Braille Learning using Haptic Feedback

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***Abstract*—Learning braille can have a significant impact on the development of blind children. Braille enables visually impaired students to communicate through writing rather than losing that method of communication altogether, empowering them to develop independence, learn strong reading and writing skills, and challenge students to participate in more social and educational activities. Beyond the child's needs, parents need to learn Braille to communicate with their children to ease the child's sense of isolation. Learning Braille takes time to master, and it is a limited resource for parents of children with visual impairments. However, our research explores the use of passive haptic learning to improve the braille learning system for parents by reducing the burden of time to make a difference in this population's lives. The research aims to understand the impact passive haptic learning has on learning rate, proficiency, and recall rate while learning Braille. Using a wearable haptic glove that indicates which keys on a brailling machine the user should press, we will assess the efficacy of this approach. A user study was conducted to determine whether haptic vibrations contribute to more effective learning than memorizing the braille system. The user study involved a series of flashcards to learn the braille letters and cells, combined with a test on a simulated brailling machine to ensure users could type the correct letters. Some participants received haptic feedback during the typing phase, while others conducted the study with no haptic feedback. Participants' accuracy, speed, and recall were measured in a follow-up session.**

***Index Terms*—Haptic, Braille, Learning**

I. Introduction

Learning Braille is crucial for visually impaired students to learn as it enables them to communicate through reading and writing, rather than losing that ability all together. Braille fluency helps improve literacy development, enabling blind students to develop reading and writing skills [1], impact the child's cognitive development [2], and requires the child to use their tactile senses to connect their touch to distinguish between letters, allowing the student to develop higher brain function [3]. Students who are taught Braille have elevated social skills compared to those who do not because Braille allows them to make more connections and improves their social skills. Learning Braille is crucial to a visually impaired child's overall development and can directly impact their future potential.

However, obtaining Braille skills are challenging for students: both from instructional support from the school systems, and from in-home support from parents. For students, less than 10% of visually impaired kids are learning Braille in the US as there has been a decline in braille usage across the United States caused by school budget constraints, new technical advancements, and changed views on how blind children should be educated [4]. Additionally, teaching Braille in schools requires specific training, which is not provided by all educational institutions. For parents with children with visual impairments, it can be a significant time commitment to try and learn Braille. The decline in certified teachers and programs places an additional burden on parents to learn and teach Braille.

To address this challenge, our research explores methods for typically sighted persons to rapidly learn to read and write simple Braille letters through a technique called "passive haptic learning" (PHL). Our goal is to improve the ability and learning rate of sighted individuals (such as parents or teachers) to more rapidly acquire Braille skills, so they can better support the Braille learning of visually impaired students and children. PHL has been shown to increase learning rates in similar tasks, such as reading musical notes and playing piano, which we seek to extend to reading Braille cells and typing Braille letters on a Braille "keyboard" called a "Brailer". Specially, we examine the impact of passive haptic learning on proficiency, learning rate, and recall rate of learning several Braille "letters". The design tackles parents' lack of time to learn Braille and helps their children continue their education at home. The system allows parents to practice learning to read and write Braille at an accelerated pace through a series of learning phases. The user study determined no significant positive impact from using passive haptic learning (PHL) for visually abled persons learning to read and write Braille. The study comprised 13 participants between 18 and 22 at James Madison University. The population group tested was much younger than those who would ideally need this system; this could be a potential factor for why the gloves did not increase proficiency, learning rate, and recall rate. The ability for participants to learn five unique braille letters was completed seamlessly. The users who completed the study with PHL seemed to be more distracted by the gloves rather than benefited.

The remainder of this paper is organized as follows: Section II discusses the general challenges faced by BVI persons, specific contexts within reading and writing, and an overview of related working PHL. Section III outlines our methodology to operationalize a study on reading and writing Braille based upon our model of learning and describes the particular details of our user study. Section IV provides the results from our user study and discusses specific conclusions on accuracy, proficiency, and recall. Finally, we conclude in Section V with a summary of our work and a look toward future endeavours.

II. Background and Motivation

In this section, we will discuss the general challenges experienced by BVI persons with a focus on educational outcomes in Section II-A, provide a general review that conceptualizes the process of reading and writing in Section II-B, and explain passive haptic learning and its application to learning braille in Section II-C.

A. Experience and Challenges for BVI Persons

For a person who is blind or visually impaired, their experiences will vary depending on factors such as the severity and type of visual impairment, access to resources and support, and ability to complete day-to-day activities [5]. It is typical for individuals with visual impairments to struggle to complete basic daily activities without assistance, such as getting dressed, cooking and cleaning, and even navigating a space alone. Often, these persons compensate for their vision loss by training to use other senses, such as auditory or tactile feedback, to provide them comfort and safety [6]. Blind persons struggle with social interactions and depend on alternative communication methods such as assistive technology or learning Braille to communicate effectively with others [7]. Communicating through Braille provides students more access to information, allowing them to continue their education, express their thoughts and ideas, and even have conversations with others [8].

These challenges are magnified for students in public school systems as they face the challenges of limited resources, fewer faculty who can appropriately support them, and limited access to braille materials [9]. While some states have schools dedicated to educating BVI persons, such as the Virginia School for the Deaf and Blind, many BVI students attend traditional public schools. They are expected to participate in the same educational activities as all other students. BVI individuals are challenged to read and write Braille to access educational materials, complete assignments, take notes and participate in classroom activities [10]. Learning Braille is critical for a BVI student to read, write, express their ideas, and broadly, be empowered for future independence and employment.

B. Learning to Read and Write

Blind students can prepare for tactile learning by becoming familiar with the sensation of reading Braille by practicing identifying not specifically the letter but even the dot orientation they feel [11]. Exposure to Braille can help students excel when learning reading and writing. Tactile systems such as raised drawings, models, and three-dimensional objects allow students to make connections between physical touch and understanding concepts. Once students have been exposed to tactile materials and have developed finger strength, specifically on the tip of the finger pad, the student can begin to learn Braille. Blind students can use audio, technology, and tactile materials or work with instructors to prepare for tactile learning.

Fig. 1: Perkins Brailler

Learning Braille follows a progression of steps, starting with learning the Braille alphabet and then gradually building skills in reading and writing [12]. Learning the braille alphabet is the first step to learning braille. The alphabet is known as Grade 1 Braille. Grade 1 braille consists of raised dots arranged in a 6-dot cell, each representing a different letter or symbol. Once the students have mastered the alphabet, they build vocabulary and learn how to form sentences. The students will be introduced to Grade 2 Braille, where they will learn contractions, prefixes, and suffixes.

The next step is to develop reading fluency; the student is trying to develop faster reading speeds and accuracy [13]. The student needs to understand how to read Braille fluently before beginning to learn how to write Braille. The child will then learn how to write with proper writing techniques such as spacing and formatting [14]. As the student becomes more proficient in reading and writing, the child can then begin to express themselves through braille writing and engage in critical thinking.

1) Challenges in Reading and Writing for Blind and Visually Impaired Individuals: For individuals who are visually impaired or blind, reading and writing can pose challenges. However, schools have limited systems available to facilitate Braille reading and writing. The Perkins Brailler is a typewriter that enables students to type Braille, Figure 1. The Perkins Brailler has six keys, one for each of the six dots that make up the Braille cell [15]. The Perkins Typewriter allows students to read and write Braille by embossing the Braille alphabet onto paper instead of printing letters. The Brailler has helped make Braille more accessible and allows blind users to communicate through Braille.

Public schools have limited resources, including many instructors and TVIs. TVIs are Teachers certified in visual impairments [16]. Typically, there is only one TVI assigned to multiple schools, and it may only reach a child with visual impairments once a week. Students who are blind or visually impaired are expected to complete the traditional curriculum. Thus, Teachers of the Visually Impaired (TVIs) must convert existing materials and lesson plans into Braille. These teachers struggle to reach students because of a lack of resources and funding [17]. Funding for Braille materials or even just materials for those with disabilities is a fixed amount regardless of the number of students or the severity of their disabilities; this makes it extremely difficult to support these students.

C. Passive Haptic Learning and Related Work

Passive haptic learning (PHL) is a learning technique that challenges a person to receive haptic or tactile stimuli without actively engaging in a task [18]. Haptic feedback is used to create the feeling of pressure or vibration to cue muscles and joints to move [19]. Haptic feedback uses touch to communicate motion to users and "nudge" their position, helping create another form of learning. The passive haptic device is controlled by a motor that commands the tactile motors to vibrate. Passive haptic learning aims to have repeated exposure to haptic feedback that can lead to learning or improvement in skill.

Several studies have investigated the effectiveness of PHL in various fields, including motor skills, learning language, and accelerating musical skills. In 2016, the Georgia Institute of Technology researched Tactile Taps Teach Rhythmic Text Entry: Passive Haptic Learning of Morse Code [20]. The study emphasized how PHL can help individuals learn Morse code. The study found that the PHL participants achieved a 94% accuracy rate keying in a phase compared to the control group, which had 53% accuracy. The study used a rhythm-based system that helped users connect their hands' functions to what the brain was processing. The study concluded that using haptics can help teach Morse code to users.

Passive Haptic Learning allows people to learn muscle memory through vibration stimuli without devoting attention to the stimulus [21]. The study facilitated PHL by designing a glove with embedded tactile motors that were used to communicate patterns of finger movements that matched piano melodies. Passive Haptic Learning of Typing Skills Facilitated by Wearable Computers used passive training to help users learn how to write phrases. In the group's exploration of PHL for typing, the group discovered that accuracy is an appropriate measurement of whether PHL is effective. Work in PHL has been studied as a technique to improve language learning and can significantly impact learning braille. Passive haptic learning is still a new area of research, but these studies suggest that it has potential as a learning technique in numerous applications.

1) Applications of PHL for BVI Persons: For visually impaired learners, passive haptic learning can be a valuable tool for learning to read and write Braille. Braille learners rely heavily on touch to communicate, and PHL can help strengthen learning by providing tactile cues [22]. Visually impaired learners can receive feedback through vibrations that can help them better understand and remember information. Passive haptic learning techniques could include tactile diagrams, braille labels, tactical graphics, and tactile feedback devices [23]. Tactile feedback devices can help blind learners understand new concepts and develop reading and writing skills. PHL can teach motor skills using vibration cues, even while the user is focusing on another task [24]. PHL can allow parents to learn at an accelerated pace to help their child with visual impairments.

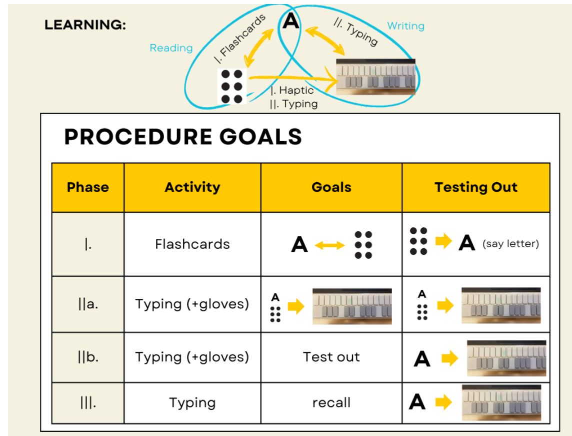

Fig. 2: Procedure Goals for the User Study.

PHL allows users to develop muscle memory and can teach individuals through vibrations. PHL has been used to teach new languages, motor skills, musical skills, Morse code, typing skills, and Braille. For blind learners, passive haptic learning can be a valuable tool for learning and developing reading and writing skills by enriching the sensation of physical touch and combining that learning style with concepts to help users make connections. PHL can also allow parents to learn Braille at an accelerated pace and lessen the time required to learn Braille. Designing a system that helps parents learn Braille could impact the lives of visually impaired children by creating a support system at home.

III. Methodology

In Section III-A we discuss our experimental design for the user study as informed by our theory of reading and writing, and the existing work in PHL, as discussed in Section II-C. Additionally, we describe the particular of the user study protocol in Section III-B.

A. Experimental Design

The study comprised three phases, each a new form of learning to write braille, which is represented graphically in Figure 2. The first phase introduced flashcards with both the letter and cell orientation and each participant was tasked to learn the association between the letter and cell. The participants then began typing using a keyboard, learning the association between the cell and the letter to the keys. Finally, each individual completed a recall test where they were shown a letter and asked to type it. Each phase Phased participants to successfully test out by achieving a 90% accuracy to move on to the next study phase.

The first phase of learning is learning to read Braille. All users were shown a flashcard with a letter and the corresponding braille cell and practiced learning five letters (a, b, c, d, e). The reading learning phase was adopted from existing techniques from Hadley Vision Resources, an educational online workshop for parents learning Braille [25]. Participants were given a maximum of 10 minutes to study and practice learning the flashcards, while most used less time. When individuals felt prepared to test out of phase 1, they would take a flashcard quiz that displayed a cell on the screen, and the individual was tasked to say the correct letter allowed. Once the participant achieved 90% accuracy in their last 20 attempts, they would successfully move on to the next phase of the study. Neither the experimental nor control groups received haptic feedback in this phase.

The second phase of the study incorporated reading and writing. Individuals were tasked to learn the association between the keys to press and the letter and the cell. In this phase, users assigned to the experimental group received haptic feedback and began receiving feedback from motor vibration. The participant was again shown a display of the letter and the Braille cell while six motors vibrated the correct fingers to type that given letter. Each participant was shown the same five letters and tasked to type the keys on the keyboard. Once the participant achieved 90% accuracy in their last 20 attempts, they would successfully move on to the next study phase.

The third phase challenged the participants to use what they had learned to type on the keyboard, only being shown the alphabetical letter. The individuals in the experimental group continued to receive haptic feedback through this phase. Phase the participant achieved 90% accuracy in their last 20 attempts, the initial part of the study would be completed. Each participant was asked to return 3–7 days later to complete a recall test. The user's recall rate was measured and compared to that of those who did not use passive haptic learning.

This study protocol was realized through an experimental setup as seen in Figure 3a. Participants were shown the Braille letters on the screen and then asked to "type" the letters on a USB piano keyboard. Participants who were in the experimental haptic feedback group also wore the gloves shown in Figure 3b

B. User Study Protocol

The research was conducted at James Madison University in the Engineering Department and approved by JMU Internal Review Board (IRB # 23-4167). Recruitment was conducted from the typical student population through email, fliers, and word of mouth. All participant completes a consent form and were briefly described educated on why the study was important, emphasizing the importance of parents learning Braille to support their visually impaired children at home. After introduction and completing informed consent, participants were randomly assigned to groups, indicating whether they would receive haptic feedback or complete the study without haptic feedback. The five letters used for testing remained the same for all participants; however, the order in which they were displayed varied. The study measured the recall rate of both groups, those with haptic feedback and those without, to measure the impact of PHL on writing Braille. Each group was provided the same amount of time to progress through each phase. The user study was conducted with visually able college students representing the seeing parent.

(a) (b)

Fig. 3: Experimental setup for user study and haptic glove prototype

IV. Results and Discussion

The research aimed to understand the impact of passive haptic learning on a visually abled person's learning rate, proficiency, and recall rate of Braille. A total of 13 participants completed the study. As described in Section III, several stages were employed to scaffold the learning experience, with the experimental condition being whether an individual received (or not) haptic feedback during the process. In the remainder of this section will discuss our results in two majors contexts: the time in which it took participants to advance between stages and the accuracy and proficiency of their performance across each stage.

A. Participant Duration Across Study Phases

As described in Section III-Athe study consisted for three phases. The duration it took each participant to complete a particular phase is shown in Table **??**.

Phase 1 served as a baseline for all participants by analyzing the overall knowledge before introducing the new feedback system. The duration it took individuals to learn flashcards for all participants varied significantly; the quickest completing the task was 22 seconds, and the longest was 422 seconds. When participants felt prepared to learn the flashcards, they were tasked to complete a test-out phase, identifying the correct letter when shown the cell.

During phase 2a, participants learned to type using the keyboard. Participants in the experimental group (glove users) completed this phase of the study with haptic feedback. The duration it took for individuals to learn to type Braille was recorded during this phase of the study. The average duration for individuals to learn to type with the feedback system was 48.01 ± 16.04 seconds, while the average duration for participants to learn without feedback was 45.99 ± 9.10 seconds, Figure 4. User 4 in the experimental group took the longest time to learn how to type, almost double the amount of time it took the others in the experimental group. It is important to note that this individual could struggle with motors on their fingers and may be more of a

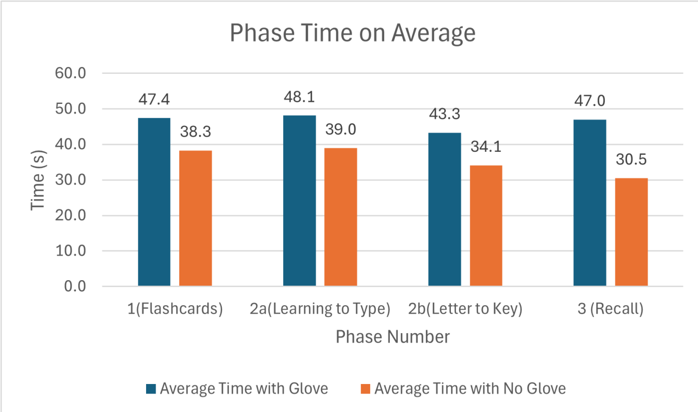

Fig. 4: Average Duration spent in each Phase

distraction than an assistance. The variance in data could be due to the individuals similar to user 4, who struggled more than the average participant.

Phase 2b tested the participant's ability to type without being shown the Braille cell. Each individual was shown a letter and tasked with typing the correct keys corresponding to that letter. The learning rate was recorded over time, and the average duration for those who received feedback was 43.29 $\pm$9.10 seconds. Note again that user 4 took extensive time to complete this phase. The average duration for those who completed the phase 2b test-out with no haptic feedback was 34.06$\pm$3.74 seconds.

Figure 4 shows the average duration across study phases. The average duration spent in each phase was significantly longer for individuals who received haptic feedback. During phase 1 (flashcards), the average completion time for those who received haptic feedback was 47.4 seconds, and the average time for those who did not receive haptic feedback was 38.3 seconds. While learning to type, participants in the experimental group completed the task in 48.1 seconds, while those in the control group averaged 39.0 seconds. Participants with gloves completed phase 2b in an average of 43.3 seconds, while users with no gloves took 34.1 seconds. Finally, the recall of participants who received feedback was, on average, 47.0 seconds, while the recall of those who did not averaged 30.5 seconds. The feedback system (glove) slowed the user's learning rate throughout all phases. The glove was observed to be more of a distraction to users than helpful. Individuals did not depend on the glove to complete each of the tasks of learning; rather, it inhibited their learning.

B. Accuracy Across Study Phases

During phase 1, every participant was given the same flashcards; no users received feedback. Results showed the average accuracy in Phase 1 for those who completed the study with no passive haptic was 99.2%. The accuracy for those who would receive passive haptic feedback was 98.6%. There is no statistically significant difference between the accuracy of the two groups in Phase 1.

Phase 2a of the study tasked participants to learn how to type Braille. During phase 2a, individuals assigned to the experimental group would begin to receive haptic feedback through motor vibrations. Each user was again shown the cell and letter and was tasked to learn the association between the cells and letters to the correct keys. Each participant's typing accuracy was recorded as they completed their test-out of the learning-to-type phase. The average accuracy for those who did not receive haptic feedback was 95.3%, with a total attempt average of 20.67 tries. The average accuracy for individuals who received haptic feedback was 87.7%, with a total attempt average of 21 tries. The accuracy for the experimental group was less than the average of the control group, demonstrating a negative effect from the glove. The glove inhibited users' learning rather than accelerating their accuracy and learning.

Phase 2b resulted in the average accuracy for those who received feedback was 93.9%, with a total average attempt of 20.85. The average accuracy for those who did not receive feedback was 100%, with a total average attempt of 20. The users who did not receive feedback completed phase 2b with 100% accuracy, while the experimental group continued to have a lower accuracy.

The participants returned 3-7 days after their initial study and completed a recall test. The recall rate test determined that those who did receive haptic feedback (glove) had, on average, a slower recall, a lower average accuracy rate, and a higher average of total attempts. Each group's average time in each phase was recorded to determine the overall learning rate throughout the study, Figure 4.

The accuracy for participants in the experimental group (glove) consistently had a lower accuracy rate in each of the phases compared to those in the control group (no glove). For example, during phase 2b, those who did not receive haptic feedback had a 100% accuracy rate while typing, while those who received feedback had an accuracy rate of 93.9%. This demonstrates that the gloves negatively affected users' accuracy. Several factors could cause the decline in accuracy when introducing a feedback system, including unclear instruction from gloves and comfort.

C. Summary of Results

Overall, the results show that using passive haptic feedback did not improve learning rate, proficiency, and recall rate. It is possible the gloves inhibited users from completing the tasks at an accelerated pace and were observed as more of a distraction of confusion than helpful. Our choice of population could impact the results because the users were much younger than the target population, meaning adults could show different results. The population could also be affected based on the need for assistance; parents who need to learn Braille may benefit more from the gloves than those tested in the study. The study was conducted only using five letters. Using more letters could make it more apparent if the individuals needed to rely on the gloves for assistance compared to memorizing the five letters. The limited number of participants makes it difficult to justify using passive haptic feedback's significance or lack of importance.

TABLE I: Study Duration by Phase for Gloved and non-Gloved Participants

	Experimental - Gloved					Control - Non-Gloved				
User	Prep.	Phase I	Phase IIa	Phase IIb	Recall	Prep.	Phase I	Phase IIa	PhaseIIb	Recall
1	422	40.98	25.45	34.38	38.52	140	40.20	45.40	31.61	31.12
2	40	45.80	39.73	36.79	52.64	160	41.84	27.72	29.93	28.70
3	44	49.79	42.93	36.66	N/A	22	39.67	43.75	33.66	30.31
4	105	55.09	80.25	58.72	51.17	76	36.95	50.76	37.63	N/A
5	85	43.39	46.54	46.32	42.67	61	33.67	54.73	40.34	N/A
6	124	58.69	42.16	54.07	56.44	59	37.22	53.64	31.18	31.79
7	123	38.07	59.02	36.15	40.72	N/A	N/A	N/A	N/A	N/A
Avg	134.71	47.40	48.01	43.30	47.03	86.33	38.26	46.00	34.06	30.48

V. Conclusions

Braille is crucial for visually impaired students to learn how to read and write. However, there has been a decline in Braille usage across the United States, and there are limited resources for these students, including certified teachers. Parents are burdened trying to fill that gap in their student's education due to the lack of resources. Braille can have a life-changing impact on the learning and development of visually impaired children. It can improve their literacy, cognitive development, and social skills.

While prior research suggests incorporating haptic feedback devices can accelerate writing Braille and enhance learning our study found no statistically significant impact of passive haptic learning on braille learning. Further research, including more participants and individuals in the parent population, could produce new data and insights into the effectiveness of passive haptic learning in reaching visually-abled people in Braille. The continued research in this field and results are advancements that can significantly impact visually impaired children's lives and allow parents to learn Braille quickly to help further their child's education.

Acknowledgments

The authors would like to thank the Virginia School for the Deaf and Blind for allowing us to tour their facilities.

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