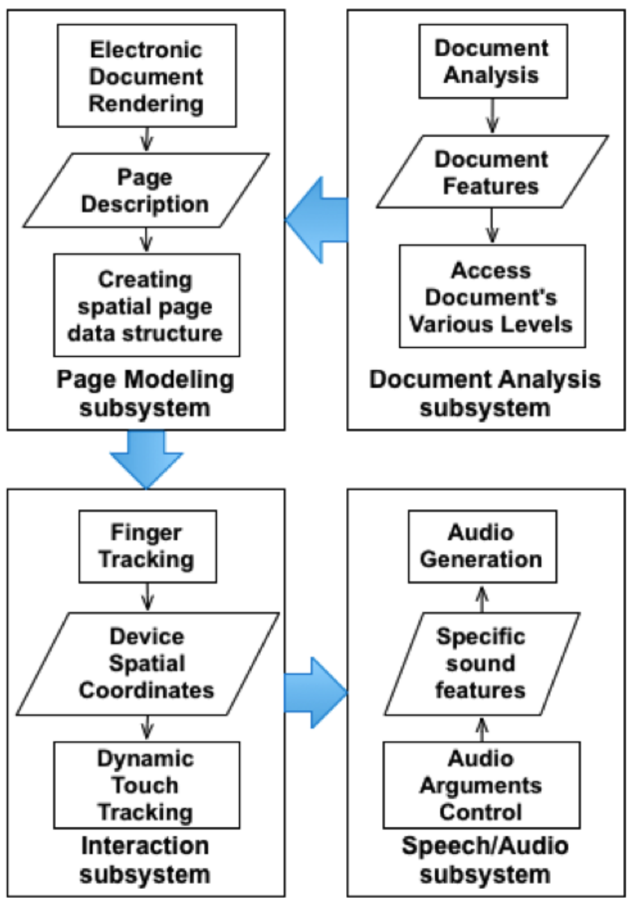


Figure 3.1: STAAR architecture.

the tactile overlay is to serve as a spatial landmarking reference. The very first design of the reader system was crafted based on two theories:

- Walter J. Ong in his highly influential "Orality and Literacy: The Technologizing of the Word" [69] observed that before the invention of printing, literature was designed for aural consumption. Authors at that age made use of mnemonic aids such as rhyme and alliteration [15]. However, after the revolutionary printing technology invented by Gutenburg, the written literature was completely altered to make use of the visual-spatial capabilities of the readers. Information transformed from a predominantly aural information medium that is sequentially consumed moment-by-moment as words are sounded into a spatial one where information is persistently available on a page for visual access and query [64].
- Psychological studies show that the size of the perceptual span of reading and information processing is 3-4 letters for general readers [79]. Words and letters can be presented in the spoken or written mode, and can be recalled in either [13].

From these 2 theories we derived the following design specifications for the reader system:

- An embossed overlay with tactile landmarks;
- A page and document modeling that support continuous reading;
- A text-to-speech engine that renders words audibly;
- Touch interaction subsystem that support self-paced reading;
- The system must support the IBSVI in forming a mental model of the page.

Based on these specifications, we derived the basic *Situated Touch Audio Annotator and Reader* (STAAR) system architecture shown in Figure 3.1. The system is composed of four integrated subsystems: the *Document Analysis*, *Page Modeling*, *Interaction Handling*, and

Speech/Audio Subsystems. The *Document Analysis subsystem* extracts information from the document to be read such as the number of pages, dimensions of each page, and the pages contents. Currently, STAAR can handle all standard PDF documents. The *Page Modeling subsystem* renders the original text on the iPad, preserving all textual and spatial information. The *Interaction subsystem* tracks finger movements and touches on the iPad screen and determines which words are being touched and when. The *Speech/Audio subsystem* renders the words touched audibly (using text-to-speech, TTS) and provides sonifications for interaction/feedback.

3.2.1 The Reader System - First Prototype

The first prototype of the reader system was built in a very similar way to the idea of Voice Over. We parsed the text on page into words, and represented each word by a button. When the user taps a button, the touch is detected and the word is sent to the TTS to be synthesized. We used the Flite TTS open source engine that was developed by CMU [2]. We ran a pilot study testing this system with one IBSVI volunteer. The pilot study showed us that the buttons are too discrete to be used for continuous reading. We decided that a more advanced page modeling is needed. We built two subsystems: A. *Text Renderer*; and, B. *Finite State Machine (FSM) Reader subsystem.*

The Text Renderer Subsystem

The *Text Renderer* is the core of the reader system. It is the module that renders a PDF document into set of accessible chapters, pages, and words on the iPad. All information about the document size, page size, and bookmark are extracted at this level of the system. Most importantly, the text renderer is responsible for representing each page of the targeted document in a format that is accurate enough to be tracked by touch. The idea is to convert a page of text into a set of geometric objects so that each object can be handled independently

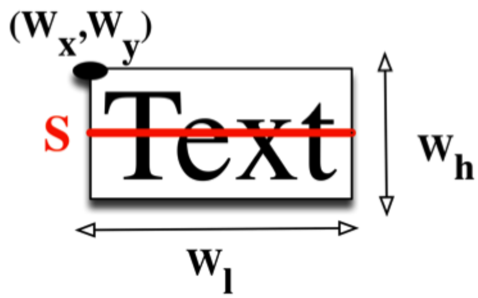


Figure 3.2: Graphical transformation of a word to segment.

in case of discrete touches. At the same time, these objects can be computationally grouped for handling continuous touch in real time. The text renderer scans all the words (W) in page (P) and transforms each word into a segment (S) using the following mathematical model:

$$\forall W_i \in P, S_i = (W_x, W_y + \frac{W_h}{2}, W_l), i = 1, .., n \tag{3.1}$$

where x and y are the coordinates of the top left corner of W's bounding box, h and l are the height and length of W respectively, and n is the number of words per page. An illustration of a word's graphical representation is shown Figure 3.2.

We make an exception to this representation for words of one character length such as "I" and "a". A word that is composed of one letter is combined with its successor to form one segment instead of two segments. For example, [Mary has a basket] a sentence of 4 words is rendered by the text renderer into 3 segments: ["~~Mary~~" "~~has~~" "~~a basket~~"]. The reason for merging very small words with the following word is to extend the region of interaction for these small words and consequently facilitate reading by touch for IBSVI. In addition to rendering the text for each page word by word, the text renderer module calculates the *Hot Spots* in the page. A Hot Spot (HS) is the area that corresponds to a whole line of text with an upper and lower margin of 1 point. The margin is added to handle minor differences in words midlines that occur in some cases, such as when using big and small font at she same line. However, if the difference in words midlines at the same line is greater than the margin value, the hot spots will not be accurate or complete.

$$\forall W_i \in P, HS_i = (W_x, W_y + \frac{W_h}{2}) : W_iy = W_iy \pm 1, i = 1, .., n. \tag{3.2}$$

The reason we pre-calculate Hot Spots is to support smooth reading as the user moves her finger continuously along the line and also to support an additional interaction for speed reading in case the user prefers to read the whole line with a single discrete touch. Returning to our example: [Mary has a basket], the Hot Spot in this case will look like this: [~~Mary has a basket~~], where the thin black lines mark the midline of the words and the thick line is the Hot Spot. In summary, the text renderer module transforms each page of text to sets of segments (words representations) and hot spots (line representations). This model could be applied to any language e.g. Arabic or Japanese, as we model words by spatial occupancy and connectivity irrespective of direction or length. The TTS must be changed for different languages.

The FSM Reader subsystem

The length of an ordinary English word is in average 4.5 letters [75]. Such words cover a space of 0.5 inches in length on the iPad screen with our current rendering parameters. When a user moves her finger from the starting location of the word to its end, she will cross about 100 touching points inside this word. If the system simply speech synthesizes the closest word to the user's touch every time she crosses a word, she will hear the same word repeatedly. We developed a finite state machine reading algorithm to solve this problem. The diagram shown in Figure 3.3 illustrates the finite states of a touched word and whether the touched word will be activated or not. A word that is touched by a user will be sent to the TTS or not depending on two variables: history of read words and context of touch. If the user touches a word for the first time, the word will be spoken aloud. If the user continues moving inside the word, the word will not be spoken. However, if the user lifts

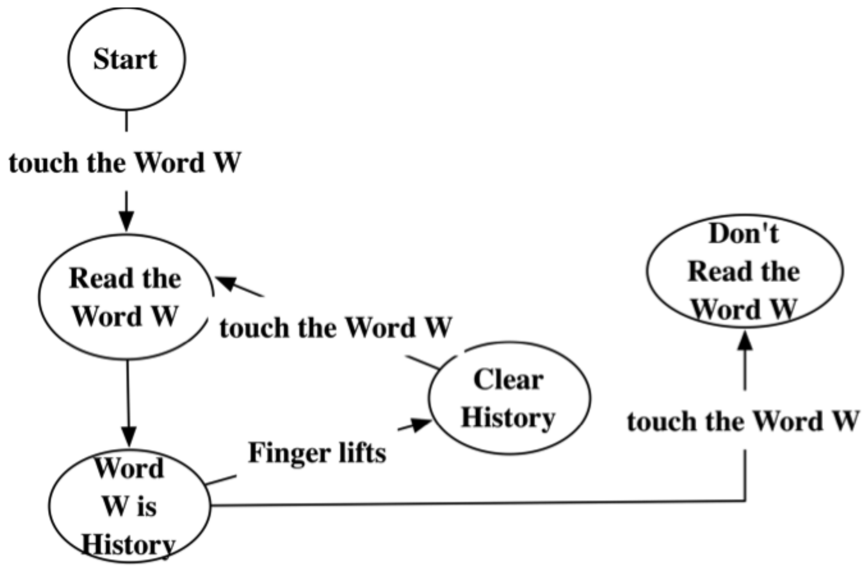


Figure 3.3: Finite state machine of reading words.

her finger of the screen and touches the same word again, the history will be cleared and the word will be spoken aloud.

3.2.2 The Overlay Model

We employ a standard embosser designed to produce Braille and raised line drawings [6] to produce our tactile overlays. We designed different sets of embossed patterns that can support navigation, exploration, spatial referencing, and location awareness on touch screens for IBSVIs. We chose standard transparent screen protector as a material for the overlays. We believe transparency of material is important because of two main reasons. First, some IBSVIs have residual vision capabilities and being able to see the iPad screen will help even with low visual acuity. Second, transparency helps the researchers in usability and accessibility studies to observe how users interact with the system, and may help users to read along with sighted compatriots. Our initial 3 prototypes are shown in Figure 3.4. The initial design of the overlay consists of a set of horizontal lines and vertical lines. The horizontal lines should help IBSVI keep their fingers moving horizontally on lines of text. The

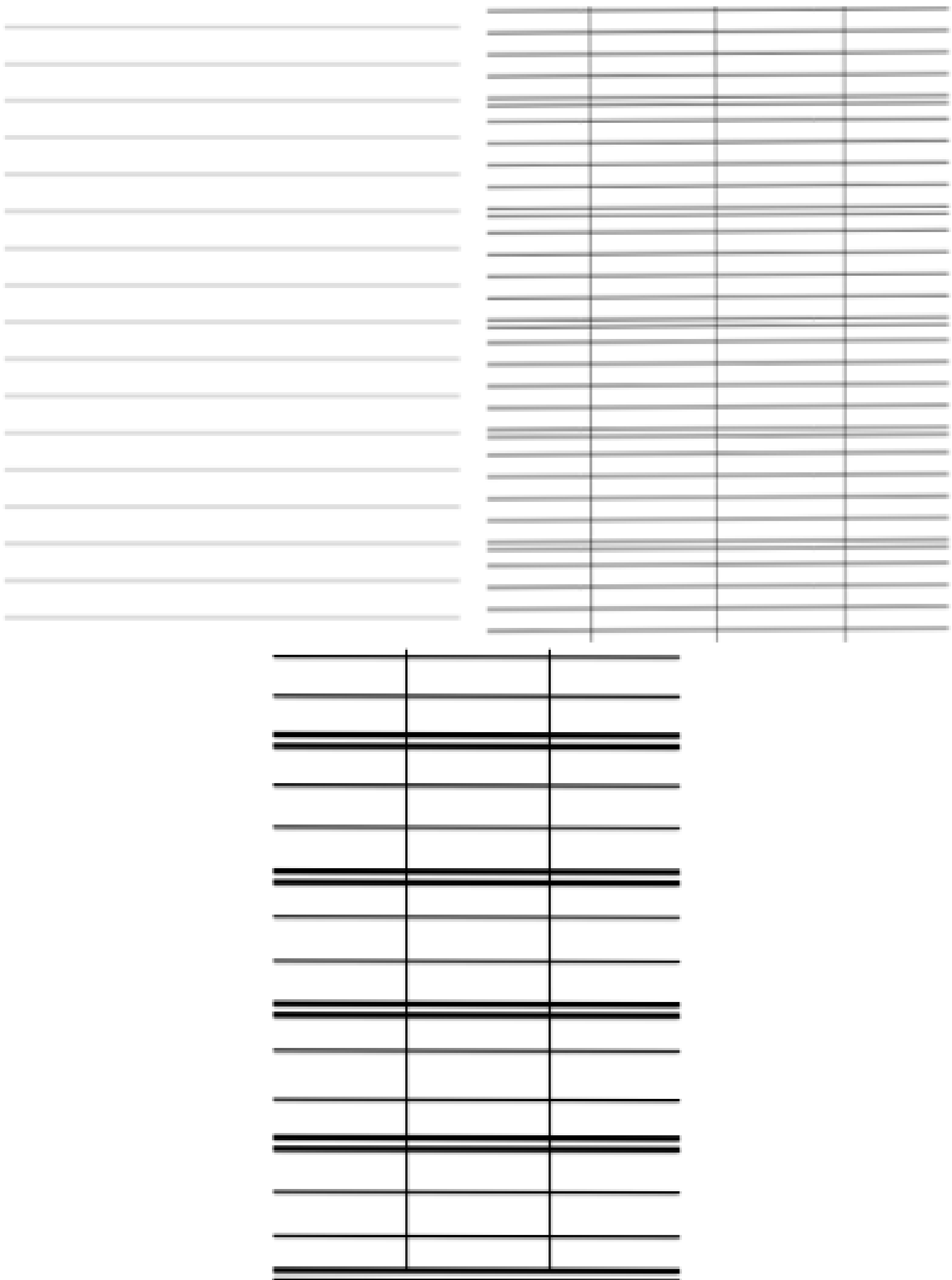


Figure 3.4: Top left: overlay A. Top right: overlay B. Bottom: overlay C.

horizontal lines are arranged with equal spaces between each line. Moreover, the horizontal lines can be defined in terms of sets, where each set consists of number of horizontal lines and a thick horizontal line. So that the IBSVI can locate their place by finding the thick lines, and for more precision, they can count and move a number of raised lines above or below the thick line. The vertical lines combined with the horizontal lines serve as a grid or a map that help IBSVI to formulate a mental reference for location awareness to maintain place on the screen. The vertical lines are also spaced equally apart. The density of these lines (or spatial interval between lines) is determined by the expected use of the overlay. For example, for reading text, we may need only 3 vertical lines to mark the quarter-locations of the screen. For reading graphics or a spreadsheet, the inter-line interval would be closer. The parameters of these basic elements that we investigated are:

- *Horizontal lines parameters*: number of raised lines (HL_n), distance between horizontal lines (HL_d) measured in inches, thick line (TL) interval (number of thin lines between thick lines), length of raised lines(HL_l) measured in inches, thickness of normal raised lines (HL_t) measured in points, and thickness of thick raised lines (TL_t) measured in points. The *point* is a typographical measurement that is used to specify small elements. One inch has approximately 72 points [48]

- *Vertical lines parameters*: number of vertical lines (VL_n), distance between vertical lines (VL_d) measured in inches, and thickness of vertical lines (VL_t) measured in points

- *General overlay parameters*: overlay punch depth (Pu_d , this is specified per overlay), and overlay material. The punch depth is set during the process of embossing using the embosser software. Varying the punch depth is important when it comes to embossing different types of materials with different thickness. Also, the punch depth setting can be useful in producing special tactile graphics.

$$Overlay_{model} =< HL_n, HL_d, TL, HL_l, HL_t, TL_t, VL_n, VL_d, VL_t, Pu_d > \tag{3.3}$$

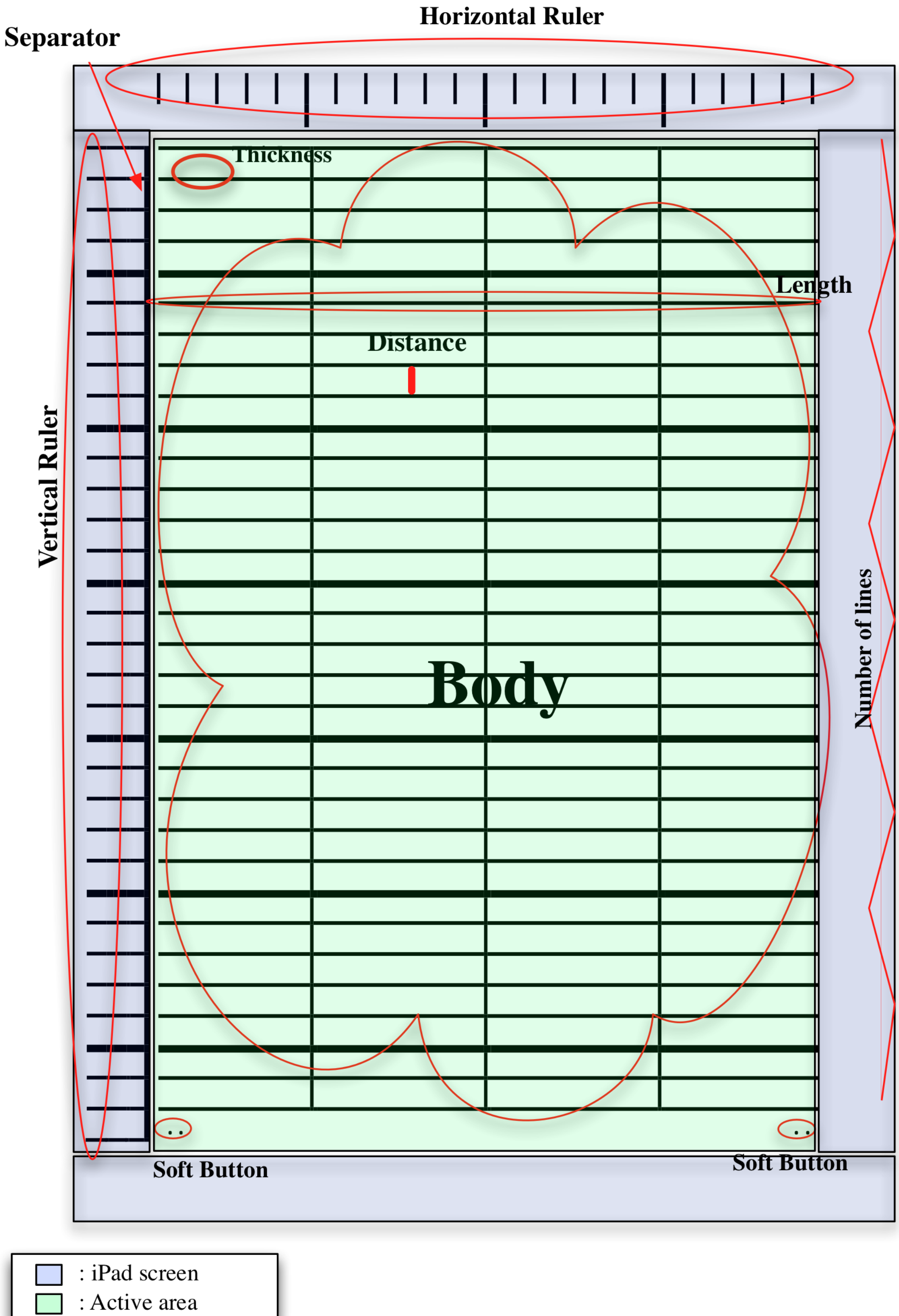


Figure 3.5: Illustration of the different elements of the overlay.

We varied the parameters of the overlay elements and designed 3 different overlays, as shown in Figure 3.4. The overlays' specifications are as follows:

$Overlay_A$= <17, 0.5, 0, 6, 1.5, 0, 0, 0, 0, 2>

$Overlay_B$= <29, 0.25, 4HL 1TL, 6, 1.5, 1, 3, 1.5, 1, 2>

$Overlay_C$= <15, 0.75, 2HL 1TL, 6, 2,1, 2, 2, 1, 2>

The overlay on the top left (Overlay A) consists only of horizontal lines. The distance between them is even, and they are all of equal thickness. The overlay on the top right (Overlay B) consists of sets of horizontal lines, each set consists of 4 raised lines and one thick (doubled) line. The rational behind this thick line is to facilitate counting for IBSVI. By locating a thick line, they can estimate their place and go back to a previous place easily. Also, Overlay B has vertical lines. The overlay at the bottom (Overlay C) is similar to Overlay B as it has vertical lines and thick horizontal lines. However, the distance between lines is larger. Hence, the number of lines is fewer. The different possible elements of overlays that we investigated are compiled in Figure 3.5.

3.2.3 The Typography Model

After designing the reader system architecture and the overlays, it was necessary to accurately model the text to be rendered on the iPad screen with respect to its typography. According to Stockl [89], there are 4 dimensions for the typographic sign system. These are:

1. Microtypography: refers to individual letters
2. Mesotypography: describes the configuration of typographic signs in lines and blocks
3. Macrotypography: describes the graphical structure of the overall page
4. Paratypography: refers to the typographic media

In this research, we used a set of the typographical grammar elements [89], which are depicted in Table 3.1. The elements include type face, type size, spacing between lines, alignment

Table 3.1: Elements of the typographic model.

Dimension of typography	**Typographic parameters**	**Typographic properties**
Microtypography	• type face • type size	• Arial font • 14, 16
Mesotypography	• line spacing • alignment • direction of lines	• single, 1.5 • left aligned, justified • horizontal
Macrotypography	• paragraphing space • page margins • number of lines	• single, 1.5 • 0.5, 1.0 inches • 15, 20
Paratypography	• typographic media	• glass (iPad screen)

of text, direction of text, spacing between paragraphs, and the left, right, top, and bottom margins of the page, Equation 3.4.

$$\begin{aligned} Page_{textModel} =< (type_{face}, type_{size}); (line_{spacing}, text_{alignment}, text_{direction}, line_n); \\ (para_{spacing}, page_{leftMargin}, page_{rightMargin}, page_{topMargin}, page_{bottomMargin}) > \end{aligned} \tag{3.4}$$

We assigned different values to the typographical model, (Equation 3.4), and rendered these different combinations on the iPad, as the iPad screen served as the typographic media in this research. We used the MSWord to format the text, and then the document was transformed to PDF to make sure the document proportions will not be distorted. Finally, the PDF document was rendered on the iPad using STAAR. An example of a rendered page annotated with the typographical parameters is shown in Figure 3.6. The example shows two values for the $type_{size}$, and left alignment text. By trial and error we reached two configurations that could be *readable* by IBSVI, which we called them *Large text*, and *Small text* page models:

- *Large text page model:*
  $Page_{large} =< (Arial, 20); (1.5, justified, horizontal, 15); (1.5, 0.5, 0.5, 1.0, 1.0) >$
- *Small text page model:*
  $Page_{small} =< (Arial, 14); (single, justified, horizontal, 20); (1.5, 0.5, 0.5, 1.0, 1.0) >$

When we chose these two configurations, we took into consideration the fact that the words, lines, and paragraphs can be tracked by the user's finger. Hence, the horizontal space between the words and the vertical space between the lines are not very narrow. At the same time, we did not map the lines of the text to the embossed lines on the overlay. That means that there could be lines of text between the tactile lines and other text lines that are exactly below the tactile lines. The advantage of keeping the page model independent of the overlay model is to preserve the dynamicity of the text. Hence, STAAR can be used to read different types

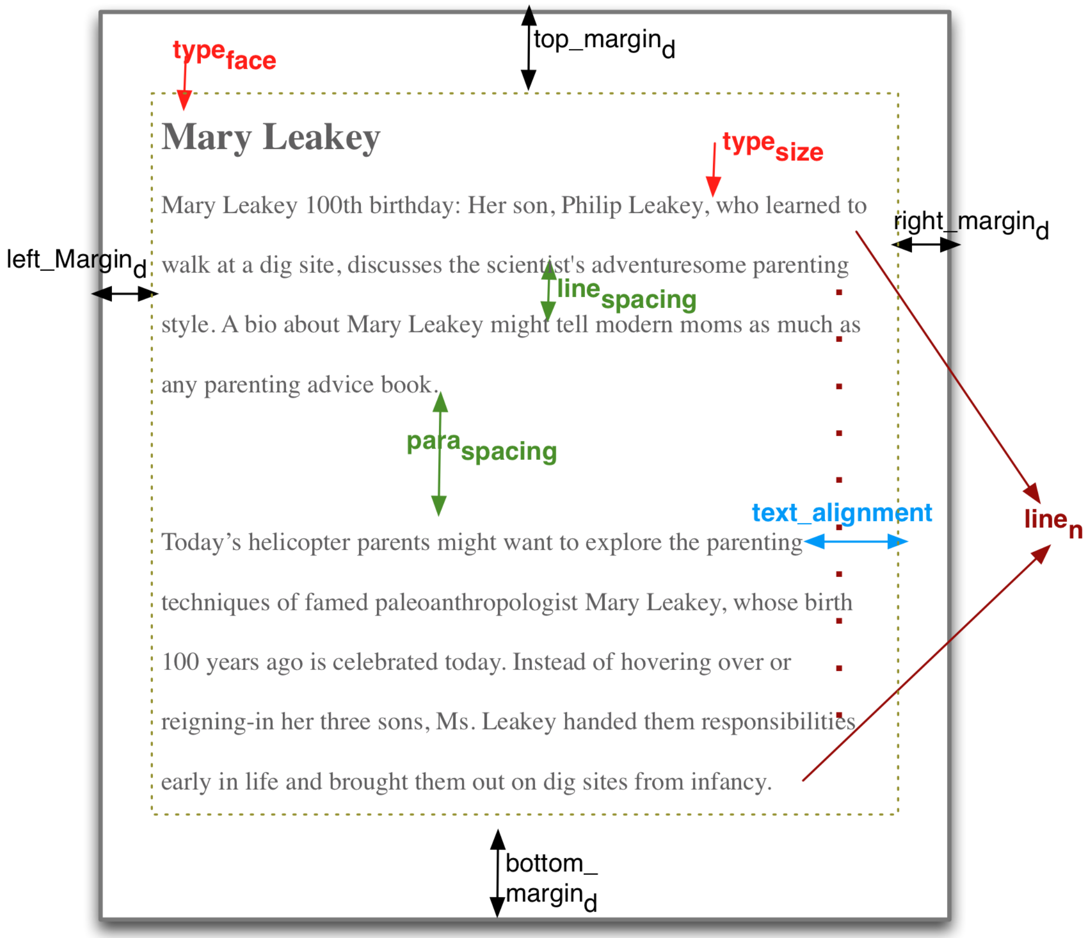


Figure 3.6: Illustration of the different elements of the typographical model.

of reading materials without the need to develop a specific overlay for each article, book, or journal. Our hypothesis is that IBSVI can practically read the text with the spatial tactile guide of the overlay. We needed to test that with IBSVI, so we conducted participatory design sessions to obtain informing feedback from the targeted population. The details of the sessions and the results are in Chapter 3.3.

Table 3.2: Consultants' background information.

Name	**Gender**	**Age**	**Residual Vision**	**Age of Blindness**	**Education**
Consultant 1	Male	70	left eye: no vision, right eye: 5 % vision	60	B.Sc degree
Consultant 2	Female	32	left eye: 24/100, right eye: 28/100	25	M.Sc. degree
Consultant 3	Female	65	20/100	birth	One-year college

3.3 Participatory Design Sessions With IBSVI

In order to design for special populations, it is essential to have input from members of the population from the outset of the interaction design [23, 86]. Hence, we employed a participatory design (PD) approach involving a cadre of IBSVI consultants. The goals of the PD sessions were to validate the system concept and to determine the system interaction parameters. We conducted a series of PD sessions where we presented our consultants with versions of the system with different interaction design components built on the architecture (Figure 3.1). Our goals were:

- To identify candidate overlay structures for later studies;
- To investigate the relationship between overlay structure and underlying text structure; and,
- To uncover unforeseen interaction issues.

3.3.1 Participants

Three IBSVI worked with us on this project as consultants. They have live experience as they have visual impairment and as they volunteer to help other IBSVI in the community

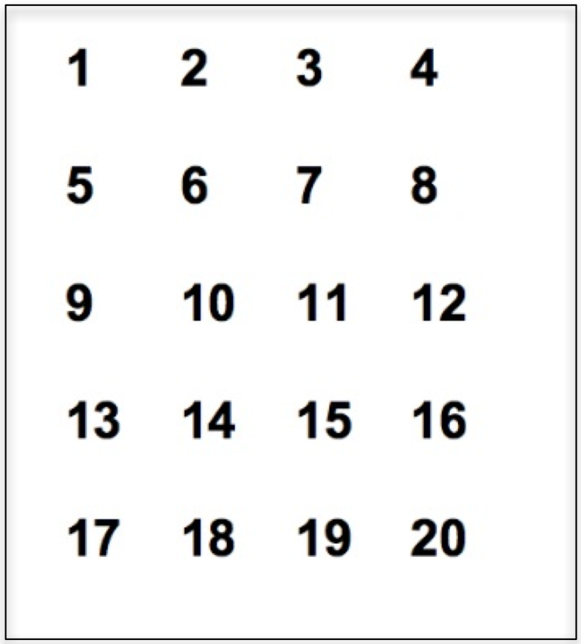


Figure 3.7: Reading exercise.

through the Roanoke Alliance for the Visually Enabled (RAVE). Also, they have experience with technology related to accessibility as they had participated in the design of several mobile technologies. They are all legally blind. They do not have other disabilities. Their demographic data are presented in Table 3.2. None of the consultants were Braille literate. Two of the consultants could read text larger than 14 point Arial bold. Audio books or large print was the preferred reading medium for all the consultants.

3.3.2 Experimental Procedure

At the beginning of the participatory design session, the consultants were given a familiarization session where we introduced the iPad and the Reader system to them. They were given an easy reading exercise in which numbers in large font size were displayed in a tabular layout (see Figure 3.7). This exercise was designed to introduce the consultants to reading using the STAAR system. In the reading task, the consultants were asked to read two pages from the novel “A Tale of Two Cities”. One page was rendered in the *Large text page model* typographical configuration, and the other was in the *Small text page model* configuration.

The consultants were asked to read both pages of text by using the three overlays A, B, and C (see Figure 3.4). The three overlays used in the study were embossed using a ViewPlus Imprint Braille embosser. Screen protective films (made of plastic) for the iPad were used in place of paper to emboss a certain pattern of lines. Plastic protective films were chosen as a material because of their sensitivity and transparency. Overlay A (Figure 3.4) had 14 embossed horizontal lines. A horizontal line on this overlay was made such that two lines without any space between them ran together from one end of the plastic overlay to another. Overlay B (Figure 3.4) had 30 embossed lines. This overlay had more embossed lines but the embossed dots making up these lines were less pronounced than overlay A. Overlay A was embossed with a line thickness of 2 points whereas overlay B had a line thickness of 1 point. After every 4 single embossed lines, double-embossed lines (i.e. two rows of embossed dots without any space between them) were provided in this overlay. Three vertically embossed lines that divided the horizontally embossed lines were also provided on the overlay. The vertical and the double-embossed lines were provided to help the users better spatially perceive the page. Overlay C (Figure 3.4) had 30 embossed lines and vertically embossed lines similar to overlay B. But in the overlay C, all the 30 lines were double-embossed i.e. each line was a combination of two embossed lines and in place of three there were two vertically embossed lines.

As the consultants used the system, they gave feedback and suggested design ideas. After each trial, s/he was asked about the good and the bad of the system, and what would be the pattern of the best overlay according to her/him. Also, they were asked about the vertical lines and whether they found them useful.

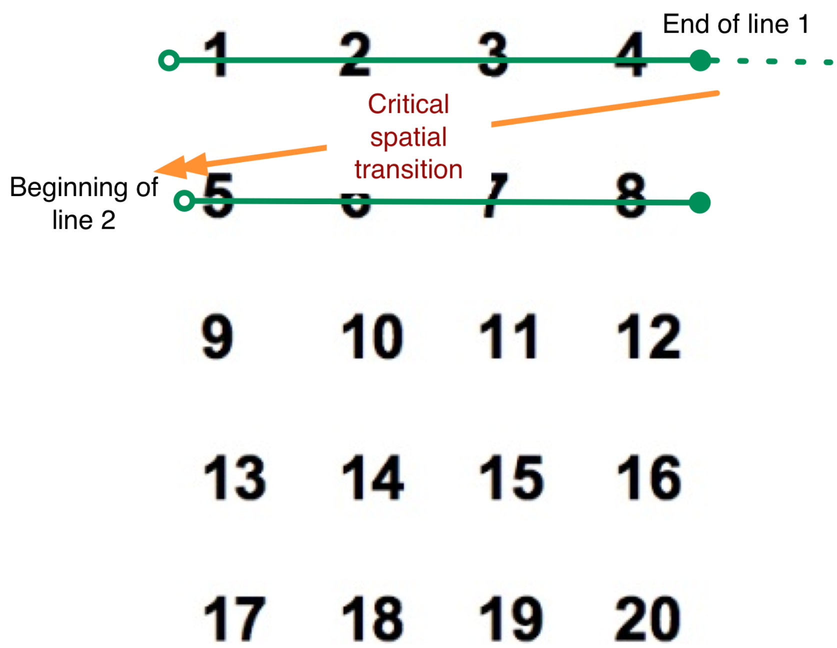


Figure 3.8: Reading problems.

3.3.3 Results and Discussion

The consultants found it difficult to read using the system because of two main problems. First, the system did not inform them when they reached the end of line of text (see Figure 3.8). Hence, when they read short lines that may occur at the end of a paragraph, and they reached the last word in the line, they continue moving their finger until the end of the physical line. As the system did not synthesize any words when they touched the blank part of the physical line, nor gave them appropriate feedback, the consultants became confused and frustrated. The second problem, we call it *the critical spatial transition* (see Figure 3.8). The biggest challenge our consultants faced while reading using STAAR was to find the beginning of the next line after finishing reading a line. For example, after reaching *number 4* in Figure 3.8, they could not find *number 5*. Sometimes they skip a line, and in other instances they went to the same line again. One of the consultants developed a strategy to solve this problem. She moved her finger along the read line backwards until s/he reached the first word of the line, then moved her finger vertically down to find the first word of the next line. Although this strategy was useful in locating lines, it was annoying to the consultant to hear the same line again and in the reverse order.

The conclusions of the participatory design session are driven by both the consultants' feedback and the researchers' observations. We grouped the consultants' feedback and their subjective opinions. All consultants found the overlay is useful in adapting to the iPad. They did not like the Thick lines and found them confusing. One of the consultants said that she likes the overlay to be even like a notebook page. They had different opinions about specific parameters of each overlay. For example, two of them said that the vertical lines helped them to remember their place on screen and to go back to a previous visited location. The third consultant said that she didn't make use of the vertical lines but they did not cause any harm. The consultants suggested adding haptic icons on the overlay to mark soft buttons in the application and to mark the application's touchable icons (or buttons). During the session, the researchers realized that the consultants were not able to differentiate between the active area of the iPad screen and the black inactive border. This is because none of the tested overlays have landmarks for the active area of the screen. Also, the system does not respond to the user's touch unless s/he touched the active area. We define the active area of the touch device as the area of the surface where the user's touch is tracked. Additionally, we realized that the consultants tended to use multiple fingers during their interaction with the iPad. Usually, IBSVI used one finger as an anchor or reference location, and one finger for interaction.

Our sessions with this system produced the following findings that were incorporated into our design for the next study. We group these findings into three categories: A. Relating to the *overlay and text layout*; B. Relating to *sonification and feedback for page mapping*; and C. Relating to the *interaction and page model* as whole.

A. With respect to the overlays and text layout

1. We narrowed the overlay designs to just two a wide (0.4 line separation) and a dense (0.25 line separation) design;

2. The text need not line exactly with the overlay embossed lines, but text size should be maximized as much as possible;

3. The line thicknesses in the overlay should be simplified to just two thicknesses (we tested different embossing thicknesses, and this led to confusion);

4. The overlay needed a tactile boundary to delineate the active touch area from the rest of the surface because the iPad has a single smooth glass sheet over both the active area and the boundary frame;

5. A vertical ruler is needed to help the IBSVI to locate herself vertically on the page. The new design would have a portion of the embossed ruler markings inside the active area and a portion in the non-active frame. This allows the IBSVI to use the portion of the ruler in the frame for spatial anchoring without inadvertently triggering a touch;

6. Tactile embossed buttons should be provided to serve as references for soft buttons in the interface. Although they were sonified as if the VoiceOver is activated, our consultants preferred having tactile confirmation of the button locations;

7. We had run a standard iPad screen protector through our embosser to produce the overlay. This overlay proved too impervious to the embossing process, and resulted in a less than satisfactory solution. We identified a Embossables [28] as a suitable material to produce the overlays. They are transparent thin plastic sheets that can be glued to the iPad screen and removed easily.

B. With respect to sonification and feedback for page mapping

1. Sonifications informing the IBSVI that she is touching whitespace is needed to help her map out the page. We selected a subtle rustling sound similar to the sliding of a finger over physical paper for this; and,

2. End-of-line sonification is needed to inform the IBSVI that she has arrived at the last word on the line. This is especially important for short lines of text, where the IBSVI may get lost trying to find the next word beyond the end of line. We employed a *typewriter ding* for this sonification. We note that because of the size of Braille letters and books, Braille typically encodes text from edge to edge on the page. This distorts the original page layout. Our solution maintains spatial integrity with page format with respect to print.

C. With respect to the interaction

Reading by IBSVI requires at least another point of tactile reference beside the reading touch point. The IBSVI consultants touched the screen either with the non-reading hand or with the base of the palm of the reading hand to provide a spatial anchor. Our interaction model thus has to model the reading touch point and distinguish it from other points of contact (that are ignored).

In sum, the PD validated our hypothesis of spatial reading. We also identified additional usability issues we had missed, and prioritized the next phase of development.

Chapter 4

The Reader System

4.1 Introduction

The participatory design sessions led to changes in both the system and the overlay patterns. We designed and developed a *Multi-touch Interaction subsystem*, which is explained in details in Section 4.2. Also, we added new elements to the overlay design, and reduced the overlay design space to two patterns. The new overlay design and the specifications of the overlays are given in Section 4.3. The *Reader System* with its new multi-touch interaction subsystem and overlay design are tested in lab-controlled usability study. Section 4.4 presents the study and its findings. The results of the study led to another iteration of the system development. The reader system was refined, and a set of page sonifications were designed and added to the system, as explained in Section 4.5. We called the system at this stage: Advanced Reader System. The system was then tested by a group of IBSVI for two weeks in an experience sampling study. Section 4.6 discusses the procedure of the study and the results. The experience sampling study showed that the system's usability was increased compared with the results of the usability study.

4.2 Multi-touch Interaction subsystem

This subsystem handles different interaction mechanisms and gestures. Depending on the number of touches on the screen, the interaction module will decide the appropriate response that the system should take. As this system is designed specifically for IBSVI, we had to study and understand how IBSVI may interact with tactile devices, especially with touch screens. There exist previous research on using devices with small touch screens such as iPods and smart phones with eye-free interaction [50, 90, 105] and IBSVI were able to use these touch devices. However, the size of such devices is relatively small. We designed the system to be run on the iPad, with dimensions of 9.50 inches by 7.31 inches. As the touch area of the iPad is relatively large, we found that a group of IBSVI users need to rest their palms on the iPad screen to provide a spatial reference for their hands while they are reading lines on the top of the page. Another group of IBSVI users were trying to use two fingers while they are reading, one finger for reading and the other one for following, also for the purposes of spatial reference. Hence, it is necessary for the interaction system to track the number, position, and direction of touches, and then to interpret these data to obtain an understanding of the real meaning of the user's touch intent. The main rule followed by this module is that as long as there is a detected touch that is moving constantly from left to right, the system will consider this touch as the reading point and will neglect any other detected touch.

In this subsystem, we handle two types of touch: reading touch and control gestures. Reading touch refers to a set of touch-configurations that can be used for reading text. Control gestures are the gestures that are used for browsing the document and navigating between pages. Each touch is handled by our system to serve the different modes of interactions that can be initiated by a BSVI user.

4.2.1 Reading Touch-One Touch Interaction

In order to read a single word on a page, the user can simply touch the word. When a single touch is detected, the system determines the closest word represented by its line segment, subject to a maximum distance. The distance of a touch point from a word is computed as its distance from the finite line as illustrated in Figure 4.1. Applying a simple inner-product computation, we determine if the touch point is within the projection of the finite line. If it is, d(C,S) is computed, else the closer of d(A,S) and d(B,S) is distance of the touch point from the line. Additionally, the user can move her finger horizontally from left to right to read a line of text continuously. Further details of how the system interprets the continuous touch are explained in Section 4.2.2. Beside single discrete touch and continuous touch, the touch interaction module gives the user the facility to read the whole line at once if the user touches the same location on a text line twice. This gesture is equivalent to double tap for sighted users. When this occurs, the system determines the text line (each associated with

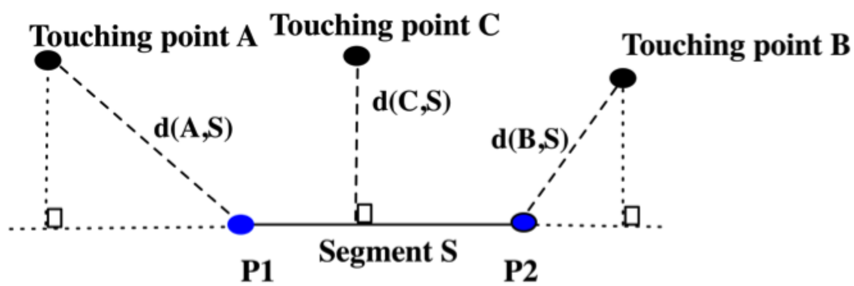


Figure 4.1: Distance between a segment and a touching point.

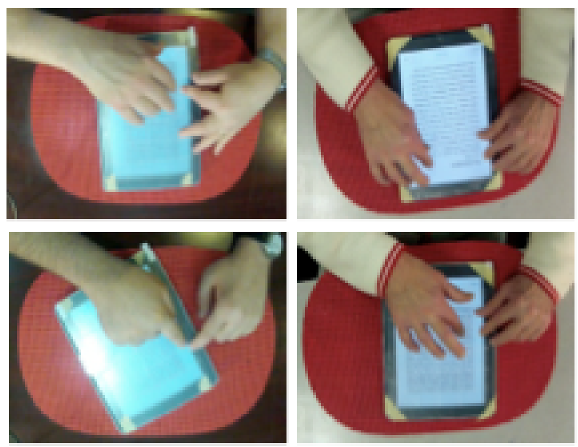


Figure 4.2: Different multi-touch interactions.

a Hot Spot) closest to the touch, and sends the entire line to the TTS to be rendered to speech. To stop reading, the user can issue the stop reading touch gesture by touching the screen with four fingers and then lifting them.

4.2.2 Reading Touch-Multi Touch Interaction

In our pilot studies, we found that IBSVI found it hard to keep place with only the reading finger on the iPad screen. They often need a secondary touch point for spatial reference. This module is responsible for handling two general cases of multi-touch: intended multi-touch and unintended multi-touch. Figure 4.2 shows IBSVI using STAAR and interacting with multiple touches. Intended multi-touch is when the user is aware of using more than one touch to read one word or one line. There are three cases of intended multi-touch:

1. The user is resting her palm on the bottom area of the iPad screen and read, with a moving finger, a line at a point higher up on the iPad screen. In this case, the multi-touch interaction module tracks the moving finger and ignores the detected touch that is below the moving finger (Figure 4.2. top left).

2. The user moves one finger from left to right for reading and moves another adjacent finger that trails the reading finger to the left. As the module detects both touches, it activates the words touched by the most right touch and ignores the touch by the most left touch (Figure 4.2. top right).

3. The user uses her left hand to move up and down on the left margin, while her right hand moves from left to right on the text lines. In this case, the system will generate the audible icon of line finding only once when the user hits a text line on the left margin. This will be followed tracking the rightmost finger and sending the touched words to the TTS (Figure 4.2. bottom left).

Unintended multi-touch is when the user assumes she is touching the iPad screen with only one finger while she is actually touching the screen with more than one finger (Figure 4.2. bottom right). This usually happens when the user has a shaking hand and she accidentally touches different points on the screen, or when the user is holding the iPad with one hand and reading with the other hand and then the holding hand accidentally touches a point on the active area of the iPad screen. In this case the system will track the consistent finger movement from left to right and ignores any other detected touches. To accomplish this, the module keeps a record of previous touches. If one of the current touches is close to the previous touch, it will be set as the reading point and the other touches will be treated as noise.

4.2.3 Navigational Control Gestures

In order to provide a multimodal interaction for IBSVI, we augmented the haptic buttons on the plastic overlay with gestures. We have appended three virtual buttons beneath the reading area for document navigation. The buttons are used for navigating the rendered document by page and by chapter. These 3 buttons are not typical buttons; they are actually regions that can be entered with a moving touch from outside the region. When a finger first enters the button region, the button label is announced audibly. A second touch with a momentary lifting of the finger activates the button. The rationale for this design is that IBSVI cannot see the button to tap it. Audible announcement of the button on first touch is needed to initiate the interactive task. Hence, we designed control gestures that treat virtual buttons as zones that can be tapped or moved into by the user. The first touch to any of the buttons zones will trigger the buttons name similar to the VoiceOver function. The second touch to the same button zone will activate the buttons function following by announcing the page number of the page moved-to. Speaking aloud the number of the new page gives the user an instantaneous audio feedback, which informs her with her current location in the document. Alternatively, users can use gestures in the reading area without having to search for the buttons. Swiping with three fingers from left to right will take the user to the next page. Swiping with three fingers from right to left will take the user to the previous page. Figure 4.3 shows the different multi-touch interaction modalities that the IBSVI could use for reading and navigating a document.

4.3 The Overlay Model: Re-visited

We incorporated the consultants' advice and feedback in the overlay design and reduced our design space to the 2 overlays shown in Figure 4.4. The overlays details are summarized in Table 4.1. In the design of these overlays we introduced 3 elements:

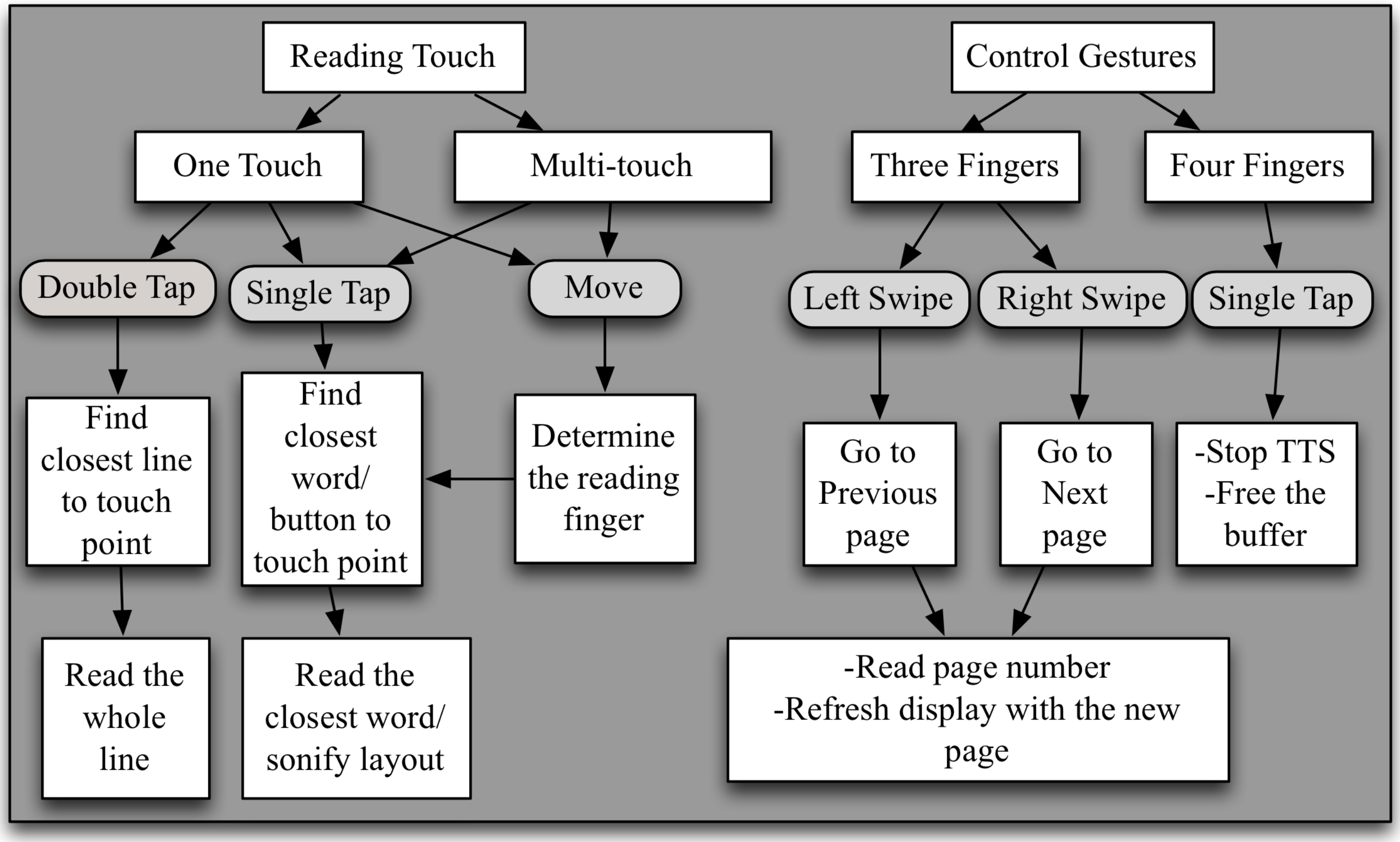


Figure 4.3: Multi-touch interaction modalities.

1. The border:

   The border marking (raised points) of the overlay serves two purposes. The first is to help the IBSVI locate the active area of the touch device. The second is to provide a kind of ruler marking to support grid-based landmarking or spatial referencing of the device surface.

2. The rulers:

   These rulers reside at the border (typically top and left) of the device. A vertical ruler comprises a vertical line that is spanned by short horizontal lines at fixed intervals. A portion of the horizontal line will be inside the active area of the surface, and a

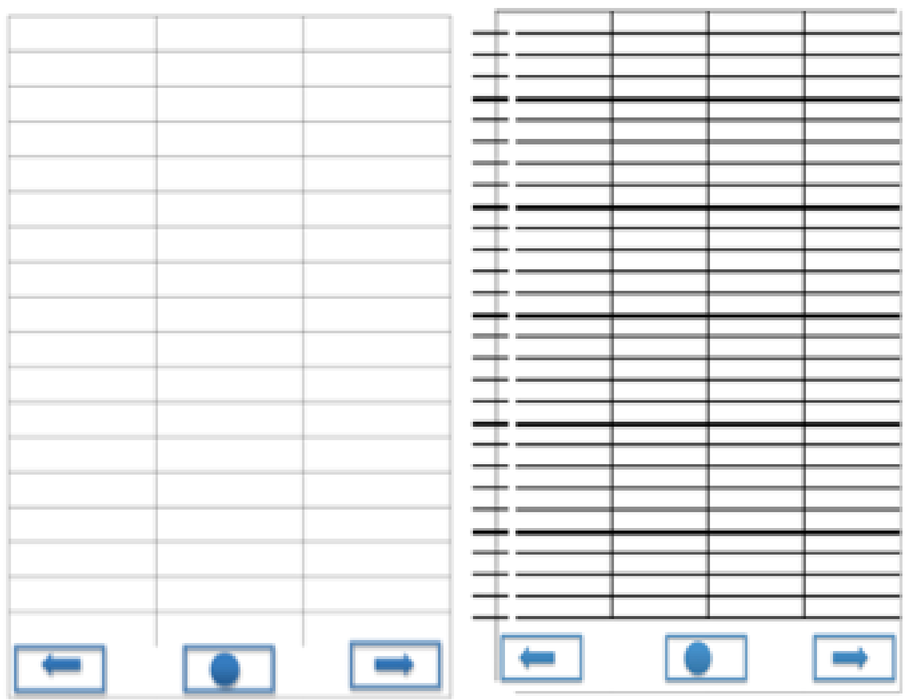


Figure 4.4: Left: Wide overlay. Right: Dense overlay.

portion will be outside. This allows the user to use the markings outside the device surface for landmarking without necessarily or inadvertently activating the device, and the portion of the marking in the active area allows the system to track the location of the touch along the vertical ruler, and to provide appropriate feedback. For example, a program for reading text can use the touch inside the active area to know if the user is at a line of text. The user can use the markings outside the active area to help navigate from memory. The horizontal ruler is identical to the vertical ruler except that it marks the vertical columnar position of the surface.

3. The tactile buttons:

   The buttons are used as tactile landmarks for the soft buttons on the touch screen. Each button consists of a rectangle with a distinguishable haptic icon mapped to it.

Table 4.1: The overlays specifications.

Parameter	**Wide Overlay**	**Dense Overlay**
Punch depth	2	2
Orientation	Portrait	Portrait
No. of Horizontal lines (HL)	20	31
Distance between HL	0.4	0.25
Thickness of HL	1.50	2.25
Thick line (TL)	N/A	4HL 1TL
Thickness of TL	N/A	4.50
No. of Vertical lines (VL)	2	3
Thickness of VL	1.50	2.25
Vertical Ruler (VR)	No	Yes
No. of VL in VR	N/A	23

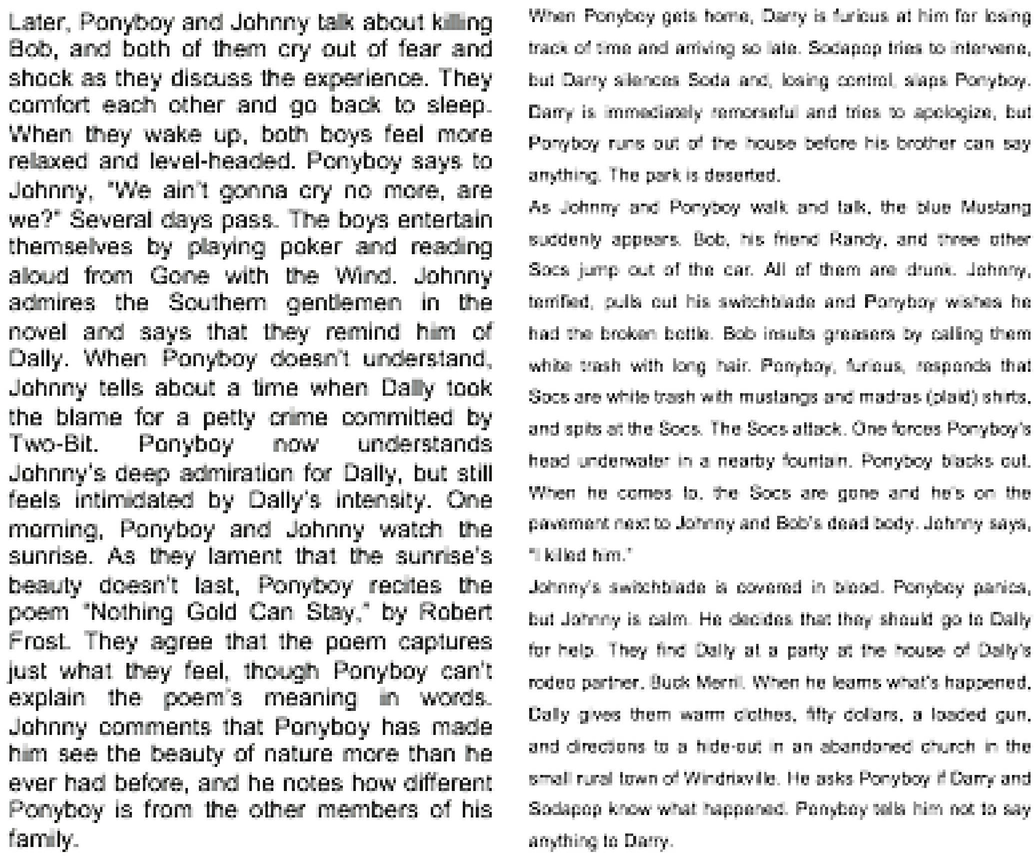
4.4 Usability Study

We tested the system derived from *the PD sessions* with a group of new IBSVI participants. The goals of the study are:

1. To learn the *maximum accessible density of text* that can effectively be tracked using overlays;
2. To learn the most *effective parameters for the overlay* that will guide users to find all text and haptic icons; and,
3. To identify *potential design concerns* to be addressed.

4.4.1 Method

We conducted a 2x2x2 full factorial within-subjects study. We tested three parameters of our system: overlay, text size, and speech rate. Each parameter has two values. The overlay



Later, Ponyboy and Johnny talk about killing Bob, and both of them cry out of fear and shock as they discuss the experience. They comfort each other and go back to sleep. When they wake up, both boys feel more relaxed and level-headed. Ponyboy says to Johnny, "We ain't gonna cry no more, are we?" Several days pass. The boys entertain themselves by playing poker and reading aloud from Gone with the Wind. Johnny admires the Southern gentlemen in the novel and says that they remind him of Dally. When Ponyboy doesn't understand, Johnny tells about a time when Dally took the blame for a petty crime committed by Two-Bit. Ponyboy now understands Johnny's deep admiration for Dally, but still feels intimidated by Dally's intensity. One morning, Ponyboy and Johnny watch the sunrise. As they lament that the sunrise's beauty doesn't last, Ponyboy recites the poem "Nothing Gold Can Stay," by Robert Frost. They agree that the poem captures just what they feel, though Ponyboy can't explain the poem's meaning in words. Johnny comments that Ponyboy has made him see the beauty of nature more than he ever had before, and he notes how different Ponyboy is from the other members of his family.

When Ponyboy gets home, Darry is furious at him for losing track of time and arriving so late. Sodapop tries to intervene, but Darry silences Soda and, losing control, slaps Ponyboy. Darry is immediately remorseful and tries to apologize, but Ponyboy runs out of the house before his brother can say anything. The park is deserted.

As Johnny and Ponyboy walk and talk, the blue Mustang suddenly appears. Bob, his friend Randy, and three other Socs jump out of the car. All of them are drunk. Johnny, terrified, pulls out his switchblade and Ponyboy wishes he had the broken bottle. Bob insults greasers by calling them white trash with long hair. Ponyboy, furious, responds that Socs are white trash with mustangs and madras (plaid) shirts, and spits at the Socs. The Socs attack. One forces Ponyboy's head underwater in a nearby fountain. Ponyboy blacks out. When he comes to, the Socs are gone and he's on the pavement next to Johnny and Bob's dead body. Johnny says, "I killed him."

Johnny's switchblade is covered in blood. Ponyboy panics, but Johnny is calm. He decides that they should go to Dally for help. They find Dally at a party at the house of Dally's rodeo partner, Buck Merril. When he learns what's happened, Dally gives them warm clothes, fifty dollars, a loaded gun, and directions to a hide-out in an abandoned church in the small rural town of Windrixville. He asks Ponyboy if Darry and Sodapop know what happened. Ponyboy tells him not to say anything to Darry.

Figure 4.5: Example of Large and Small font size.

could be wide or dense. The text size could be small or large. The speech rate could be varied or fixed. The full combination of these parameters leads to 8 conditions. We built STAAR using Objective C, and ran it on iPad 2 with operating system iOS 5.1. We rendered two sets of text, which were compiled by MSWord. The first set was in the *Large text page mode* typographical configuration. The second set was in the *Small text page model* typographical configuration. An example of a Large (LF) and a Small font (SF) is shown in Figure 4.5 at left and right respectively. The SF and the LF pages had 1.5 line spacing. The top, bottom, left, and right margins were set to 1.0 in both SF and LF pages. The LF page has an average number of lines = 21, average number of words = 178, and average number of characters without spaces = 872.5. The SF page has an average number of lines = 24, average number of words = 235, and average number of characters without spaces = 1126.67.

Table 4.2: Conditions of the study.

Task	**Overlay**	**Font Size**	**Speech Rate**	**Article**
1	WO	LF	FSR	1
2	WO	LF	VSR	2
3	WO	SF	FSR	3
4	WO	SF	VSR	4
5	DO	LF	FSR	5
6	DO	LF	VSR	6
7	DO	SF	FSR	7
8	DO	SF	VSR	8

In order to examine the effect of the overlay on the system accessibility, we designed two overlays: one with wider spacing (WO), and one with denser spacing (DO) as shown in Figure 4.4. The number of horizontal lines in former overlay is 20 and the distance between the horizontal lines is 0.4 inch. For the denser overlay, the number of horizontal lines is 31 and the distance between them is 0.25 inch. The specifications of the overlays are summarized in Table 4.1 To test self-paced reading, we added two conditions: fixed speech rate- FSR (default TTS speech rate) and variable speech rate VSR (TTS speech rate is regulated by finger speed). The study conditions are summarized in Table 4.2. For the dense overlay, we added a vertical ruler on the left (see Figure 4.4-Right) and horizontal ruler above the landmark grid. Every 5th line in the rulers was thickened. This allowed us to gauge the effectiveness of these features.

4.4.2 Participants

Sixteen BSVI participants were recruited for this study. Because of the demographics of the community group that helped in our recruitment efforts, the participants ages ranged from 34 to 91, with mean age of 69 (SD = 33.3, Median=75). Figure 4.6 shows a summary for the participants data. Nine participants were females and seven were males. Three participants

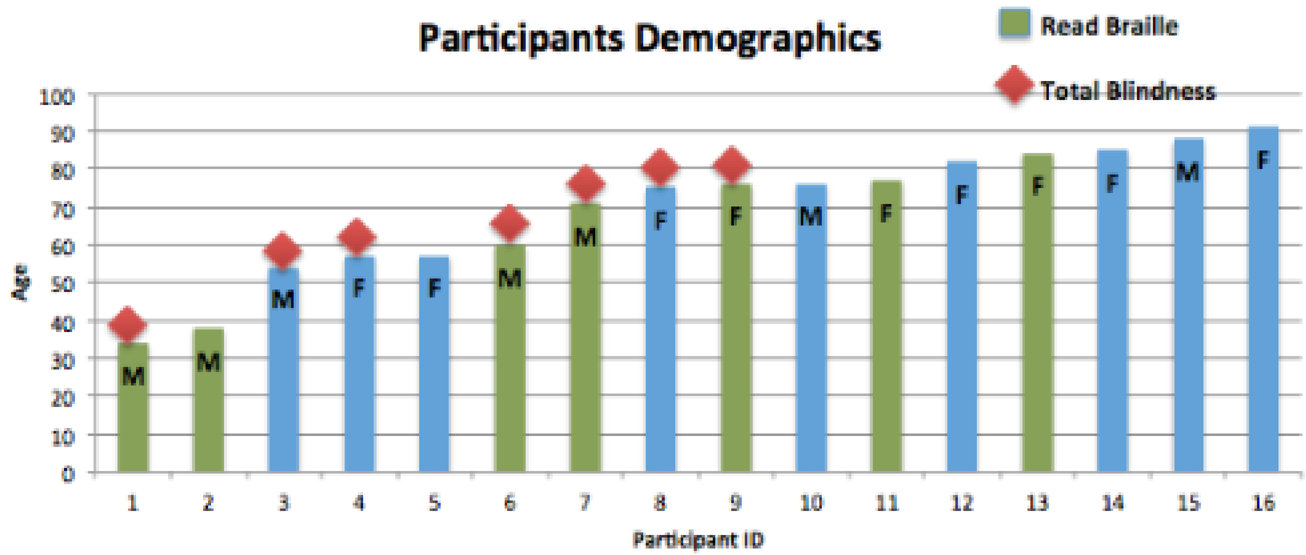


Figure 4.6: Demographics of the participants.

were born blind, four had total blindness and eight have severe visual impairment. As defined by the American Foundation for the Blind (AFB) and Individuals with Disabilities Education Act (IDEA), severe visual impairment is a term that describes individuals with visual acuity less than 20/200. Six of the participants could read Braille and 15 participants preferred audio as a reading medium.

4.4.3 Experimental Procedure

We conducted a within-subjects study with all participants doing all eight conditions in Table 4.2. The order by which the conditions were presented to the participants was counterbalanced using a Latin square matrix. We prepared 8 articles of one page length to be used for each trial. Each participant was given 5 minutes as a maximum time to complete reading the page and then was asked 3 questions about the article. All articles were at a 8th grade level based on the Flesch-Kincaid Reading Ease scale [36]. The Flesch-Kincaid scale is typically used to ensure readability of text [29, 34, 97]. The usability metrics employed were scenario completion, errors, time on task, and mental workload that is measured by

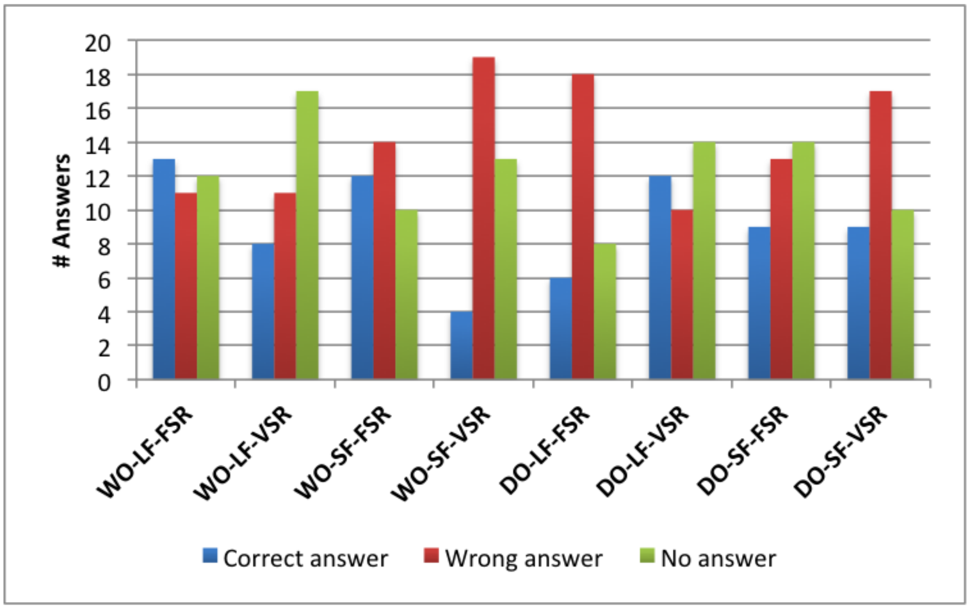


Figure 4.7: Knowledge transfer results.

the NASA Task Load Index (TLX) [43]. At the beginning of the study, participants were introduced to the system through a preset 5-10 minute familiarization session, and at the end of the study each participant was interviewed using a post questionnaire and semi-structured interview. The tasks were audio and video recorded for further analysis. Two video cameras mounted on tripods were used to record the participatory design session. One of the cameras was mounted at the face height of the consultants and the second camera was mounted so as to capture the hand gestures of the consultants from the top view.

4.4.4 Data Analysis

We divided the participants' answers into 3 categories: correct answer (CA), wrong answer (WA), and no answer (NoA). We considered an answer to be NoA if the participant was not able to reach the part of the article where the answer is on time. Also, if the participant simply said "I cannot remember" or "I am not sure" we considered this as NoA. CA and WA categories are self-explanatory. Of the 16 participants, only 12 were able to go through the whole series of benchmark tests for logistic reasons. In this analysis, we report the frequencies

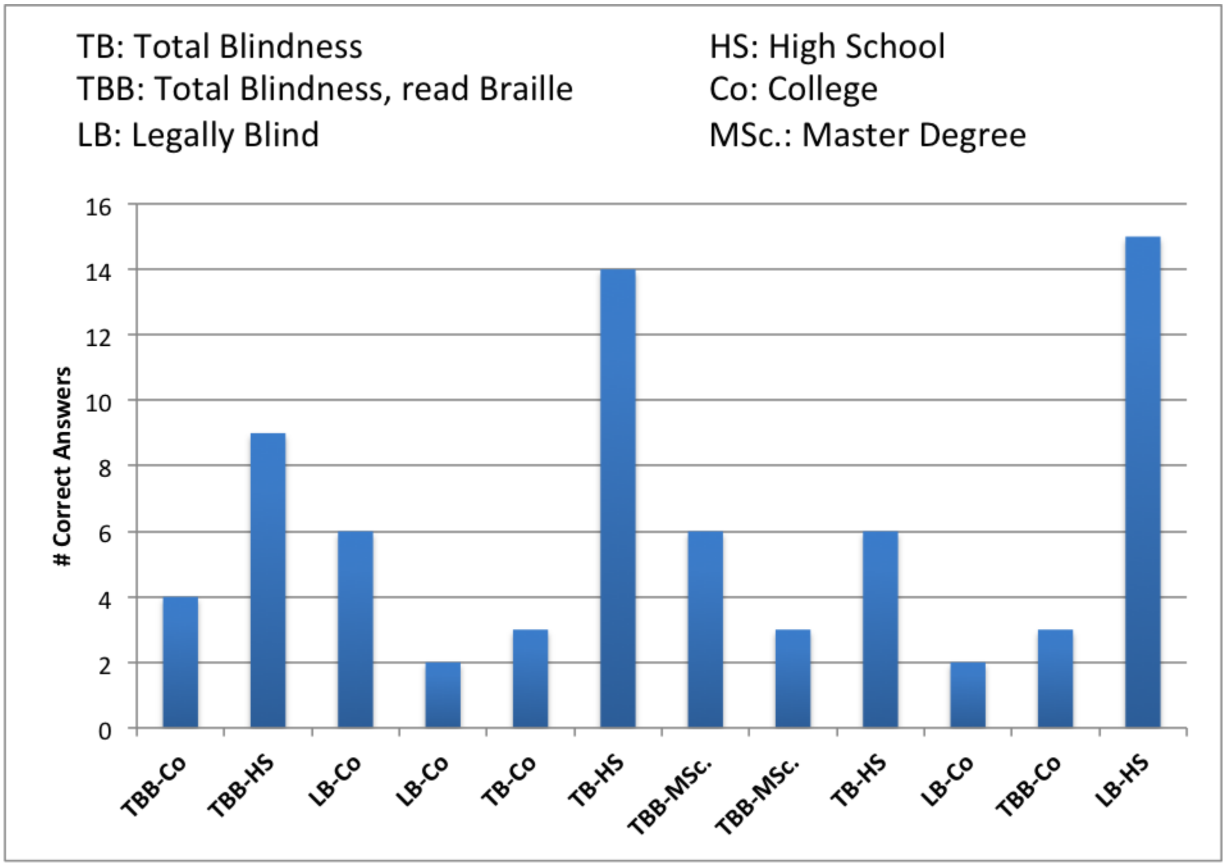


Figure 4.8: Number of correct answers for each participant.

Table 4.3: Critical incidents extracted from the videos.

Critical Incident	**Abbreviation**	**Description**
Whole Line	WL	A whole line of text was read successfully.
Longest Sequence of Words	LSW	The longest sequence of words that was read successfully.
Skip Line	SL	The user skipped a line while moving from line to line.
Wander Between Lines	WBL	The user while reading a line accidentally read the line above or below.
Repeat Same Line	RSL	The user read the same line more than once in a row.

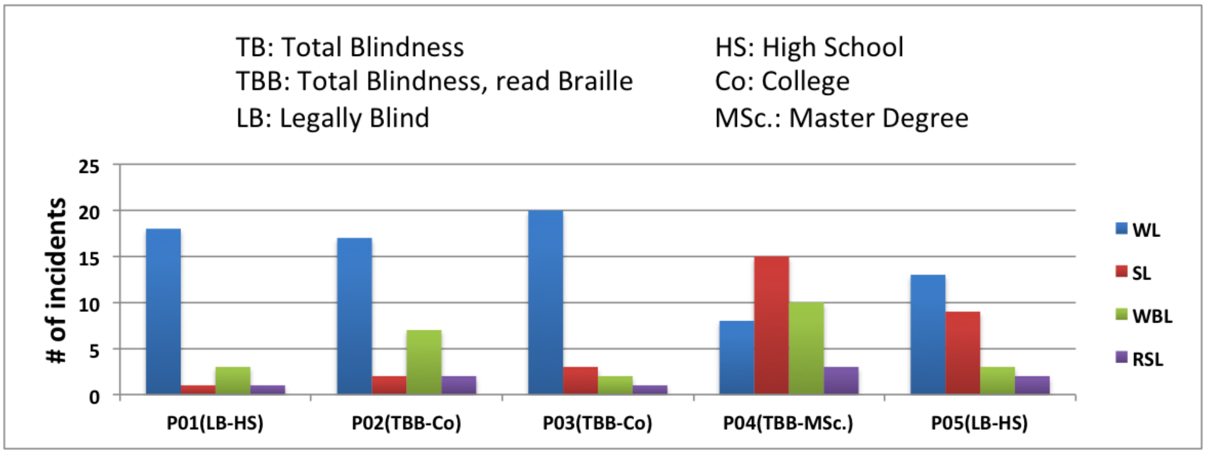


Figure 4.9: Video coding using the critical incidents analysis.

of CA, NoA, and WA rather than the means. This is because the data is nominal in its nature. The total number of questions is 288 (8 articles X 3 questions X 12 participants). The total number of CAs was 73; WAs totaled 113, and the number of NoAs was 102 (Figure 4.7). The worst results occurred at the fourth benchmark test (WO-SF-VSR). Only 4 answers out of 36 were correct, (19 NoAs, and 13 Was), which indicates the current design and conditions were difficult for participants. Obviously, participants were not able to locate all the text and large amounts of information were missed. The reason for this is that the landmark information is not dense enough with the wide overlay and small font, and the TTS fast speech mode of the VSR compounded the difficulty in comprehension. We re-analyzed the results taking individual differences into consideration. The data for 12 participants (P01 to P12) are shown in Figure 4.8. The graph shows the number of correct answers for each participant, along with her level of blindness, level of education, and Braille literacy. We find that 2 participants answered 14 and 15 questions correctly, whereas other 2 participants could only answer 2 questions correctly. Participants who obtained the highest CA in the benchmark tests were not frequent readers. Participants who are used to read using audio books obtained average CA. Braille readers (BR) participants obtained the lowest CA. This counter-intuitive finding results from the fact that Braille readers stroke the Braille characters from top to bottom to read. This is a deeply-learned and practiced skill. The STAAR model is for the reading point to move smoothly from left-to-right, and the stroking was interpreted as multiple touch and lift instances. They also expected one-to-one correspondence between the overlay embossed lines and the underlying text. Although researchers repeatedly advised them that the overlay is not coincident with the electronic text, BRs continue searching for text at the raised lines. In the post study interview, participants who read regularly using Audio books find our system boring and slow, they do not like the idea of scanning a whole page with a finger to read word by word or even a line at a time, they prefer to just tap a button to read the whole page at once. On the other hand, participants who do not read on daily basis find the system easy and fun to use.

During the study, we observed that the participants were able to operate STAAR to read most of the assigned pages. However, they were not able to answer most of the article-related questions correctly. To better understand the reasons behind these low knowledge transfer results, we analyzed the recorded videos. The recorded videos were analyzed using the critical incident technique [35]. Critical incidents are incidents when some functions of the system can either obstruct or support the comfortable use of the system by the users. We extracted a set of critical incidents from the videos, the incidents were chosen for the goal of answering the research questions, and to give us insight about the interaction modeling and the interface of the system. A description and an abbreviation for the critical incidents are given in Table 4.3. We focused our analysis on 5 participants' videos. Two participants (P01 and P03) reported no answer for all the questions. Two participants (P02 and P05) reported relatively high percentage of correct answers, and one participant (P04) reported all her answers wrong. Additionally, in video analysis of Study 1, we coded the critical incidents as described in Table 4.3. Figure 4.9 shows the number of occurrences of critical incidents for each of the 5 participants. The abbreviations used in the chart legend are the same as described in Table 4.3. The first two critical incidents (reading a whole line without errors and longest sequence of read words without errors), are considered incidents of success, while, the other three incidents are considered incidents of no success. The critical incidents analysis showed that 3 participants skipped only 1, 2, and 3 lines respectively, while

2 participants (P04 and P05) skipped 15 and 9 lines respectively. We should note here that the high occurrences of failure in critical incidents were observed with the participants who were assigned to the condition SF-WO. Participant 02 skipped 2 lines and was assigned to a SF page as well; but she had the DO. Based on these data, there is some preliminary evidence that STAAR may enable IBSVI to read text with a density up to 235 words per page, where the dimensions of the page's reading area are 7-inch length and 5.5-inch width, provided that the page has similar dense tactile references.

The wandering between lines (WBL) is an important incident because it can reveal the multimodal interaction problems that could exist. Figure 4.9 shows that WBL occurrences ranged from 2 to 10, (M = 5, SD=3.39). When users could not maintain a horizontal line with the presence of the tactile overlay, it may be necessary to address this problem through the system software. Enabling IBSVI to maintain location on the same text of line without accidentally moving to another line is important for an effective reading experience. Since the IBSVI cannot see what she is reading, she also cannot know that she has wandered off the text line she is reading. Hence the words rendered by the TTS as she wanders off the lines will become a confusing jumble if the system provides no appropriate feedback that she has wandered off the horizontal line.

We investigated the repeating lines (RSL) incidents, and found that it occurred 1 to 3 times (M = 1.8, SD=0.8). It is confusing and distracting to users to read the same line more than once consecutively. Although RSL occurred with all of the participants, it had very low frequency. By analyzing the successful critical incidents, we found that participants P01 and P03 recorded the highest number of reading whole line (WL) incidents, and they read the Large page with widely spaced overlay. Following them in the third rank is participant P03, who read Small page with the densely spaced overlay. Our conclusion is that the matching between the text density and the overlay density is a critical factor for effective access of the reading material. The results also proved that Large page might be read with fewer errors than the Small page. We started our video coding assuming that there might be instances when a participant could not read a whole line, and that is why we tracked the longest

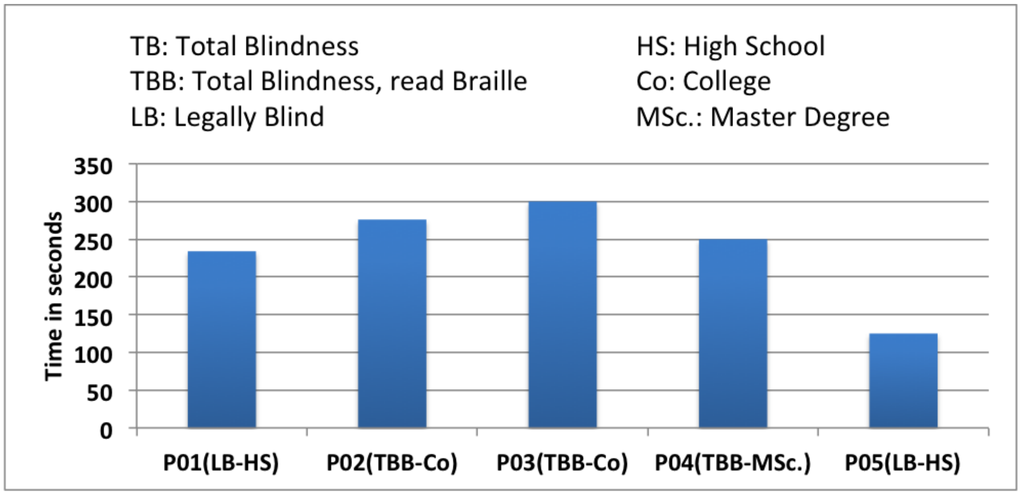


Figure 4.10: Task completion time.

sequence of read words (LSW) incidents. However, all the participants were able to read whole lines. Hence, there was no need to report the longest sequence of words. The time users need to spend in order to read with an acceptable performance should be convenient and at least equivalent to the time needed to read the same amount of information using Braille. As illustrated in Figure 4.10, the completion time ranged from 125 seconds to 300 seconds with a mean of 237 (SD= 67.5). Relating the time spent to read a whole page to the number of scored success and failure critical incidents, we can see that the more time the user spent on reading the page the more success critical incidents he/she scored and the less failure incidents too. On the contrary, when a participant spent less time reading, her performance is poorer. Four minutes as an average time to read a page can be acceptable as a preliminary timing threshold. However, we plan in our future work to shorten this amount of time. More flexible and coupled integration between the reading touch interaction and the speech generation can lead to more fluent reading with a significant reduction in the time taken.

4.4.5 Discussion

The results show that the users were able to let the iPad read most of the displayed pages, but the knowledge transfer results were low. We explained this by the lack of spatial contextualization in addition to the lack of enough familiarity with the system. The first point was revealed to us as we discovered that the relationship between the static overlay and the rendered text are difficult to correlate without a convenient immediate audio response from the system. The buffering model of the speech led to more spatial confusion to the participants. We found that the post interview feedback is consistent with the results of benchmark tests. Our explanation for these results is that BRs are well trained to read using a particular mechanism, which has similarities with STAAR (raised dots). STAAR requires the reader to move horizontally over the text while keeping contact with the iPad overlay. Braille is read by repetitively stroking the Braille raised dots up-and-down character by character hence experience BRs would habitually lift their fingers off the iPad surface as they read. The role of the raised dots in the system is completely different than its role in Braille code, and that is why BRs were confused. In a single session, it was hard for the BRs to adapt from such a deeply-learned skill as Braille reading. We believe that if BRs use STAAR for longer period of time, they will be able to use it more effectively. The results of Study 1 showed that STAAR can be operated by IBSVI, but the version tested is not yet functional enough to help with knowledge transfer. Our conclusions from the usability study are:

- The horizontal ruler is of no use for reading pages of text
- The vertical ruler is essential in helping IBSVI find next line of text, but feedback is needed when using the ruler
- The distance between horizontal embossed lines can be wide enough to have 2 lines of text in between at maximum. This allows an above-line, beneath-line strategy
- A tighter distance between horizontal lines on the overlay gives the user more location awareness

- Thick horizontal lines in the overlay are confusing
- VSR is confusing to the users with the current TTS configuration. Rather than being smooth faster text reading, the current TTS renders fast text in staccato fashion
- Speech buffering to allow the TTS to catch up when the reading finger moves too quickly leads to serious confusion. It violates the premise to allow the reader to form a mental spatial map of what she is reading. The user thought that the buffered words heard are under her finger, leading to more search behavior to find the place of reading leading to even more buffering and confusion
- More information needs to be conveyed to the users to help them create a mental map for the page, e.g. reaching end of page, and, moving to next line
- IBSVI needs longer time of exposure to the system before they can read fluently and smoothly. Reading is a high cognitive skill task that requires greater familiarity

4.5 Advanced Reader System

At this point of the research, we stabilized the Reader system interface and the overlay pattern. The reader interface (see Figure 4.11) is made up of 3 interaction areas: the vertical ruler area, the reading area, and the buttons area. These 3 areas are delineated for the IBSVI in the tactile overlay (Figure 4.12 and in the underlying system design. The *vertical ruler* runs along the interface on the left. It is composed of a vertical line spanned by a set of short evenly spaced horizontal lines. The ruler is designed to help the user to locate and situate themselves with respect to the text lines in the reading area. When the user's finger traverses along the vertical ruler, she will hear a click whenever the finger crosses a line of text. On the overlay, the vertical ruler is divided into two halves, the right half (R.H.S) is inside the iPad screen active area, and the left half (L.H.S) is on the non-active area of the iPad screen. The L.H.S. of the vertical ruler can be used by the IBSVI to anchor or

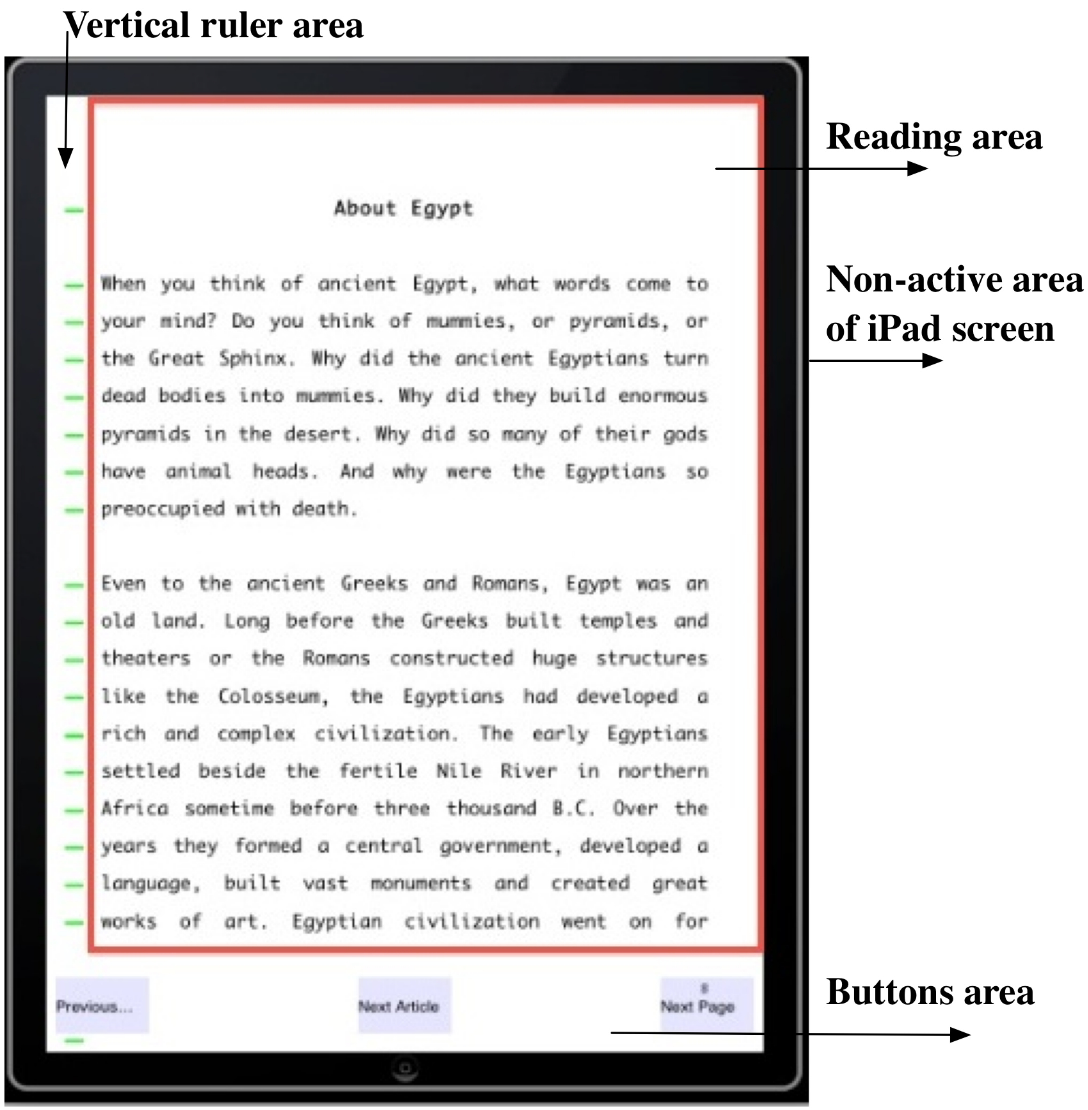


Figure 4.11: STAAR interface.

Figure 4.12: STAAR overlay.

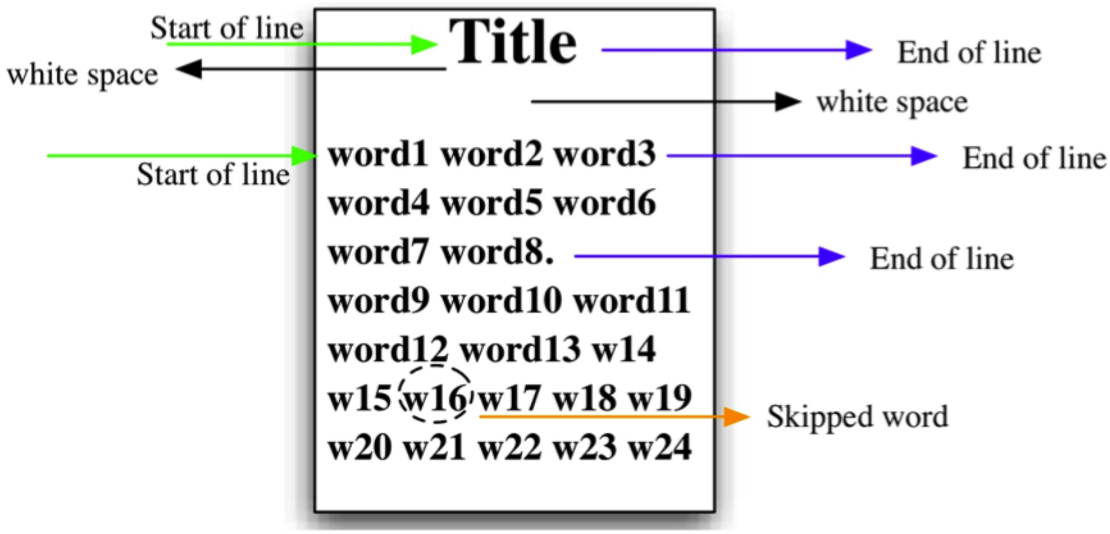


Figure 4.13: Example of a page layout.

rest their hands to hold their place without activating the reader system and inadvertently triggering some system function. The R.H.S. of the vertical ruler is a haptic landmark to facilitate location of lines of text in the reader system. The *reading area* at the center covers about 90% of the iPad screen, which is surrounded by a bounding rectangle is the reading area. The reading area contains text and white space around the text. The overlay features a border that defines the active area of the iPad screen, horizontal lines to help IBSVI follow straight lines, vertical lines to give more spatial information, and a separator line that is a thick horizontal line, which separates the reading area from the buttons area and indicates end of page. The raised border separates the active area of the screen from the surrounding glass frame. The *button area* at the bottom of the interface provides a consistent place for the user to locate the system's interaction buttons. The function of these buttons is to navigate the rendered document by page and by chapter. On the overlay, the buttons are embossed as rectangular boxes, each containing a different haptic icon; e.g. next page button contains a haptic icon of a right arrow.

Informed by the PD *sessions* and *Study 1*, we found that speaking aloud the words or lines on the page is not enough to provide the IBSVI with a rich spatial experience. There are other kinds of information that need to be conveyed to IBSVI to help them read with their touch combined with hearing rather than reading with touch alone as in reading Braille, or receiving text information by hearing alone as in audio books. Figure 4.13 shows an example of an example page layout: a page title in the middle of the first line in a big font size and then a set of lines of different lengths, different number of words and different word lengths. This page format has lines with different starting points and different ending points. The IBSVI has to be able to explore such a page without having any visual access. To facilitate this we added sonification to the reader system to support white space mapping, line finding, end-of-line awareness, and skipped word notification. We chose the audio feedback based on the meaning they should convey as follows:

1. White space sonification: We chose a sound that is similar to a finger sliding over paper. It is a low amplitude sound repeated at a 10 ms. interval. The sound stops when the user finger exits the white space area.

2. Line location sonification ($line_{loc}$): We selected a modified *lamp on* sound [45]. It is short and played only once. It is activated when the user is moving her finger along the vertical ruler and the finger crosses a text line. If the user lifts her finger and then goes back to the same location, the sound will be played again.

3. End-of-line sonification (EoL): We selected a *ding* sound that resembles a typewriter end of line sound. It is sounded after the *last word* in each line of text is read by the TTS system. This helps the user to know when to move to next line.

4. Skipped word sonification ($Skipped_w$): This is a short and fast *click* sound that is aurally distinct from the line location sound. It is activated when the reading finger moves too fast for the TTS to keep up. To illustrate this consider the word sequence w15 ... w18 in Figure 4.13. The reading point moved through w16 to w17 before w15 is completely sounded. In this case, the reading finger is in w17 when w15 completes. Our rule is that a word can only begin sounding if the read point is in it. Hence, w16 is skipped. STARR will sound "w15 <Click>w17" to let the user know that the skip occurred.

These page sonifications are crucial because they couple the plastic tangible overlay to the page rendered on the iPad screen, (see Figure 4.14). Without the sonifications, there would be no mapping to the structure of the underlying text. Moreover, the reader system needs to provide these responses in real time for the system to be usable. The importance of the page sonifications can be understood from Boyd's work [21], Boyde provided identification to the barriers that cause difficulties for IBSVI to access graphical user interfaces. The first problem is the psycho-motorical problem that is caused from the lack of feedback. As readers use their finger touch for interaction, it carries the function of the mouse. With each touch, users expect feedback. If the feedback is visual in the default interface, it must be substituted with another form for IBSVI to avoid the psycho-motorical problem. The *White Space* sonification is designed to give IBSVI feedback when they touch non-text area. The second barrier that is described in [21] is the semantic of the pictorial elements and layout [39] that sighted individuals can recognize and be informed with its typography and topology with additional information. The *End-of-line* and *Line location* sonifications will support IBSVI in accessing the semantics of the text in the page on the line level. These sonifications can leverage the usability of the system and give more support for IBSVI in developing a cognitive map for the page. With these incremental development to STAAR, we tested the system in an experience sampling study, see Section 4.6.

4.6 Experience Sampling Study

The goal for this study was to examine how STAAR may function in a typical use situation with the STAAR tablet reader functioning more as a portable device 'in the wild'. The goal is to investigate how experiencing STAAR for a longer time can improve the users' performance, and to follow up with the participants how they can use the system in their daily routine and what problems they might face with the system. We were interested particularly in individuals for whom reading is an integral part of their normal activity, and in Braille readers to see whether the problems we observed in *the usability study* would be

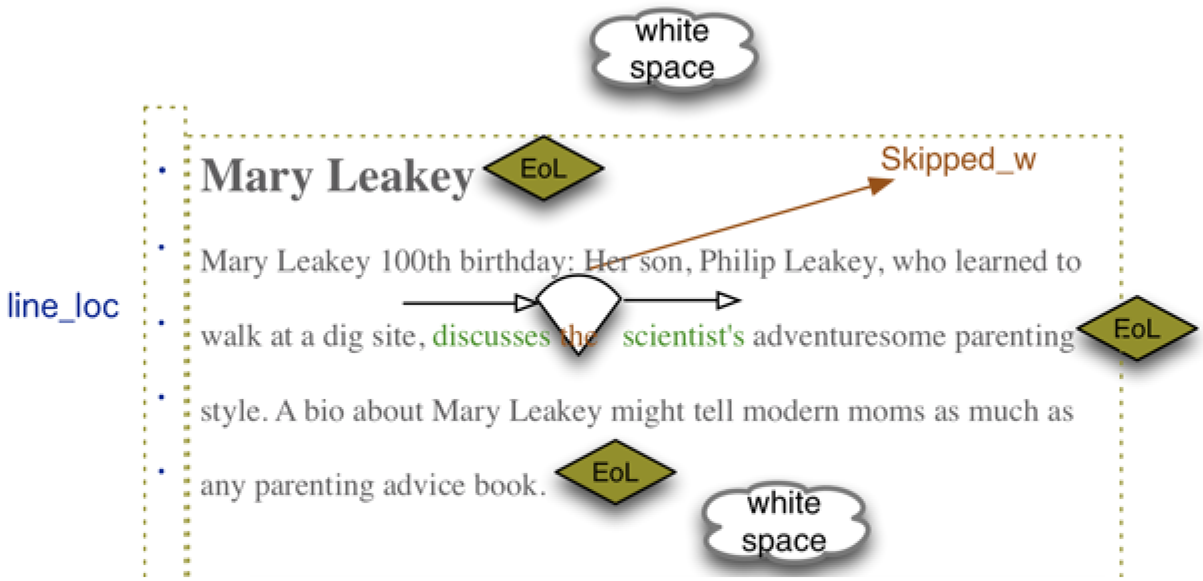


Figure 4.14: A graphical illustration for the page sonifications.

eliminated with greater familiarization.

4.6.1 Method

We designed a 2x2 full factorial within-subjects study. It was an experience sampling study [54] in which we seeded IBSVI with the device for a two-week period of use. The independent variables we tested in this study were text size and overlay. The text size took two forms: large (font size is 16) or regular (font size is 14). The overlay was either wide or dense. The differences between both overlays were the number of horizontal lines and the distance between the horizontal lines. Other than that, they were identical as both had a vertical ruler, border, buttons, and a separator line. Each participant was assigned to all possible combinations of the two variables, leading to 4 conditions.

4.6.2 Participants

We recruited 7 IBSVI, focusing on younger participants, and those with a need to read documents rather than those who only read for pleasure (where automated audio book readers have an obvious advantage). Participants' ages ranged from 27 to 77 with a mean of 53 (SD=16.01). Three participants were females and four were males. Five participants have total blindness, four of them were born blind, and two are legally blind. All participants could read Braille.

4.6.3 Experimental Procedure

Participants were asked to use STAAR for two weeks. We collected data using two methods. The first one was interviewing participants at the beginning, and at the end of the study. The second method was phone-interviewing the participants twice a week. We used the phone interview, in addition to collecting data, to encourage the participants to continue reading, and to answer any questions they may have concerning using the iPad or STAAR. The iPad given to the participants was only loaded by STAAR and all other apps of the iPad were disabled. Additionally, auto rotation, voice-over, and multi-touch gestures were disabled. These precautions were taken in order to make sure that we are testing only STAAR without interference of other variables that may be introduced by other iPad features. One overlay was glued on the iPad screen at the beginning of the study and then at the end of first week we replaced it with the other overlay, so that each participant will test both wide and dense overlays. The order of overlay presentation was counterbalanced. At the beginning of the study, the participants were introduced to the iPad device and then to STAAR. They had the opportunity to use the system for 10 minutes. They were then asked to read one article of 1.5 pages length and to answer three questions about this article. At the end of the two weeks, another benchmark test of equivalent length and difficulty was given to the participants, and data were collected by a post questionnaire and a semi-structured interview. During the two weeks, we phone interviewed the participants twice a week for

4 times in total. The participants were encouraged to read all the reading materials that were uploaded to the system during the two-week period. The reading materials included 5 articles for a total of 27 pages; all were equivalent to the 8th to 10th grade reading level according to Flesch-Kincaid scale. We prepared two documents of the same articles, one beginning with half of the pages in large font size and the other half in regular font size (Large-Regular), and the second document was the opposite (Regular-Large). Again, the order of conditions was counterbalanced, for example participant 01 began the study with the wide overlay and the document Large-Regular, and participant 02 was assigned to dense overlay with Regular-Large document. Four participants read all the reading materials in the two-week period, while 3 participants finished reading the 27 pages in only one week. As we wanted to see the effect of exposure to the system for a longer period and also for having the opportunity to compare between the two overlays (planned to be switched at end of week 1), we gave the 3 participants who completed the material in one week another 5 topics that were equivalent in length, order, reading level and font size to the first reading material collection to read at week 2.

4.6.4 Data Analysis

We analyzed the data of the knowledge transfer tests for all participants. We compared the results of the tasks at the beginning and at the end of the study. We, also, compared the results of the tasks of the beginning of the study to the results of the tasks of *the usability study*. We used the same coding categories that we used in the usability study: Correct Answer (CA), Wrong Answer (WA), and No Answer (NoA). As the main goal of this study is to test the effect of longer exposure to the system on the reading performance of the participants, we compared the participants' performance after initial familiarization (we label this 'after week 0') and after 2 weeks use. As the graph in Figure 4.15 shows, an increase in the number of CAs occurred at the end of week 2, and a dramatic drop in the NoA category is noticed. The number of WAs is decreased; five and 2 questions out of 21 were answered incorrectly at week 0 and week 2 respectively. More interestingly, we find that 3 participants answered all the questions correctly at week 0. This observation may indicate that the refinement for STAAR succeeded in reducing the time needed by users to use the system effectively. At week 2, 5 participants answered all the questions correctly. This data shows that the system usability increased after using it for longer period. In order to examine the influence of the new system design, we compared the percentage of correct, wrong, and "no answer" answers at the usability study and week 0 of the experience sampling study. The participants had no experience with the tested system in both cases. The graph in Figure 4.16 shows that percentage of CA was highly increased and percentage of WA and NoAs were highly decreased. The results of the experience sampling study showed that STAAR at this stage is both operational and functional. Most of the participants were able to read using the system. Achieving a satisfactory usability level does not mean that STAAR is perfect. Participants' feedback in the semi-structured interview shows that there are still issues with the reader system. Their biggest concern was the speech quality. Two aspects of the speech caused dissatisfaction to the users, which are familiarity and quality. The speech synthesizer Flite was not familiar to the users, since it is an open source TTS that is usually used for research purposes, and it is not similar to other screen reading applications such as JAWS for Windows or the iPad Voice Over. More importantly, the quality of speech was not satisfying. This is because the speech suffered from choppiness and sharp pauses, which made it difficult to follow and understand.

Post-interview Results

Participants were asked about their opinions in the system and the overlays they used. We group their feedback into three categories:

1. Speech:

   Participants found difficulties with the speech with respect to its quality and its speed. Their comments are: *"It is monotone"*, *"Speech when sliding the finger over the text*

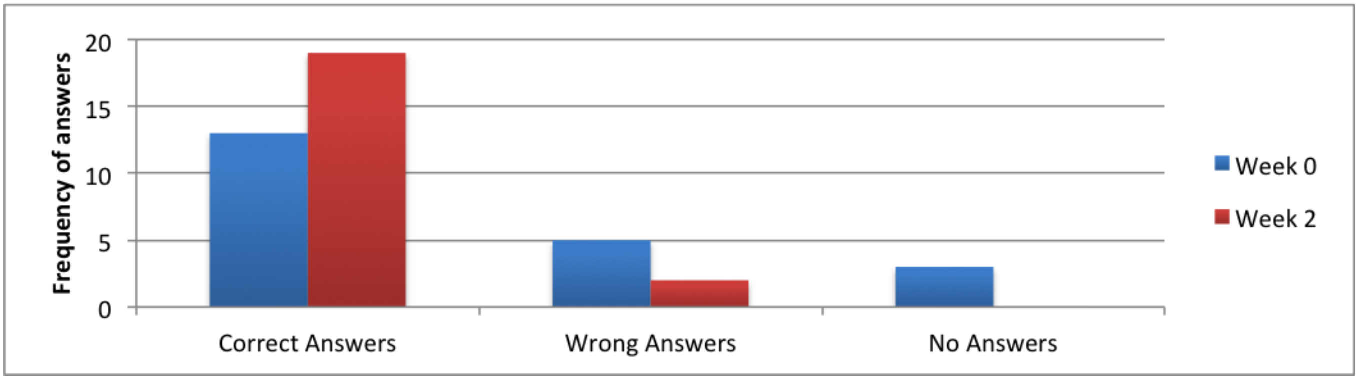


Figure 4.15: Benchmark results for week 0 and week 2.

should be faster", *"Words are difficult to understand"*.

2. Overlay:

   Participants described the usefulness of the overlay as: *"Helped to keep orientation"*, *"It was helpful to know a point of reference"*. Six participants preferred the dense overlay to the wide overlay. They expressed the difference as: *"Denser overlay - gives greater precision while reading"*, *"Kept more in place with denser overlay"*. One participant had fat finger, she mentioned that: *"Wider overlay was easy to use"*

3. Reading:

   Participants found that they need to pay more attention to the articles when they read using STAAR comparing to other audio-based systems. One participant said: *"Can do other stuff when listening to Victor reader but couldn't do it with STAAR system"*, and another one said that: *"It is not a talking book, it is more like really reading a book"*

4.6.5 Discussion

We evaluated STAAR according to the time of exposure to it. In the short term, almost all participants were able to read word by word, find next lines, and navigate to other pages. The interface is simple and reading gestures are easy to perform. However, users

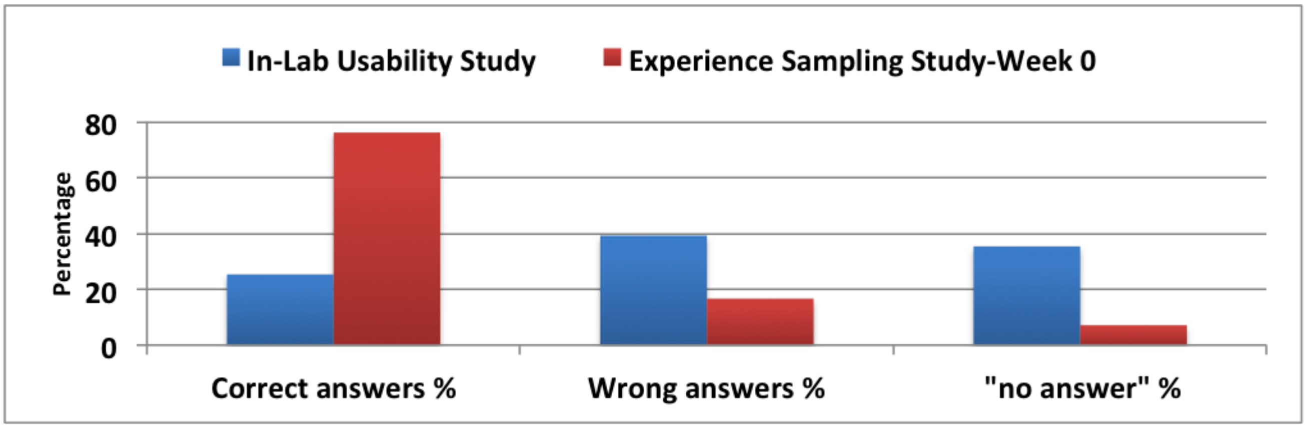


Figure 4.16: Comparison between the *usability study* and week 0 of the *experience sampling study* percentages of benchmarks test results.

had difficulty with the system when exposed to it for the first time. This is because reading is a high cognitive activity, and one of the most complex skills that requires accuracy and automaticity [53]. Effective reading requires training, and developing a new mental model for reading takes time and needs practice [31]. For example, a Braille reader is used to move her finger fast from the leftmost edge to the rightmost of the page looking for the raised dots, while stroking the Braille characters vertically. She is trained for years to recognize the six dot patterns rapidly. To use STAAR, we are asking the Braille reader to:

1. Move her finger slower, which is a change in the physical action of reading (although reading speed may be the same or faster because Braille is typically spaced far more sparsely than in STAAR, and STAAR reads by the word and not by the letter as in Braille);

2. Wait to hear the word or the audio feedback, which is a change in perceiving activity;

3. Fuse more words per line and more lines per page than in a Braille page, which is a change in the spatial recognition; and,

4. Change her reading action – going from stroking the characters vertically to moving smoothly along a line of text with the reading finger in constant contact with the

STAAR surface.

Obviously, all these physical and mental adaptations cannot happen in 5 minutes or even an hour. An evaluation for the system in the long-term is needed. In the long term, we found that participants were able to develop a mental model of how to fuse multi-channel information in order to read using their spatial, aural, and tactile capabilities. Participants better understood the auditory signals and reacted faster to them over time. They were able to read and understand the reading materials. Moreover, participants were able to recover from mistakes, e.g., if a user skipped a line, she can know that it happened and can go back to find the correct line in sequence. Braille used to be the main approach that provides IBSVI with a spatial medium for reading and enables IBSVI to read, search, and skim text at their own pace. We argue that STAAR could have an advantage over Braille with respect to modality and spatial cognition because:

1. Braille utilizes a single model of information encoding (tactile), while STAAR utilizes a multimodal information representation (tactile and audio).
2. STAAR is more powerful spatially than Braille.

The first point is self-proven as the dimension and the type of both Braille and STAAR modalities are inherited by definition. Braille's tactile information is delivered with the embossed Braille cells, whereas STAAR's tactile information is delivered with the embossed grid on the overlay. Multimodal information representation in reading materials is important because it increases the learning outcomes [22, 44]. However, STAAR cannot compete with Braille in case of the readers are IBSVI with hearing loss. To prove the second point, we compared the space capacity of Braille and STAAR. Braille is accessed through two media: embossed materials and digital Braille. Braille codes characters into six or eight dots in a rectangular array 3x2 or 4x2 called a Braille cell [55]. An A4 sized paper can allow the embossing of 34 to 37 cells per line, and an average of 27 lines per page. Hence, Braille coding utilizes multiplies of spaces of original text. For example, a standard textbook of 300 pages can be transcribed into 1800 Braille pages [70]. This size challenge is inherited by 'Digital Braille' as the needed real-estate makes it typically necessary to restrict the information displayed to a single line. Braille is accessed digitally through piezoelectric Braille displays that display refreshable Braille characters. Commercially-available refreshable Braille displays have a typical limit of 80 Braille cells that can be displayed. Tactobook [70] is an eBook reader with a tactile display. Despite its functionality as a translator from English to Braille, its display area is relatively small (20 x 9.8 x 5 cm), meaning that only a very small window of information may be presented at any time. Compared to these, STAAR presented a practical and efficient solution for accessing reading materials in reasonable dimensions.

Chapter 5

Active Reading Support

5.1 Introduction

The experience sampling study that was presented in Chapter 4.6 showed that the reader system is usable and functional. The study also revealed two interaction problems. The first problem is that the system forces the user to move her finger slowly to read the words otherwise the word will be skipped. The experience sample study participants reported this slow interaction as a feature that should be enhanced. The second problem is that IBSVI strayed off the line when reading without realizing they did. Although the participants did not report this interaction problem but the researchers observed it during the study and the critical incident video analysis confirmed the seriousness of this interaction problem. In this chapter we address these two problems to provide IBSVI with further support while spatially read using STAAR.

The slow speech-touch interaction problem is discussed in Section 5.2. We developed a new audio dynamics model to make the reader system more adaptable to the user's reading speed. In Section 5.3, we address the second interaction problem which is supporting IBSVI user to stay on line. We developed an intelligent reading support model that is capable of predicting the direction of reading, correct the reading word if the user drifts, and notify the user using a sonic gutter to help her from straying off the reading line. We tested the new audio dynamics model, the sonic gutter, and the reading support model in participatory design sessions. The consultants' feedback helped us fine-tune the parameters of the two models.

In Section 5.4, we present an evaluation for the new design of the reader system. We conducted a session with our consultants to compare the reader system with its latest design to other VoiceOver technologies. The results showed preponderance to STAAR. Although these results were important to us in the sense of verifying STAAR as a powerful reading system, it was not possible to generalize the results among IBSVI. This is because the consultants are more familiar with STAAR than the other VoiceOver systems. The positive results we obtained opened to us the way to evaluate STAAR among IBSVI who are not familiar with it in the next study that is presented in Chapter 6.

5.2 Speech-Touch Interaction Model

By looking at the current status of the system and the results, we find that the main weakness point is the speech-touch interaction. We started designing our system by the idea of sending all touched words to the TTS. A buffer was created to save an ordered list of touched words according to the timing of the touch. Our *usability study* results revealed a flaw in this approach. When the IBSVI traverses the iPad surface beyond the maximum TTS speech render speed, her reading finger will be distantiated from the word currently spoken. However, she does not know this and may keep moving farther ahead of the system, filling the buffer with yet more words. At some point, she becomes lost and disoriented as the words she hears have little relation with her touch reading activity. The graph in Figure 5.1 represents the average duration needed by TTS to speak a set of words of average length each, 4.5 letters, and the average time taken by IBSVI to move her finger along the same words in one continuous touch.

Our current solution is to remove the buffer and to simply read the word that is the user is currently touching. If the user leaves the word that is currently being sounded, and moves into a second word, the first word will complete and the next one will be sounded while the touch is still in this second word. If however, the touch passes through to the third word before the original word is completed, the second word will be elided, and the third word will be sounded because the finger is touching the third word. To inform the user that a word is elided, our system initiates a click sound of 0.1 seconds duration long. The user then can make her decision to either go on and read the rest of the line or go back to read the previous word. The advantage of this interrupting speech technique is that the IBSVI can always know the location of the word in its spatial context. In addition, BSVI user is in control of the reader system, if she wants to read word by word she can move her finger at

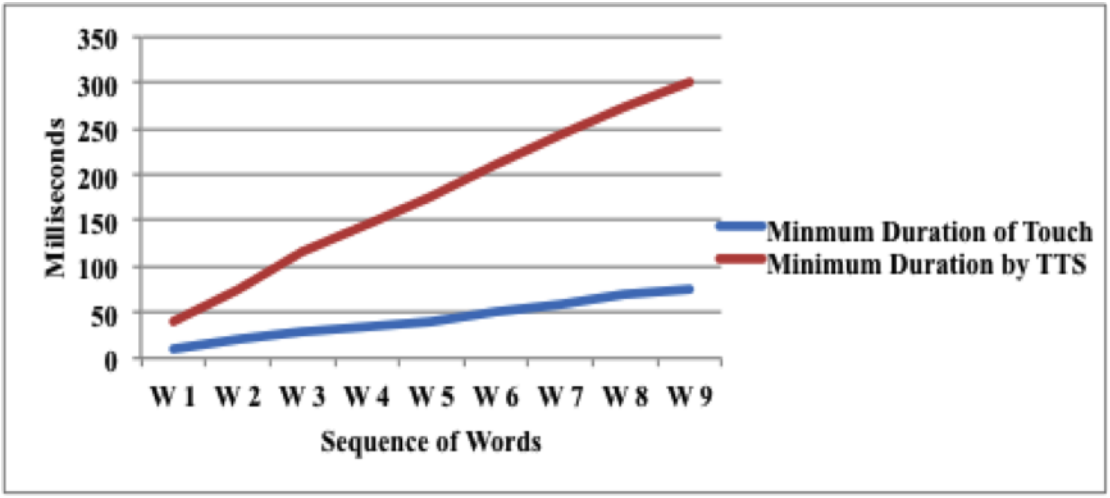


Figure 5.1: Timeline of touch-speech interaction.

the appropriate speed. If she wants to jump over the words she can move her finger quickly and she will hear the first couple of letters if it is a long word followed by the click sound, or she will hear only the click sound if the word is too short. However, *the experience sampling study* results showed that the way we implemented the speech modeling forces IBSVI to move their fingers very slow across the horizontal text line. The users need to move their finger faster to keep the reading and the interaction smooth.

5.2.1 Audio Dynamics Model

The touch interaction model should be synchronized with the TTS module. We developed a robust temporal model that predicts the future touched words and update this list dynamically according to the touch location and the speech machine timing. Figure 5.2 shows a graphical illustration to the audio model. We build a model that calculates the current speed of the users finger. Also, the duration of the word at the normal speed $t^0(w_i)$ for word i is calculated. We apply a set of scales, S, to each word $t^0(w_i)$ where $S = [s_1, s_2, ...S_K]$ where S is monotonic (I.e. $s_i < s_j$ iff $i < j$). For now, we arbitrarily have $K = 3$ and $S = [0.5, 0.75, 1.0]$. Then we estimate the time the finger will enter the next words in the sequence of reading. The difference between the duration of the word to be spoken by the

TTS at its 3 different speeds and the time left till the finger leaves the word is calculated, we call this: time budget. Assume the current word being articulated is w_c, and the end time of the audio snippet is t_c^e. If the estimated time for the finger to exit w_{c+1} is $\hat{t}_e(w_{c+1})$, then the time budget for w_{c+1} is $(\hat{t}_e(w_{c+1}) - \hat{t}_s(w_{c+1}))$. Assume that the estimated time the reading finger will arrive at w_{c+1} is $\hat{t}_s(w_{c+1}) > t_c^e$. Then, there would be a gap of $(\hat{t}_s(w_{c+1}) - t_c^e)$ before w_{c+1} is articulated.

Hence, we select s_j s.t. $(s_j * t^0(w_{c+1})$ is closest to the time budget $(\hat{t}_e(w_{c+1}) - \hat{t}_s(w_{c+1}))$. The word w_{c+1} will be rendered when the finger actually enters w_{c+1}. This will make w_{c+1} the new w_c and the process repeats. It is possible in our model for $\hat{t}_s(w_{c+1}) < t_c^e$, in which case there will be no gap and the time budget for w_{c+1} will be reduced to $(\hat{t}_e(w_{c+1}) - t_c^e)$.

If the user's finger speed is within the limits of the word duration, the word will be rendered. If the user's finger would leave the location of the word before the fastest word could be spoken, the word will be skipped. To inform the user that she has skipped a word, a click sound will be played. Figure 5.3 illustrates an example where a user is reading while moving her finger with a varied speed. Clocks (C1,..,C4)) are the estimated times for entering/leaving the words. While she is moving from word to word, the time remaining to audibly render the word is calculated (t1, t2,..,etc.). When the user's finger enters W4 and the TTS has not yet started rendering W3, W3 will be skipped, and W4 will be synthesized. We believe that this audio model will solve the slow touch interaction problem and at the same time will keep the speech smooth and fluent. The preliminary results of the S and the K values showed acceptable inter-word gap.

5.2.2 Off-line Speech Synthesis Technique

In our previous work, we generated the speech at runtime by sending each touched word to the Flite TTS on the fly. The resulted speech suffered from being choppy. We altered our technique of generating speech to solve the choppiness problem. We off-line synthesize whole sentence using Acapela TTS. Then using a speech processing software we segment the

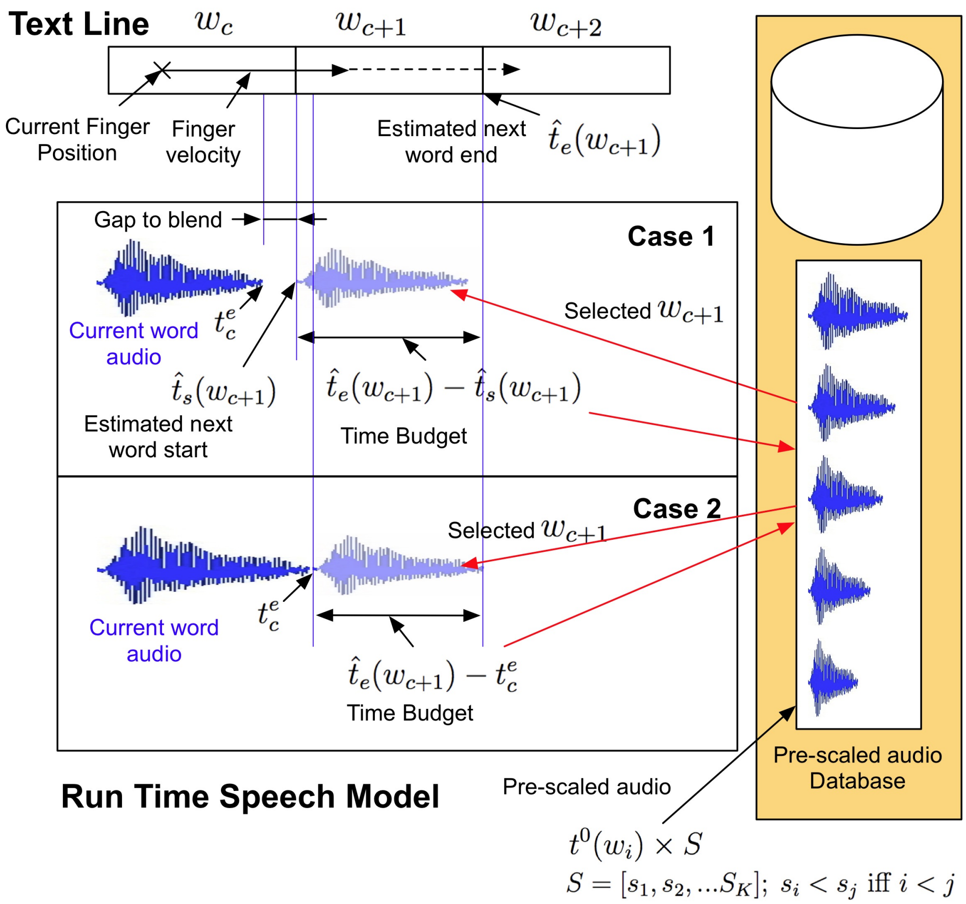


Figure 5.2: A graphical illustration to the audio model, courtesy of Prof. F. Quek.

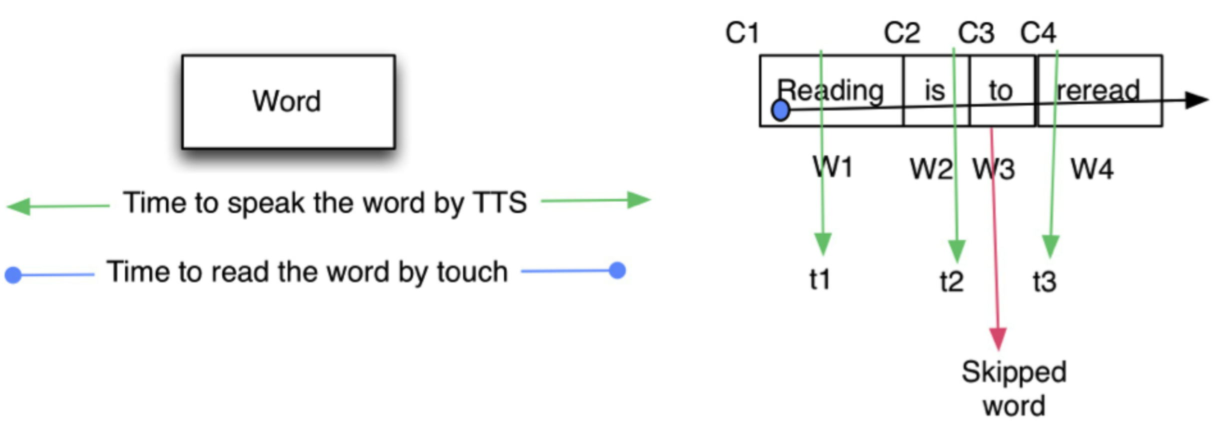


Figure 5.3: Left: Word temporal modeling. Right: Reading-Speech modeling.

sentence back to individual words. The advantage of this technique is that the blending of words in sequence is automatically included by the TTS when the whole sentence is passed to the engine. Figure 5.4 shows an example of the audio signal of a sentence of 3 words generated by the TTS. The two black vertical lines in Figure 5.4 mark the end of the signal of one word and the beginning of the next one. Each segmented block is saved separately. For each words audio signal, we generate three versions, each with a different speech rate as needed by the audio dynamics model. We create a database of audio files for the text, and a metadata file that contains the word index, its speed, and duration. The metadata is used by the audio dynamics model to play the right audio file upon touch. Table 5.1 shows an example for the word "Learning". The word is trimmed of the sentence and three versions of the word are generated, each has a different speed, and duration. As can be shown from the data in the table that the signal can be scaled down into a certain degree with keeping its articulation comprehensible. Further scaling down makes the articulated word very fast to be comprehensible. Each Audio Signal (AS) is associated with a code that is composed of three terms:

$$AS_{code} = p_i t_j x_n, i < i_{max}, j < k + 1, n < n_{max} \tag{5.1}$$

The first term (p_i) represents the page number where the text word (w_c) is located. The second term (t_j) reflects the word's speed (s_i). The last term (x_n) represents the index of the text word (w_c) within the page it is located. By embedding the positional and the scale information of each audio signal into its word representation, the *Text Renderer* module can directly handle its assigned tasks. The example given in Table 5.1 shows a word in which its index is 150 in the first page of the rendered document.

5.2.3 Participatory Design Session

We realized that using this model in reading could lead to reading one sentence with various speech rates, e.g. one word with normal speed, and the next word in faster speed, depending

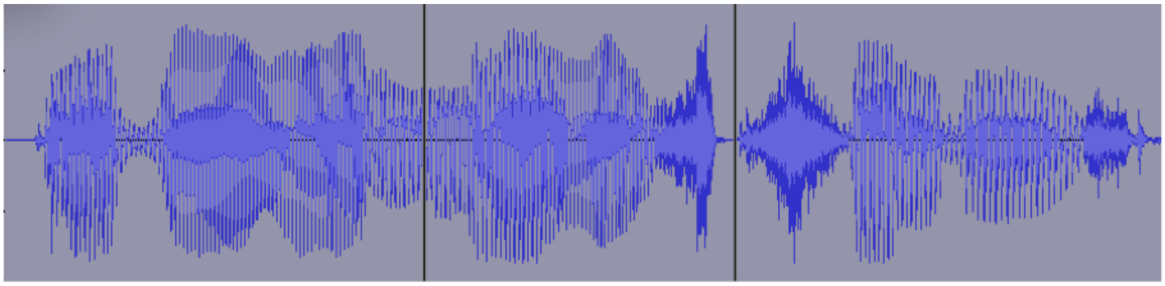
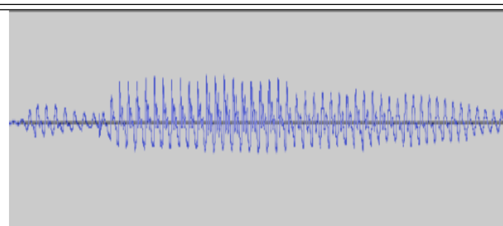
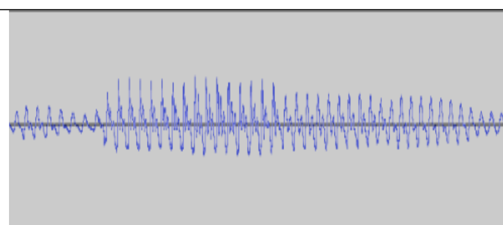
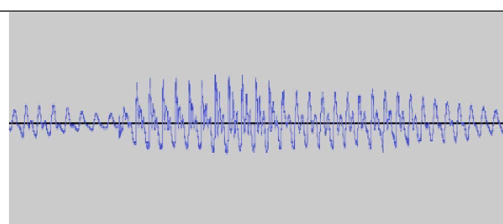


Figure 5.4: Audio signal of a sentence of 3 words.

Table 5.1: Example of the word "Learning" at S=0.5, 0.75, and 1.0.

S_i	**S value**	**Duration**	**Signal**	AS_{code}
1	1.0	0.357 seconds		011150
2	0.75	0.285 seconds		012150
3	0.5	0.238 seconds		013150

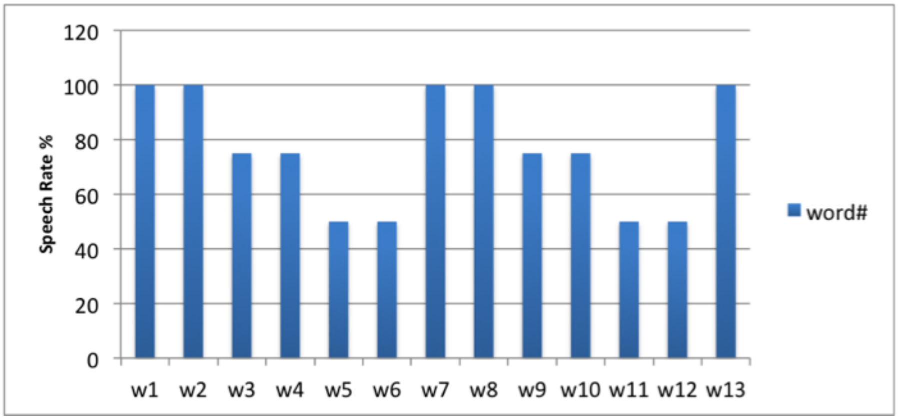


Figure 5.5: Synthesized variable speech rate sentence.

on the spatial occupation of the word, temporal period of the word articulation, and the finger's speed. We ran a participatory design session with our 3 IBSVI consultants. The goals of the session are:

1. Test the effect of using the audio dynamics model on the comprehensibility of the speech.

2. Test whether the audio dynamics model enhances the speech-touch interaction.

The session consisted of two parts. For the first part, we pre-compiled 2 sentences consisting of 13 words, where each two words in sequence have different speech rate as illustrated in Figure 5.5. We played the audio file to each of the 3 consultants. Two of them find that the speech is clear and easy to comprehend. The third consultant could not comprehend only one word from the 2 sentences. This word was articulated in 50% of its normal speed. For the second part of the session, we prepared a passage of 3 lines of text. Each consultant was asked to read the 3 lines using STAAR with the audio dynamics model and the off-line speech synthesis technique implemented as described in the previous section. They were then asked whether the speech rate helped them to better interact with the system with respect to finger speed. All of them reported that the dynamic speech rate helped them to better interact with the system. The results we got from this session showed us that both the audio

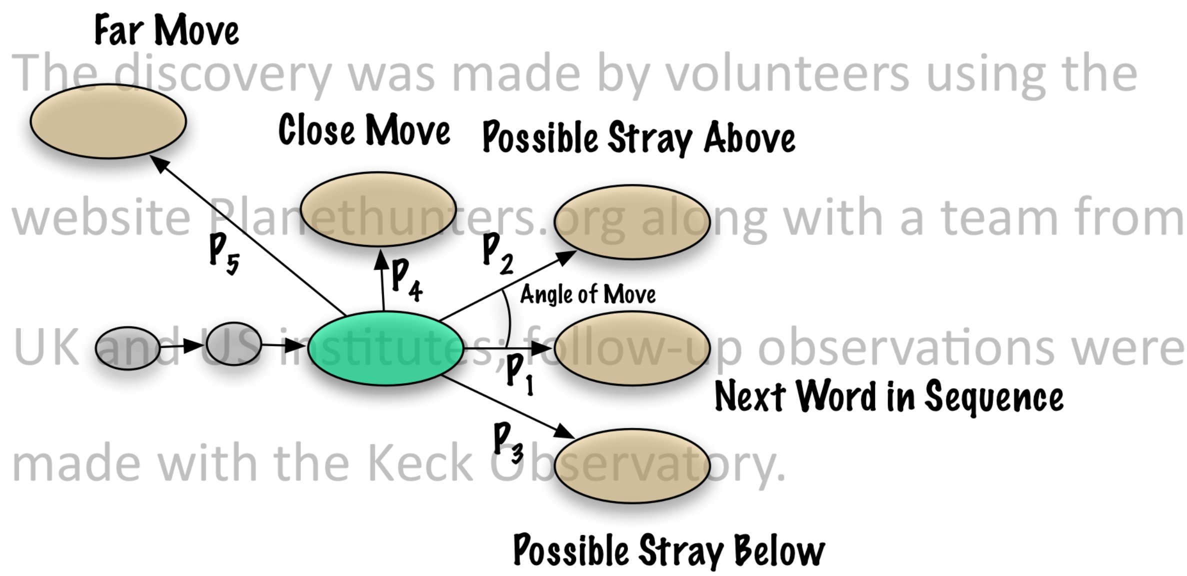


Figure 5.6: Intelligent reading support model to predict the intended word.

dynamics model and the off-line speech synthesis technique enhanced the user interaction with the system without decreasing the comprehensibility of the speech.

5.3 Line Straying Problem

As revealed by the critical incidents analysis of the usability study, we found that if a BSVI user slightly moved her finger to the line below or to the line above while reading horizontally, she cannot know that she had without an appropriate feedback.

To solve this problem, we want to enforce the reader system to complete reading the horizontal line if the system recognizes that moving off the line is a mistake. However, to give the IBSVI an indication of their current spatial location, an audio feedback will be activated. We believe that helping IBSVI stay on the horizontal line while informing them with their location will eliminate the confusion that might occurred when their touch deviates and out of context words are heard. We developed an intelligent active reading support model that predicts the word the user wants to access, as shown in Figure 5.6. The green oval represents the current touched word (w_c). The next transition could be one of the following 6 states:

1. Next word in sequence: (w_{c+1})
2. Possible stray below: (w_{below})
3. Possible stray above: (w_{above})
4. Close move: (w_{close})
5. Far move: (w_{far})
6. Same word: (w_c)

The intelligent active reading support model estimates the intended word (w_i) based on the following factors:

1. The number of previous in-sequence read words, or shortly length of history ($history_l$) .
2. The distance (d_t) between the location of next word to current word (w_{c+1}) and the touched point (p_t).
3. The angle (θ_t) between the current horizontal line and the touch point.

Our hypothesis is that the length of history is the most critical factor. If the current word is the initial state or the previous state is not its previous word; that means the user is in random reading mode. Consequently, the 6 states will have equal probability. While if the current word was preceded by a minimum length of history, and the d_t, and θ_t are below a threshold, that means the user is in active reading mode. Consequently, the first state ($wc + 1$) will be triggered. Table 5.2 summarizes the transitional behavior of the intelligent reading support model.

Table 5.2: Transition matrix of the reading support model.

Reading Mode	**Condition**	**Intended word**
Random	$W_c\| \ history_l < history_{min}$	$W_c; W_{c+1}; W_{above}; W_{below}; W_{close}; orW_{far}$
Active	$W_c\|history_l \geq history_{min}$ and $d_t < d_{max}$ and $\theta_t < \theta_{min}$	w_{c+1}

Table 5.3: Tested values of the reading support model parameters.

	Value 1	**Value 2**	**Value 3**	**Value 4**
θ_t	10^o	30^o	50^o	70^o
d_t	0.2 inch	0.4 inch	0.6 inch	0.8 inch
$history_l$	2	3	4	5

5.3.1 Intelligent Active Reading Support Model parameters

In order to get an accurate prediction of w_i, we have to find approximate values for $history_{min}$, d_{min} , and θ_{max}. We conducted a parameters-searching session with five blindfolded participants to help us determine these three values. The participants' ages ranged from 25 to 67 with a mean of 39 (SD=16.92). Three participants were females and two were males. Each participant was familiarized with the system for 5-10 minutes. Then she was asked to read a passage of 8 lines using STAAR with different values of the model parameters as summarized in Table 5.3. A full factorial design of testing these values will lead to 192 conditions. Alternatively, we applied a hierarchical study design (see Table 5.4), where we started the study with initial values for d_t and $history_l$. For the 1st condition we tested the 4 values of θ_t and keep d_t and $history_l$ constant. The value of θ that got the most positive results according to the participant was then used in the second condition of the study. In the second condition, four different values of d_t were tested, where the θ_t and $history_l$ are constant. Finally, in the 3rd condition we fix the θ_t and d_t values as elected from the previous two conditions. The value of $history_l$ was varied from 2 to 5. Each condition took 20 minutes.

During the task, the participant was asked to report every word she hears and she thinks it does not belong to the sentence. The researcher kept a log of these occurrences. We consider

Table 5.4: Conditions of the prediction model parameters study.

	Condition 1	**Condition 2**	**Condition 3**
θ_t	10^o, 30^o, 50^o, 70^o	Output θ of condition 1	Output θ of condition 1
d_t	0.8 inch	0.2, 0.4, 0.6 inch	Output distance of condition 2
$history_l$	2	2	3,4, 5

them failure of reading-support. The graph in Figure 5.7 shows that all participants had fewer drifting correction failures when θ was set to 30^o. In condition 2, θ_t was set to 30^o, and we changed the values of d_t. The frequencies of drifting correction failures are shown in Figure 5.8. The best results were observed with d_t =0.6 inches. Finally, we used these values in condition 3 where we varied the history$_l$. As illustrated in Figure 5.9, the highest drifting correction frequency occurred when history$_l$ was set to 2. The conclusion is that participants consider themselves engaged in active reading when they start reading horizontally at least 2 words in sequence. If the user's finger drifts with a distance that is at maximum 0.6 inches away from the end point of the previous read word, and with angle not more than 30^o, the user expects a correction from the system to this drift. However, when the finger's movement is more twisted than that, it is highly likely that the user is not in the active reading mode, and so the system should read for her what she is really touching.

5.3.2 The Sonic Gutter

If the active reading support model detects drifting behavior in active reading mode and decides to play a word that is different than the physically touched word, a sonification will be played to alert the user that she is going off the line. We call this the sonic gutter. We used white static noise and pink static noise to sonify moving above the line or below the line, respectively. This audio feedback is played concurrently with the articulated word. Figure 5.10 shows an example of set of lines, where the second line is the current reading

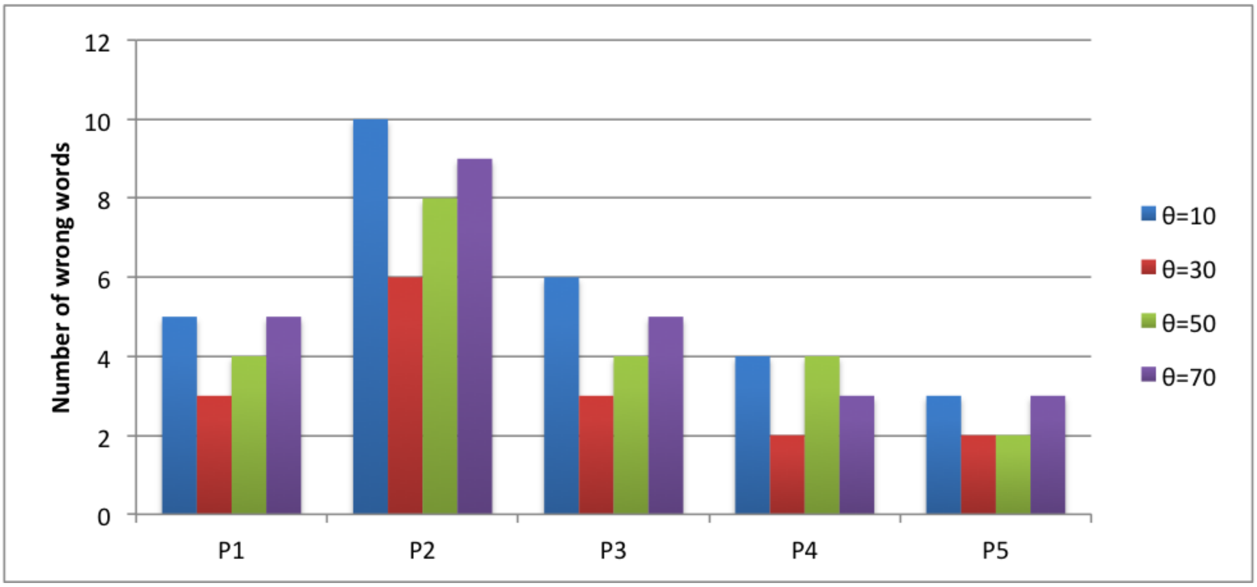


Figure 5.7: Frequencies of drifting-correction failures in condition 1.

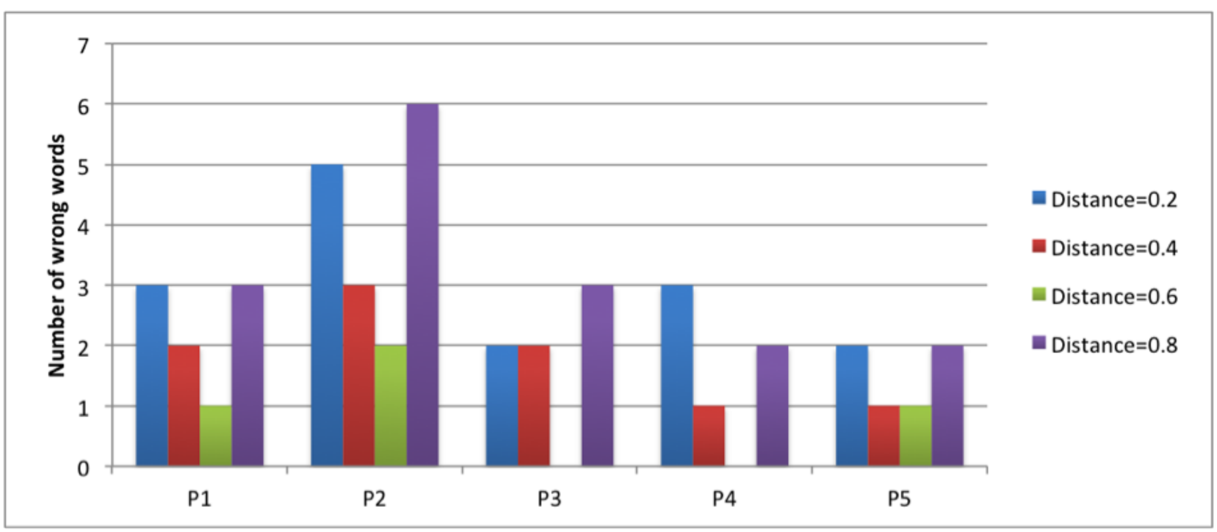


Figure 5.8: Frequencies of drifting-correction failures in condition 2.

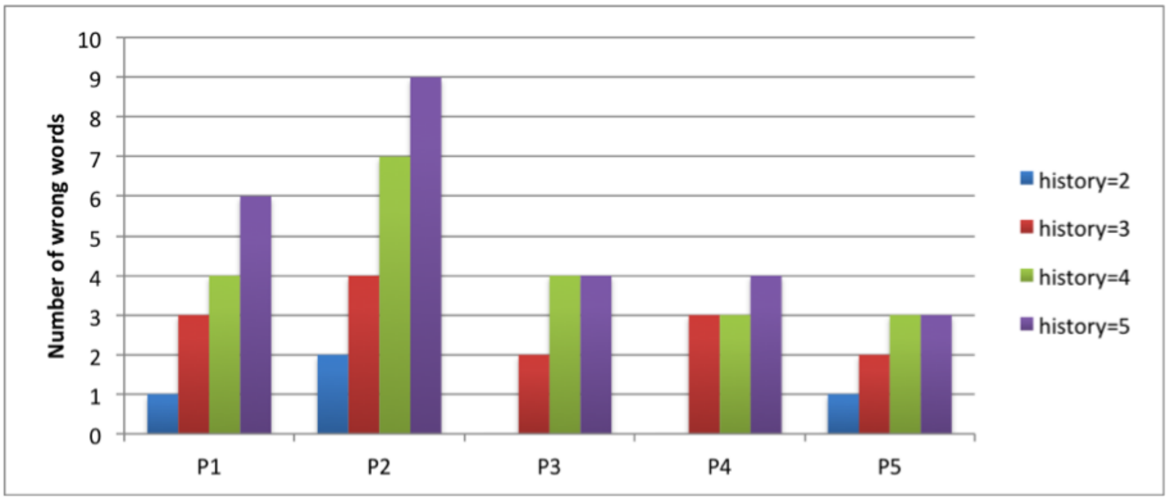


Figure 5.9: Frequencies of drifting-correction failures in condition 3.

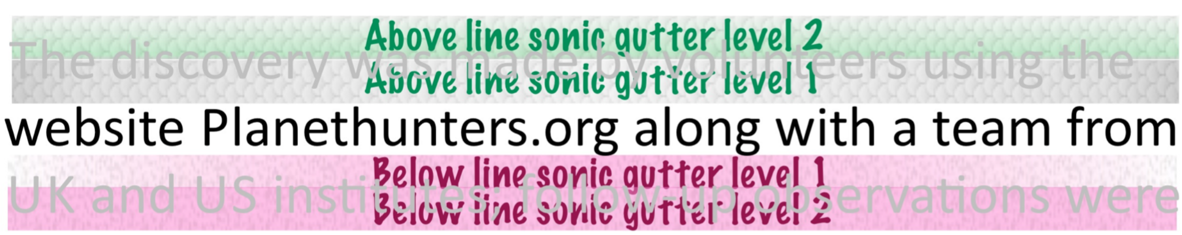


Figure 5.10: Visual illustration for the sonic gutter.

line. If the user starts drifting above or below the reading line, the sonic gutter will be activated. The above line, as well as the below line, sonic gutter is divided into two levels. The difference between the two levels is the frequency of the sound, where level 2 has higher frequency than level 1. The goal of having 2 levels of straying-alarm sonification is to provide the IBSVI with enough spatial information about the distance she drifted, so that she may be enabled to develop an accurate mental model of the spatial relation between her physical touch and the text she is reading. The challenge was to find sonifications with the following characteristics:

1. Sonic gutter level 1 is audibly different from sonic gutter level 2, for both above the line and below the line.
2. Above line sonic gutter is audibly different from below line sonic gutter, for both levels.
3. All sonifications must be loud enough to be heard with the articulated word.
4. Articulated words must be clear enough to comprehend while the sonic gutter is played synchronously.

5.3.3 Intelligent Active Reading Support: PD Session

We conducted a session with the 3 IBSVI consultants. The session was divided into two parts, hearing session, and interaction session. The first part was a hearing session, where we played for them a set of sonifications to ask them whether they can audibly differentiate between them or not. Then, we played a set of precompiled audio files. Each audio file consists of a whole synthesized sentence with one of the sonifications. The consultants were asked if they could hear and comprehend the sentence despite the noise or not. Consultants 1 and 2 were able to differentiate between all the sonifications, while consultant 3 was not able to differentiate between the above line sonic gutter and the below line sonic gutter. Consultants 1, 2, and 3 were able to hear and comprehend the sentences despite of the sonifications. However, consultant 3 was not able to hear the above line sonic gutter level 1 that was combined with a sentence. Consultant 3 is 71 years old, and that could be the reason behind his feedback. Based on the preliminary results, we recommend that future systems could have various sets of sonifications with adjustable settings e.g. pitch, volume, and frequency, so that the user can personalize the sonic interface according to her preferences.

In the second part of the study, we asked the 3 consultants to read a passage of 4 lines with the reading support model and the sonic gutter. They were encouraged to try navigating in between the lines of the text to see the effect of the reading support model and the sonic gutter, and give us suggestions. The three consultants found that the new features helped them stay on line. Moreover, they all found that the new features guided them back to the reading line when they drifted. One of the consultants found that having that support and audio feedback from the system eliminated her need to the physical affordance of the tactile overlay. She had a successful trial reading the text again without the overlay. This opens the question for the effect of tactile feedback compared with audio feedback and how much each component participates in supporting spatial reading for IBSVI.

5.4 Evaluation of the Active Reading Support System

The goal of this study is to evaluate the efficiency and effectiveness of STAAR with its Intelligent Active Reading support in re-finding information and spatial perception. We define efficiency as the mean time taken by the IBSVI to read a page. By effectiveness, we mean participants success of recalling and re-finding the information. Our operational definition of spatial perception is the ability to locate short sentences or phrases, and the ability to estimate the number of paragraphs in the page. STAAR system is unique with its features of enabling IBSVI to read spatially word-by-word at their own pace, and supporting IBSVI stay on line and finding next line. In order to evaluate STAAR, we decided to compare it to another reading tool that utilizes audio modality for information and does not elaborate the spatial information. The most advanced current technology that satisfies these conditions is the iOS VoiceOver. In general, the VoiceOver technology is based on the idea of announcing what the user touches, and wait for interaction. For reading, Apple has developed software called iBook, which is announced as fully compatible with VoiceOver. By default, iBook is set to read whole line once the user touches it. If the IBSVI wants to read word-by-word, she has to turn the rotor to the 'word' mode, then swipes in up-bottom direction to read word by word. If she wants to go back to a specific word, she has to swipe in the bottom-up direction until she reaches the word. Starting from iOS version 6.0, the VoiceOver sonifies empty spaces with a bonk sound. Hence, the only audio feedback provided by VoiceOver is the white space sonification. If we compare STAAR to iBook as is, we will have the problem of comparing reading whole line versus reading word-by-word. This difference has implications in both spatial perception, and information recalling and re-finding. To overcome this shortage in iBook, we tweaked the default mode to force it read only one word at a time upon touch, instead of reading the whole line at once. We call this: "word-by-word VoiceOver".

5.4.1 Method

We conducted a single factor within-subjects study. The independent variable is the system type, 4 levels, which are:

1. STAAR + overlay
2. Word-by-word VoiceOver
3. Word-by-word VoiceOver + overlay
4. iBook + VoiceOver

Per each condition, the participant was asked to read one page of text. We prepared 4 sets of reading materials. Each set is of equivalent length, layout, and content. All reading materials were at 8th grade level based on the Flesch-Kincaid Reading Ease scale. Two reading materials were arranged in two paragraphs, and the other two were arranged in 3 paragraphs. For conditions 1 and 4, the same overlay was used, which is the dense overlay. The order by which the conditions were presented to the participants was counterbalanced.

5.4.2 Participants

The participants of this study are the three consultants. They are 2 females and one male; their ages are 33, 66, and 71. They are all legally blind. The oldest one has no vision in his left eye, and 5% vision in his right eye. The youngest one has 10% vision in her eyes, and the last one's vision is 20/100. One of the participants uses iPhone with VoiceOver.

5.4.3 Procedure

Each participant was asked to read one page of text using the 4 systems: STAAR, word-by-word VoiceOver, word-by-word VoiceOver with the overlay, and iBook with VoiceOver. For each condition the following steps were followed:

1. Familiarization session with the tested system.
2. Read one page using the tested system.
3. Answer 4 questions about the reading material.
4. Answer a user experience questionnaire about the tested system.

Before starting each task, the participant was familiarized with the system by reading a separate passage. After reading the page of the task, the participant was asked 4 questions. Two questions were knowledge transfer questions, and the other 2 were for spatial perception assessment. The two spatial perception assessment questions were consistent among the 4 conditions. The first question was to locate a sentence in the page. The sentence was chosen to be the first or the last sentence in a paragraph. The second question was to estimate the number of paragraphs in the reading page. In order to answer the 4 questions, the participants were allowed to re-access the page. After completing each task (reading and answering), participants were given a user experience questionnaire about the system they used. The questionnaire included rating questions and open-ended questions. Participants took a break between each 2 conditions. The 4 tasks were video recorded.

5.4.4 Results and Discussion

In this section, we analyze the data we collected from the reading tasks, and then we discuss the user experience questionnaires. By analyzing the knowledge transfer questions, we found that the participants were able to answer all the questions correctly in the case of STAAR, and word-by-word VoiceOver conditions, see Figure 5.11. In conditions word-by-word VoiceOver with overlay, and iBook, participants answered 4 and 2 questions wrong, respectively, although they re-read the page when tried to answer the questions. These preliminary results show us that STAAR and word-by-word with VoiceOver were more effective than word-by-word with VoiceOver and overlay, and iBook. To evaluate the efficiency of STAAR comparing to the other 3 systems, we measured the time taken by participants to read the page, and the time they spent in answering the questions. Figure 5.13 shows the mean of the reading time, and Figure 5.12 shows the mean of the answering time for the 4 systems. The time is measured in seconds. We can see from the graph that the participants needed about double the time to read the same amount of text using word-by-word VoiceOver comparing to STAAR. When adding the overlay to the condition word-by-word VoiceOver, the reading time dropped by half. The number of lines in the page participants read with iBook was 17 lines, whereas the number of words they read with STAAR was 126 words. That means that reading a page with iBook needs at minimum17 touches, while with STAAR needs at minimum 126 touches. However, the difference in the mean reading time between the two systems was only 1 minute. What we observed during the study that in the word-by-word VoiceOver and the iBook conditions, the participants tend to repeat reading the same line several times and had difficulty finding the next line. That can explain why they were able to recall information with these conditions more than they did with STAAR, see Figure 5.14. The graph in Figure 5.14 shows both successful and failure trials of answering the knowledge transfer questions categorized by the answering strategy. In the user experience questionnaire, the participants were asked to rate the ease of recalling information, and re-finding information on a scale from 1 to 10. They were also asked about how easy or difficult it was to find next line and maintain location on page. The graph in Figure 5.15 shows the mean of the participants' responses. Again, the results show that the word-by-word VoiceOver was the most difficult to find next line and to maintain location on page. Adding the overlay helped the participants according to their responses. STAAR received the highest scores in the participants' experience questionnaire with respect to ease of use and supporting spatial awareness. When answering the open-ended questions, the participants mentioned that for reading word-by-word, STAAR is much better than VoiceOver. One participant said she was lost without the sonifications. Also, one participant mentioned that the overlay helped a lot in the word-by-word VoiceOver with overlay condition. For the iBook, as it basically reads whole lines, the participants said that for active reading they may prefer to mix the two modes of reading word by word and reading whole lines in one system. In sum, these preliminary results with the 3 participants show us that STAAR is more effective than iBook in finding the correct answers, and more efficient in reading time than word-by-word VoiceOver. Additionally, the overlay was shown that it highly reduced the time needed for reading and re-finding when combined with VoiceOver compared to VoiceOver alone. But the overlay was not effective enough to support the participants finding the correct answers.

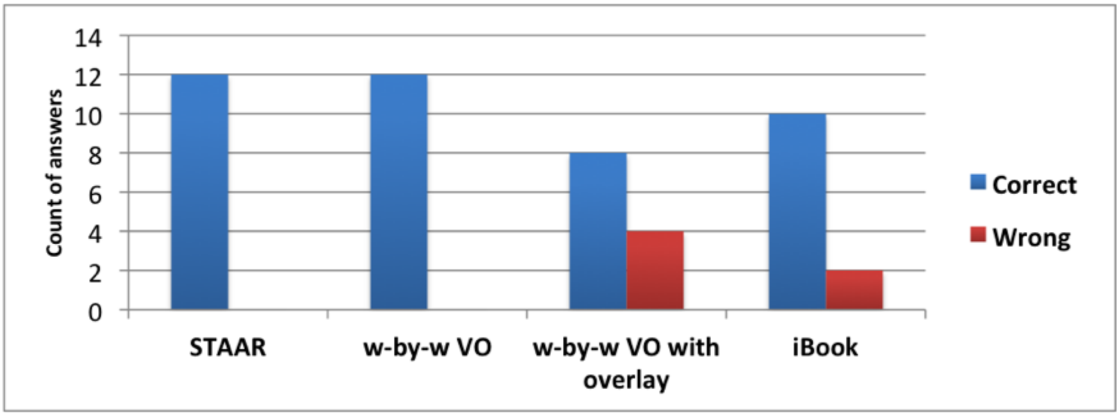


Figure 5.11: Knowledge transfer results.

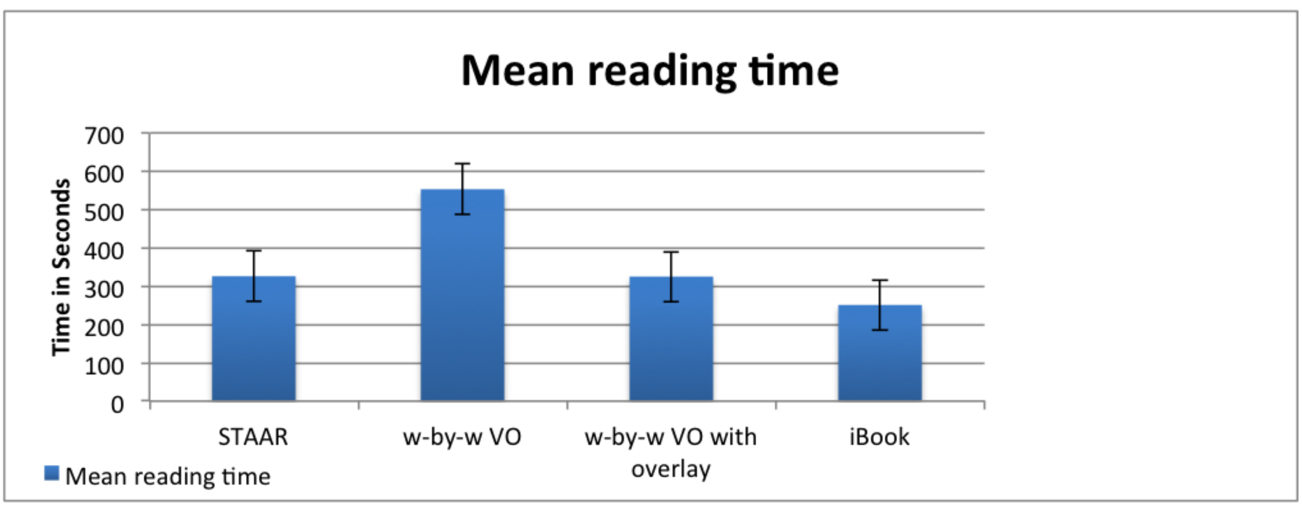


Figure 5.12: Mean of reading times by the four systems.

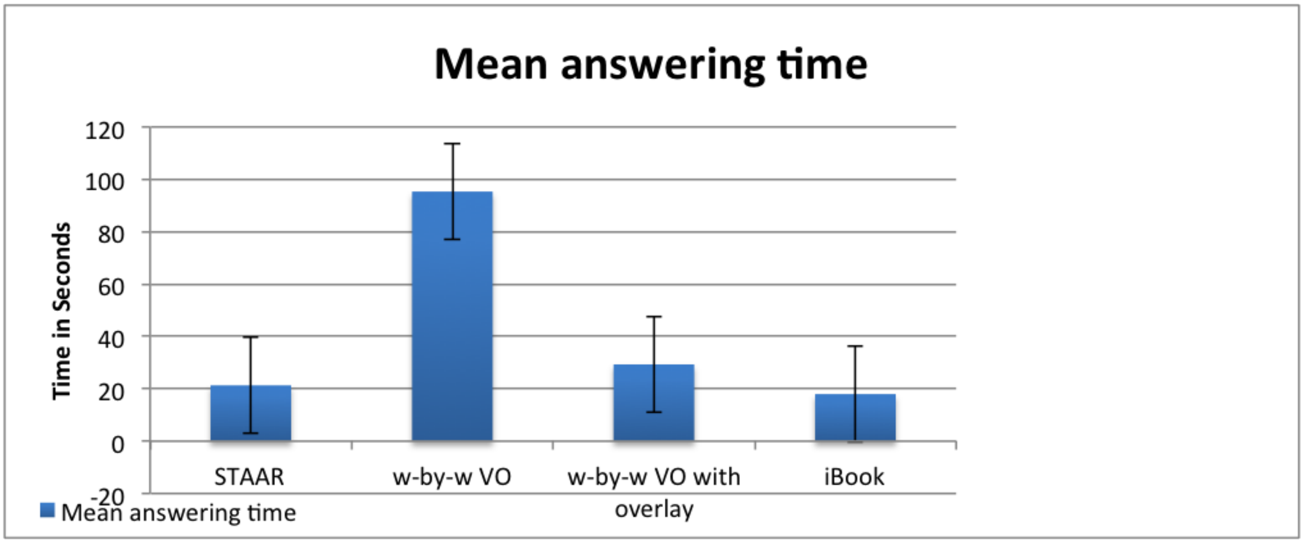


Figure 5.13: Mean of answering times by the four systems.

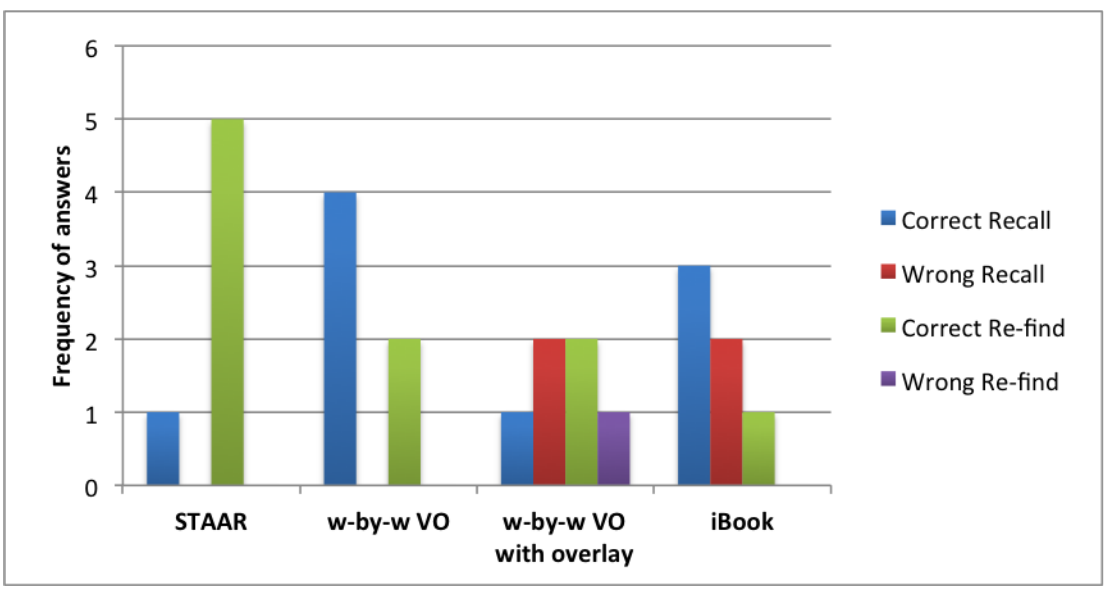


Figure 5.14: Strategies of answering: recalling and re-finding.

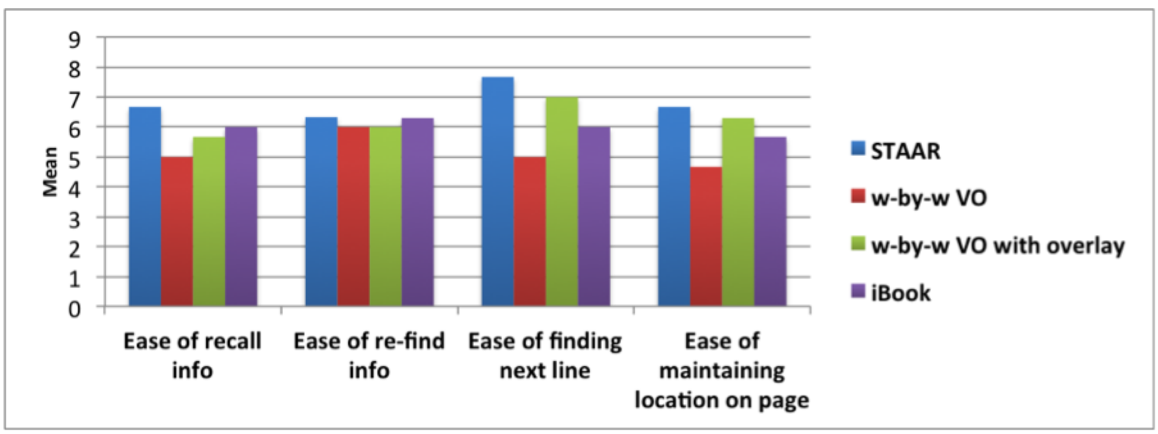


Figure 5.15: Mean user experience rating.

Chapter 6

Reader System Evaluation

6.1 Introduction

The reader system is designed to fulfill a missing reading need for IBSVI, which is self-paced active reading on a digital and portable medium. In the previous sections, we explained the evolution of the reader system from its first prototype that was explained in Chapter 3.2, to its last design as described in Chapter 5. In this chapter, we evaluate the reader system to assess its capability on performing the functionalities it was designed for. Two studies were conducted for the purpose of evaluating the reader system.

In Section 6.2, we present the first study of the system evaluation. We conducted a lab-controlled decomposition study, where we investigated the contribution of the different components of the reader system and how the system functions with and without its different components. The key finding of this study is that sonification of words by itself is not enough to support self-paced reading. Spatial access to the page requires more sophisticated information to be conveyed to IBSVI. Multimodal interaction was shown to be an effective way of carrying the spatial information needed to read a page. STAAR with its tactile overlay and intelligent active reading support enabled IBSVI to self-paced read formatted text, answer questions about the content, re-find phrases, and even correctly describe the layout of the page.

In Section 6.3 , the second evaluation study is presented. It is a lab-controlled comparative study with the purpose of validating the spatial reader system. We compared STAAR to the state-of-the-art iBook with the VoiceOver technology. At the end of the section, a discussion about the results is held to reveal the main differences between the two systems based on the objective and the subjective data we collected during the study. The key finding of this study is that STAAR is preferred and more effective in serious reading scenarios, while iBook was faster and preferred in leisure reading scenarios.

Figure 6.1: Spatial reader system main components.

6.2 Decomposition Study

The spatial reader system is composed of two main innovations: the *Tactile Overlay* and the *Active Reading Support (ARS) subsystem*, in addition to the page sonifications of the spatial-mapped information. Fig 6.1 is an illustration for these three main components. The active reading support has two levels:

- The first one is a simple sonic gutter that generates a sort of auditory-fence around the line to keep IBSVI from straying. For short, we call it *Simple ARS*. At this level, the system assumes the user wants to read the line for the word she currently touches. The system will only read the word the user touches, and with the alert of the sound fence the user should self-correct.
- The second level is what we call the Intelligent active reading support (*Intelligent ARS*). The system detects the history of the reading points, and based on the current

finger movement direction and angle, the system decides whether the reader is engaged in active reading process or she is just scanning or skimming the page. The sonic gutter will be activated only if the active reading mode is determined. In this case, the system predicts the intended word and read it to the user disregarding the actual word she is really touching.

We conducted a lab-controlled user study to reveal the effect of adding the active reading support model to STAAR, and the effect of the overlay. Also, the study was designed to show whether the sonic gutter by itself without the predicting model can support reading on its own or not.

The goal of the study is to evaluate STAAR in terms of the following functionalities:

- Effectiveness: Success of answering the knowledge transfer questions.
- Efficiency: The time needed by the user to read one page of text successfully (e.g. without skipping lines). We used the text density that was determined to be effective in reading in prior studies. Each page was designed to arrange the text in 18-20 lines, 2-3 paragraphs, and 135-140 words.
- Spatial Perception: Success of spatially locating the information and estimating the layout of the page, e.g. trying to figure out the number of paragraphs in the page.

6.2.1 Method

We designed a 2x2 full factorial within-subjects study, with pre-planned comparisons. The first factor is the overlay, 2 levels (with and without). The second factor is the active reading support with its 2 levels (Simple and Intelligent). As depicted in Table 6.1, the 4 conditions can be summarized as follows:

- Cell 1: Tests the full condition where the *Intelligent Reader* is supported by both sonifications and overlay

Table 6.1: The decomposition study design.

	Intelligent Active Reading Support	**Simple Active Reading Support**
With Overlay	Overlay + Reader Prediction Model + Sonic Gutter (Cell 1)	Overlay + Sonic Gutter (Cell 2)
Without Overlay	Reader Prediction Model + Sonic Gutter (Cell 3)	Sonic Gutter (Cell 4)

- Cell 2: Isolates the condition of sonic gutter when you have the tactile overlay
- Cell 3: Isolates the condition when the sonic gutter is paired with the prediction system
- Cell 4: Isolates the effect of sonic gutter alone as long as we know we are in reading mode

Our hypotheses are as follows:

- H1: Best performance will be achieved with the condition "*With Overlay, With Intelligent ARS*"
- H2: Worst performance will occur with the condition "*Without Overlay, With Simple ARS*"
- H3: Condition "*Without Overlay, With Intelligent ARS"* will result in poorer performance than the condition "*With Overlay, With Intelligent ARS*", and better performance than the condition "*Without Overlay, With Simple ARS*"
- H4: Condition "*With Overlay, With Simple ARS*" will result in poorer performance than the condition "*With Overlay, With Intelligent ARS*", and better performance than the condition "*Without Overlay, With Simple ARS*"

6.2.2 Participants

Ten IBSVI participated in this study. Their ages ranged from 18 to 77, with a mean of 50.8 (*SD*=15.75). Five of them are females, and 5 are males. Six are totally blind, two have 20/400 acuity, and two have 20/800 acuity. Seven of them had their visual disability since birth. One of the participants had nerve damage that prohibited him from feeling the tactile overlay. One of the participants was left-handed. Eight participants could read Braille, but only one uses the Braille medium for reading regularly. The other 9 participants access reading materials using screen readers and audio books. Only two participants have touch devices e.g. iPhone.

6.2.3 Experimental Procedure

At the beginning of the study, the participants were introduced to the complete system in a prepared familiarization session for 10 minutes.

At the study, each participant was asked to read one page of text per each condition. We precompiled 4 articles, each is one page length, with similar layout and content. According to Fischer-Kincaid measurement, they are equivalent to 8th grade level. After finishing reading the text, the participant was asked 4 questions:

- Two questions are knowledge transfer questions. The participants were encouraged to find the answer by re-reading the page
- The other 2 questions are for spatial perception assessment. The first question is to locate a sentence in the reading material. The second question is to estimate the number of paragraphs in the reading material

At the end of each task, a user experience questionnaire and semi-structured interview were conducted. The duration of each task was set to be 25 minutes as a maximum limit. A

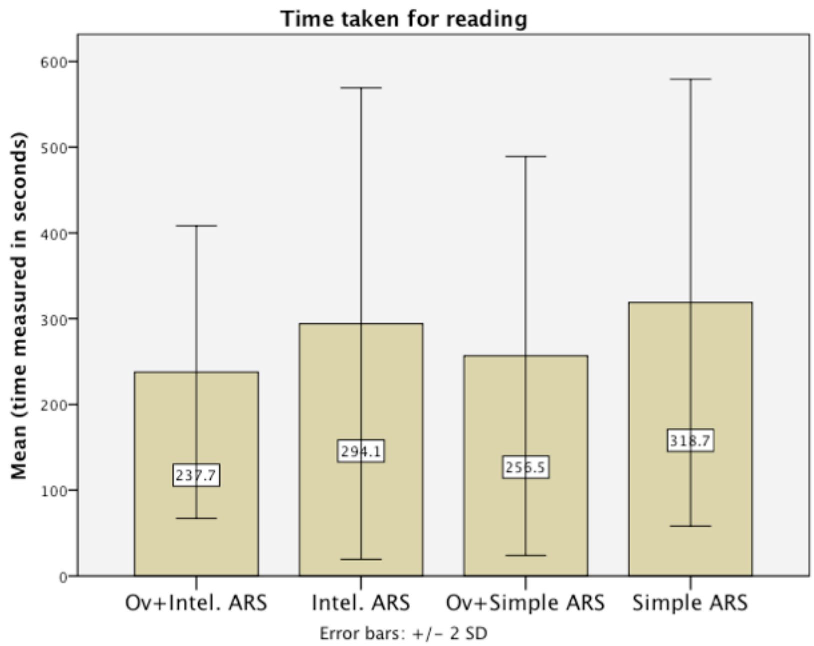


Figure 6.2: Graph of means of elapsed reading time.

break of 10 minutes was given to the participants in the middle of the study. The order of conditions was counterbalanced using the Latin Square matrix.

6.2.4 Data Analysis

We applied objective measures of usability using performance metrics of time and accuracy in reading and re-finding information. Accessibility, ease-of-read, ease-of locating, and memorability were measured using a subjective usability questionnaire (Likert ratings) and the comprehension test.

With Respect To System Efficiency

The operational definition we used for system efficiency is the time taken by the user to read and re-find information. Hence, we measured the elapsed time of reading and the elapsed

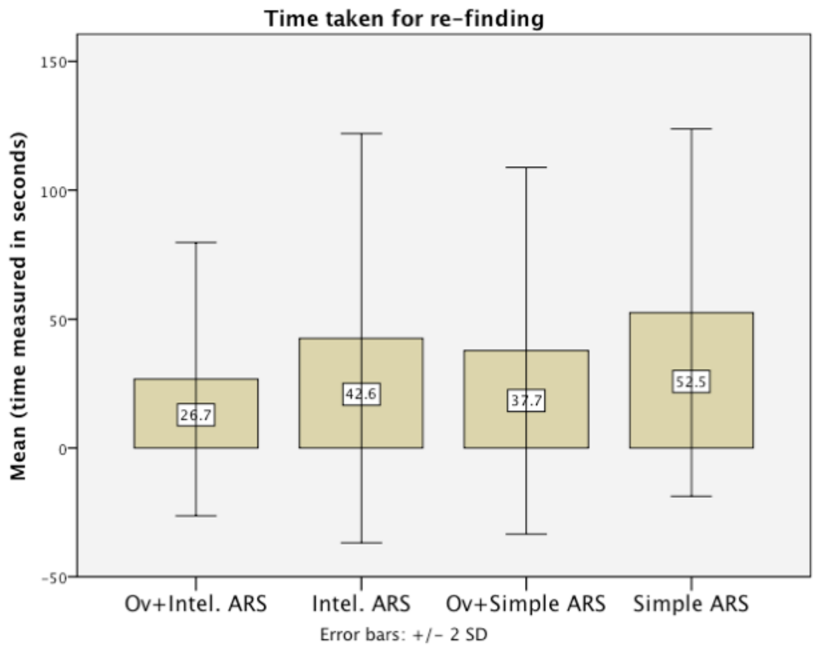


Figure 6.3: Graph of means of elapsed re-finding time.

time of re-finding previously read information. The time was calculated in seconds. The reading time was calculated from the moment the participant touched the iPad screen to read until she reached the last word of the page.

We compared the means of elapsed reading time of the 4 conditions using 6 paired t-tests with alpha level set at 0.05. We found a **statistically significant difference, t(9)=-2.485, p <0.05** in the reading time with *With Overlay, With Intelligent ARS* (M=237.70, SD=85.290) and *Without Overlay, With Simple ARS* (M=318.70, SD=130.245) conditions. These results suggest that the system's efficiency increases when the overlay and the intelligent reader prediction model are added, and the IBSVI took more time to read equivalent amount of text when these components are removed. Also, there was a **statistically significant difference, t(9)=-2.057, p <0.05** in the reading time with *With Overlay, With Intelligent ARS* (M=237.70, SD=85.290) and *Without Overlay, With Intelligent ARS* (M=294.10 , SD=137.357) conditions. Figure 6.2 shows the means of the elapsed reading time for the four different configurations of STAAR. In this figure the *Ov* refers to the *Over-*

lay, and *Intel. ARS* refers to *Intelligent Active reading Support*. The graph shows that the highest means occurred when the overlay was removed during the reading task. While the 2 conditions when the overlay was added, the mean of reading time decreased. Least reading time mean was accompanied with the existence of the *Intelligent ARS, and the Overlay*. The results indicate that this combination leads to the highest efficiency.

For the *re-finding time*, the elapsed time was calculated from the moment the participant touched the iPad screen until she realized the answer. We added the condition of realizing the answer because at few cases the participant found the answer (the researcher could hear it), but she kept on moving not realizing she had just passed it.

We compared the means of elapsed re-finding time of the 4 conditions using 6 paired t-tests with alpha level set at 0.05. We found a **statistically significant difference, t(9)=-2.613, p<=0.05** in the elapsed time with *With Overlay, With Intelligent ARS* (M=26.70, SD=26.516) and *Without Overlay, With Simple ARS* (M=52.50 , SD=35.597) conditions. These results suggest that the participants tended to find the correct answers much faster when they used the system that has the emphIntelligent ARS, and the Overlay, than when they used the system that has only the *Simple ARS* component. Figure 6.3 shows the means of the elapsed re-finding time for the four different configurations of STAAR. The graph shows that the *Intelligent ARS* slightly improves the system's efficiency with respect to re-finding, comparing to the mean of re-finding time when only the *Simple ARS* is provided. When the system is capped with the overlay, the system's efficiency with respect to re-finding further increased. These results are going with the analysis of the reading time means, and both of them support hypotheses H1, H2, H3, and H4.

With Respect To System Effectiveness

The operational definition we used for system effectiveness is the success of answering the knowledge transfer questions either by recalling or re-finding, in addition to the success of describing the structure of the page, i.e. number of paragraphs in the page. We divided the

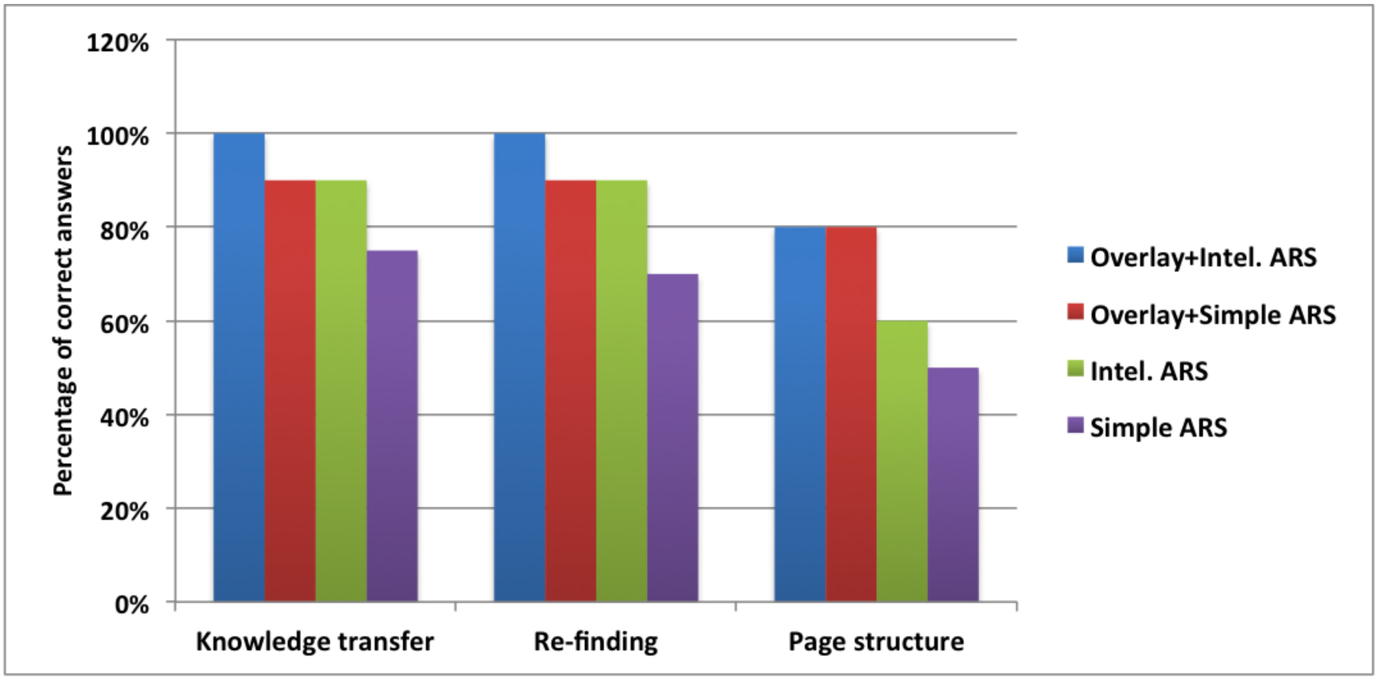


Figure 6.4: Percentages of correct answers of the 4 conditions.

questions asked to the participants into three groups. The first group is knowledge transfer questions, as two questions were asked to each participant about the content of the article. The second group is re-finding question, where the participants were asked to re-find a phrase that occurred only once along the article. The third group is a page structure question, where the participants were asked to find out the number of paragraphs in the page.

We calculated the percentages of correct answers for the ten participants for each questions group, (see Figure 6.4). The graph in Figure 6.4 shows that the participants were able to answer all the knowledge transfer and re-finding questions correctly when they used the *Spatial Reader system* with all its components in. However, for estimating the number of paragraphs in the page (page structure question), only 80% of the answers were correct. Removing the *Intelligent ARS* from the system lead to a decrease in the percentage of correct answers of both the knowledge transfer and the re-finding questions. The least percentage of correct answers along the four conditions occurred with the condition *Without Overlay, With Simple ARS*. These data suggest that the system is most effective with the condition

With Overlay, With Intelligent ARS, and least effective with the condition *Without Overlay, With Simple ARS*, as claimed in our hypotheses H1 to H4.

As the values of the collected data of knowledge transfer questions were either correct or wrong, i.e. nominal data, and given the small sample size, we analyzed the data using *Non-Parametric Chi-Square Test*, instead of comparing means. For each condition, we considered answering both knowledge transfer questions correctly as success, and answering both wrong as a failure. We analyzed the frequency of successful trials by calculating the Chi-square statistic to determine if actual frequencies were significantly different. A summary of the results is shown in Table 6.2. For the *Ov+Intel. ARS*, *OV+Simple ARS*, and *Intel. ARS* independent variables, there exist 0 cells (0.0%) have expected frequencies less than 5. For the *Simple ARS*, there exist 3 cells (100.0%) have expected frequencies less than 5. The number of participants who succeeded on the knowledge transfer questions task **varied significantly** in the conditions *Without Overlay, With Intelligent ARS*, and *With Overlay, With Simple ARS*, but not in the condition *Without Overlay, With Simple ARS*. I.e. there was a greater chance for participants to succeed in the first two than in the last one. These results suggest that the system with the support of the sonic gutter alone would not help IBSVI to reach perfect accuracy with respect to knowledge transfer. On the other hand, further reading support with the help of the overlay and the intelligent reader prediction model improves the IBSVI ability to answer all the knowledge transfer questions correctly, meaning leverages the system effectiveness to the top.

We also analyzed the re-finding and the page structure questions using the Non-Parametric Chi-Square Test. A summary of the results of the two questions are shown in Table 6.3, and Table 6.4, respectively. In the page structure task, Chi-square was **significant** for the conditions *With Overlay, With Intelligent ARS*, and *With Overlay, With Simple ARS*. Here by, we can see that the existence of the overlay was critical in supporting IBSVI exploring the page and correctly identifying the number of paragraphs in the page. In the re-finding task, Chi-square was **significant** in the conditions *With Overlay, With Simple ARS*, and *Without Overlay, With Intelligent ARS*. Thus, the number of participants who succeeded on the re-finding task varied significantly in the conditions "Without Overlay, With Intelligent ARS", and "With Overlay, With Simple ARS" but not in condition "Without Overlay, With Simple ARS". I.e. there was a greater chance for participants to succeed in the first two conditions than in the last one. These results show that the system configuration that consists of only the sonic gutter lead to difficulty in re-finding information comparing to the other conditions, which support our hypotheses.

Finally, we evaluated the total effectiveness of the system with its four configurations by analyzing the frequencies of successful answers to all questions of the 3 tasks; the knowledge transfer, re-finding, and page structure tasks. Table 6.5 shows the Chi Square statistics for success on all tasks. For the condition *With Overlay, With Intelligent ARS*, zero cells (0.0%) have expected frequencies less than 5, and the minimum expected cell frequency is 5.0. With the conditions *Without Overlay, With Intelligent ARS*, and *With Overlay, With Simple ARS*, 3 cells have expected frequencies less than 5. The minimum expected cell frequency is 3.3. In the condition *Without Overlay, With Simple ARS* 4 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 2.5. Eight participants out of 10 were able to perform all the tasks correctly using the system with all of its components (Ov+Intel. ARS), (see Figure 6.5). When the RPM was removed, the number of participants who correctly solved all the tasks was 7 (see Figure 6.6), and when the Overlay was removed 5 participants correctly solved all the tasks, (see Figure 6.7). When both the Overlay and the Intelligent ARS were removed, only one participant was able to perform all the tasks correctly, (see Figure 6.8). These results show a degradation of the system's overall effectiveness accompanied with the absence of each of its tested components. The observed degradation matches our hypotheses H1 to H4.

User Preferences

Upon the completion of each condition, the participants were asked to answer a set of questions about their preference to the system configuration they used. They were asked to

Table 6.2: Chi Square statistics for success on the knowledge transfer task.

	Ov+Intel. ARS	**Ov+Simple ARS**	**Intel. ARS**	**Simple ARS**
Chi-Square	0.000	6.400	6.400	3.800
df	1	1	1	2
Asymp. Sig.	1.000	**0.011**	**0.011**	0.150

Table 6.3: Chi Square statistics for success on the page structure task.

	Ov+Intel. ARS	**Ov+Simple ARS**	**Intel. ARS**	**Simple ARS**
Chi-Square	3.600	0.400	3.600	0.000
df	1	1	1	1
Asymp. Sig.	**0.058**	**0.058**	0.527	1.000

Table 6.4: Chi Square statistics for success on the re-finding task.

	Ov+Simple ARS	**Intel. ARS**	**Simple ARS**
Chi-Square	6.400	6.400	1.600
df	1	1	1
Asymp. Sig.	**0.011**	**0.011**	0.206

Table 6.5: Chi Square statistics for success on all tasks.

	Ov+Intel. ARS	**Ov+Simple ARS**	**Intel. ARS**	**Simple ARS**
Chi-Square	3.600	6.200	2.600	10.800
df	1	2	2	3
Asymp. Sig.	**0.058**	**0.045**	0.273	**0.013**

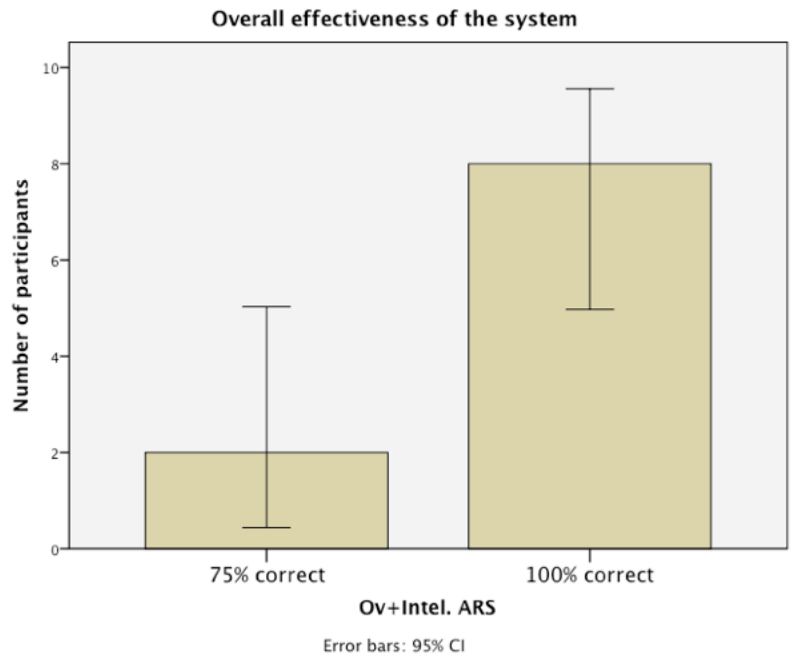


Figure 6.5: Overall effectiveness of the condition *With Overlay, With Intelligent ARS*.

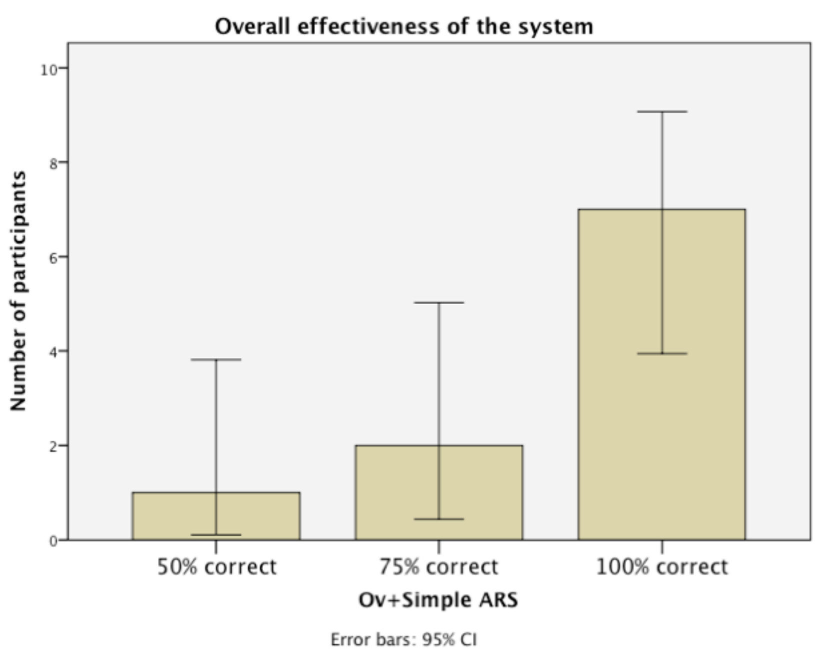


Figure 6.6: Overall effectiveness of the condition *With Overlay, With Simple ARS*.

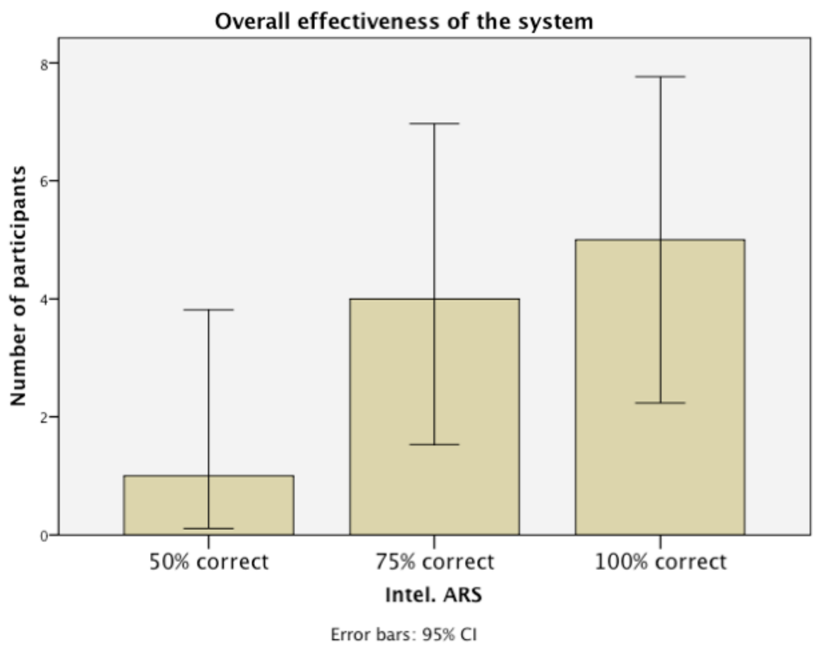


Figure 6.7: Overall effectiveness of the condition *Without Overlay, With Intelligent ARS*.

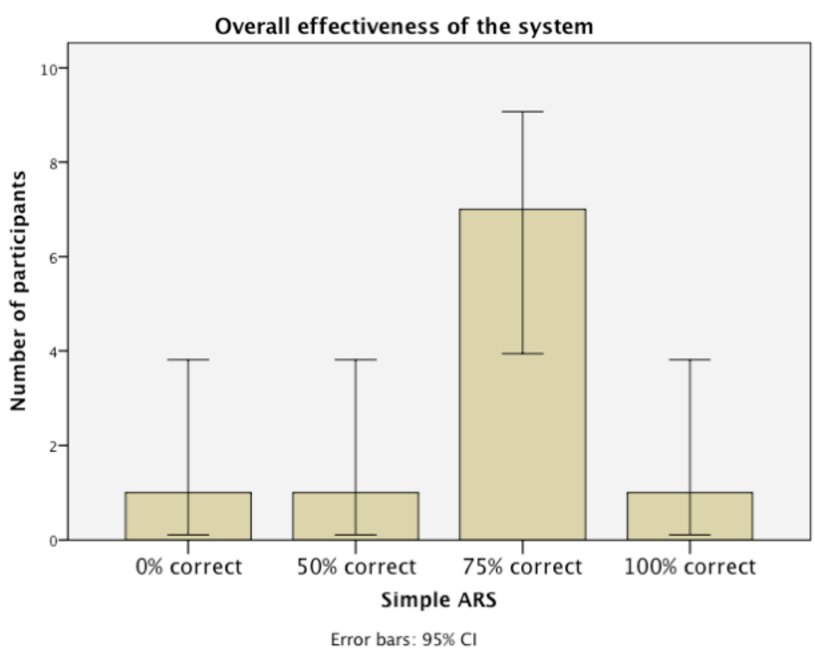


Figure 6.8: Overall effectiveness of the condition *Without Overlay, With Simple ARS*.

rate the ease of the different functionalities of the reader system such as recalling, re-finding, navigation, and staying on line. The scale was set from zero to ten, where zero indicates the lowest rate and 10 indicates the highest rate. We compared the means of the participants' allover preference using 6 t-tests with alpha level set at 0.05. The participants preferred the conditions where the overlay exists more than the other conditions where the overlay was removed. The means of the ratings for the 4 conditions are plotted in the Figure 6.9. There was a **statistically significant difference, $t(9)=4.7$, $p<0.05$** in the users' preference to the condition *With Overlay, Intelligent ARS* to their preference to the condition Without Overlay, With Simple ARS (M=2.05 , SD=1.36). Table 6.6 summarizes the paired t-test results for users' overall preference.

For each dimension, the means of the users preferences were analyzed and compared using 6 t-tests with alpha level set at 0.05. We found statistically significant difference in the following dimensions:

- Navigation:
  We found four **statistically significant differences** in the ease of navigation and maintaing location on the page between the two conditions that has *Overlay* and the other two conditions in which the overlay was eliminated, e.g. there is **statistically significant difference; $t(9)=5.071$, $p<0.05$** *With Overlay, With Intelligent ARS* (M=7.8 , SD=1.2) and *Without Overlay, With Intelligent ARS* (M=3.8 , SD=2.5) conditions. On the other hand, when the two conditions have the *Overlay*, or the overlay is eliminated from both conditions, there was no statistically significant difference between the means. Table 6.7 shows the paired samples test for the 6 t-test. The data shows the effect of the existence of the overlay on increasing the participants's positive feedback with respect to navigation and spatial perception.

- Staying on line:
  We found four **statistically significant differences** in the ease of staying on line of text between the two conditions that has *Overlay* and the other two conditions in

which the overlay was eliminated, e.g. there is **statistically significant difference, t(9)=5.511, p <0.001** *With Overlay, With Intelligent ARS* (M=7.6 , SD=1.07) and *Without Overlay, With Intelligent ARS* (M=4.0 , SD=1.8) conditions. On the other hand, when the two conditions have the *Overlay*, or the overlay is eliminated from both conditions, there was no statistically significant difference between the means. Table 6.8 shows the paired samples test for the 6 t-test. The data shows the effect of the existence of the overlay on increasing the participants's positive feedback with respect to staying on line and not drifting, (see Figure 6.10). The participants feedback with respect to their confidence in staying on line was very similar to their feedback for ease of navigation, which gives more support to the hypotheses H1 and H4.

- Re-finding and recalling:

  When we asked the participants about how easy they found it to re-find previously read information, they gave the highest preference to the condition *With Overlay, With Intelligent ARS*, and the lowest preference to the condition *Without Overlay, With Simple ARS*. Figure 6.11 shows the means for the participants subjective opinion in the ease of re-finding for the 4 conditions. By comparing the means using 6 t-test with alpha level set at 0.05, we found **statistically significant difference, t(9)=2.86, p <0.05** between *With Overlay, With Intelligent ARS* (M=7.0 , SD=1.49) and *Without Overlay, With Intelligent ARS* (M=5.9 , SD=2.07) conditions.

  A key finding in this dimension comparison, is a ***statistically significant difference, t(9)=-2.077, p<0.05*** between the conditions *Without Overlay, With Intelligent ARS* (M=5.9, SD=2.07), and *Without Overlay, With Simple ARS* (M=5.0, SD=2.49). These results give an indication that the overlay helps IBSVI in the re-finding tasks, and when the overlay is removed they found re-finding easier when the system is supported by the Intelligent ARS. These findings support our hypotheses H1 to H4.

  We also asked the participants about their opinion in the ease of recalling information

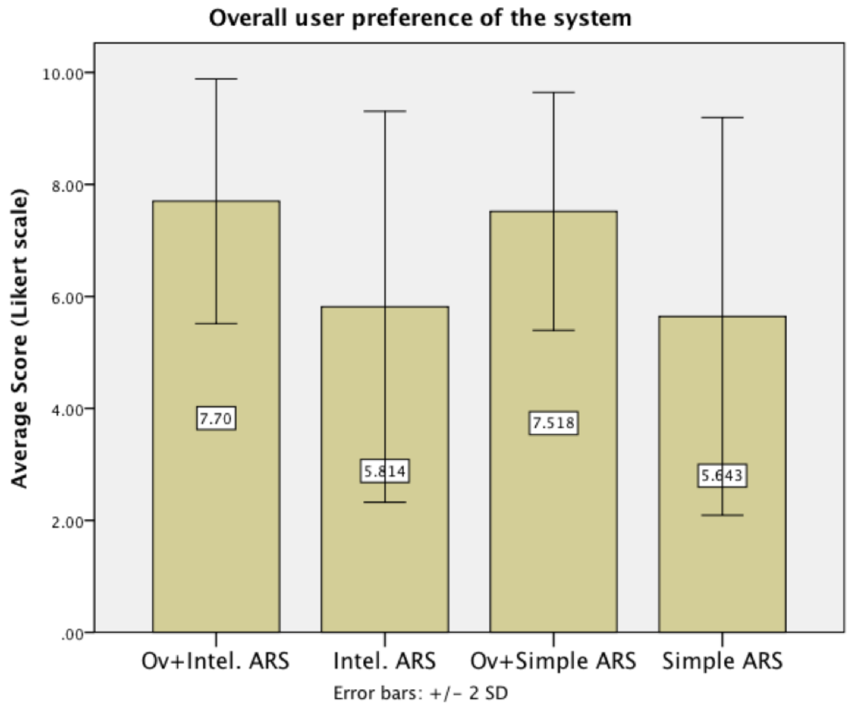


Figure 6.9: Participants' rate of the overall preference of the system.

using the four system configurations. They reported different rates for the four conditions, (see Figure 6.12), but there was no statistically significant difference between them.

Participant's Strategies for Page-layout Exploration

During each condition of the study, we asked the participants to estimate the number of paragraphs in the page they read. In this analysis, we excluded the participants who gave an estimate without trying to re-access the page. We observed that the participants developed different strategies to explore the structure of the page in order to find the answer. We categorized these strategies into three groups:

1. Semantic Approach:

   Only one participant developed this approach. She was re-reading the page and re-

Table 6.6: Paired samples test for users' overall preference to the system.

Pair	**Mean**	**Std. Deviation**	**t**	**df**	**Sig. (2-tailed)**
Ov+Intel. ARS and Intel. ARS	1.8	1.4	4.03	9	0.003
Ov+Intel. ARS and Simple ARS	2.05	1.36	4.751	9	0.001
Ov+Simple ARS and Intel. ARS	1.7	1.3	4.07	9	0.003
Ov+Simple ARS and Simple ARS	-1.87	1.17	-5.02	9	0.001
Ov+Intel. ARS and Ov+Simple ARS	0.18	0.68	0.84	9	0.423
Intel. ARS and Simple ARS	-0.17	1.6	-0.337	9	0.744

Table 6.7: Paired samples test for users' preference w.r.t navigation.

Pair	**Mean**	**Std. Deviation**	**t**	**df**	**Sig. (2-tailed)**
Ov+Intel. ARS and Intel. ARS	3.6	2.06	5.51	9	0.000
Ov+Intel. ARS and Simple ARS	4.0	2.16	5.8	9	0.000
Ov+Simple ARS and Intel. ARS	2.8	2.6	3.3	9	0.009
Ov+Simple ARS and Simple ARS	3.2	1.8	5.5	9	0.000
Ov+Intel. ARS and Ov+Simple ARS	0.8	2.39	1.0578	9	0.318
Intel. ARS and Simple ARS	0.4	1.95	0.647	9	0.534

Table 6.8: Paired samples test for ease of staying on line.

Pair	**Mean**	**Std. Deviation**	**t**	**df**	**Sig. (2-tailed)**
Ov+Intel. ARS and Intel. ARS	4.0	2.49	5.07	9	0.001
Ov+Intel. ARS and Simple ARS	3.6	2.02	5.6	9	0.000
Ov+Simple ARS and Intel. ARS	3.7	2.8	4.1	9	0.003
Ov+Simple ARS and Simple ARS	3.3	1.5	6.6	9	0.000
Ov+Intel. ARS and Ov+Simple ARS	0.3	1.25	0.758	9	0.468
Intel. ARS and Simple ARS	-0.4	2.5	-0.5	9	0.625

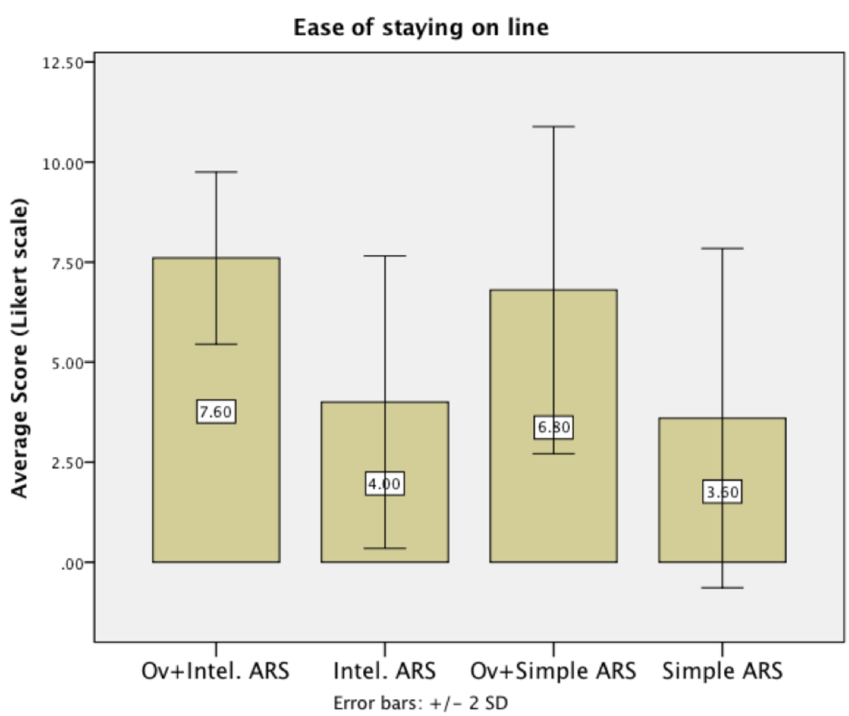


Figure 6.10: Participants' rate of ease of staying on line.

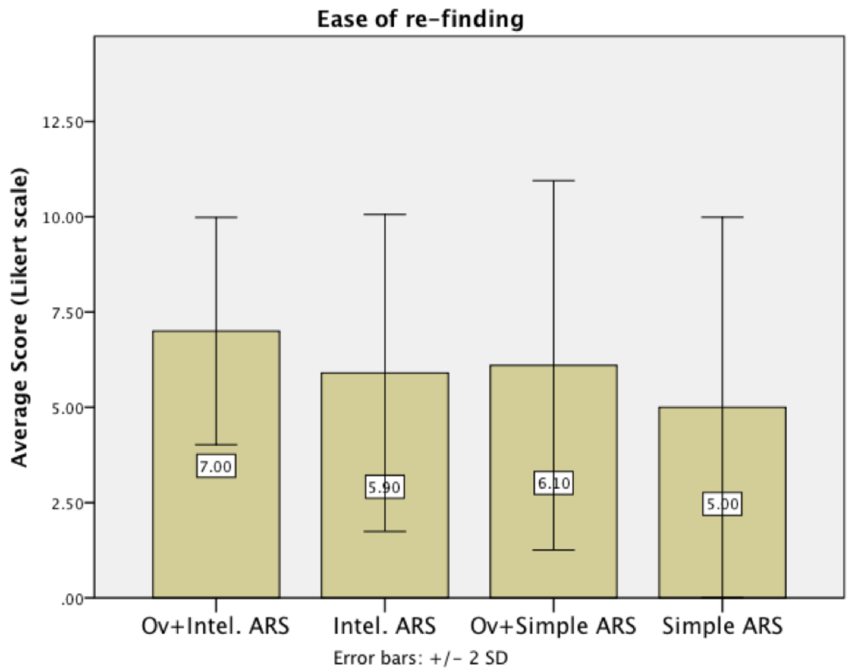


Figure 6.11: Participants' rate of ease of re-finding information.

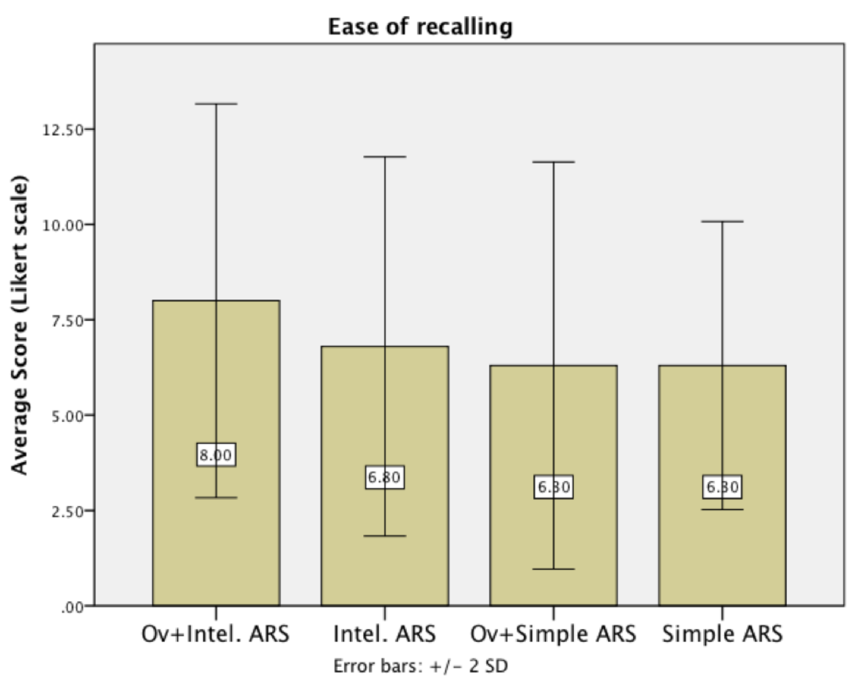


Figure 6.12: Participants' rate of ease of recalling information.

thinking of the main themes that she read. Based on the sequence of the different ideas in each block of text, she estimated the number of paragraphs in the page. For example, in one page, she said: *"This is a dialogue, that must be a new paragraph"*. This strategy mislead or confused its user at some instances, specifically when the number of paragraphs in the page is three, as she perceived them as two paragraphs.

2. Spatial Perception Approach:
   Two of the participants tried to make use of the short lines at the end of each paragraph. We observed that these participants noted the fact that the text was justified and that all the lines were along up to the end of the right side of the page. The only exception for this rule is the last line of the paragraph, where they heard the *End of Line* sonification far from the physical end of the right side of the page. This method was more accurate than the previous one, as the participants were able to find the correct answer at most of the instances.

3. Auditory-based Exploration Approach:
   Six participants were looking for auditory feedback to spatially perceive the page. Five participants focused on searching for the *White Space* sonification. Their technique was to move their finger from the top of the page towards the bottom, and every time they heard the *White Space* sonification triggered repeatedly with their vertical movement followed by hearing words of the text, they perceived this gap as a space between two paragraphs. The sixth participant depended on the auditory feedback of the system, but she used the *Vertical Ruler* sonification instead of the white space sonification. She started sliding her finger along the vertical ruler from the top of the page towards its end at the bottom. Every time she hit a line of text, she heard the sonification. In the gap between the paragraphs, the sonification stopped. The silence of the vertical ruler sonification in between the paragraphs was her clue to perceive the spatial structure of the page. The two techniques of this approach were the most successful comparing to the semantic and the spatial perception approaches.

Interestingly, each participant developed an approach to explore the spatial layout of the page, was following the same approach across all conditions. We did not observe any participant who followed different techniques in exploring the page structure during this study. As the participants were able to reach the same result using different functionalities of the *Reader System*, we can see that STAAR could successfully support IBSVI to create a mental model of the page they are reading, despite the fact that 70% of the participants had their visual disability since birth.

Participants Interviews

At the end of each condition, participants were interviewed with semi-structured interview. In this section, we report their responses grouped into the following categories:

- Page sonifications

  The participants were asked about their opinion in the page sonifications e.g. the end of line, and the line location sonifications. All participants found the page sonifications useful in navigating the page and helpful in constructing a cognitive map of the page they are reading. One participant said: *"sounds definitely help."*, while other said: *"The ruler sound and the ding help reading a page."*

- Sonic gutter

  The participants were asked about their opinion in the sonic gutter. Seven participants found it useful in alerting them when they strayed, and helpful in guiding them back to the correct line. One participant found it annoying, and interferes with what she is trying to read. Two participants could not memorize which sound means they strayed above the line, and which sound means they strayed below the line.

- Comments on the overlay

  One of the participants had a nerve damage and she could not feel the embossed landmarks on the overlay. All other participants highly appreciate the support of the overlay. Below are quotes from the participants words about the overlay:

“Definitely need the template”

“I do much better with the tactile overlay”

“Without it, it was very frustrating”

“I feel more secured with the overlay”

“It was difficult to find the vertical ruler without the overlay”

“Easier to read with the guide”

- Quality of speech

  Three participants found difficulty understanding some words because the speech pronunciation was not clear to them. Two of them suggested to add ”Spelling” function to the system, so that they can use it when they hear a word and could not recognize it. One participant mentioned that it is hard to understand short words, long words are easier.

- Learning curve

  The researcher observed that the participants felt more confident the more they used the system, and tiring effect appeared by approaching the end of the study. The participants were aware with their increasing capability on using the system despite the change in the system’s configurations from one condition to another. Six participants self-reported their confidence using the system is directly proportional to the time they spent using it. Below are few quotes from the participants words:

  ”Practice will enhance that”

  “I get used to it”

  “The more I play with, the better I read with”

  “With some practice, you can really use this very well”

  “There is a learning curve, I can do better overtime”

6.2.5 Discussion

In this section, we discuss the results of the decomposition study. The discussion is arranged into three parts. First, we discuss how the *Reader System* helped IBSVI to perform different reading strategies that require spatial access to the reading materials. Second, we discuss how the presence of the system's components lead to an accumulative effect that is shown in the participants' performance. Also, we will discuss the hidden effect of the *Intelligent ARS*. Finally, we will discuss the effect of the user's background on her performance using the system.

Performing Different Reading Strategies

As the goal of this research is to enable IBSVI to read effectively and to be engaged in different reading strategies for different reading purposes, it was very important for us to see whether the objective of the research has been achieved. Section 1.2.1 carried an overview on the reading strategies. The *Receptive Reading* is basically reading without interrupting the one's train of thought. We consider this is as the basic reading skill, which means that the user can operate the system to read all the text. This is obviously done during the reading task. Details about the objective measurement of the reading task were given in Section 6.2.4.

The second strategy that requires a little bit higher intellectual engagement from the reader, is the *Scanning strategy*. This skill is measured by the *Locate a phrase* task, (see Section 6.2.3). The researchers observed that while the participants were trying to locate the phrase, they were switching between the *Scanning* and the *Skimming* strategies. For example, one participant stopped reading a line and jumped vertically three lines ahead because she realized that she was looking for the phrase in the wrong paragraph. In most cases, the participants were able to recall the approximate position of the phrase in question. That means that they were able to construct a cognitive map of the page they were reading, and were able to assign the text to its physical location. *Skimming* was also followed by some participants when they were asked about the number of paragraphs in the page. To answer this question, some participants started from the top of the page and skimmed it moving downwards as they heard the words. When they found blank line, they stopped for a moment to make sure they found an end of a paragraph, and then they continued skimming the page.

Finally, the system was tested to find out whether it could enable IBSVI to be engaged in *Active Reading*, which requires the highest intellectual engagement with the reading material. Participants were asked knowledge transfer questions about specific details in the text with the allowance of re-reading. The participants were able to find the correct answers as illustrated in Section 6.2.4. They follow the *Active Reading* strategy. In some cases, participants were able to recall the answer to the knowledge transfer question, but they said they want to make sure it is correct and they re-read the text in *Active Reading* mode looking for the specific details. The last reading strategy is the *Searching Strategy*. To test if STAAR could enable IBSVI to follow this strategy, we will need to provide the participants with different reading materials to search among all of them for an information. This task is beyond the limits of this study. In the future work, we will work on testing the *Searching Strategy*.

Accumulative Effect of the Systems' Components

The hypotheses of the decomposition study are that the system with the overlay and the intelligent active reading support will have the highest objective and subjective measurements, e.g. the efficiency, effectiveness, and ease of use. By removing the overlay or the intelligent active reading support, these measurements will decrease. By removing both the overlay and the intelligent reading support, the measurements matrix will be the lowest. The results we presented in Section 6.2.4 gave support to these hypotheses. There were statistically significant differences between the two conditions where both components exist and when both components are removed. The results also showed the high influence and preference of the tactile overlay, for both the objective and the subjective measurements. This conclusion is supported by the statistically significant differences between the conditions where the overlay was presented in one and removed from the other.

Although there was no direct indication to the influence of the intelligent active reading support, we claim that it has a ''hidden" effect. The researchers observed that in the case where the intelligent active reading support was removed, the participants were more sensitive to the line straying problem. This is because they heard a sentence that did not make sense to them, as the system only activated the touched word even if the user strayed. That leads to frustration to the participants. Moreover, they tend to re-read the whole line again because they wanted to understand what they were reading. On the other hand, when the intelligent active reading support was enabled, the participants tend to continue reading the text even if they activate the sonic gutter by straying of the line. This is because the intelligent active reading support predicts the intended word and sonifed it to the reader. For the objective measurements, we found that the means of the reading and the re-finding times were better when the intelligent active reading support was enabled. For the subjective measurements, the participants gave the credits of the ease of use to the overlay or to the sonic gutter because they were not aware with the function or the existence of the intelligent ARS.

In sum, the page sonifications gave the IBSVI the basic platform to self-paced read in a spatial medium. The overlay gave them more fluency in navigating the page and more confidence in mistakes-free reading, e.g. the self-confidence she did not skip a line. The sonic gutter supports IBSVI spatially reading on the line level. Finally, the intelligent active reading support corrects the drifting errors, leading to smoother reading and comprehension.

Special User Groups

In this section, we will discuss the backgrounds of the participants and how that might affected the way they used and perceived the system. As the size of the study population is small, n=10, we by here do not generalize any results. Rather, we report our observations that could shed the light on the research results, and could help us in the design of any related future studies.

We found two criteria that can have influence on the usage of the reader system for the first time. The first criteria is the age, and the second criteria is the participant's history of reading. For the age, the younger the participants, the faster they learned the system, and the more effectively they used it. Older participants tend to perform more mistakes while using the system, such as not responding to the different provided sonifications. For the participant's history of reading, we found that participants who read Braille reported that they can not resist pushing hard as they used to do when reading Braille. On the other hand, participants who are used to audio books reported that they prefer to listen to bigger chunks of audio than listening to the text word-by-word.

One of the participants was left-handed. She had difficulty using the system the way we described during the familiarization session, i.e. anchoring on the left side of the page and traversing vertically on the ruler to find the lines, and then read by sliding the finger vertically. The system does not have an accommodation for left-handed users. She adapted the way she interacted with the system to have more comfort while reading. She anchored with her left hand to find the line and then she left the reference point and moved horizontally for reading. To get back to the starting point of the next line, she moved across the previously read line backwards until she reached the first word, and then she moved vertically downwards to go to the next line. It will be optimal if the system has settings that can handle left-handed interactions, but it was good to see how readers might use the system in a different manner.

When participants were asked whether they use any touch devices or not, we found that only two used touch devices. Interestingly, one of the participants mentioned that yes she uses ''keyboards". The participant perceived "touch device", as something that she can recognize by the touch, meaning that it can be distinguishable by the touch. Obviously, the glass-touch devices are not an example of this description. This high propensity towards tactile feedback by IBSVI was confirmed by other participants who mentioned that they prefer phones with buttons, and do not like smart touch phones. That was also revealed in one of the participant's description to the overlay, as a "guide".

To sum up, individual differences could have an effect on the use of the reader system. The reader system could have additional features or add-ons to be user friendly to older people who have shaking hands, or hearing deficiency problems. The IBSVI population is very diverse. More understanding to the target population will help in designing better future systems.

6.3 Comparative Study

STAAR is a novel reader system that can be used to perform different reading strategies such as skimming, scanning, and active reading. In order to validate the reader system, we conducted a comparative study, where we compared STAAR to the iBook with the VoiceOver technology. iBook is a reading system that is fully compatible with the VoiceOver technology. It is considered to be the state-of-the-art at the time of conducting the study. VoiceOver can be configured to read continuously, but for the purpose of this study, we used the default settings i.e. reading line by line. Our logic is that this is the mode where the user reads what she touches, so that the user will be spatially oriented to some extent comparing to the continuous reading where the space dimension is completely elaborated. STAAR was tested with all of its components; the overlay and the intelligent active reading support. iBook was tested in its default mode, where it reads a whole line at once. We consider iBook with VoiceOver as a similar system to STAAR because:

1. It is a multimodal system, where the user tries to situate herself within the space of the screen/page, and the text is carried to the user with the audio modality

2. It reads what the user touches, similar to STAAR, but it reads in a "Line" unit instead of a "Word" unit

The goal of the study is to compare the two systems with respect to:

- Effectiveness: Success of answering the knowledge transfer questions
- Efficiency: The time needed by the user to read one page of text successfully (e.g. without skipping lines)
- Spatial Perception: Success of spatially locating the information and estimating the layout of the page, e.g. trying to figure out the number of paragraphs in the page

6.3.1 Method

We designed a single factor within-subjects study, to compare STAAR to iBook. The independent variable is the system type, 2 levels (STAAR, iBook). The dependent variables are: time of reading, time of re-finding, accuracy of re-finding, spatial orientation, and subjective ratings of usability using a Likert scale. The study was designed to be at the same session of the decomposition study, so we have the same participants of the decomposition study. We report the participants' data in this section again for the fluency of reading.

6.3.2 Participants

Ten IBSVI participated in this study. Their ages ranged from 18 to 77, with a mean of 50.8 (SD=15.75). Five of them are females, and 5 are males. Six are totally blind, two have 20/400 acuity, and two have 20/800 acuity. Seven of them had their visual disability since birth. One of the participants had nerve damage that prohibited him from feeling the tactile overlay. One of the participants was left-handed. Eight participants could read Braille, but only one uses the Braille medium for reading regularly. The other 9 participants access reading materials using screen readers and audio books. Only two participants have touch devices e.g. iPhone.

6.3.3 Experimental Procedure

We prepared a paragraph of four lines and compiled them using the two tested systems. Before the participants started any tasks, they were introduced to the systems, and were asked to practice by reading the short paragraph. During the task, the participants were asked to read a page of text per each condition. Both pages are of equivalent length, and with similar layout and content. Both pages are equivalent to the 8th grade level according to the Fischer-Kincaid measurement. After finishing reading, the participant was asked 4 questions:

- Two questions are knowledge transfer questions. The participants were encouraged to find the answer by re-reading the page
- The other two questions are for spatial perception assessment. The first question is to locate a sentence in the reading material. The second question is to estimate the number of paragraphs in the reading material

At the end of each task, a user experience questionnaire and semi-structured interview were conducted. The duration of each task was set to be 25 minutes as a maximum limit. The order of conditions was counterbalanced using the Latin Square matrix.

6.3.4 Data Analysis and Discussion

We applied objective measures of usability using performance metrics of time and accuracy in reading and re-finding information. Accessibility, ease-of-read, ease-of locating, and memorability were measured using a subjective usability questionnaire (Likert ratings) and the comprehension test.

With Respect To System Efficiency

We measured the time taken by participants to read the given pages using STAAR and the iBook. The time was measured in seconds. The means of the reading time are plotted in Figure 6.13. As illustrated in the figure, the participants took nearly double the time when reading with STAAR comparing to reading with iBook. This result was expected because the speech rate of the iBook is faster. Moreover, the design of STAAR requires the reader to actively interact with each word in the page to read it. With iBook, only one interaction is required to listen to a whole line.

We also measured the time taken by participants to re-find previously read information. The time was measured in seconds. In the case of STAAR, the participants were asked to accurately locate the phrase. But in the iBook condition, they were asked to find the line where the phrase is located. This is because iBook enables the users to read word by word with a swipe gesture, where the touch is decoupled from the position of the word. Hence, this interaction design does not contribute to our research as it does not provide the users with a spatial reference. The means of the time taken to re-find information is illustrated in Figure 6.14. The participants took less time in re-finding with STAAR then they did with the iBook. Although the researchers expected that iBook will be more efficient in re-finding, that was not the case. The reason behind that is that the participants had to listen to the whole line to find out whether the information exists in this line or not. But with using STAAR, they were able to *Skim* the page. Following the *Skimming strategy* was easier with STAAR than with the iBook condition.

With Respect To System Effectiveness

The participants were asked three types of questions after reading with each condition. A comparison between the percentages of correct answers for all participants using the two systems is illustrated in Figure 6.15. Using STAAR, four participants were able to answer

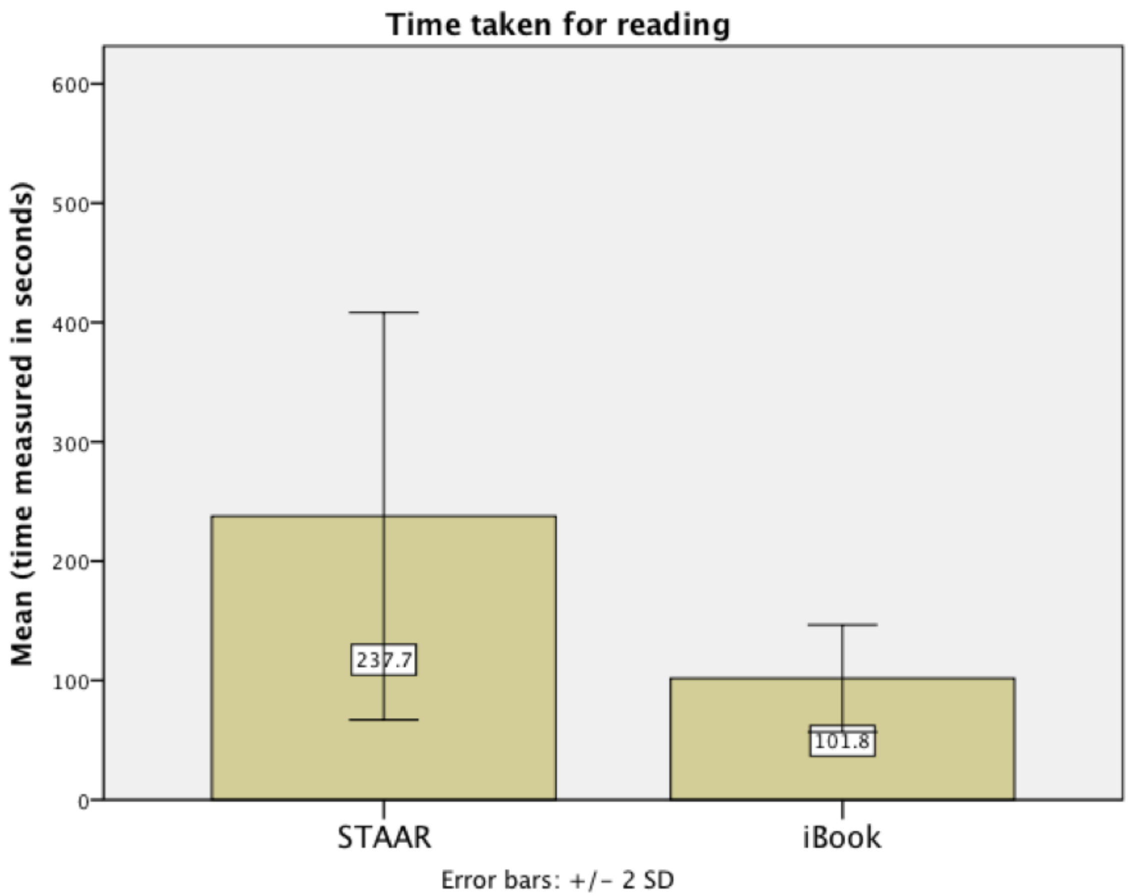


Figure 6.13: Graph of means of elapsed reading time.

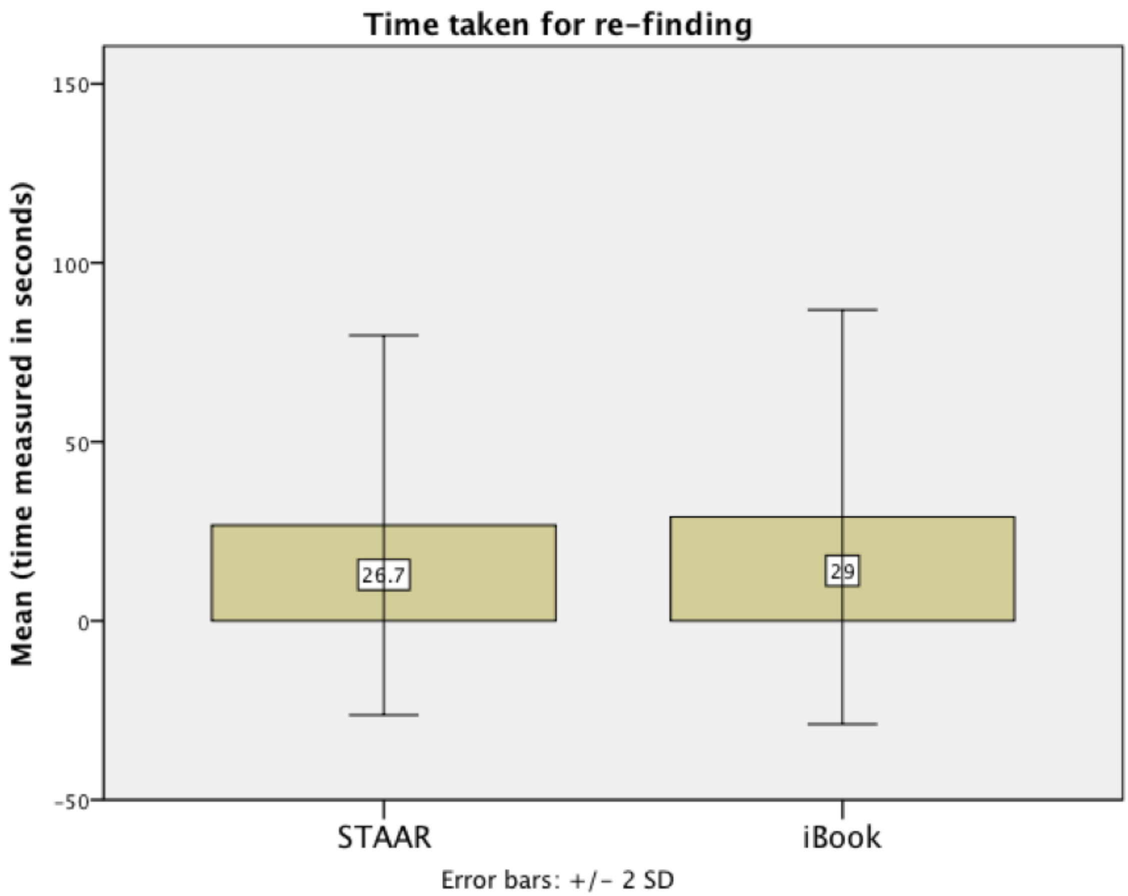


Figure 6.14: Graph of means of elapsed re-finding time.

all the questions correctly, five participants answered 3 questions correctly out of four, and one participant answered two questions correctly. A summary for the overall effectiveness of STAAR is illustrated in Figure 6.16. Using iBook, only one participant answered all the questions correctly, five participants answered three out of four questions correctly, three participants answered 2 out of four questions correctly, and one participant answered only one questions correctly. A summary for the overall effectiveness of iBook is illustrated in Figure 6.17.

In order to better understand the difference in effectiveness between the two systems, we analyzed the data of each task independently. As the values of the collected data were either correct or wrong, i.e. nominal data, and given the small sample size, we analyzed the data using Non- Parametric Chi-Square Test. We analyzed the frequency of successful trials of the knowledge transfer, re-finding, and page structure tasks by calculating the Chi-square statistic to determine if actual frequencies were significantly different. The summary of the results for the three tasks are shown in Table 6.9, Table 6.10, and Table 6.11, respectively. Chi-square was significant for the three tasks. These results indicate that STAAR is more effective than iBook with respect to knowledge transfer, re-finding, and page structure exploration.

The above data indicates that the page structure exploration task was the most difficult for IBSVI when they used the iBook system. Our analysis to this finding is that the lack of page sonifications caused a lack of spatial perception of the page. Moreover, the iBook reads short lines when the user's finger is on the same horizontal line of the text, even if the user does not touch the text. Figure 6.18 illustrates this problem. Reading text that is not actually touched violated the user's expectations, and hence she was not able to construct a cognitive map of the page she is reading.

With Respect To User Preference

Upon the completion of each condition, the participants were asked to answer a set of questions about their preference to the system they used. They were asked to rate the ease

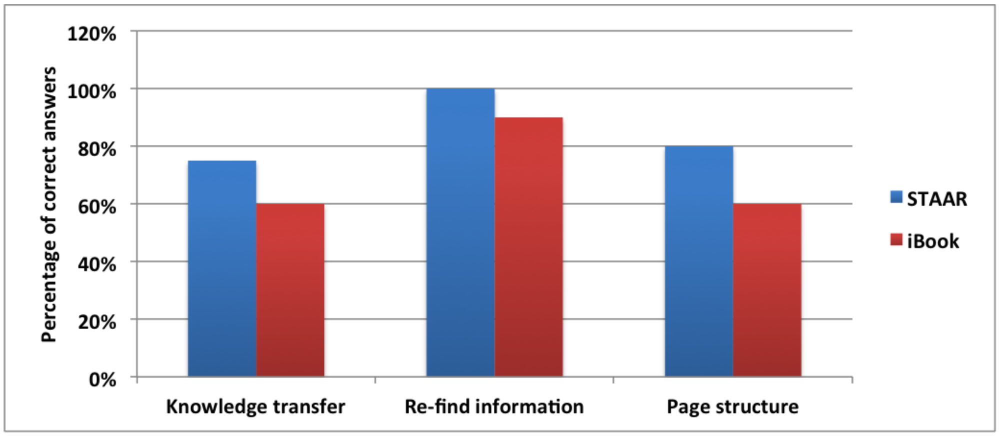


Figure 6.15: Percentages of correct answers using the two systems.

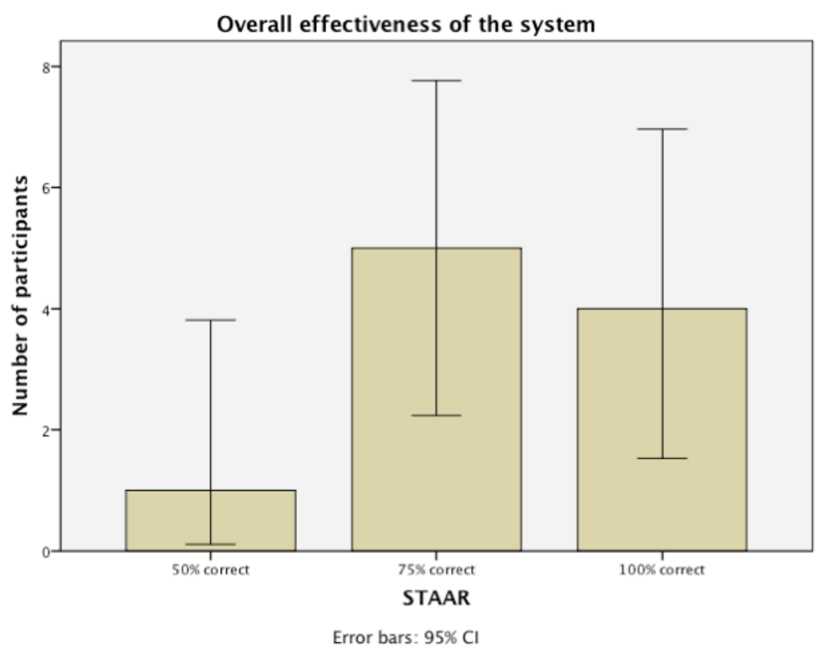


Figure 6.16: Overall effectiveness of STAAR.

Table 6.9: Chi Square statistics for success on the knowledge transfer task.

	iBook
Chi-Square	6.4
df	1
Asymp. Sig.	**0.011**

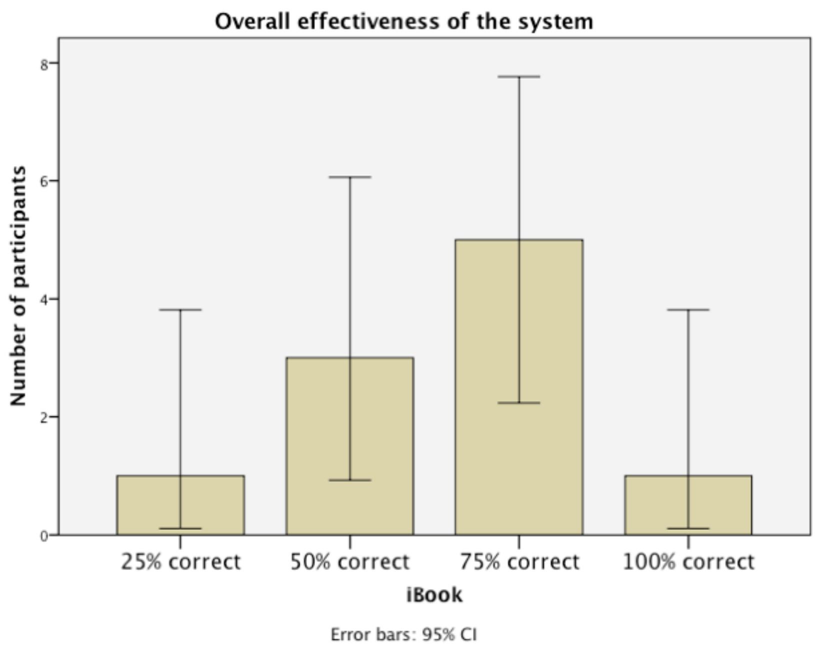


Figure 6.17: Overall effectiveness of iBook.

Table 6.10: Chi Square statistics for success on the re-finding task.

	iBook
Chi-Square	6.4
df	1
Asymp. Sig.	**0.011**

Table 6.11: Chi Square statistics for success on the page structure task.

	iBook	**STAAR**
Chi-Square	0.00	3.6
df	1	1
Asymp. Sig.	1.00	**0.05**

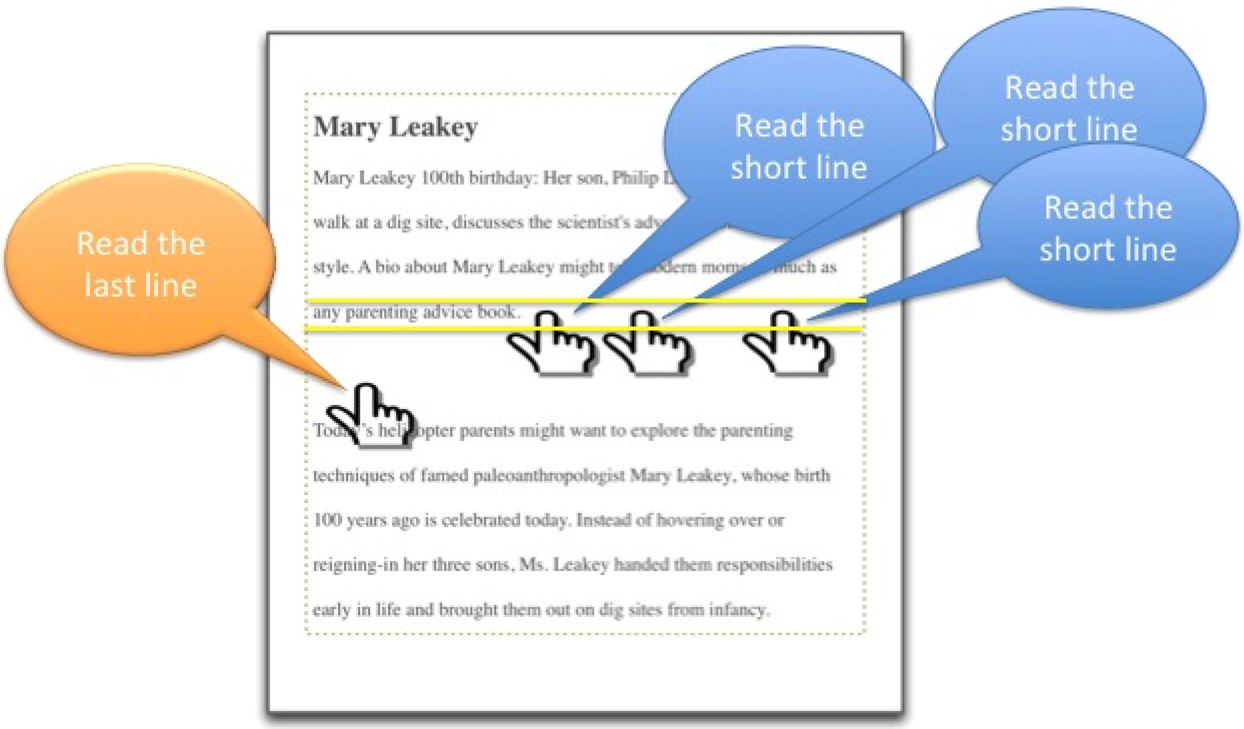


Figure 6.18: iBook responses to touches of blank areas around the text .

of the different functionalities of the system such as recalling, re-finding, navigation, and speech rate. The scale was set from zero to ten, where zero indicates the lowest rate and 10 indicates the highest rate. The participants rating of their preference to STAAR (M=7.7, SD=1.09) and the iBook (M=6.85, SD=2.08) as a whole is plotted in Figure 6.19. For each dimension, the means of the users' preferences were analyzed and compared. The participants found that recalling information (see Figure 6.20) is easier with the iBook, where activities that require spatial awareness such as re-finding (see Figure 6.21) and page navigation (see Figure 6.22) were easier with STAAR. The speech rate of the iBook was fixed during reading the whole page. With STAAR, the speech rate varied with the speed of the user's finger movement. The participants' preference for the iBook speech rate (M=8.0, SD=2.49) and the STAAR speech rate (M=7.9, SD=2.13) was very close as depicted in Figure 6.23. There was no statistically significant difference in the preference of the two systems.

At the end of the study, a semi-structured interview was conducted. When the participants were asked about their opinions in the iBook, they said that continuous reading is more pleasant. One participant said: *"For leisure reading line by line is the way to go"*. Another participant mentioned that: *"I like the line by line, but I want more the sonifications and the static noise and the ding"* When they were asked about their opinions in STAAR, they said:

"When I go back to look for the answers, the word feature was nicer, no need to hear the whole line"

"With word-by-word I have definitely more control, knows where I was a lot better"

"It is helpful and important"

"I would use it for studying"

"word-by-word slows me down"

Discussion

The objective and the subjective data collected from the comparative study showed that iBook system was preferred in *Receptive Reading* without statistically significant difference, while STAAR was more effective in *Skimming, Scanning, and Active Reading* with asymptotic significance.

The study results indicate that performing different reading strategies require different levels of complexity that is proportional to the level of intellectual engagement with the reading material. For example, for receptive reading, most participants preferred to read in big chunks with minimum effort on their side. One participant said that she wanted to tap one button to read the whole page at once. During the knowledge transfer tasks, the participants had to acquire higher level of engagement to find the answers. Because STAAR provides them with instant and accurate feedback for what they are really touching, the participants were more successful in performing the comprehension tasks. While in the iBook, they were not provided with page sonifications or accurate ”Read what you touch” system. These two drawbacks lead to failure of constructing a cognitive map to the page, and consequently less successful trials on the knowledge transfer, re-finding, and page exploration tasks. Additionally, hearing the whole line at once as in the iBook condition overloads the reader working memory. Hence, it was more difficult for the participants to answer the knowledge transfer question that requires high attention to the details.

To sum up, self-paced reading on the ”word level” is crucial in enabling the readers to develop a cognitive map to the reading material. This spatial awareness supports the reader in performing advanced reading skills that facilitates and enhances comprehension. Reading on the line, paragraph, or page levels are more useful in leisure reading. There is no single reading mode that can be useful in following all the reading strategies. A complete reading system will optimally enable the reader to read on multiple levels of chunking, so that the reader will have the flexibility to switch between the various reading strategies according to her purpose of reading.

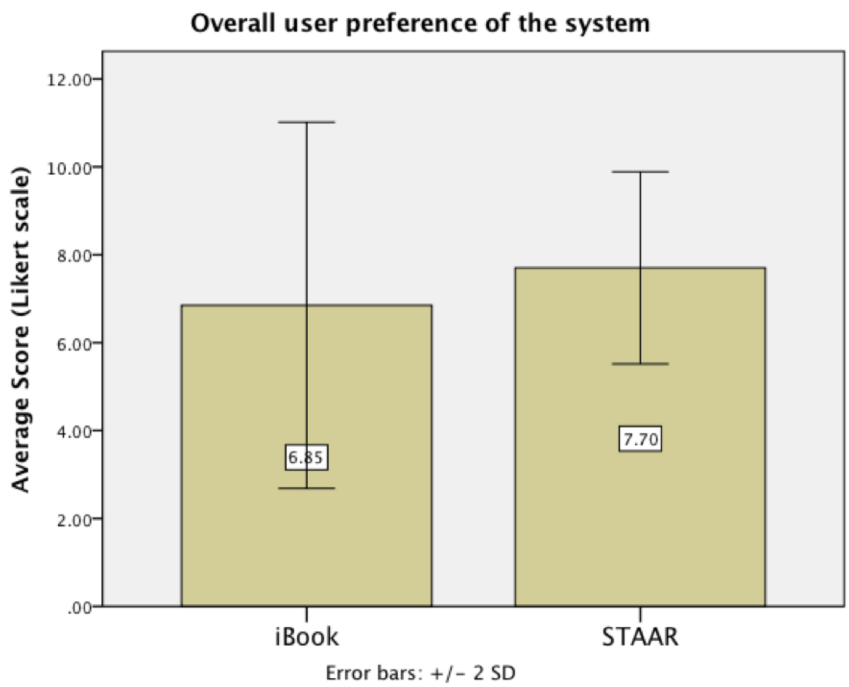


Figure 6.19: Means of rating to the overall preference of STAAR and the iBook.

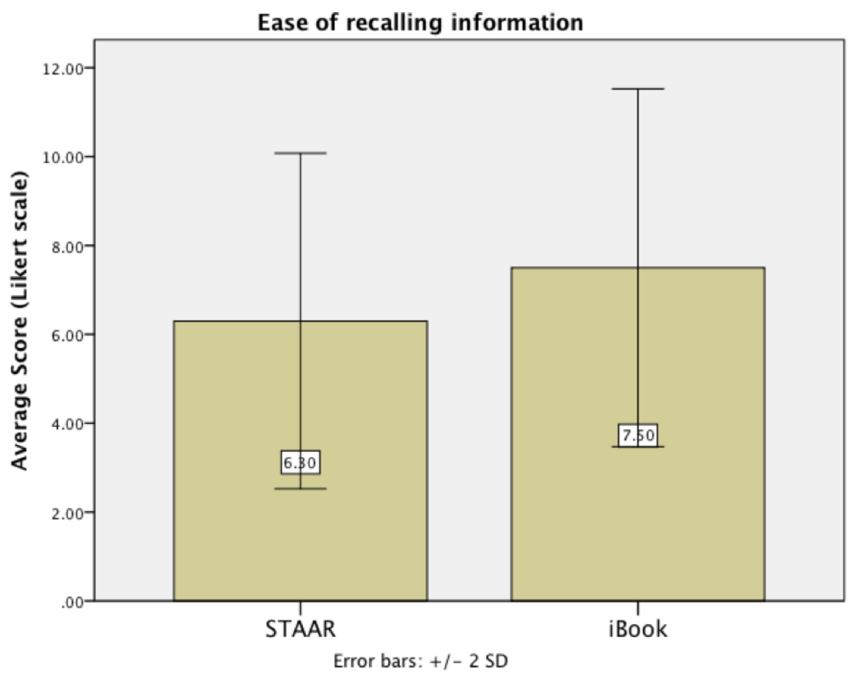


Figure 6.20: Means of rating to the ease of recalling information using STAAR and the iBook.

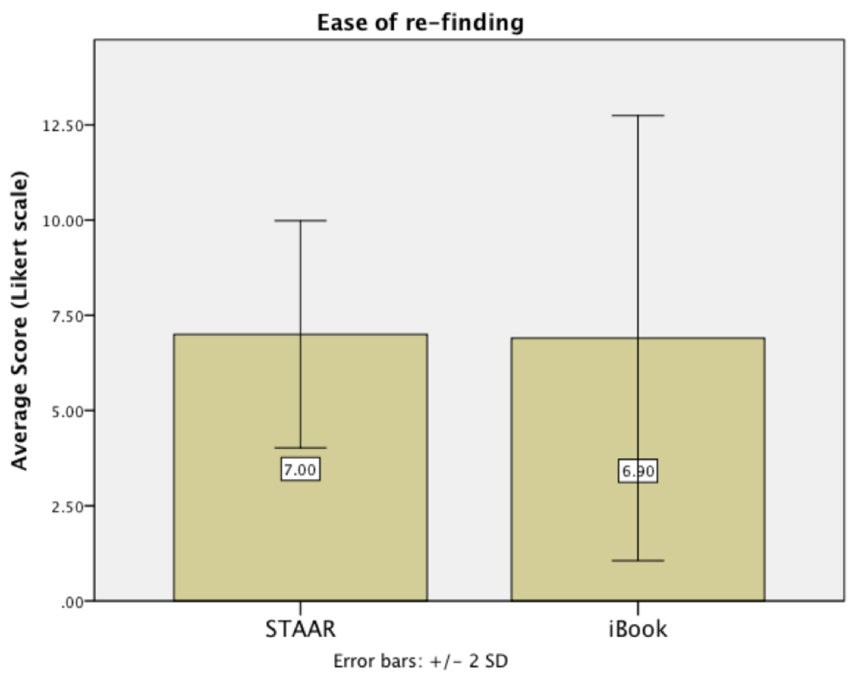


Figure 6.21: Means of rating to the ease of re-finding information using STAAR and the iBook.

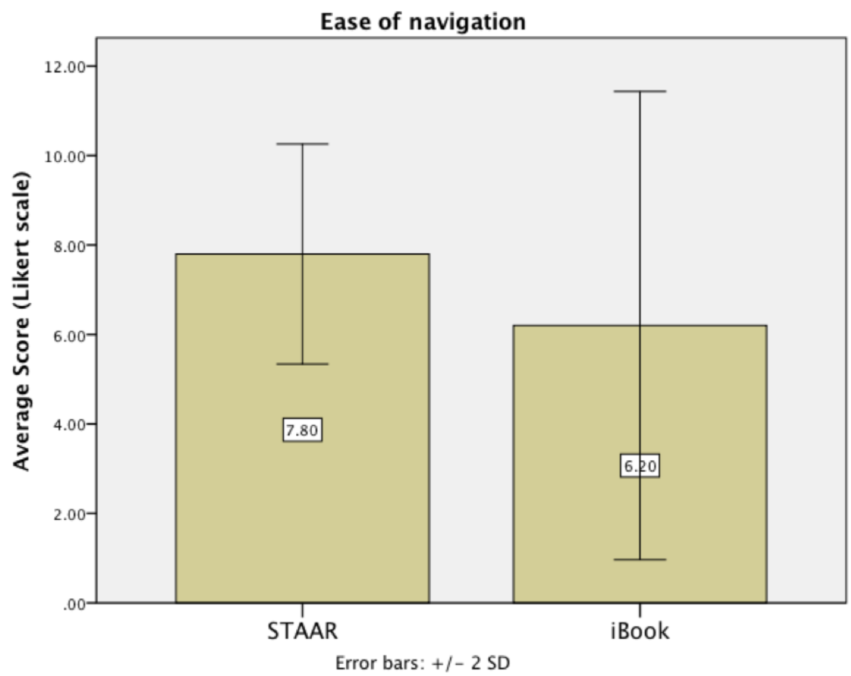


Figure 6.22: Means of rating to the ease of navigation information using STAAR and the iBook.

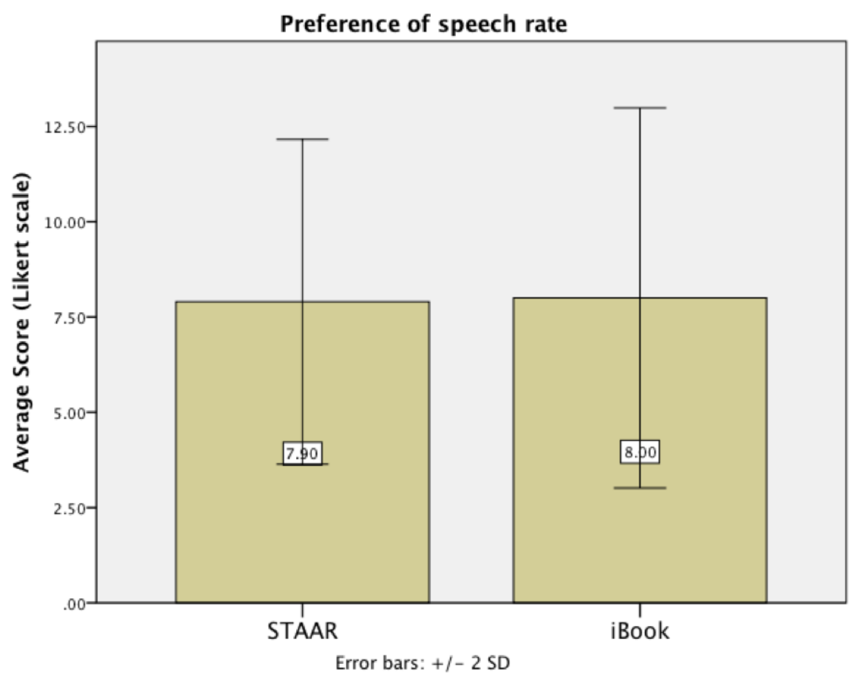


Figure 6.23: Means of rating to the preference of speech rate of STAAR and the iBook.

Chapter 7

Conclusions and Future Work

7.1 Conclusions

In this research, we proposed a multimodal reading system that enables IBSVI to self-paced read in a spatial domain. This novel system enables IBSVI to read and make use of their spatial, auditory, and haptic capabilities. The critical goal of our approach is to enable IBSVI to read with the same self-pacing that individuals with sight have when reading a text. The system is developed on the iPad platform to make use of its tactile and speech capabilities. Our system integrates and fuses these two powerful modalities to achieve our research goals. Touch is the primary interaction mode in the presented multimodal system. IBSVI were enabled using STAAR, to use their hands for exploring reading materials on a touch device. The touch channel was used as a substitution for the vision channel to carry the functions of eye glancing in addition to focusing and reading. Complementarity between sonification and audible text, and spatial layout is the major organizational theme of the system's multimodal interaction. STAAR was tested at its different stages of development. The results showed that IBSVI could read in space using STAAR. IBSVI can consume more significant amount of text in the space provided by STAAR, compared to other spatial media of reading for IBSVI. The results showed that STAAR is usable by IBSVI with different reading "backgrounds" (e.g., Braille, Audio books, or non active readers). STAAR encourages IBSVI to perform active reading, and to enrich their reading activities with multimodal information channels by which they can maximize their benefits of reading outcomes.

Additionally, we addressed the speech-modeling problem. As the reader system responds to user's touch and reads word by word, the speech is generated word by word, and that causes choppiness to the speech. The audio dynamics model and the offline speech synthesis technique enhance the speech features and enabled IBSVI to better read at their own pace. We also increased the interaction robustness by embedding a supporting sonic gutter and intelligent reading support model into the system. We conducted a set of participatory design sessions to test the sonic gutter and the intelligent active reading support. The sessions helped us fine tune the parameters of the prediction model and confirmed the usefulness of the sonic gutter.

Finally, we conducted an evaluation study to test the latest design of STAAR. The evaluation was divided into two phases. In the first phase, we conducted a decomposition study, where we tested four different configurations of the system to reveal the effect of two of its components: the overlay and the active reading support with its two levels. The results show with statistically significant difference that the multimodal interaction is more effective and efficient in reading, re-finding and spatial perception than the single audio modality. The second phase was a comparative study, where we compared STAAR to iBook and VoiceOver with respect to efficiency, effectiveness, and spatial perception. The results show higher efficiency of STAAR in re-finding previously read information, higher effectiveness in comprehension, and better development of a cognitive map of the reading pages. These results are supported by the experimental psychology theories that state that readers can recognize a whole word as fast as they can recognize a single letter [26], and that reading in the unit of 'words' is easier and more efficient than 'sentences', and 'letters' [16]. When IBSVI typically have access to literature in the units of 'characters' such as Braille, or 'chunks of words' such as Victor Reader, STAAR steps in to fill the gap of enabling IBSVI to access the most efficient unit of reading, which is 'words'. Our goal is to enable IBSVI to access the reading materials in its original format without any layout distortion by phonologically recoding words, so that they may have equal opportunity in learning to the sighted readers.

7.2 Research Contributions

The main contribution of this research is the design a novel digital spatial reading system for IBSVI that is grounded in theories of embodiment.

Contributions with respect to HCI

We enabled IBSVI to read digital pages of text by enabling them to engage their spatial affordances and utilizing the physicality of the iPad device. The multimodal system we designed supports the lack of the IBSVI's visual sense by conveying spatial information so that IBSVI may be enabled to acquire spatial awareness. We support IBSVI to stay on line while reading so they may be enabled to devote their cognitive resources to comprehend instead of concentrating on operating the system.

1. Design a new interaction model for IBSVI that enables them to read pages of text with touch. With this enabling interaction model, IBSVI can:

    - Read word by word with touch
    - Keep place on screen by anchoring on any location on the touch screen while reading
    - Control the reading speed with their finger

    In the core of this interaction model, multi-finger tracking subsystem, page description model, and audio dynamics model.

2. Develop a multimodal system to convey spatial information

    - Identify the spatial information necessary for reading text through a series of participatory design sessions and a usability study
    - Touch is the primary interaction mode in the presented multimodal system
    - IBSVI were enabled to use their hands for exploring reading materials on a touch device
    - The touch channel was used as a substitution for the vision channel to carry the functions of eye glancing in addition to focusing and reading

  - Complementarity between sonification and audible text, and spatial layout is the major organizational theme of the system's multimodal interaction

3. Intelligent Reading Support

  - Support continuous reading
  - Correct drifting errors intelligently
  - Reading-specific support (i.e. reading not in the sense of deciphering isolated words as in a button label, but as expression of language)

Contributions with respect to Assistive Technology

We provided a pragmatic approach to support reading for IBSVI that is motivated by the importance of spatial access to reading materials. We designed a novel digital spatial reading technology based on the capabilities of touch tablet devices. The system empowers IBSVI by:

- Supporting self-paced spatial reading
- Supporting IBSVI to skim and explore the page, read, and engage in active reading mode
- Among many features, the system enables IBSVI to read word by word, find location of next line, and detect the end of paragraph
- IBSVI can control the speech rate with their touch on the fly
- This spatial reading experience facilitates the process of recalling or re-finding information, when needed
- It is more efficient and effective than other reading technologies e.g. Braille, and Audio books
- Providing IBSVI with more accurate spatial orientation

Contributions with respect to Touch Screen Accessibility

We operationalized the theory of spatial cognition for a new tactile interface:

1. Touch screens are not fully tactile interfaces for IBSVI because they do not distinguish spatial location (note location in the plane of the display is precisely what is offered by such devices to the sighted); we investigated the fusing of tangible interaction with touch glass in readers for IBSVI. We investigate how to enable IBSVI to fuse tangible landmark patterns with layout of page and location of lexical elements – words, phrases, and sentences.

2. We designed a tactile overlay that gives tangible feedback to IBSVI when using touch devices for reading. The overlay was tested in a usability study, and the results showed the role of tangibility in leveraging accessibility of touch devices and supporting reading for IBSVI.

3. We introduced guidelines on how to design the tactile overlay that supports reading on touch screens. We investigated the elements and the parameters that should be considered when designing an overlay. We focused our research on the tablet size screens because of their relatively large screen, which makes it more challenging than the phones for IBSVI to use. Also, the size of the tablet, that resembles the physical dimensions of pages in printed books, is better suited for presenting textual material.

4. Research contributes to understand the difference between reading activity and interaction on touch screen devices. Reading material on touch interaction devices is essentially text under featureless glass for the IBSVI. The contribution of our research is to imbue touch screens with tactile landmarks that enable the IBSVI to read. This goes beyond what voice over technologies can provide. While it has been shown that 'trial-and-error exploration can allow an IBSVI to decide what screen button to activate, this does not help reading. There is no such thing as trial-and-error reading.

7.3 Future Work and Broader Impacts

We group our future work into two parts. The first is related to how STAAR can be improved and extended. The second part is about how this research work can be applied to other domains.

Extended and Improved STAAR

The research we conducted so far focused on finding the needed spatial information for enabling IBSVI to actively read text documents. We used a static tactile overlay and a set of page sonifications to carry the spatial information. In the future, we can try to use dynamic haptic feedback instead of the static overlay. Research will be required to find out how the haptic feedback can be designed. Additionally, 3-D sound design can be examined to test if it can provide the reader with better and faster interaction. In the future, the *Reader System* can have additional function, which is taking contextual notes for the purpose of more effective learning. This will open further research questions, such as how IBSVI may take notes. If the sound will be used e.g. by dictation, how will that interfere with the design of the reading system?

Spatial Communications for IBSVI

This research reminded the community of the importance of the spatial access to IBSVI in *Active Reading*. It revealed what the important spatial information are in reading text, and suggested different means for communicating this spatial information such as the audio and the haptic channels. Additionally, this research highlighted the need for supporting moving along straight lines and proposed the sonic gutter and the intelligent active reading support to solve this problem. This spatial communication can help IBSVI to access more complex documents. In the future, we can try to enable IBSVI to spatially access spreadsheet documents, for example, by applying suitable spatial functions. Staying on line support can be further explored to see if it can help IBSVI to practice drawing. In the future, other geometrical shapes e.g. circle, can be supported also.

Broader Impacts

The broader impacts of this research are threefold. First, our immediate research aim is to assist IBSVI to increase their learning outcomes by using both spatial and sequential memory while reading, in addition to taking personal notes within reading materials for more effective learning. This has significant implications for society as IBSVI will have equal opportunity to sighted people in accessing digital materials effectively. It will provide IBSVI with digital reading materials with low cost comparing to current alternatives such as OCR readers or Braille translators. Second, because of the underlying technology of the reading system, translating the system to read different languages is straightforward. Hence, the reading system can be widely available to IBSVI all over the world, providing wide opportunities of reading and learning. Third this research can be beneficial for other target users. For example, people with learning disabilities such as dyslexia can use our system to help them read books through the speech synthesizer component. Also, for foreign language learning our proposed system can support scaffolding reading exercises that match visual presentation of foreign text with sonification.

7.4 Publications From the Presented Work

- El-Glaly, Y. N., Quek, F., Smith-Jackson, T., and Dhillon, G. Touch-Screens are Not Tangible: Fusing Tangible Interaction with Touch Glass in Readers for the Blind. In *Proceedings of the 7th International conference on Tangible, embedded, and embodied interaction* (2013), ACM.
- El-Glaly, Y. N., Quek, F., Smith-Jackson, T., and Dhillon, G. Audible rendering of text documents controlled by multi-touch interaction. In *Proceedings of the 14th ACM*

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- El-Glaly, Y. N. Enabling spatial reading using multimodal system for individuals with blindness. *SIGACCESS Access. Comput.*, 105 (Jan. 2013), pp. 15 -18.

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- El-Glaly, Y. N., F. Quek, Tonya Smith-Jackson, and Gurjot Dhillon. Spatial Tactile Audio Reader System For People With Blindness or Severe Visual Impairment. *Grace Hopper Conference*, 2012.

- El-Glaly, Y. N., Francis Quek, Tonya Smith-Jackson, Haptic Reading System for The Blind.*Interdisciplinary Research Symposium* at Virginia Tech, 2011.

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Appendix A

Post Interview Questionnaires

A.1 Participatory Design Session Set 1

Background Information Sheet

1. Name:
2. Age:
3. Degree of sight:
4. Age of blindness:
5. Read Braille: Yes No
6. Level of education:
7. Do you have other disabilities beside blindness? If yes, please specify
8. Do you use touch device such as iphone or iPad? Yes No How often?
9. What is your favorite medium for Reading? Why? Braille Books Audio Books Other, please specify
10. What other kinds of media do you use for Reading?

Overlay Questionnaire

1. Rank the provided overlays from 1 to 3 where 1 is the best overlay and 3 is the worst overlay

   Overly 1 Overlay 2 Overlay 3

2. Please specify what do you like the most about your favorite overlay
3. Please specify what is bad about your most disliked overlay

4. How easy for you was locating/tracing/reading text using your favored overlay?

   Very easy Easy Neither easy nor difficult Difficult Very difficult

5. How would you improve your favored overlay?

6. Which material do you prefer? Why?

   Plastic Thin card

7. You find your favored material sensitive enough to your touch?

   Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

8. Do you prefer that the overlay material be transparent? Why? Yes No

Reading Questionnaire

1. Rank the easiness of navigation through pages. (go to next/previous page)
   Very easy Easy Neither easy nor difficult Difficult Very difficult

2. Do you prefer touch gestures to buttons? Why? Yes No

3. How do you find navigating from line to line in the same page? Why?

   Very easy Easy Neither easy nor difficult Difficult Very difficult

4. If you are reading in page 3 and you decide to go back to a specific paragraph in a previous page, how do you guide yourself to go back to this specific paragraph? Rank level of easiness?

   a. You are guided by your memory only b. You are guided by overlays landmarks only
   c. You are guided by both memory and overlay

5. If the page you are reading is too dense with text, do you find our reading system is still useful?

   Yes No

6. Do you think the rate of speech speed is acceptable? Why?

   Yes No

A.2 Usability Study

Questionnaire for reading system

1. How easy was it for you to navigate from one page to another (going to previous/next page)?

1	2	3	4	5	6	7	8	9	10
Not at all easy									Very easy

2. How did you find navigating from line to line on the same page?

1	2	3	4	5	6	7	8	9	10
Not at all easy									Very easy

3. Rank the level of ease for going from one page to a particular paragraph on another page?

1	2	3	4	5	6	7	8	9	10
Not at all easy									Very easy

4. If the page you just read was too densely or widely spaced with text, did you find the reading system to be still useful?

   _______Yes
   _______No

5. Do you think the speed of speech of the reading system is acceptable? How would you like to improve the speech?

   ______Yes
   ______No
   ____
   ____
   ____
   ____

6. Were there instances when you were expecting the system to notify you or give some feedback after you gave a particular command/input? Please elaborate if there were such instances.

   ______Yes
   ______No

   ____
   ____
   ____
   ____
   ____

7. How easy or difficult was it for you to find/locate the 'Previous', 'Next' and 'Stop' buttons?

1	2	3	4	5	6	7	8	9	10
Not at all easy									Very easy

8. How pleasant did you find the voice of the narrator in the software?

1	2	3	4	5	6	7	8	9	10
Very Unpleasant									Very Pleasant

9. I found the sound notification when I strayed into no-text area to be pleasant?

1	2	3	4	5
Strongly Disagree				Strongly Agree

Overlay Pattern Questionnaire

1. I felt that the overlay did help me in adapting to the iPad

1	2	3	4	5
Strongly Disagree				Strongly Agree

2. Please specify the attributes that you liked about the overlay of your preference

   ____
   ____
   ____

____
____

3. How easy or difficult was it for you to locate/trace text using the overlay you liked?

1 2 3 4 5 6 7 8 9 10

Not at all easy — Very easy

4. How easy or difficult was it for you to read text using the overlay you liked?

1 2 3 4 5 6 7 8 9 10

Not at all easy — Very easy

5. Were there instances when you could not follow the overlay and lost track of the text you were reading?

_____Yes
_____No

6. I think the material of the overlay was sensitive enough to my finger touch?

1 2 3 4 5 6 7 8 9 10

Strongly Disagree — Strongly agree

7. Were the vertical lines on the overlay helpful in guiding you through the text?

_____Yes (If yes, then please elaborate how it was helpful)
_____No

____
____
____
____

8. Did the overlay help you to anchor yourself on the page you were reading?

_____Yes
_____No

User Satisfaction Questionnaire

1. I would like to use this system frequently for reading purposes

1	2	3	4	5
Strongly Disagree				Strongly Agree

2. I found the system unnecessarily complex

1	2	3	4	5
Strongly Disagree				Strongly Agree

3. I felt the system was easy to use

1	2	3	4	5
Strongly Disagree				Strongly Agree

4. I felt there's too much inconsistency in this system

1	2	3	4	5
Strongly Disagree				Strongly Agree

5. I would imagine that most people would learn to use this system very quickly

1	2	3	4	5
Strongly Disagree				Strongly Agree

6. I found the system very cumbersome to use

1	2	3	4	5
Strongly Disagree				Strongly Agree

7. I felt very confident using the system

1	2	3	4	5
Strongly Disagree				Strongly Agree

8. I needed to learn a lot of things before I could get going with this system

1	2	3	4	5
Strongly Disagree				Strongly Agree

A.3 Experience Sampling Study

Interview Questions

3-Day Check-point (by phone)

1. Have you used the iPad to read the materials? If yes, go to question 2. If no, ask “Is there a reason why?” Then, encourage them to use it and remind them of the ending date of the study.
2. What would like to say about your experience?
3. What worked well when reading with the iPad?
4. What did not work well when reading with the iPad?

Final Interview Questions:

1. Overall, would this iPad benefit you in terms of giving you a richer or clear reading experience than what you already use for reading? Please explain.
2. How would you modify this design to make it easier to use?

A.4 Participatory Design Session Set 2

A. For the line straying sonifications:

1. Can you hear the low "above line" straying sonification ?
   Yes No
2. Can you hear the high "above line" straying sonification ?
   Yes No
3. Can you hear the low "below line" straying sonification ?
   Yes No
4. Can you hear the high "below line" straying sonification ?
   Yes No
5. Can you distinguish between the "above line" and "below line" straying sonifications?
   Yes No
6. Can you distinguish between the low "above line" and the high "above line" straying sonifications?
   Yes No
7. Can you distinguish between the low "below line" and the high "below line" straying sonifications?
   Yes No
8. Can you hear the text with the low "above line" sonification running?
   Yes No
9. Can you hear the text with the high "above line"sonification running?
   Yes No
10. Can you hear the text with the low "below line" sonification running?
    Yes No
11. Can you hear the text with the high "below line" sonification running?
    Yes No

B. For the variable speech rate:

12. Can you realize the variable speech rate?
    Yes No
13. Does the variation of the speech rate interfere with your comprehension of the speech?
    Yes No

Familiarization session with STAAR questionnaire

1. Did line straying sonification help you to stay on line?

   Yes No

2. Did line straying sonification guide you back to the reading line when you drifted?

   Yes No

3. Do you think that speech rate helped you to better interact with the system with respect to finger speed?

   Yes No

4. Is there any other thing you want to add?

A.5 Evaluation Study

USER EXPERIENCE QUESTIONNAIRE FOR STAAR

Please indicate your level of agreement. Remember, we are not evaluating you. You are evaluating the technology, so please feel free to give your honest opinions.

1. How easy was it to recall information (meaning remember what you read)?

1 2 3 4 5 6 7 8 9 10

Not Easy Very Easy

2. How easy was it to re-find information, if needed (meaning look for it again)?

1 2 3 4 5 6 7 8 9 10

Not Easy Very Easy

3. How helpful was the STAAR overlay in re-finding information (locating information you already read)?

1 2 3 4 5 6 7 8 9 10

Not Helpful Very Helpful

4. How easy was it to stay on a line of text?

1 2 3 4 5 6 7 8 9 10

Not Easy Very Easy

5. How easy was it to find the next line?

1 2 3 4 5 6 7 8 9 10

Not Easy Very Easy

6. How easy was it to keep your location on the touch pad display?

Very Easy

Not Easy

7. When navigating a page what do you think about the sounds used to tell you that you had strayed to another line?

1 2 3 4 5 6 7 8 9 10

Not Helpful Very Helpful

8. When navigating or moving around a page, how helpful was the STAAR overlay?

1 2 3 4 5 6 7 8 9 10

Not Helpful Very Helpful

9. The use of the sounds used to tell me I strayed from a line improved my ability to read the text on the page.

1 2 3 4 5 6 7 8 9 10

Strongly Disagree Strongly Agree

10. The use of STAAR's overlay feature improved my ability to recall the information on the page.

1	2	3	4	5	6	7	8	9	10

Strongly Disagree Strongly Agree

11. The use of STAAR's overlay feature improved my ability to re-find the information on the page.

1	2	3	4	5	6	7	8	9	10

Strongly Disagree Strongly Agree

12. What do you think of STAAR's word-by-word feature in helping you read the material?

1	2	3	4	5	6	7	8	9	10

Not Helpful Very Helpful

13. How helpful is the various speech rates in reading the material at your own pace?

1	2	3	4	5	6	7	8	9	10

Not Helpful Very Helpful

14. Is there anything else you want to share with us about your experience with STAAR?

____

____

____

IBOOK USER EXPERIENCE QUESTIONNAIRE

Please indicate your level of agreement. Remember, we are not evaluating you. You are evaluating the technology, so please feel free to give your honest opinions.

1. How easy was it to recall information (meaning remember what you read)?

1 2 3 4 5 6 7 8 9 10

Not at all Very easy

2. How easy was it to re-find information if needed (meaning look for it again)?

1 2 3 4 5 6 7 8 9 10

Not at all Very easy

3. How easy was it to navigate the page (meaning know where you are as you were reading and moving through the page)?

1 2 3 4 5 6 7 8 9 10

Not at all Very Easy

4. How easy was it to find the next line?

1 2 3 4 5 6 7 8 9 10

Not at all Very easy

5. What do you think of iBook's word-by-word feature in helping you read the material?

1 2 3 4 5 6 7 8 9 10

Not Helpful Very Helpful

6. How helpful is the speech rate in reading the material at your own pace?

1 2 3 4 5 6 7 8 9 10

Not Helpful Very Helpful

7. Is there anything else you want to share with us about your experience with iBook with VoiceOver?

Appendix B

Reading Materials

B.1 Participatory Design Session Set 1

I

The Period

It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way—in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only.

There were a king with a large jaw and a queen with a plain face, on the throne of England; there were a king with a large jaw and a queen with a fair face, on the throne of France. In both countries it was clearer than crystal to the lords of the State preserves of loaves and fishes, that things in general were settled for ever.

It was the year of Our Lord one thousand seven hundred and seventy-five. Spiritual revelations were conceded to England at that favoured period, as at this.

B.2 Usability Study

The Outsiders

Chapter 1 Summary

Ponyboy Curtis, the narrator of *The Outsiders*, walks out of a movie theater in Tulsa, and heads home. He enjoys watching movies alone, but now wishes he had some company because greasers like him aren't safe from members of a rival gang, the Socs. Greasers, Ponyboy says, are from the East Side and are poorer than the West Side Socs. Greasers wear their **hair** long, dress in jeans and leather jackets, and some steal, rob, and fight in public. Ponyboy, however, avoids such behavior because his strict older brother **Darry** would kill him (or his middle brother **Sodapop**) if they got into trouble. Ponyboy adds that Darry, who cares for his two younger siblings in the wake of their parents' deaths, would yell at him if he knew he was walking alone. He'd also say that he wasn't using his head.

The next night, Johnny and Ponyboy meet Dally and head to the drive-in. On the way, they make a little bit of trouble at a drugstore, where Dally shoplifts cigarettes. The boys then sneak in to one of the drive-ins that greasers often visit. There are some Socs at the drive-in, and the boys sit down behind two Soc girls. Dally harasses the girls with dirty talk. Ponyboy feels uncomfortable and declines to join in, while Johnny leaves to get a Coke. One of the girls, a redhead named Cherry Valance, calmly tells Dally to shut up. He doesn't listen. The girls refer to the boys as "greasers" and "hoods." Soon Dally walks off to the concession booth, and Cherry and Ponyboy start talking. Cherry compliments Ponyboy's name, and as they talk about school Ponyboy reveals that he's skipped a grade. They also talk about Sodapop, whom Cherry calls a "doll." She wonders where Sodapop has been recently.

Cherry and Marcia realize that they don't have a ride home from the drive-in. Two-Bit talks them into accepting a ride from him, and the three boys and two girls walk to Two-Bit's to get his car. On the way, Cherry tells Ponyboy about what it's like to be a Soc, including the search house for fulfillment from sources beyond just material possessions, and the pressure to be cool and unemotional. The two of them agree that in contrast to the aloof Socs, who try to hide their emotions, the greasers tend to feel their emotions too strongly.

As they talk, the two of them also discover a shared love of reading and watching sunsets. Ponyboy realizes that, despite their different classes and friends, the two of them see the same sunset. Just then, Marcia notices a blue Mustang coming down the street, and everyone becomes nervous, especially Johnny. The car passes slowly and keeps going.

Cherry then asks Ponyboy about Darry. Ponyboy responds that Darry doesn't like him. Two-Bit and Johnny are surprised. They had thought all was well among the Curtis brothers. Ponyboy gets upset and comments on Johnny's own dysfunctional family, but he quickly apologizes after Two-Bit smacks him in the head.

When Ponyboy gets home, Darry is furious at him for losing track of time and arriving so late. Sodapop tries to intervene, but Darry silences Soda and, losing control, slaps Ponyboy. Darry is immediately remorseful and tries to apologize, but Ponyboy runs out of the house before his brother can say anything. The park is deserted.

As Johnny and Ponyboy walk and talk, the blue Mustang suddenly appears. Bob, his friend Randy, and three other Socs jump out of the car. All of them are drunk. Johnny, terrified, pulls out his switchblade and Ponyboy wishes he had the broken bottle. Bob insults greasers by calling them white trash with long hair. Ponyboy, furious, responds that Socs are white trash with mustangs and madras (plaid) shirts, and spits at the Socs. The Socs attack. One forces Ponyboy's head underwater in a nearby fountain. Ponyboy blacks out. When he comes to, the Socs are gone and he's on the pavement next to Johnny and Bob's dead body. Johnny says, "I killed him."

Johnny's switchblade is covered in blood. Ponyboy panics, but Johnny is calm. He decides that they should go to Dally for help. They find Dally at a party at the house of Dally's rodeo partner, Buck Merril. When he learns what's happened, Dally gives them warm clothes, fifty dollars, a loaded gun, and directions to a hide-out in an abandoned church in the small rural town of Windrixville. He asks Ponyboy if Darry and Sodapop know what happened. Ponyboy tells him not to say anything to Darry.

Later, Ponyboy and Johnny talk about killing Bob, and both of them cry out of fear and shock as they discuss the experience. They comfort each other and go back to sleep. When they wake up, both boys feel more relaxed and level-headed. Ponyboy says to Johnny, “We ain’t gonna cry no more, are we?” Several days pass. The boys entertain themselves by playing poker and reading aloud from Gone with the Wind. Johnny admires the Southern gentlemen in the novel and says that they remind him of Dally. When Ponyboy doesn’t understand, Johnny tells about a time when Dally took the blame for a petty crime committed by Two-Bit. Ponyboy now understands Johnny’s deep admiration for Dally, but still feels intimidated by Dally’s intensity. One morning, Ponyboy and Johnny watch the sunrise. As they lament that the sunrise’s beauty doesn’t last, Ponyboy recites the poem “Nothing Gold Can Stay,” by Robert Frost. They agree that the poem captures just what they feel, though Ponyboy can’t explain the poem’s meaning in words. Johnny comments that Ponyboy has made him see the beauty of nature more than he ever had before, and he notes how different Ponyboy is from the other members of his family.

The next morning, Ponyboy wakes up before his brothers and starts making breakfast. As he does, Two-Bit and Steve Randle drop by. They show him the morning paper, which contains an article with the headline “Juvenile Delinquents Turn Heroes.” Two-Bit objects to the verb “turn,” asserting that Ponyboy and Johnny were heroes all along. The article credits the boys with saving the children’s lives. The report also quotes Cherry and Randy regarding the killing of Bob—both of them insist that Johnny acted only in self-defense. The article finishes by saying that the Curtis boys should be allowed to stay together. But this final bit of news panics Ponyboy, who hadn’t realized that there was a chance that he and Sodapop might be separated from Darry. With Sodapop and Darry now in the kitchen too,Ponyboy shares the news that on the previous night he had one of his recurring nightmares, which he can only vaguely remember in the morning. Darry becomes very concerned. Ponyboy explains that the dreams began when the boys’ parents died, though they had lately seemed to taper off.The conversation turns to Sodapop’s girlfriend Sandy, who suddenly moved to Florida to live with her grandmother.

As they drive past the church where they had been hiding, they see that it's burning. A crowd is standing outside, and a bystander tells them that a school group was having a picnic there. A woman shouts that some of the children are missing inside the church. Suspecting that their discarded cigarette butts may have started the fire, Ponyboy and Johnny dash into the burning building. They find the children and lift them one-by-one out a window, continuing even after Dally runs in shouting that the roof is about to collapse.

The roof collapses, just as they save the last child, and Johnny knocks Ponyboy through the window, saving him. Ponyboy hears Johnny scream behind him, but before he can go back Dally smacks him on the back and knocks him unconscious.

Ponyboy wakes up in an ambulance with Jerry Wood, a teacher and the bystander whom Ponyboy spoke with before rushing into the burning church. Jerry tells him what happened: Dally knocked Ponyboy out while smothering a fire that had caught on Ponyboy's back. Dally then saved Johnny. He adds that Dally is burned but will be fine, while Johnny is in very bad condition. He praises the boys' courage.

Ponyboy responds that they're greasers and that Johnny is wanted for murder. Jerry doesn't know the term "greaser" and is surprised by this news about Johnny, but he continues to try to comfort Ponyboy as they head toward the hospital.

B.3 Experience Sampling Study

About the VT iPad Reader

This is the iPad. It is like a sheet of glass on the top and has a plastic cover at the bottom. It is about the size of a book. The area inside a three-quarter-inch boundary of the glass surface is a touch-sensitive area. This touch area allows you to interact with the iPad.

Plastic sheet on the screen: The iPad screen is covered with a sheet of plastic which has a pattern of raised dots over it. It is to help you know where you are on the page, and to locate different buttons.

Areas on the iPad screen: The iPad screen consists of three main areas. These are the areas covered by a Vertical Ruler Area, the Reading Area, and the Button Area.

The Vertical Ruler: There is a Vertical Ruler on the left side of the page. You can place a finger of your left hand to feel the raised dot ruler pattern. The left half of ruler is outside the iPad touch-sensitive area, and the right half is in the touch sensitive area. The ruler will help you to anchor the page, and to find lines of text on the page. As you move your finger along the right side of the ruler vertically you will hear a clicking sound telling you that you are lined up with a line of text. The left side of the ruler is just to let you rest your hand in place without any response from the iPad reader.

The Reading Area: Most of the surface of the iPad to the right of the Vertical Ruler is the Reading Area. This area contains the text to be read. The plastic sheet on this area contains patterns of raised dots. This pattern is designed to help you to know where you are in the reading area. The iPad will read aloud any word you touch in the Reading Area. If you move your finger along a line of text from left to right, the iPad will read the line word-by-word as it is being touched. If you move too fast, and miss a word, you will hear a click telling you that a word has been skipped. You will hear a ding sound when you have read the last word on a line. The raised dot pattern in the Reading Area will help you to move around. An important thing to note is that the raised dot pattern of the plastic sheet may not exactly coincide with the text lines on the iPad screen. This means that lines of text might lie on or between the raised dot lines on the plastic sheet. Also, the lines in the text might not start exactly where the raised dot pattern on the plastic sheet starts.

The Button Area: The bottom part of the plastic sheet below the Reading Area is the Button Area that contains three buttons. These buttons will take you to different pages and articles of the text. The buttons are marked with raised dot patterns. The Previous Page button is on the left side, and the Next Page Button is on the right. The middle button allows you to skip to the Next Article. When you move your finger into a button area, the iPad will read the button name to you. If you lift your finger and touch the button again the iPad will perform the action of the button. For example, when you move into the Previous Page button, you will hear the words Previous Page Button. Touching the button again will take you to the previous page. The Next Article button allows you to advance through the articles. When you get to the last article, the button will take you to the first article in the library.

Starting the iPad: If you move your finger over the top-left edge of the iPad, you will feel a button at the top right edge of the iPad. This button switches the iPad ON and OFF. You will hear a click sound when you turn the iPad OFF. There is no sound when you turn the iPad ON. After you turn the iPad ON, you have to swipe your finger from left to right across the entire button area, from the Previous Page to the Next Page buttons, you will activate the reading program.

Adjusting the Volume of the system: On the top-right edge of the iPad, you will find a volume control button. Pressing the top part of this button increases the volume of the speakers and pressing the bottom part of this button decreases the volume of the speakers. Keeping the bottom part of the volume button pressed for a few seconds mutes the sound. Press the top part of the volume button to unmute the iPad.

Using Headphones: If you move your finger over the top-left edge of the iPad, you will feel a depression in the plastic cover which indicates the slot for inserting your headphones.

Charging the iPad: If you move your finger toward the middle of the bottom edge of the iPad, you will find a port to insert the charging connector. You can insert the connector to recharge the iPad. The iPad should be charged every night and the battery will then last for the next day. You can read with the iPad while it is being charged.

Gestures:

Reading the entire line gesture: When you are reading in the Reading Area, you can make the iPad read to the end of the line by double tapping on any word. This means that if you double tap on the first word of a line, iPad will read the whole line. You can also have iPad read a whole line by double tapping on the right side of the Vertical Ruler after you have found a line.

Scrolling pages gesture: In addition to using the Next Page and Previous Page buttons, you can move from page to page using the Three Finger Swipe gesture in the Reading Area. You can go to the previous page by sliding three fingers together from left to right horizontally on the current page. Similarly, sliding three fingers together from right to left horizontally across the page will take you to the next page.

Stop reading gesture: Tapping four fingers together anywhere on the iPad screen will stop the system from reading the current text aloud. The system will resume usual reading at the point at which is touched next.

Ben Franklin

Ben Franklin was the fifteenth in a family of seventeen children. At the age of twelve he became an apprentice, working in his older brother's print shop. This was the beginning of a life of writing articles and books. He even became a newspaper publisher in later years. He was a man of many talents. The famous kite experiment is one example of his work. To prove that lightning is electricity, he flew a kite outside during a thunderstorm. Sure enough, lightning hit the kite, and made sparks fly from a key he had attached to the end of the string. Ben Franklin used this experiment for inventing the lightning rod. A simple metal rod is attached to a roof to attract lightning. When lightning hits the metal, it travels down the rod into the ground instead of setting the building on fire. Franklin also invented bifocal glasses, and he designed a stove that saved fuel and provided better heat. He discovered that poor ventilation causes disease to flourish, and he later established the first city hospital in America. In Philadelphia he established the police department, the fire department, a public library, and a university. In addition, he was the founder of the United States Postal Service.

He signed both the Declaration of Independence and the Constitution. He served as a US delegate to England and France, and the people of Philadelphia sent him to represent them at the Second Continental Congress. In recognition of his many accomplishments, his image has appeared on US stamps, coins, and paper money.

Source: http://fcit.usf.edu

About Egypt

When you think of ancient Egypt, what words come to your mind? Do you think of mummies, or pyramids, or the Great Sphinx. Why did the ancient Egyptians turn dead bodies into mummies. Why did they build enormous pyramids in the desert. Why did so many of their gods have animal heads. And why were the Egyptians so preoccupied with death.

Even to the ancient Greeks and Romans, Egypt was an old land. Long before the Greeks built temples and theaters or the Romans constructed huge structures like the Colosseum, the Egyptians had developed a rich and complex civilization. The early Egyptians settled beside the fertile Nile River in northern Africa sometime before three thousand B.C. Over the years they formed a central government, developed a language, built vast monuments and created great works of art. Egyptian civilization went on for thousands of years until Egypt was conquered by the Romans around three hundred B.C. The pyramids and ruined temples remained, but no one knew much about the ancient Egyptians. They had left a wealth of written documents. But no one was able to read their Hieroglyphics. It was not until the early eighteen hundreds that the code was broken. Today, we know more about the ancient Egyptians than anyone has known since their civilization died out. The Egyptians lived in the middle of a hostile desert. They depended on the Nile to provide them with rich harvests. They believed that their prosperity continued only because of their active relationship with their gods. Every natural event was related to a god. They believed the world began with the sun god Ra, who journeyed across the sky every day and under the earth every night. Egyptians associated animals and their amazing physical powers with the gods. The falcon, which flies to great heights and sees long distances stood for Ra. Anubis, god of the dead, had a long, sharp, dark jackals head. Sobek, the river god, was a powerful crocodile. Thoth, god of wisdom, had the head of a bird or a monkey. Nekhbet, goddess of protection, had a vultures head. These figures were very significant to the Egyptians; they appeared in most pieces of writing and art.

Although best remembered for tombs, pyramids, and mummys, the ancient Egyptians were not always thinking about death. They liked many of the same things we enjoy today. From the paintings, sculptures, and objects they left, we know they liked to socialize. They liked large banquets, good food, storytelling, and music played on flutes, lyres, harps. They were especially fond of board games. Young people enjoyed dancing. To cool off after sports or dancing, they would go swimming.

Both men and women were very concerned with their appearance. While exploring Egyptian tombs, archaeologists have found ancient makeup kits, razors, skin creams, and mirrors. The Egyptians usually wore simple, light clothing, but for formal occasions, both women and men wore elaborate jewellery, wigs, and perfume. Men had short hair or shaved heads; women wore nail polish and a great deal of makeup, especially around the eyes. Pharaohs or kings, wore false beards as a sign of power.

The Egyptians made what we think of as art for very different reasons than we do today. They didn't create paintings or sculptures to express themselves. Their creations were not meant to represent the present or to record the past. Images were made either for practical use, for communication, or for religious purposes. In Egyptian art, the figures are always eternally young and ideal. Nature is always lush and perfect.

Most Egyptian art is very stylized. Nearly every object and figure had a symbolic meaning. In order to make each image immediately recognizable, its shape was simplified. The visual quality that identified its sharp snout, long, thin neck, curved beak was exaggerated. Painted figures were usually made up of separate parts seen from their most recognizable viewpoints. Jewellery and sculpture were also highly stylized.

The story of the gods Isis and Osiris explains why the ancient Egyptians felt they had to turn dead bodies into mummies and build vast pyramids to put them in. Osiris, the first king of Egypt, was murdered by his brother Seth and his body was divided into pieces. Osiriss wife, Isis, put the body together and breathed life back into it. Horus, son of Isis and Osiris, defeated Seth. Osiris became one of the gods of the dead. This legend explains how life after death came to be part of Egyptian culture. Mummification was important to the ancient Egyptians because they believed if the body was properly prepared, the dead person would live on in the afterlife. The funeral ceremony allowed the deceased to make the transition from one life to the next. The process of mummification took seventy days. Anubis, god of embalming a priest in a jackal mask, supervised the ceremony. First, the internal organs were removed and placed in jars with stylized animal heads. After the brain was removed, the body was soaked in chemicals, dried, then filled with straw. The arms were crossed on the chest in the pose of Osiris. The body was coated with resin, then wrapped in linen. Spells were repeated at each wrapping. A scarab beetle-shaped amulet was placed over the heart so the deceased would be able to enter the underworld. The underworld was believed to be in the west, where the sun died every night. So after the mummy was laid in the coffin it was taken down the Nile to the west bank. There, a tomb sometimes a huge pyramid had been built and filled with items the dead person would need in the afterlife. In the burial chamber, the most important ceremony was held the Opening of the Mouth. The Egyptians believed that when the body died, the spirit left it. For a person to be reborn, the spirit had to return, enter the kyylummy through the mouth, and breathe life back into the body. To begin the ceremony, the mummy was set upright above. Then the priest chanted while touching the mummys face with various tools. At the end of the ritual, the body was placed in a mummy-shaped container. If the deceased was a queen or pharaoh, the case would be nested in a series of increasingly elaborate containers. The mummy would then be sealed in the tomb, ready for its final journey.

Source: http://panthers.k12.ar.us/

The Silver Lake

It was on a cold winter morning long ago, that Robin Gore, a bold hunter of the backwoods of America, entered his parlour and sat him down to breakfast.

Robins parlour was also his dining-room, and his drawing-room, besides being his bedroom and his kitchen. In fact, it was the only room in his wooden hut, except a small apartment, opening off it, which was a workshop and lumber-room.
Robins family consisted of himself, and his wife, and his son Roy, who was twelve years of age and his daughter Nelly, who was eight, or thereabout. In addition to these, his household comprised a nephew, Walter and an Irishman, Larry ODowd. The former was tall, strong, fearless, and twenty. The latter was stout, short, powerful, and forty.

The personal history of Robin Gore, to the point at which we take it up, runs briefly thus

He had been born in a backwoods settlement, had grown up and married in the little hamlet in which he had been born, and hunted around it contentedly until he was forty years of age. But, as population increased, he became restive. He disliked restraint; resolved to take his wife and family into the wilderness and after getting his nephew and an Irish adventurer to agree to accompany him, carried his resolution into effect.

He travelled several hundreds of miles into the woods beyond the most remote settlement built three wooden huts, surrounded them with a tall stockade, set up a flagstaff in the centre thereof, and styled the whole affair, Fort Enterprise.

I am sorry to bring you to such a lonesome spot, Molly, my dear, said Robin, as he sat on the trunk of a fallen tree on the afternoon of the day on which he arrived at the scene of his future home; till be rather trying at first, but you will soon get used to it, and we wont be bothered here away all the new-fangled notions of settlement folk. We will dwell in the free wilderness, where there are no tyrannical laws to hamper a man, and no nonsensical customs to fix the fashion of his coat and leggings. Besides, you will have Roy and Nelly and Walter and Larry to keep you company, lass, not to mention our neighbours to look in upon now and again

Very true, Robin, replied the wife, I have no doubt it will be quite cheery and homelike in course of time.

She looked out upon the broad bosom of the lake which lay before the site of their forest home, and sighed.

It was evident that Mrs Gore had a strong partiality for the laws and customs which her husband abhorred.

The neighbours to whom Robin referred lived in a leather tent twenty miles distant from the Fort. They were an Indian, named The Black Swan, his wife, named The White Swan, and a half-caste trapper, whose proper name was unknown to all save himself. His cognomen in the wilderness was Slugs, a name which originated in his frequent use of clipped pieces of lead instead of shot in the loading of his gun.

But to return to the point from which we started:
It was on a cold winter morning that Robin Gore entered his parlour and sat him down to breakfast.

It was not only cold very cold; colder than ever was experienced in our favoured British isles but it was also very dark. Robin had risen before daybreak in order to visit his traps, and shoot some game as early in the day as possible. The larder chanced to be nearly empty that day, a fact which was all the more to be regretted that it was New Years day, and, as Robin remarked, that day did not occur more than once in the year. This statement Larry ODowd disputed, affirming that it occurred at last twice every year once at the beginning and once at the end of it

Come along, lad, said Robin, trimming the candle as his nephew Walter entered, we will have to make the most of our time to-day, for we dine at sharp five p.m., and our dinner leastwise the most of it is at this moment alive and kicking, if it is not sleeping, in the forest, and has got to be found and shot yet. Hallo! boy, where are you bound for?

For the woods, father, with you and Walter, replied his son Roy, sitting down and coolly helping himself to a portion of bears meat with which the hunter was regaling himself.

Nonsense, boy, said Robin, somewhat gruffly.

You will not be able to keep up with us, added Walter, for we have little time before us, and a long way to go.

If I break down I can turn back, retorted Roy.

Very good; please yourself; said Robin in a tone of indifference, although his glance seemed to indicate that he was not sorry to see his boy determined to attempt an expedition which he knew from experience would be very trying to a lad of his years.

Breakfast over, the three hunters clothed themselves in habiliments suitable to the climate leather coats and trousers which were impervious to the wind; cloth leggings to keep the snow from the trousers; leather moccasins, or shoes with three pairs of blanket socks inside of them; fur-caps with ear-pieces; leather mittens with an apartment for the fingers and a separate chamber for the thumb, powder-horns, shotpouches, guns, and snow-shoes. These latter were light wooden frames, netted across with deerskin threads, about five feet long and upwards of a foot wide. The shoes were of this enormous size, in order that they might support the wearers on the surface of the snow, which was, on an average, four feet deep in the woods. They were clumsy to look at, but not so difficult to walk in as one might suppose.

In silence the three hunters entered the dark woods in front of Fort Enterprise. Robin went first and beat the track, Walter followed in his footsteps, Roy brought up the rear. The father sank about six inches at every step, but the snow which fell upon his snow-shoes was so fine and dry, owing to the intense frost, that it fell through the net-work of the shoes like dust. Walter and Roy, treading in the footsteps, had less labour in walking, but Walter, being almost as strong as his uncle, took his turn at beating the track every two hours.

Through the woods they went, over mound and hollow, across frozen swamp and plain, through brush and break, until near noon, when they halted for rest and refreshment. While Walter cut firewood, Robin and Roy cleared away the snow, using their snow-shoes as shovels, and prepared their meal. It was simple; a few mouthfuls of dried meat and a tin can of hot tea the backwoods mans greatest luxury, next to his pipe. It was short, too. Half an hour sufficed to prepare and consume it.

Let us see, now, what we have got, said Robin, counting the game before resuming the march.

More than enough, said Walter, lighting his pipe for a hurried whiff, ten brace of white grouse, four rabbits, six red foxes and a black one, and two wolves. We cannot eat all that.

Surely we wont eat the foxes and wolves! cried Roy, laughing.

Not till we are starving, replied his father. Come, let us go on are ye tired, lad?

Fresh as Walter, said the boy, proudly.

Well, we wont try you too much. We will just take a sweep round by the Wolfs Glen, and look at the traps there after which make for home and have our New Years dinner. Go ahead, Walter, and beat the track; it is your turn this time.

Without speaking, Walter slipped his feet into the lines of his snow-shoes, extinguished his pipe, and led the way once more through the pathless forest.

Mushrooms

Most of us are familiar with one or two kinds of mushrooms, usually white or brown varieties that find their way onto pizzas. Actually, more than three thousand types grow around the world in a wide variety of flavors and sizes. Some are less than an inch high, and others are more than fifteen inches tall. Some have unusual names like Portobello and Black Trumpet, and they are listed on sophisticated menus in fancy restaurants. But many centuries ago, long before pizzas and fancy restaurants existed, people were eating mushrooms.

Ancient hieroglyphics from more than five thousand years ago tell us Egyptians called mushrooms "the magic food." They believed eating them resulted in immortality, and only pharaohs were given this privilege so that they could live forever. Of course, this meant Egyptian royalty enjoyed all the delicious mushrooms since no commoner could touch them! Other ancient civilizations in places such as Russia and Mexico thought mushrooms had ingredients that could produce superhuman strength and even help locate lost objects.

Centuries ago, people still associated magic with mushrooms. Sometimes they observed unusual places in a meadow, like a patch of bright green grass or a spot of bare soil. Then they imagined these places were the result of footprints left by fairies dancing at night. When mushrooms appeared near the edge of these "fairy rings,"

people liked to think of them as seats where the tired fairies could rest. But today we have a more scientific approach to the mushroom.

All of the many species of mushrooms are classified as fungi. They are plant-like organisms that usually grow in damp, dark places like caves or forest floors, but they can also grow in grassy areas. Fungi work with other plants and animals called decomposers to keep the soil fertile for plant growth. Like many other plants, mushrooms serve as a source of food for insects and small animals. Mushrooms differ from green plants because they lack chlorophyll and do not require sunshine to grow.

As the demand for mushrooms increased over the centuries, people established mushroom farms to plant and grow the fungi in special environments. Some farms were in caves, some underground, and some in special buildings. In the sixteen hundreds, for example, France developed the formal cultivation of mushrooms in special caves near Paris. Until the nineteen forties, most mushroom farms were in the Far East, especially China and Japan.
Then during World War II, many American soldiers tasted the delicious varieties of mushrooms and learned about mushroom farming. After the war, they took this knowledge back to the United States, which soon became one of the world's major mushroom producers.

Health and safety are always concerns when growing any crop. One of the complications with mushrooms is that they can be poisonous or nonpoisonous.

Common nontoxic varieties such as table and field mushrooms are safe to eat and can be purchased in grocery stores. These mushrooms are praised by health experts because they are fat-free, cholesterol-free, and low in calories. They are rich in Bvitamins, potassium, phosphorus, and iron. Chefs use them in dishes ranging from soups to gourmet sauces, and some mushrooms even have medicinal benefits. The silver-ear mushroom, for example, can be used to lower blood pressure.

Over the years, edible mushrooms have proven to be extremely popular in the marketplace. Today the USA is the world leader in supplying mushrooms, and other major contributors include France, China, Canada, Great Britain, and Italy.

Source: http://fcit.usf.edu

B.4 Evaluation Study

Once there were three dwarves, Gerda, Darok, and Berin, who lived in a city underground. Gerda was an apprentice in the Cave Rangers guild, and was learning how to explore tunnels. Darok was an apprentice to the Machinists Guild, and was learning the crafting of clockwork devices. Berin, the youngest, had an apprenticeship with the Loremasters guild, where he studied the histories of the dwarves.

One day, the watchmen hammer on warning bells.

“Our enemy has returned!” announced the High Councilor to the crowd. “Mendlin, the Chief Cave Ranger has confirmed that our city will be besieged.”

Teams of dwarves were being sent out to gather supplies for the siege. Gerda, Darok, and Berin, were sent to gather mushrooms. Each was given a backpack with a pickaxe, a lantern, and a camping kit that included cooking tools, and a knife.

Written by: Joshua Tanenbaum

Q & A

SET A: Recalling information, re-reading is permitted

1. What was Berin studying?
   The history of the dwarves

2. The 3 dwarves were sent to gather one kind of food. What was it?
   Mushrooms

SET B: Spatial perception, re-reading is permitted

3. Locate the sentence: “our enemy has returned”
   The second line in the second paragraph

4. How many paragraphs in this page?
   3 paragraphs

Once there were three fairies, Ella, Brokk, and Elvin, who lived in the Fairies valley. Ella was learning how to bake fairy cakes in Mrs. Field's bakery. Brokk was an apprentice warrior learning to fight using the Fairy knife. Elvin was working in the Grand Library of fairies and was learning about the history of the fairy tribes.

One day, Ella, Brokk, and Elvin were on their way to work, when they met Rosa.

"Did you hear about the hidden path?" asked Rosa. It exists behind the ancient Mushroom and leads to a magical place.

Ella, Brok, and Elvin smiled to each other. They wanted to go see the hidden path. They went home and got a knife, a light orb, and a cooking leaf. To get to the ancient Mushroom, they had to wade through the bushes.

Written by: Sharon Chu

Q & A

SET A: Recalling information, re-reading is permitted

1. From where did the fairies get the cooking leaf?
   From home

2. What does the hidden path lead to?
   A magical place

SET B: Spatial perception, re-reading is permitted

3. Locate the sentence: “the Grand Library of fairies”
   The fifth line in the first paragraph

4. How many paragraphs in this page?
   3 paragraphs

Since this falcon is one of the fastest fliers, this may not be much of a contest. Here comes the underdog. It is the green darner. This dragonfly is one of the fastest flying insects. There is even one kind of darner that can jet around at almost 90 kilometers (55 miles) per hour. There they go! Bird and insect are off to a fast start.

Wait. What is that? The dragonfly has stopped. It is hovering. Now it is diving. Oh, this is too much. Now it is flying backward! <u>Those are awesome antics</u>, but the dragonfly cannot out-fly the falcon. The bird's normal speed is close to the dragonfly's best effort. In a race between dragonflies and falcons, the checkered flag goes to the birds.

Source: http://kids.nationalgeographic.com/kids/

Q & A

SET A: Recalling information, re-reading is permitted

1. In this competition, who was the winner?
   The falcon (the bird)

2. What is the color of the insect mentioned in this article?
   Green

SET B: Spatial perception, re-reading is permitted

3. Locate the sentence: “Those are awesome antics”
   The third line in the second paragraph

4. How many paragraphs in this page?
   2 paragraphs

If an insect meets its goal, it survives. To do this, an insect needs to beat its competition. Insects are incredible, but can they beat other members of the animal kingdom?

To find out, we have put together the Insect Olympics. We have matched insects with some other amazing animals. We will test each for speed, strength, or even their ability to spit. Let the games begin!

Everyone knows cheetahs are fast. These cats can go from zero to 112 kilometers (70 miles) per hour in seconds. You might think that nothing can outrun these fast felines. <u>You should think again</u>. Imagine that we shrank a cheetah down to the size of a tiger beetle. Both animals are now at the starting line.

Source: http://kids.nationalgeographic.com/kids/

Q & A

SET A: Recalling information, re-reading is permitted

1. In this article, it was said they would test insects for speed, strength, and what else?
   Their ability to spit

2. What is the speed of the Cheetah?
   112 Kilometer (70 miles) per hour

SET B: Spatial perception, re-reading is permitted

3. Locate the sentence: "you should think again"
   The fourth line in the third paragraph

4. How many paragraphs in this page?
   3 paragraphs

The tiger beetle moves 170 times its body length in just a single second. The cheetah covers about 20 body lengths per second. The tiger beetle races past the finish line long before the cheetah.

In the wild, the tiger beetle moves so fast, its large eyes cannot keep up with it. When chasing its dinner, it briefly loses its sight. <u>It has to stop to see.</u> Now that is blinding speed.

Our next two competitors are ready. The peregrine falcon is stretching its wings. This falcon is known throughout the skies for its speed. While diving through the air, it can reach over 390 kilometers (242 miles) per hour.

Source: http://kids.nationalgeographic.com/kids/

Q & A

SET A: Recalling information, re-reading is permitted

1. The tiger beetle moves 170 times its body length in how many seconds?
   One second

2. What is the falcon's speed?
   390 Kilometers per hour

SET B: Spatial perception, re-reading is permitted

3. Locate the sentence: "It has to stop to see"
   The third line in the second paragraph

4. How many paragraphs in this page?
   3 paragraphs