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Display of Virtual Braille Dots by Lateral Skin Deformation: A Pilot Study

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Abstract. When a progressive wave of localized deformations occurs tangentially on the fingerpad skin, one typically experiences the illusion of a small object sliding on it. This effect was investigated because of its potential application to the display of Braille. A device was constructed that could produce such deformation patterns along a line. This enabled us to test blind subjects' ability to read the truncated Braille characters '○○', '○●', '●○', and '●●'. While subjects could identify two-character strings with a high rate of success, several factors need to be addressed before a display based on this principle can become practical.

1 Introduction

Commercially available refreshable Braille displays have changed little in the past 25 years. Today's displays do not differ substantially from what is described in [11]. Typical systems use cantilevered bimorph piezo-actuators (reeds) supporting vertical pins at their free end. Upon activation, a reed bends, lifting the pin upward. Braille characters are displayed by assembling six or eight of these mechanisms inside a package called a cell (see Fig. 1). A basic system includes 40 or 80 cells to display a line of text, plus switches to navigate in a page.

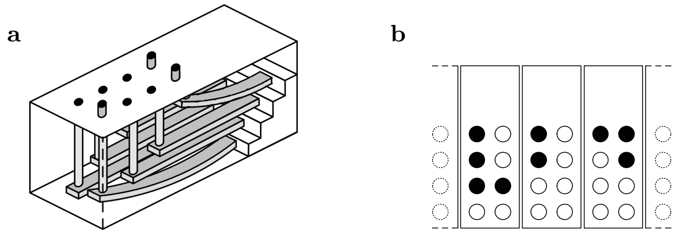

Fig. 1. Conventional Braille display: **a**) cell actuation mechanism, **b**) array of cells.

While the elements of these cells are simple and inexpensive, the cost is driven by the necessity to replicate the cell 40 or 80 times, or more if one contemplates

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the display of a full page. In recent years many designs have been described (too many to review here), all sharing the principle of raising individual pins out of a surface [1]. While most focus on the problem of miniaturizing actuation, very few are concerned with new approaches to the display of Braille.

Of note is a system proposed by Tang and Beebe who sandwiched discrete electrodes in a dielectric [10]. The application of high voltage to these electrodes causes the skin to adhere locally to a glassy surface, thereby creating small tactile objects. Patterns resembling Braille characters could presumably be displayed with this method, however it appears to suffer from sensitivity to environmental factors such as humidity or skin condition.

Several investigators proposed the idea of a single display moving with the scanning finger rather than the finger scanning over an array of cells. Fricke mounted a single Braille cell on a rail and activated its pins with waveforms resembling “pink noise” in an attempt to imitate the effect of friction of the skin with a pin [2]. Ramstein designed an experiment with a Braille cell used in conjunction with a planar “Pantograph” haptic device in an attempt to dissociate character localization from character recognition. The haptic device was programmed to indicate the location of the characters in a page, while the cell was used to read individual characters. Comparative tests were performed in different conditions with one or two hands. Again, the goal was to create an “array of Braille characters” with a single cell and reasonable reading performance could be achieved [8].

It is important to recall some important facts about Braille reading [6, 9]. Reading results from “brushing” over the dots. We suggest that the act of brushing has a dual purpose. It is frequently mentioned that one function is to “refresh” the skin receptors to combat adaptation [2]. We suggest that brushing also creates a tactile signal used to regulate the contact condition between the skin and the dots’ upper surfaces. Reading movement patterns are highly idiosyncratic and vary greatly from individual to individual. These considerations motivate the design and the experiments reported here.

2 Virtual Braille Display

When the skin of the fingertip is locally deformed in the manner of a progressive wave, one experiences the illusion of objects moving on the skin even if the deformation contains no normal deflection [3]. In order to leverage this for the display of Braille dots, a specialized electromechanical transducer similar to the STRESS tactile display was constructed [7]. The Braille dots were “virtual” in that we attempted to recreate the essential aspects of the skin deformation when it rubs against dots; without actually having dots. This was accomplished by programming the ensemble movement of a high density array of skin contactors that strain the skin in the tangential plane.

For the present study, a special transducer and a particular strain pattern — collectively termed “VBD” for Virtual Braille Display — were empirically designed with the assistance of the fourth author, a blind accessibility specialist, who also participated in the study in the capacity of “reference subject”.

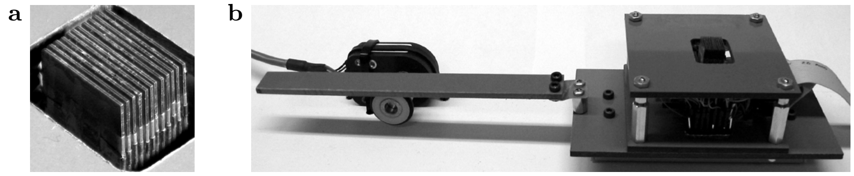

Fig. 2. Virtual Braille Display: **a**) STReSS-type display, **b**) mounted on a slider.

Device. The device comprised a tactile display (Fig. 2a) mounted on a frictionless slider moving laterally (Fig. 2b). The display had 12 piezoelectric benders, 0.38-mm-thick, sandwiched at their base between 0.5-mm-thick neoprene spacers (Fig. 3a). The corners of the blades were beveled to create a linear array of skin contactors with spatial period $\epsilon = 0.88$ mm, each providing a contact area of about 0.2 mm^2 as indicated in Fig. 3b. When activated, the benders caused longitudinal deformations to the fingertip skin. When unloaded the actuator tips deflected by approximately ±0.5 mm. Lack of knowledge of the skin's mechanical properties prevented us from estimating the deflection when loaded by a finger. Unfortunately, we could not measure it either. The position of the slider was measured by optical encoder with a resolution of 17 μm. Interfacing electronics was constructed to permit the refresh of the 12 actuators at 500 Hz according to patterns programmed on a personal computer. This enabled us to program the deflection of each actuator with an arbitrary functions of space $\delta_i(x), i = 1, \cdots, 12$, where i is the actuator number, and x is the position of the slider. Reading virtual Braille was done with the index by sliding the display laterally as shown in Fig. 3c.

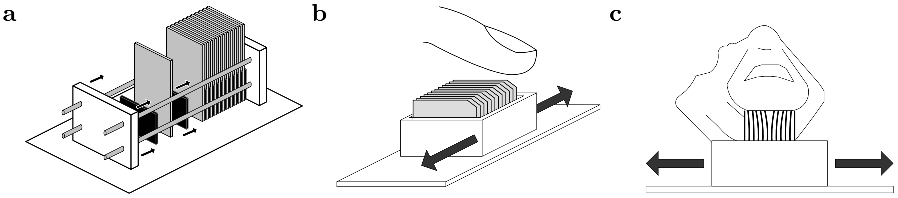

Fig. 3. **a**) Sandwich construction, **b**) exposed contactors, **c**) exploration.

Skin Deformation Patterns. Experimentation led us to select a pattern based on the judgment of the reference subject solely on the basis of its resemblance with actual Braille; both from the view point of perceived dot size and spacing. We are however unable to offer a principled explanation as to why this particular pattern creates sensations that resemble Braille dots more than others.

What we found was a pattern such that the deflection of each single actuator swept the first half cycle of a sinusoid, starting from the left position as it scanned a virtual dot as shown in Fig. 4. A small-amplitude, higher-frequency

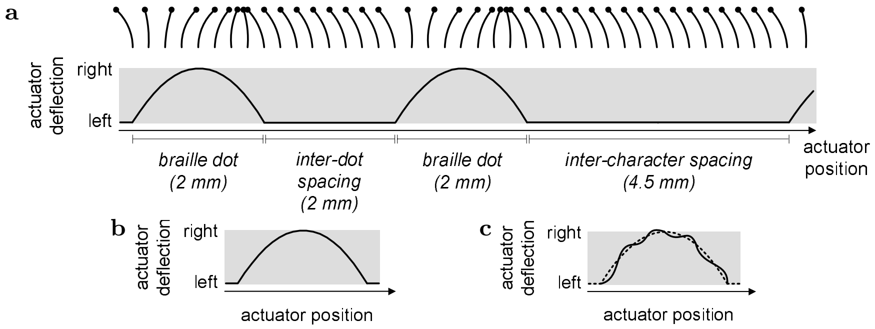

Fig. 4. Actuator deflection: **a**) traversing two dots, **b**) nominal dot, **c**) with texture.

sinusoid could also be superimposed to the original waveform to enhance contrast (Fig. 4b,c). These representations were termed nominal and textured.

Each actuator i was commanded with a spatial phase differences $(i\,\epsilon)$. Fig. 5 illustrates their movements as a virtual dot traverses the length of the display. Moving the slider from left to right across a region containing a dot resulted in a wave of actuator deflections traveling at the same speed from right to left on the tactile display, creating the illusion that the reading finger was scanning over stationary Braille dots.

Interestingly, the deflection pattern was always as shown by Fig. 5, but the resulting sensation did not seem to depend on whether dots were scanned from left to right or right to left.

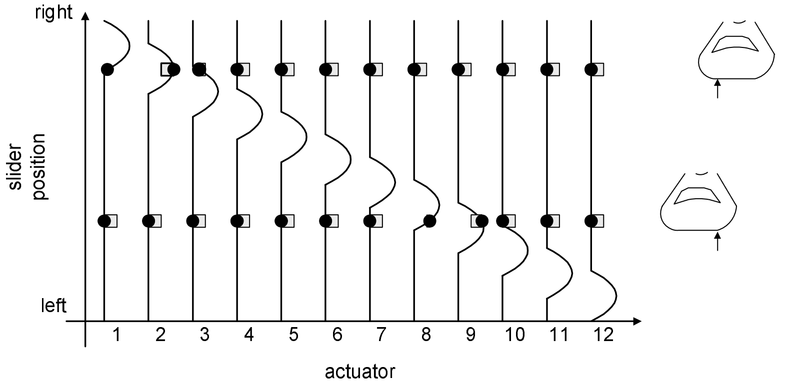

Fig. 5. Actuator movement with position indicators at two particular slider positions.

This pattern had two effects on the skin deformation. The first was to cause a net displacement of a skin region around each contactor. The second was a pattern of compression and expansion of each small region of skin located between two contactors [5]. It is not known whether one, the other, or both forms of stimulation caused the illusion of the dot moving under the finger.

3 Pilot Study

Experiments were carried out to evaluate how well blind subjects could read with the VBD.

3.1 Method

Subjects. Five experienced Braille readers (two females and three males) participated in the study. All subjects were blind from birth. Their ages varied between 22 and 55. The subjects' primary reading finger was the right-hand index. Four subjects had never seen or heard about the VBD and the remaining subject was the reference subject.

Reading Task. The VBD could display the 4 Braille characters that have dots in row 1 only (‘`a`’, ‘`c`’, ‘dot #4’, and ‘ ’, see Fig. 6; there is no character in the Braille alphabet that is made of the dot number 4 only.) The reading task was designed to evaluate the legibility of sequences of these characters displayed on the VBD. Subjects were asked to read individual 4-character strings using their dominant reading finger. The first and last characters of each string would always be ‘c’ (●●) because it was the most obvious string delimiter. The two middle characters could be any of the 16 combinations of the characters ‘`a`’(●○), ‘`c`’(●●), ‘dot #4’(○●), and ‘ ’(○○): “●● ●○ ○● ●●”, or “●● ○○ ●● ●●” for example.

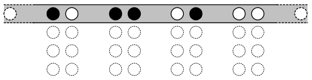

Fig. 6. String “`ac`[dot#4] ”.

Procedure. The subjects were given written Braille instructions and had supervised practice trials until they felt comfortable with the task. They were presented with strings to read in block trials. They placed the slider to the left, waited for an auditory cue, read the string, and reported verbally the two middle characters. There was no time limit but they were strongly encouraged to answer quickly. In case of doubt, they were asked to give their best guess. Subjects could stop at any time if they no longer felt comfortable (loss of tactile sensation, fatigue). The experimenter logged the results of each trial and the system recorded the slider trajectory and trial durations automatically.

A trial block comprised 80 strings with each of the 16 possible combinations appearing 5 times in a randomized order. The block trials were administered with and without texture. Some subjects were tested with and without texture while others decided to experiment with only one type.

3.2 Results

Legibility. Legibility was defined by the proportion of correct identifications of 2-character strings, see Table 1. Results suggest that the effect of adding texture was idiosyncratic. A dramatic improvement in performance was seen in one subject while a loss was observed in two other subjects. Retaining the best conditions for each subject, the legibility rate was between 71.3% and 98.8%.

Table 1. Results summary.

	number of trials		legibility (%)		average trial duration (s)	
subject	nominal	textured	nominal	textured	nominal	textured
CN	80	160	97.5	88.1	4.8	4.6
RB	0	80		95.0		10.8
ML	80	0	98.8		4.6	
AB	40	80	45.0	86.3	18.6	10.5
MS	80	80	71.3	66.3	8.0	9.1
average	56	80	78.1	83.9	9.0	8.8

Legibility rates were also plotted over time to assess the effect of fatigue. Without texture, no significant change with time could be noticed. However, for some subjects, performance tended to decrease noticeably after about 50 trials when texture was used (see Fig. 7 for one of the worst-case examples).

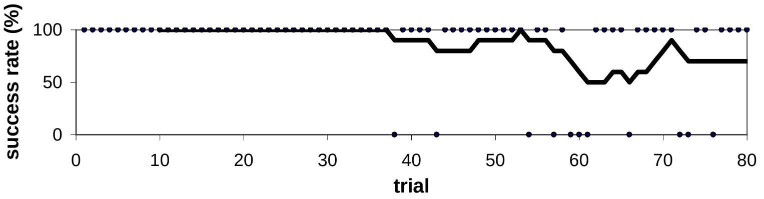

Fig. 7. Gradual decrease in performance over time (subject AB, with texture). Dots indicate individual trial results. The curve is a moving average over the past 10 trials.

Character Pairs Legibility. Regardless of the string, individual characters having one dot, '●○' or '○●', were harder to read than characters having no or two dots, '●●' or '○○' (see Table 2). The legibility also varied significantly with the 2-character string (see Table 3). Except for special cases such as the pair "○○ ○○" which was read perfectly, no insight could be gained regarding the cause of variations in reading difficulty. It is not clear why the string "○● ●○" had high legibility while "●○ ○●" had a low one.

Table 2. Average character legibility (%).

●○	○●	●●	○○
83.3	88.9	92.2	98.1

Table 3. Average 2-character string legibility (%).

●○ ○●	●○ ○○	○● ●●	●○ ●●	●● ●○	○● ○●	●● ○●	●○ ●○
66.0	74.0	76.0	77.5	78.0	81.0	81.7	84.5

○○ ●○	○● ●○	●● ○○	○● ○○	○○ ●●	○○ ○●	●● ●●	○○ ○○
85.0	90.0	92.0	92.0	94.0	95.0	98.0	100.0

Reading Patterns. Table 1 shows the average duration of trials. The reading speed was far from the expected Braille reading speed of 65 to 185 words per minute [4], but the conditions are so different that a comparison is not possible.

Correlations between reading speed and string legibility were also investigated but none could be found, even though there could be important duration variations between trials of a same subject. If it is assumed that the time taken to read a pair of characters is an indication of the confidence the subject has in her or his answer, this would imply that the characters that the subjects thought were hard to read were not necessary the ones they had difficulty reading.

The recorded trajectory of the slider was used to investigate the reading pattern used by the subjects. Three classes of patterns were identified (see Fig. 8). Subjects often used one or two straight passes over the dots. On other occasions, they would explore the virtual Braille with short back-and-forth motions. In all cases it appeared that subjects read from left to right.

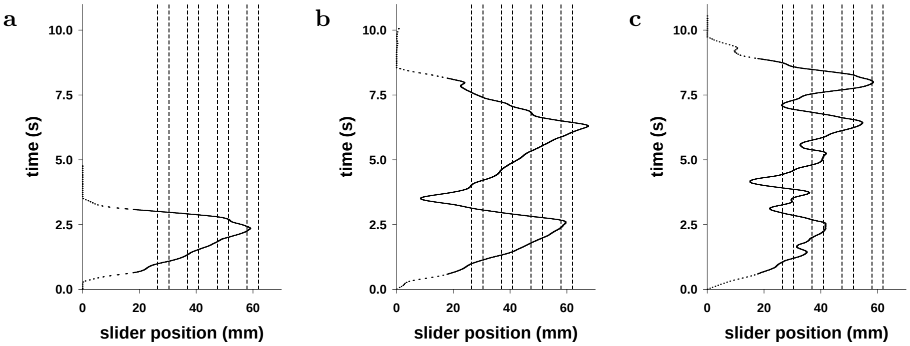

Fig. 8. Typical reading patterns: **a**) one pass, **b**) two passes, and **c**) character rescan. Dashed lines indicate the location of the four Braille dots. Dotted sections of the position curve are not taken into account when computing trial durations.

4 Discussion and Verbal Reports

This study does not permit to draw strong conclusions, but the results suggest that reading Braille with devices based on the principle of the VBD is possible with a high legibility rate. This is encouraging considering that the subjects had little prior training with the device and that the character strings were meaningless.

Reading with the VBD is nevertheless difficult. Prolonged use seems to cause a tactile fatigue (numbness in the reading finger) resulting in an increase in the number of reading errors. More importantly, all subjects also reported that reading requires concentration, mostly because the dots were subtle and differed from real Braille dots. Legibility was improved by using texture for some subjects. For other subjects, texture was a nuisance.

Tactile fatigue and/or weakness of the dot sensations was not the only difficulty which was reported verbally. Subjects also reported difficulties with locating the finger on the virtual Braille line. Most subjects mentioned that the display of characters with more than one row of points and having meaning would help reading significantly. Reading first-row random Braille characters is likely to be difficult on any Braille medium.

Finally, subjects reported that scanning constrained by a slider was actually beneficial because it guided their hand movement. They found it to be an advantage over paper Braille.

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5 Conclusion and Future Work

The study suggests that Braille characters can be displayed by lateral skin deformation and helps identifying how a device could be designed. Most importantly, the strength of the dot sensation must be increased to realistically convey the illusion of a Braille dot. This issue involves the improvement of the actuators used. Experimenting more with various deflection functions will also be important to perhaps find better virtual Braille representations. The cause of tactile fatigue must also be addressed. It is not clear what causes it and how it can be avoided. It is likely however that improving the tactile display's surface for more uniform contact could significantly delay the onset of tactile numbness. Finally, the VBD should be extended to display complete Braille characters.

6 Acknowledgments

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References

1. Blazie, D. 1998. Refreshable Braille now and in the years ahead. Transcript of lecture available online at `http://www.nfb.org/bm/bm00/bm0001/bm000110.htm`.
2. Fricke, J. 1997. Substituting friction by weak vibration on a tactile pin array. Proc. *IEE Colloquium on Developments in Tactile Displays*, London.
3. Hayward, V., Cruz-Hernandez, M. 2000.Tactile display device using distributed lateral skin stretch,Proc. *Haptic Interfaces for Virtual Environment and Teleoperator Systems Symposium*, Proceedings of ASME, Vol. DSC-69-2, pp. 1309–1314.
4. Legge, G. E., Madison, C. M., Mansfield, S. J. 1999.Measuring Braille reading speed with the MNREAD test,*Visual Impairment Res.*,Vol. 1, No. 3, pp.131–145.
5. Levesque, V., Hayward, V. 2003. Experimental Evidence of Lateral Skin Strain During Tactile Exploration. Proc. *Eurohaptics 2003*, pp. 261–275.
6. Millar, S., 1997. *Reading by touch*, Routledge: New York, London.
7. Pasquero, J., Hayward, V. 2003, STRESS: A practical tactile display with one millimeter spatial resolution and 700 Hz refresh rate, Proc. *Eurohaptics 2003*, pp. 94–110.
8. Ramstein, C., 1996. Combining haptic and braille technologies: design issues and pilot study, Proc. *second annual ACM conference on Assistive technologies, ACM* SIGCAPH Conference on Assistive Technologies, pp. 37–44.
9. Schiff, W. and Foulke, E. 1982. Reading Braille, in *Tactual Perception*, Schiff, W. and Foulke, E. (Eds). Cambridge Univ Press, pp. 168–208.
10. Tang, H., Beebe, J. D. 1998. A microfabricated electrostatic haptic display for persons with visual impairments. *IEEE T. on Rehabilitation Engineering*, Vol. 6, No. 3, pp. 241–247.
11. Tretiakoff, O., Tretiakoff A. 1977. Electromechanical transducer for relief display panel. US Patent No. 4,044,350.