A Comparative Study of the Learning Curve of a Novel Interface for the Deafblind: Implications for Educational Environments

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Abstract. In addition to communication and mobility issues, the blind and the deafblind suffer from poor social inclusion and illiteracy, and extremely low employment rates. This is particularly due to lack of access to dedicated educational resources and to technology for learning.

In this paper, we introduce dbGLOVE, an innovative and low-cost wearable interface based on a tactile communication system especially designed for the deafblind. We compare the performances of dbGLOVE with the state-of-the-art technology for the blind and the deafblind, i.e., the Braille display.

Results from our study show that dbGLOVE has a faster learning curve, and it outperforms the Braille display both in accuracy and in speed. Finally, we discuss the implications of our findings in regard to learning and we detail the features that render dbGLOVE particularly suitable for educational purposes.

1 Introduction

According to demographic research [1], the world's blind population is estimated between 40 and 45 millions. Every year, 7 million people become blind, that is, two individuals every 10 seconds (one child per minute) lose their vision. Recent studies anticipate that all blind-related numbers will double by the year 2020 [2]. Although less is known about the deafblind due to poor statistics, they account for 0.016% of the population. Despite being a minority of the world population, they pose additional challenges in terms of public health and social security, and education. Limited access to assistants, resources, and technology, prevent deafblind people from achieving autonomous living, independent mobility, social inclusion, and adequate literacy [3]. Only 10% of children receive education due to the unavailability and to the cost of both specialized teachers and technology. As a result, school and working-age blind have very high unemployment rates (about 75%).

In addition to technology for Augmentative and Alternative Communication (AAC), the deafblind require dedicated systems for getting access to computers, mobile devices, and to the Internet [3]. In the last decades, a variety of interactive communication technology have been introduced in the market. Nevertheless, users still rely on the constant presence of assistants in order to communicate, to learn, and even to read simple text.

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Indeed, they need to be autonomous in achieving high quality educational resources [5]. Assistive technology is crucial for providing people with disabilities and cognitive impairments with means for social inclusion, access to information, and learning [4]. Systems, such as the Braille display, have been used by the visually impaired for years, and they are the state-of-the-art devices for communicating and interacting with the outside world. Unfortunately, they are extremely expensive. As a result, they are available in certain communities and schools, only, and they are not affordable by the majority of target users, who usually have insufficient financial resources. This is especially true for developing countries, where 90 percent of the blind and deafblind population live.

In this paper, we introduce dbGLOVE, an innovative low-cost wearable device for interacting with computers and with smartphones [6]. dbGLOVE is a natural interface based on the Malossi alphabet, a simplified tactile communication system invented by a deafblind. Both the Malossi and the Braille alphabets were invented by individuals with sensory impairments, and both rely on prior language training, because they conform to the syntax and grammar of common verbal languages. However, as the Malossi alphabet does not require sophisticate sensory or cognitive abilities, it is especially suitable for children education. Also, dbGLOVE is fifteen times cheaper than Braille displays. Thus, we propose dbGLOVE as a replacement for the Braille alphabet for improving learning speed and engagement, and for democratizing access to technology and education. To this end, we evaluate the performances of dbGLOVE in training users who are novice of both the language and the device. Specifically, we compare the learning curve of the Malossi alphabet with a standard Braille display, and we show that dbGLOVE outperforms the Braille display by 200% both in accuracy and in speed.

2 Related Work

The Braille code is the most famous and adopted system for encoding text in a tactile form. It utilizes series of raised dots to form letters: each symbol is represented using a cell consisting of six dots that can be raised or flat in order to obtain different configurations. As alphabet consists of 6 dots each assuming two values (i.e., raised or flat), it supports 64 configurations. Nevertheless, it has a very powerful encoding: there are conventions for associating different meanings to the same configuration, and for switching between domains (e.g., music, or mathematics). Words are written as sequences of adjacent cells. These can be read by people who are blind (or whose sight is not sufficient for reading printed material) with their fingers, by simply passing the fingertip over the cells. Usually, teachers, parents, and others who are not visually impaired can read Braille dots with their eyes.

Indeed, as Braille is a code by which languages (e.g., English) can be written and read, Braille readers are required to learn the alphabet, the grammar and the syntax, before they can communicate. Although studies in the literature demonstrate the efficiency of the Braille alphabet in encoding information, the Braille alphabet has important limitations from a learning perspective. Specifically, in order to understand Braille, readers should be able to explore and recognize similarities and differences in objects and materials. This can be especially difficult in case of cognitive or sensory impairments, which usually occur in case of deafblindness. In general, discriminating the dots and associating configurations to letters has a long learning curve, and it requires extensive effort from both the learner and the assistant. Consequently, Braille displays are not suitable for supporting education of children in their pre-school age and in K-12.

Over the years, several simplified communication systems, such as on-body signing, have been developed in order to provide children (even infants) and people in their early stage of blindness with alternative means for basic learning and for interacting with others. The Malossi alphabet is among the most popular codes based on on-body signing. It is named after his inventor, an Italian who became deafblind in his early life. The Malossi system defines an on-hand signing method and a tactile alphabet based on two types of stimuli: touch and pinch. Figure 1 shows the configuration of the language. Letters from A to O are distributed over the palm, on the 15 phalanxes from the thumb to the little finger, in a clockwise fashion. Each phalanx is associated with a different letter depending on the touch cue (i.e., touch or pinch). Letters from P to Z (excluding the letter W, which is located close to the proximal phalanxes between the second and the third metacarpal bones) are distributed over the distal and the proximal phalanxes, and they are activated when the area is pinched.

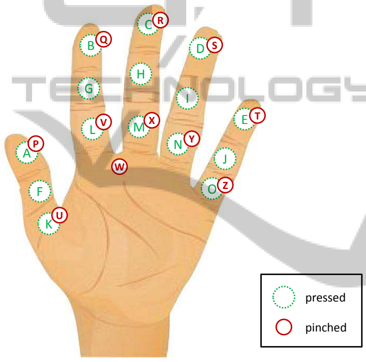

Fig. 1. Layout of the Malossi alphabet over the palm of the left hand.

Two deafblind individuals communicate using Malossi method as follows: the hand (usually, the left one) becomes a typewriter for the receiver of the message. As a result, they type messages on each other's hand, in turns: the sender writes words by subsequently touching and pinching in sequence different parts of the receiver's phalanxes that correspond to the alphabet. Then, they exchange their roles in order to achieve bidirectional communication. This method is used by those who had learned to read and write prior to becoming deafblind. Nonetheless, as the alphabet is based on simple touch cues, phalanxes can be associated with elementary objects (e.g., *water*, *mom*) and actions (e.g., *eat*) in order to achieve functional communication. As a consequence, the Malossi alphabet is effectively employed with infants. Then, the communication system can be evolved into an alphabet. Consequently, the speed at which two deafblind people can communicate using the Malossi alphabet is impressive.

3 dbGLOVE

Research on vibrotactile perception showed that vibration can stimulate the skin in a way that it can induce a large set of sensations ranging from soft displacement to painful cues (depending on the waveform, and on its intensity and frequency). Nowadays, miniaturized motors, similar to those employed in smartphones, can be utilized as inexpensive means to provide individuals with sophisticated vibrotactile feedback that can simulate touch cues. These, in turn, can provide users with means for easily recognizing on-body signing. As a result, vibrotactile interfaces for touch-based communication are emerging as an alternative to conventional assistive technology for AAC [7], [8].

dbGLOVE is an interactive glove based on the Malossi alphabet. It provides blind and deafblind people with bidirectional interaction with the computer and computer-mediated communication with others. The deafblind can wear the device on the left hand, and they can type messages on their own palm, as on a keyboard. The device incorporates an array of sensors and actuators into a pad that can be worn on the palm of left hand as if it was a glove. This can be connected to a computer, or to a smartphone. As a result, the deafblind can type on their own hand, instead of that of the receiver. Input is acquired and processed as a command to the PC (e.g., *open application*), or as a message to be displayed to another individual (e.g., *I want to eat*). Also, dbGLOVE includes a tactile monitor. So, the deafblind can receive messages in the form of tactile stimulations, as if someone was typing on their palm. Responses can be received by the user in the form of vibrotactile stimulation at different intensity and frequency that simulate touch and pinch cues, as if someone was typing on their hand. As a result, the device is able to provide the user with bidirectional communication. Figure 2 shows the device, whose architecture is extensively described in [6].

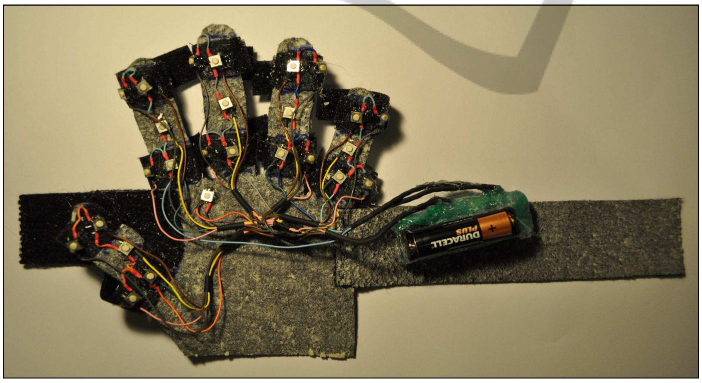

Fig. 2. A prototype of dbGLOVE: the white dots correspond to input/output areas.

4 Experimental Study

In this study, our objective was measuring the learning curve of the Malossi alphabet with respect to the Braille system by comparing the performance of dbGLOVE with a standard Braille cell. The main purpose of the experiment was to understand whether dbGLOVE and the Malossi alphabet can improve learning. To this end, we focused on output, only, which is the most interesting feature with respect to education: enabling users to autonomously read documents without requiring the constant presence of a interpreter is a crucial issue. Specifically, considered speed and accuracy over a fixed number of runs that gave users sufficient training time to learn to associate symbols to stimuli.

4.1 Experimental Tasks

We designed two similar experimental tasks, one focusing on dbGLOVE and one on the Braille display. As the experiment focuses on the output layer, in order to realize a comparison between the training time required by dbGLOVE with respect to a Braille-based device, we evaluate subjects' accuracy and speed in recognizing letters in the form of vibrotactile or pressure cues, respectively. To this end, in each of the two tasks, participants were involved in a guided output routine: they were presented with sequences of letters randomly chosen, and they were required to speak them back to the technician. We employed single letter instead of using words, as the latter could have introduced some error in the experiment routine. Specifically, the predictability of the last letters could have biased the experimental results. Differently from other experiments, as both the Malossi and the Braille alphabets were given to subjects without prior training, learning required some time. All the tasks consisted of 30 runs each consisting in 240 seconds, with an inter-run interval of 2 minutes. Each trial had duration of 5 seconds. Runs were divided into groups of 10, and each group was executed within several days from one another.

In task I, we evaluated the learning curve of dbGLOVE with respect to the output function in sending meaningful tactile stimuli to the user. Participants were presented with sequences of letters represented into a vibrotactile form by the actuators embedded into the device. The different areas of the hand associated with the letters were stimulated with vibrotactile patterns simulating touch and pinch cues, and participants were asked to speak the letter to the technician. The objective of the subject was identifying as many letters as possible. The procedure in Task II was exactly the same as that in Task I. We evaluated the performance of Braille cells in sending perceivable tactile stimuli to the user. Participants were presented with sequences of letters via a single Braille cell. They were asked to decode the configuration of the dots, and to speak the letter back to the experimental technician.

4.2 Participants

13 volunteer participants were recruited for this experiment. They were 5 female and 8 male. All had a normal sight, hearing and tactile sensitivity. Subjects ranged in age from 18 to 25 with an average of 22. All use computers on a daily basis (1.5-8 hours usage per day). They were all novice of the Malossi alphabet and of the Braille system. All had no prior knowledge of the device; two of them had prior experience with vibrotactile feedback, as they were involved in other studies about tactile feedback. Subjects participated on a voluntary basis and they were not paid or rewarded. All subjects were right-handed as assessed by the Edinburgh inventory [9]. All subjects were prepared to the experiment by a technician who gave them instructions about the test and the experimental tasks.

4.3 Experimental Setup and Protocol

A device consisting of one piezoelectric Braille cell was utilized in Task II. We employed an International Building Standard [10] compliant cell (2.5mm for horizontal and vertical dot-to-dot distance, with a dot diameter of 1.5mm - 1.6mm and a dot height ranging from 0.6mm to 0.9mm). Its activation was ∼100 milliseconds, which is comparable with that of vibrotactile actuators, given the timing of the experimental task. Prior to the experiment, subjects were provided with a preliminary explanation of the Malossi and the Braille alphabets. Also, before each task, they were given sufficient time to manipulate the stimulation devices. In each trial, individuals had 5 seconds to speak the letter back to the technician. We evaluated the training level by comparing speed (measured in CPM). Moreover, we logged the accuracy in recognizing letters. In this regard, we associated a trial timeout to an error, as if the wrong letter was recognized. With respect to the task involving Malossi, we also logged the number of errors due to germane load, that is, letters biased due to the fact that they are on the same phalanx.

5 Results and Discussion

We evaluated language proficiency using speed and accuracy as the main metrics. Specifically, we adopted the number of Characters Per Minute (CPM) as a standard performance measure, and we distinguished correctly written and wrong characters. Also, we logged the time users spent in recognizing each letter, in order to identify the symbols that required more effort, and to evaluate the presence of germane load. All the subjects were able to understand the task. We utilized sequences of characters, as this is an easier way to measure subjects' ability in recognizing vibrotactile stimuli in the different areas of the hand, and to associate touch and pinch cues to letters of the alphabet. Participants were only required to speak the letter to the technician, who recorded the answer as correct or wrong. This was to avoid subjects to actually type the letter on a keyboard, which could have introduced some additional cognitive load.

Figure 3 represents the experimental results about speed and accuracy. In order to evaluate speed, we calculated the number of letters that subjects were able to process, that is, the number of answers they were able to give before the run timeout. Subjects started at very low speed. Initially, participants were able to recognize only a few of the characters being displayed, with an average of 30.82 and 45.29 letters displayed to participants using the Braille cell and dbGLOVE, respectively. During the experiment, we registered an increasing trend in speed. Also, the training effects persists until the last run, when the performances of dbGLOVE and the Braille cell are 212.17 and 93.24 letters displayed (on average), respectively. Consequently, the improvement is +166.87 and +62.41 with our device and with the Braille cell.

In regard to accuracy, results show an increasing curve in the use of both devices. Participants using dbGLOVE started at 20.11%, and they increased their performance by 76.3% after 30 runs, thus, reaching an average accuracy of 96.41%. The training effect vanished at run 24, when subjects' performances were over 90%. Conversely, using the Braille cell, participants found more difficult to decode the letter by reading the dots. They began with an accuracy of 15.14%, and they improved their performance by 44.01%. In run 30, subjects' accuracy was 59.15%, -37.26% with respect to dbGLOVE.

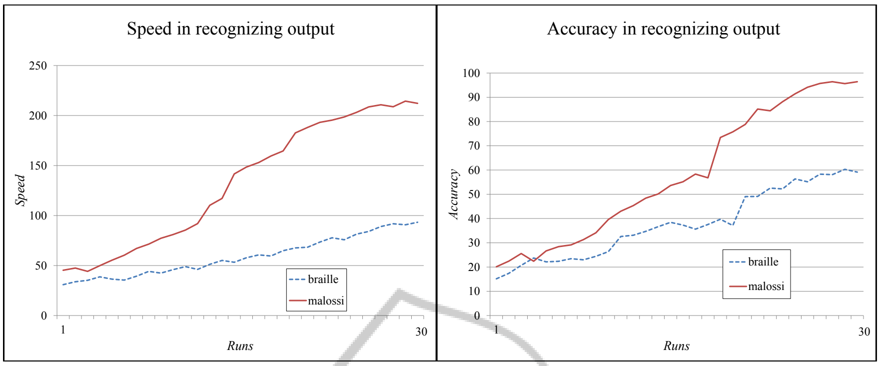

Fig. 3. Experimental results: performances with dbGLOVE and with the Braille cell.

6 Conclusions

Although the Braille alphabet is the most widely adopted system for enabling blind and deafblind people to read text, it has limitations in terms of technological implementation and costs. Also, it requires cognitive abilities and sensory perception to be intact. Conversely, teaching Augmentative and Alternative Communication requires systems that can cope with developmental, physical, and sensory impairments [3]. In this regard, the Malossi alphabet is extremely intuitive, and it relies on basic touch cues. It is widely employed with people having cognitive impairments, who cannot learn more complex communication methods, such as alphabets involving shapes.

In this paper, we compared the Malossi alphabet and the Braille system with the purpose of evaluating their learning curve. Our main hypothesis was that dbGLOVE is suitable for substituting Braille displays in everyday interaction, and particularly, during early life or in the first stage of deafblindness, that is, when individuals require an immediate system for basic communication. As shown by our results, the Malossi alphabet implemented in dbGLOVE outperforms the Braille alphabet both in speed and accuracy, in people with no previous training. As a result, dbGLOVE can be utilized as a substitute of systems implementing the Braille alphabet, especially in circumstances in which a shorter learning curve is required. The present study has several limitations. Being an early-stage prototype, we evaluated dbGLOVE with people having normal vision and hearing. Therefore, our results should be validated with further experiments with blind and deafblind users, which will be part of our future work.

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