Tactile Letters: a Tangible Tabletop with Texture Cues Supporting Alphabetic Learning for Dyslexic Children

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Abstract
Dyslexic children have great difficulty in learning to read. While research in HCI suggests that tangible user interfaces (TUIs) have the potential to support children learning to read, few studies have explored how to help dyslexic children learn to read. Even fewer studies have specifically investigated the design space of texture cues in TUIs in supporting learning to read. In this paper, we present *Tactile Letters*, a multimodal tangible tabletop with texture cues developed to support English letter-sound correspondence learning for dyslexic children aged 5-6 years old. This prototype is used as a research instrument to investigate the role of texture cues in a multimodal TUI in alphabetic learning. We discuss the current knowledge gap, the theoretical foundations that informed our core design strategy, and the subsequent design decisions we made while developing Tactile Letters.

Keywords
Tangible user interfaces; dyslexia; children; reading; texture cues; material.

Figure 1. Tactile Letters: a TUI with a display and a set of tangible letters with or without texture cues.

Figure 2. Tangible letters with texture cues.

ACM Classification Keywords
H.5.2. [Information interfaces and presentation]: User Interfaces.K.3.1 [Computers and Education]: Computer Uses in Education-*Computer-assisted instruction*.

Introduction
Dyslexia is a specific learning difficulty that influences learning to read [10]. Children with dyslexia struggle to automate the 'alphabetic principle' (i.e. letter-sound correspondences) and therefore have difficulty in word decoding and reading [4]. Research in HCI suggests that tangible user interfaces (TUIs) have the potential to support learning to read for children [17, 19], but it has seldom explored how to better help dyslexic children learn to read [8,13]. Moreover, we have not seen any studies that specifically investigated the role of texture cues in TUIs in supporting learning to read.

The important role of tracing letters in learning to read for dyslexic children has been highlighted in previous research [2,3,4,10]. In many successful multisensory programs, dyslexic children are encouraged to see letters, hear their sounds, and trace them with their fingers on a textured surface such as sandpaper [4,10], cards [16], digital screens [1] or physical letters made of foam [2,3]. Despite using different surfaces, these tracing activities share one common characteristic. That is, dyslexic children trace all the letters on the ***same*** textured surface in each approach. The new opportunity provided by TUIs is to better leverage the use of ***various*** textures through constantly coupling them with cross-modal digital information (e.g., associating textures with letter sounds) [12]. The association between textures (embedded in letter shapes) and letter sounds may act as affordances to efficiently support dyslexic children learning letter-sound correspondences. We believe it is of great value to explore the design space of texture cues in TUIs designed for alphabetic learning for dyslexic children. Filling this knowledge gap would lead us to a better understanding of how to design TUI learning materials and texture cues to better augment visual/auditory modalities of information representations.

In this paper, a proposed tangible tabletop incorporating two sets of letters (one with texture cues and the other without texture cues) was designed to help dyslexic children aged 5-6 years to learn letter-sound correspondences (Figures 1 and 2). The core design strategy of texture cues is based on the metaphoric mapping strategy used in education [8]. This prototype is a research instrument that allows us to investigate whether a tangible tabletop with texture cues can help dyslexic children learn letter-sound correspondences more effectively than a tabletop without texture cues.

Related Work
Learning to Read in Dyslexic Children
Learning to read is a systematic, complex and difficult process, particularly when learning opaque languages such as English, where the orthographic rules are not entirely consistent [4]. For dyslexic children, the most difficult part in learning to read is understanding letter-sound correspondences [4]. They also have difficulty in identifying mirrored or flipped letters [4]. However, dyslexic children can learn to read well under systematic and multisensory instruction. Multisensory training involves activities that make clear links between multiple senses (e.g., visual, auditory, and tactile) to teach children basic reading, spelling, and writing skills [10]. Many empirical studies have

Figure 3. In level 1, a child placed a tangible letter "b" and three letter cards on the interactive table. Digital images and sounds were triggered.

Figure 4. In level 2, a child placed two tangible letters "oa" on the interactive table. Because "oa" were irregular, the system triggered the visual-audio feedback to indicate they are grouped.

demonstrated that multisensory training has great potential to induce strong reading improvements in dyslexic children [11,16].

The importance role of tracing activities in learning to read for dyslexic children has been highlighted in both education and neuroscience communities [2,3,4,16]. Researchers suggest that tracing the contours of textured letters could help dyslexic children associate each letter with a distinct motor gesture and therefore benefits them in learning mirrored or flipped ***letter shapes,*** such as *b, d, p,* and *q* [4,16]. Some further suggest that tracing physical letters involves more than simply learning letter shapes [2, 3]. Bara and his colleagues presented two studies that specifically investigated how tracing the contour of physical letters could benefit learning the alphabetic principle in kindergarten children. In one study targeting non-dyslexic children with a mean age of 5 years old, the results revealed that improvement in the pseudo-word reading task was greater after visual-haptic training than with visual training alone [2]. Similar results were found in the second study, which focused on children from low socio-economic status families, who usually have reading difficulties [3]. Bara et al. suggest that the multiple cues naturally embedded in the physical letters (e.g., colour, shape, and texture) add values in learning letter-sound correspondences. Although the studies did not focus on texture cues, the results showed the potential of using textures together with visual and auditory cues to help dyslexic children effectively learn ***letter-sound correspondences***.

TUIs for Learning to Read for Dyslexic Children

Research in HCI suggests that TUIs have potential to support learning to read for children for three main reasons. First, TUIs incorporate intuitive spatial mappings through consistently coupling digital data with physical artefacts [12]. Literacy is inherently spatial for learners who need to decipher a series of letters in a certain spatial order. Second, by incorporating physical objects, TUIs engage multiple senses (i.e., visual, auditory, and tactile) [12], which is also important in learning to read [10]. Moreover, TUIs promote attention and engage children in playful literacy learning [19].

The implication of TUIs for learning to read for children is considerable [17,19], but it has not been fully explored in the context of dyslexia. Only several works have been found. The *Tiblo* prototype consists of interactive blocks with colour and sound cues designed to help dyslexic children aged 8-12 years old to remember and follow sequence-based instructions (e.g., reading narratives/or words). The evaluation study suggested that children had great interest in playing around multimodalities in TUIs [13]. Hengeveld et al. developed *LinguaBytes*, a tangible interface including a set of digitally augmented dolls, pictogram cards, and puzzle pieces designed for toddlers with disabilities aged 1-4 years old [8]. The researchers concluded that the TUI afforded more natural and accessible interaction for the children.

These studies suggest the potential of designing multimodal TUIs to help dyslexic children learn to read. However, few studies have discussed which specific design feature(s) of TUIs may benefit learning outcomes. The role of texture cue as a design element in learning to read remains unclear. This demonstrates the opportunity to explore design space of tactile modality, particularly texture cues, in supporting literacy education for dyslexic children. The results will

Figure 5. Twenty-four pieces of letter cards

Letter	Object	Material
a	Apple	Shiny smooth paper
b	Balloon	Rubber
d	Dog	Fur
o	Orange	Leather
p	Pillow	Pillow cloth
q	Quilt	Quilt cloth

Table 1. Letter-Material Mapping Strategies (texture cues) based on the OIP method.

contribute to a better understanding of designing learning materials in TUIs [5,7].

Theoretical Foundations

Cross-modal research suggests that human beings naturally associate letters or letter sounds with textures. Research on synesthesia suggests that some synesthetes can see textures on certain letters [6], while studies on sound symbolism suggest that human beings may associate frequency of sounds or phonetic sounds with roughness of textures [14].

The metaphoric approach suggests that human beings are able to associate letters/sounds with certain objects/materials based on what is learnt in everyday life. In education programs, researchers and practitioners often use the Object-Imaging-Projection method (OIP) to teach children letter-sound correspondences [9]. This method associates letters/sounds with particular objects that have forms very similar to the letter shapes and whose beginning sounds are the letter sounds. For example, "a/a/" is often associated with "apple.

In our prototype, we designed the texture cues based on the metaphoric approach because (1) this approach has been applied in the education domain [9]; and (2) we target children and this mapping strategy may provide better contextual information (e.g., word/picture associated with the letter) that helps them to learn to read [1].

Prototype Design and Implementation

Learning Goal

The main learning goal was to help dyslexic children aged 5-6 years old to improve their understanding of the 'alphabetic principle,' including learning both transparent (one-to-one) and opaque letter-sound correspondences. Due to time restrictions, a limited set of eight graphemes was chosen, including four consonants and four vowels. They are b/b/, d/d/, p/p/, q/kw/, a/a/, o/o/, oo/u/, and oa/au/.

Design Goals

Our main objective was to create a system that we could use as a research instrument to explore the learning effects of adding texture cues in a tangible tabletop that enabled dyslexic children to learn letter-sound correspondences. We proposed three specific design goals, as follows: (1) *Systematic learning*: Learning contents should start from simple to complex; (2) *Texture cues*: The system should allow for two conditions of playing: with texture cues or without texture cues; (3) *Affordances*: Affordances should be designed to ensure dyslexic children easily distinguish mirrored or flipped letters.

Overview

In Tactile Letters, dyslexic children can choose an appropriate level and learn about letter sounds by placing 3D tangible letter(s) or letter card(s) on the interactive table. Each tangible letter (sound) is associated with three letter cards with a pseudo-word on each (Figure 5). Visual-audio feedback is provided once children make correct/incorrect associations between 3D tangible letters and letter cards (Figures 3 and 4).

Implementation

The research prototype is comprised a digital display, an interactive table, 24 pieces of letter cards, and two sets of 3D tangible letters (Figures 1,2,5). The

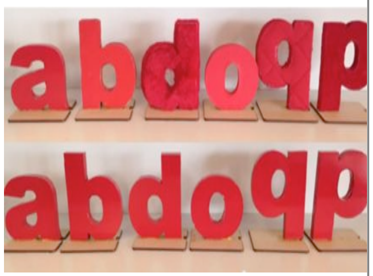

Figure 6. Tangible letters with texture cues (up) and the same set of letters without texture cues (down).

Figure 7. A transparent acrylic frame with constraints

interactive table contains a camera vision system implemented with a reacTIVision engine. Each tangible letter or letter card is identified by the reacTIVision engine, which passes identification and location information to a custom application written in Processing.

Two Levels of Learning Contents
This application includes two levels of learning contents. The first level was designed to support learning of single letter-sound correspondences (e.g., b/b/) while the second level was designed to support learning of opaque letter-sound correspondences. In level-1, when the user places one tangible letter and three letter cards on the interactive table, this action triggers the associated digital contents on the display, including the letter sound(s), the object, and the 2D uppercase and lowercase letters (Figure 3). In level-2, the user can place two letters on the interactive table. When the first letter is placed on the table, the system displays the letter and plays its sound. The user then can place the second letter. If the two adjacent letters do not generate a new sound, the system displays the second letter and plays its sound. If the two adjacent letters generate a new sound (e.g. oo/u/), the system triggers the new sound and displays a red frame to indicate the two letters are grouped. The user then is allowed to place letter cards to practice the new sound (Figure 4).

Texture Cues and Non-texture Cues
There are two sets of 3D tangible letters and each set contains seven letters (*a, o, o, b, d, p, q*). In one set, each letter's wood surface is wrapped with a particular texture. The design of texture cues was based on the OIP method (Table 1). In the second set, all the letters have the same standard texture (wood with sticky paper). In order to control the possible influence of colour, all letters are a single colour – red (Figure 6).

Affordances
In order to allow dyslexic children to know the correct orientation of letters, a transparent acrylic frame with constraints was also designed. When placing the frame on the digital tabletop, the notch on the frame (the red circle in Figure 7) has to match the one on the 3D letter, which results in the correct placement of 3D letters. When children are more familiar with the learning contents, they can remove the frame.

Discussion and Future Work
In this paper, we discuss the knowledge gap, the theoretical foundations, and the design and implementation of our research instrument. The design of texture cues leverages the use of physical characteristics of objects to support learning. Although several works have explored the design space of materials in TUIs [5,7], none of them focused on using texture cues to promote learning. We believe there is an opportunity to investigate the potential of texture cues in learning to read based on research on dyslexia. It is also worth noting that there are various mapping strategies based on different theoretical approaches. Although we have employed the metaphoric strategy, we believe there is potential to explore other approaches in future research.

Our next step is to conduct a small-scale user study to refine the prototype design. Then we will conduct a controlled comparative experiment with this prototype to investigate the role of texture cues of a tangible tabletop in supporting learning to read for dyslexic children.

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