Universal Access in the Information Society
https://doi.org/10.1007/s10209-020-00709-8

LONG PAPER

Braille learning materials for Braille reading novices: experimental determination of dot code printing area for a pen-type interface read aloud function

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Abstract
This study clarifies a previously established method in which Braille reading novices obtained Braille information aurally. Therein, users touched the vicinity of the Braille with a pen-type interface characterized by a Braille-to-voice function. Two-dimensional (2D) dot codes were printed on the Braille paper, and voice information corresponding to Braille was linked to these dot codes. This study aims to establish quantitative data regarding an acceptable size for the 2D dot code printing area. Nine Braille reading sighted novices, blindfolded and without Braille reading experience, were recruited to participate in an experiment, where they were asked to identify which of the six dots in a Braille character were missing, touch the pen-type interface to a sheet layered with the dot code printing area and TRUCT Braille, and evaluate the system's effectiveness on a scale from 1 to 5. All participants correctly identified the missing dot. Participants gave the Braille-to-voice function an average effectiveness rating of 4.6/5.0, with a standard deviation of 0.7. A dot code printing area was determined to be 8 mm above and 10 mm below the midpoint between dots 2 and 5 of the Braille character, with a width of 16 mm from the midpoint of the Braille. Based on these results, design guidelines were identified for the dot code printing area to improve the success rate of obtaining voice information corresponding to the Braille with the pen-type interface equipped with the Braille-to-voice function. This has numerous potential applications in Braille education methods for Braille reading novices.

Keywords TRUCT Braille · Braille learning materials · Pen-type interface · Dot code printing area

1 Introduction

Louis Braille invented the Braille system, widely known as a code that enables individuals with visual impairments to read and write at their own pace through a tactile system of characters. The reading speed for Braille is typically one-quarter of that for visual characters [1]. Highly experienced Braille readers can read up to 200 letters per minute [2].

There are numerous methods for printing Braille, including paper-embossed and silk screen printing, where paper-embossed printing is the widely accepted Braille printing method. However, with recent progress in screen printing technology, transparent resinous ultraviolet (UV)-cured-type (TRUCT) Braille signs are becoming increasingly popular in Japan, especially when printed together with visual characters. TRUCT Braille is more rigid than paper-embossed Braille. Additionally, the forefinger of Braille readers receives sufficient stimuli from the dots to be able to read TRUCT Braille. TRUCT Braille is considered to be relatively easy to read for Braille reading novices. The

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Act for Eliminating Discrimination against Persons with Disabilities was implemented on April 1, 2016, in Japan. Based on this legislation, public facility tactile guide maps and information booklets with TRUCT Braille have been widely dispersed throughout Japan. Owing to certain advantages that characterize TRUCT Braille, such as durability and high readability, we expect TRUCT Braille to become more widespread.

Figure 1 shows the silk screen printing process, which can also be applied to print TRUCT Braille [3]. First, the plate is painted with UV-cured ink, which is packed into the pores of the plate with a sliding squeegee. Next, the squeegee is slid over the plate while the plate is being pressed. Then, by sliding the squeegee, the ink that was packed into the pores of the plate is transferred to the printing material. Finally, the ink is cured by irradiating the printing material with UV light. Issues associated with the silk screen printing method, however, make it difficult to express detailed images, as well as occasionally resulting in insufficient height for the Braille/tactile map. As certain Braille/tactile maps printed with the silk screen printing method are difficult to read, we must improve the printing quality. Additionally, the silk screen printing method is not well suited for printing a small number of Braille or tactile maps. As an alternative to overcome such drawbacks associated with the silk screen printing, we devised a new method for producing TRUCT Braille in a previous study [4]. This new printing method has a major advantage: It prints TRUCT Braille with high printing quality. This high printing quality is achieved by injecting a high-viscosity UV curable resin ink at high speed and precision via pressure control with a compressor. The

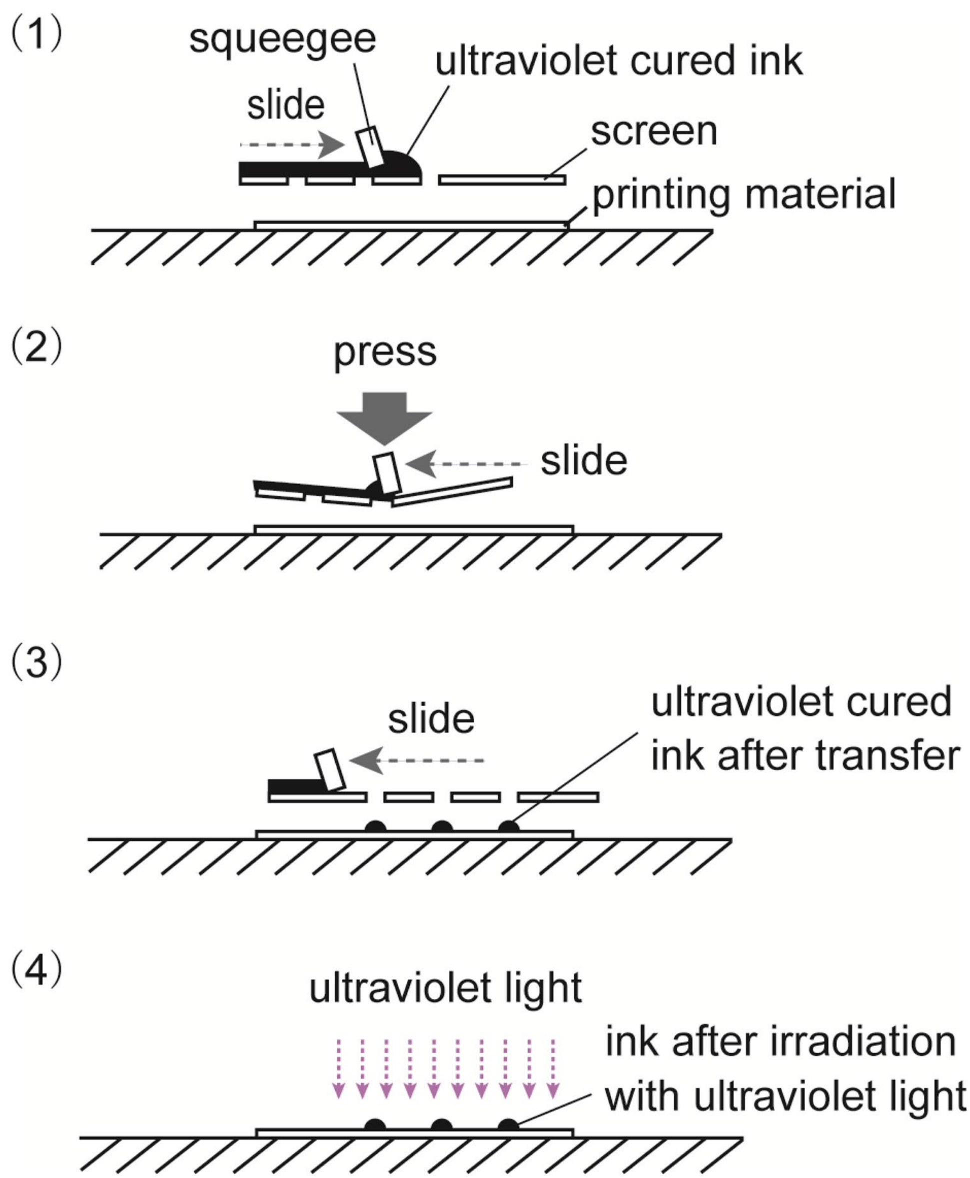


Fig. 1 Steps in the silk screen printing method [3]

method produces raised dots with an adequate height and prints Braille with high accuracy.

Based on the development of this new method for printing TRUCT Braille, teachers at schools for the blind have directly requested, for several years, that our research team create Braille learning materials with TRUCT Braille. Given the various requirements of special needs education teachers for visually impaired persons, we subsequently prototyped new Braille learning materials (Fig. 2) in another study [5]. In that study [5], we investigated a simple, yet suitable, dot code area for a preliminary experimental trial evaluation. Therein, visually impaired persons in the process of learning Braille were able to obtain voice information corresponding to the Braille when they touched the vicinity of the Braille with a pen-type interface equipped with an image sensor and Braille-to-voice functionality. In the study, 2D dot codes (Fig. 3) were printed on the Braille paper and voice information corresponding to the Braille was linked to them. These dot codes were read by the image sensor mounted on the pen-type interface, such that the Braille information was output as a synthetic voice with good pronunciation. Further, we asked Braille reading novices in the process of learning Braille to test our new Braille learning material. As they were able to obtain voice information corresponding to the Braille when touching the vicinity of the Braille with the Braille-to-voice function-equipped pen-type interface, we obtained favorable reviews regarding the use of the Braille-to-voice function.

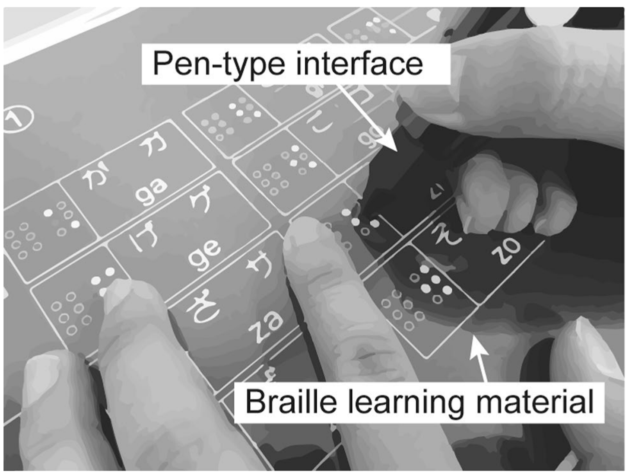


Fig. 2 Braille learning materials prototyped in a previous study [5]

TRUCT Braille size is fixed as defined by the ISO [6] and Japanese Industrial Standards [7]. However, to improve the usability of Braille learning materials, there are no available academic quantitative data regarding the size of the printing area of two-dimensional (2D) dot codes acceptable for printing on Braille paper. If the printing area of the 2D dot codes is too narrow with respect to the TRUCT Braille, voice information corresponding to the Braille cannot be properly output as the image sensor is unable to read the dot codes when users touch the surface with the pen-type

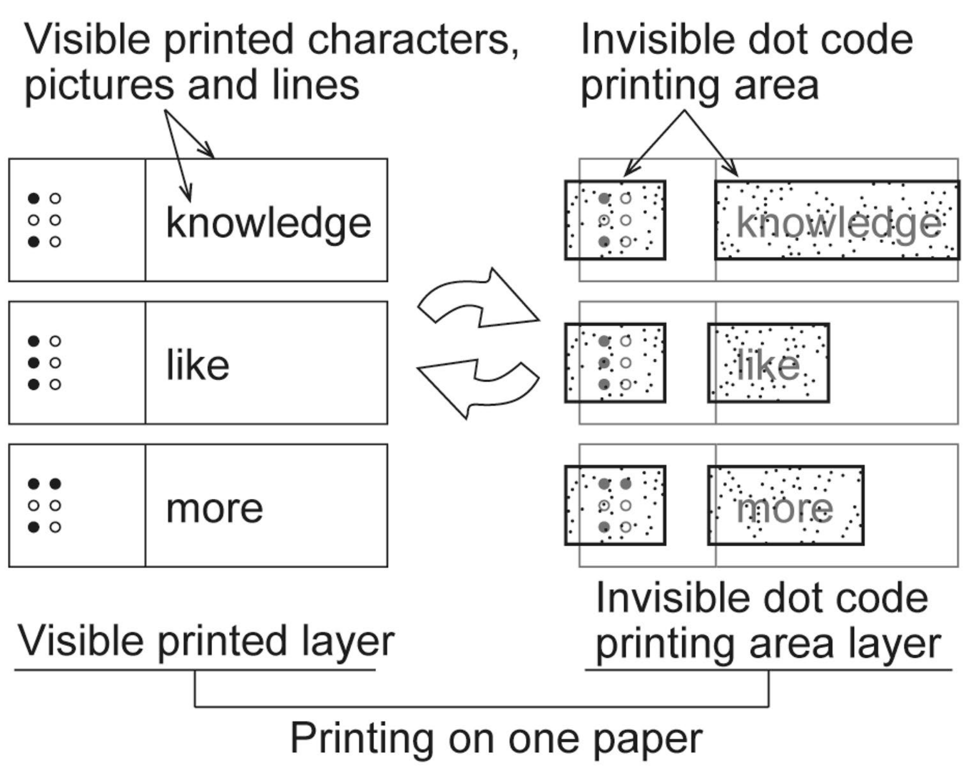


Fig. 3 Printing mechanism for the dot code printing area

interface. Conversely, if the printing area of the 2D dot codes is too wide, rapid deterioration of the usability of the Braille learning material occurs. Therefore, the appropriate printing area for the 2D dot codes that ensures consistent and reliable usability must be clarified. In this study, we obtained an adequate dot code printing area to prevent decreased usability of the pen-type interface with the Braille-to-voice function for Braille reading novices. This was verified by an expert Braille teacher who participated in an easy user test designed to confirm whether the dot code printing area based on the results of this study is appropriate and useful for Braille learners.

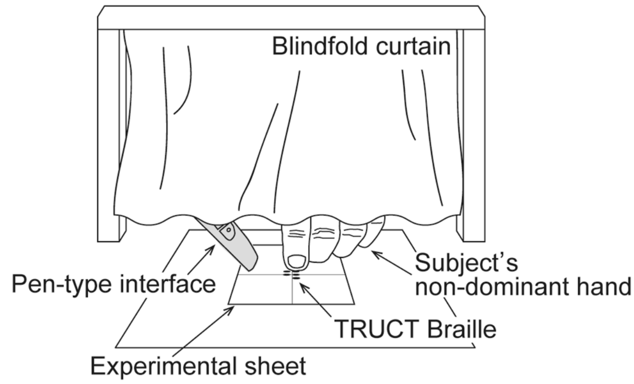


Fig. 4 Conceptual diagram of the experimental equipment

2 Methods

2.1 Experiment participants

This study aimed to clarify an adequate dot code printing area for a pen-type interface equipped with Braille-to-voice functionality for Braille reading novices. This eliminated any effects from the Braille reading experience for visually impaired Braille reading novices more familiar with Braille reading based on the legibility of the TRUCT Braille. Seeing blindfolded persons without Braille reading experience participated in this experiment to eliminate any effects associated with the Braille reading experience. The participants comprised nine Braille reading novices (25.7 ± 6.3 years). All participants were right-handed. The finger pad width of the index finger of the dominant hand used to identify Braille was, on average, 14.5 mm (standard deviation = 1.3 mm). Additionally, the participants had no perception impairments or associated medical history that hindered their performance of the experimental tasks. The experimenter provided oral description of the experimental outline to each participant in advance and obtained informed consent. This experiment was conducted in line with the ethical guidelines on research at the National Institute of Special Needs Education.

2.2 Experimental procedure

The participants sat in a chair in front of an experimental table with both hands under a curtain, obstructing visual information. Figure 4 shows a conceptual diagram of the experimental equipment. The experimenter instructed the participants to identify the TRUCT Braille on the center of the experiment sheet with the finger pads using their nondominant hands. The participants were asked to identify six TRUCT Braille Japanese characters (Fig. 5), each consisting of five dots with a Japanese standard dot height of 0.4 mm and standard dot distance of 2.3 mm [7]. Then, when signaled by the experimenter, the participants were asked to actively and tactilely identify the Braille. When they identified the numbered location of a single dot missing from among the six dots (Fig. 6), they immediately released their fingertips from the Braille. Immediately after releasing their fingertips, they verbally stated the number of missing dots and their degree of confidence in their TRUCT Braille identification result based on a five-point scale from 1 to 5 (1: completely not confident; 2: not confident; 3: confident; 4: very confident; and 5: extremely confident). Based on the advice of Japanese ergonomic scientists, we used a subjective five-point scale rating system to consider the subject's answerability.

Subsequently, when signaled to do so by the experimenter, the participants used the pen-type interface held in their dominant hand to obtain auditory information associated with the missing TRUCT Braille dot while identifying the TRUCT Braille with the index finger of the non-dominant hand. At this time, the participants were asked to touch the vicinity of the TRUCT Braille on the experiment sheet with the tip of the pen-type interface. As the purpose of this study is to clarify the vocal reaction area in which the user can naturally manipulate the location of the pen-type interface while touching the TRUCT Braille, the experimenter constructed the experimental system such that information on the one missing Braille dot was correctly fed back to the participant by voice, regardless of where on the experiment sheet the pen-type interface made contact. After reading aloud the Braille information from the pen-type interface, the participants verbally evaluated the effectiveness of the system on a five-point scale from 1 to 5.

The above process constituted one trial, and five trials were conducted for each of the six types of Braille, which lacked one dot from dots 1–6 (Fig. 6), for a total of 30 trials. Taking into account the influence that the order had on the results, the presentation order of each Braille display was randomly set for each participant. Prior to the experiment, a practice trial was conducted to familiarize the participants

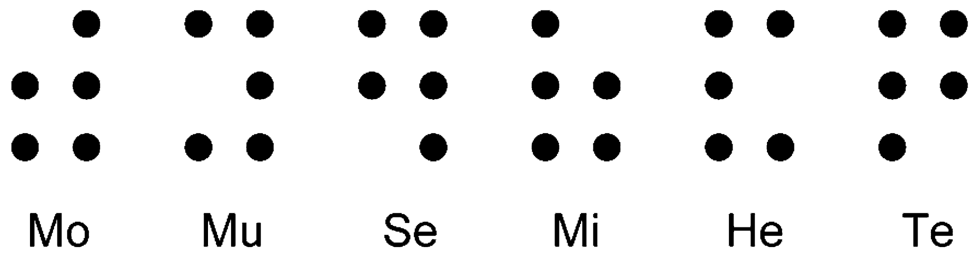


Fig. 5 TRUCT Braille used in the experiment

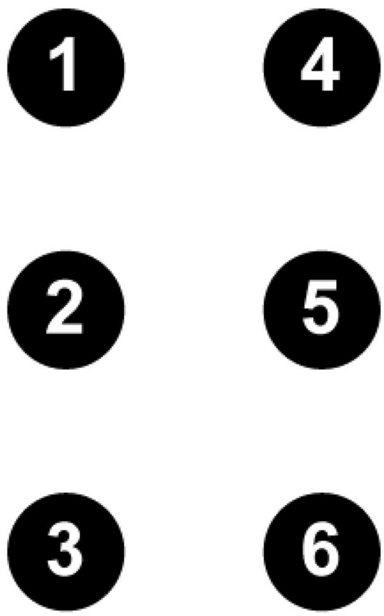


Fig. 6 Dot numbers of the TRUCT Braille

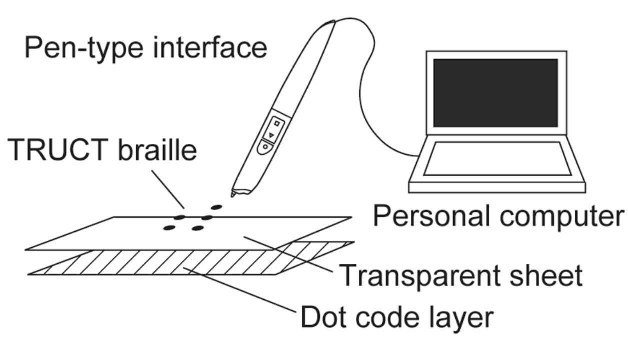


Fig. 7 Measurement system for the touch point with the pen-type interface

with the experimental procedure. The experiment time was approximately 1 h for all of the participants.

2.3 Experimental equipment

Figure 7 shows the system configuration of the experimental apparatus. The system consisted of a pen-type interface with Braille-to-voice functionality, personal computer, transparent sheet with TRUCT Braille, and dot code layer. The G-Pen 2 (Gridmark Inc.) was used as the pen-type interface equipped with the Braille-to-voice function. The outer dimensions of the pen-type interface were 14 mm width, 16 mm height, and 130 mm length, with a weight of 16 g. The experimental participants were easily able to use the pen-type interface based on explanation from our experimenters.

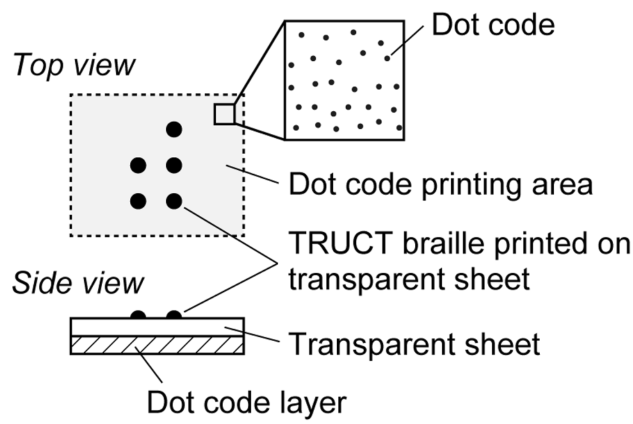


Fig. 8 Components of the experimental sheet

An image sensor was mounted on the tip of the pen-type interface. The small dot code printed on the dot code layer sheet was identified with the image sensor. Braille-to-voice functionality was achieved by outputting the information linked to the code as sound. Carbon ink was used to absorb the infrared light in the dot code printing. The experiment sheet comprised a printed sheet on which the dot code was printed and overlain with a transparent sheet with TRUCT Braille (Fig. 8).

To detect the contact position between the pen-type interface and the surface of the experiment sheet, the pen-type interface was connected to a personal computer via USB. The dot code was read by placing the pen tip on the experiment sheet, which triggered a buzzer sound as voice feedback. The 2D coordinate pointing position on the experiment sheet was detected by dedicated software and recorded by the personal computer. Six types of TRUCT Braille were prepared as presentation stimuli, each missing only one of the six dots that constituted one Braille character. As shown in Fig. 5, these characters correspond to the “Mo,” “Mu,” "Se," "Mi," "He," and "Te" sounds of the Japanese language. Braille consisting of five dots was adopted because the number of dots that constitute a Braille character influences the tactile legibility, such that it is not easy to read Braille composed of five dots. Because Braille reading beginners identify dot positions individually, Braille characters composed of five dots are more difficult than other characters. Sato et al. [8] found that Braille lacking one to six dots is considered the most difficult to read. Therefore, we used six characters, as shown in Fig. 5.

TRUCT Braille was created using a highly accurate TRUCT Braille fabrication device, which we developed independently [4]. This device is capable of creating TRUCT Braille using air pressure to spray ink in a noncontact manner from nozzles filled with UV curable resin ink. TRUCT Braille is created with high precision because the UV curable resin ink is sprayed onto position coordinates on any $X - Y$ plane specified by the computer while controlling the amount of applied ink.

In this study, this device was used to accurately create presentation stimuli necessary for the experiment. The character size of the TRUCT Braille was created based on the results of our previous studies on the tactile legibility of TRUCT Braille [3, 8]. This takes into account the ISO [6] and Japanese Industrial Standards [7]. Specifically, the diameter and height of the raised dots constituting the TRUCT Braille were set at 1.4 and 0.4 mm, respectively. The vertical dot distance between the first and second dots, within a single Braille character, was 3.1 mm, while the horizontal dot distance between the first and fourth dots was set to 2.9 mm.

2.4 Evaluation indices and analysis method

For the tactile legibility of TRUCT Braille, the correct rate, identification time, and degree of confidence in TRUCT Braille, identification as evaluation indices were adopted to investigate how precisely and quickly the participants performed tactile legibility of the TRUCT Braille. The correct rate was calculated based on the results of identifying Braille via oral responses from the participants after each trial. The percentage of the number of trials in which the participants found the correct missing dot number from among the six dots was calculated, as well as the arithmetic average among the nine participants. The identification time was measured using a digital stopwatch. The arithmetic mean and standard deviation for the nine participants were also used in the evaluation. Their degree of confidence in their TRUCT Braille identifications based on a five-point scale from 1 to 5 (1: completely not confident; 2: not confident; 3: confident; 4: very confident; and 5: extremely confident) was calculated as the confidence based on the results of identifying the Braille via oral responses from the participants after each trial, as well as the arithmetic average among the nine participants.

Each participant evaluated the effectiveness of using the pen-type interface for the Braille-to-voice function on a five-point subjective scale after each trial. The labels on the scale were as follows: 1 (completely ineffective), 2 (not effective), 3 (effective), 4 (very effective), and 5 (extremely effective). The arithmetic average and standard deviation of the verbal evaluation values were calculated and adopted as the evaluation indices.

Furthermore, to clarify the adequate dot code printing area for reading aloud of the information within the TRUCT Braille by voice, the position where the tip of the pen-type interface was brought into contact with the printed TRUCT Braille experiment sheet was measured by the measurement system for the touch position with the pen-type interface (Fig. 7) and used as an evaluation index. The 2D coordinates of the pen-type interface touch position on the sheet were recorded by the personal computer. Recorded data with a robust z-score of 3 or more were rejected as outliers. The centroid coordinates and standard deviation (σ) for both the x- and y-axes were obtained for the recorded 2D coordinate data. As errors based on the manipulation of human hands generally follow a Gaussian distribution [9], the distribution of the touch positions was evaluated as a Gaussian distribution.

2.5 User test by expert Braille teacher

An expert Braille teacher with visual impairment (40.0 years) was asked to participate in an easy user test designed to confirm whether the dot code printing area based on the results of this experiment is appropriate and useful for Braille learners. Specifically, we prototyped a Japanese syllabary Braille learning sheet to which the dot code for the voice readout function based on the results of this experiment was added. After reading aloud the Braille information from the pen-type interface, the teacher verbally evaluated whether the dot code printing area based on the results of this experiment is appropriate and useful for Braille learners.

3 Results

3.1 Tactile legibility of TRUCT Braille

Figure 9 shows the results of the TRUCT Braille identification. The average correct rate was 100%, with a standard deviation of 0%. In all trials, all participants were able to accurately provide the number of missing dots in the Braille character. The average identification time of the TRUCT Braille was 4.1 s, with a standard deviation of 1.4 s. Most participants took approximately 3.0–5.0 s to read the Braille with only one dot missing. The average confidence rate was 4.6, with a standard

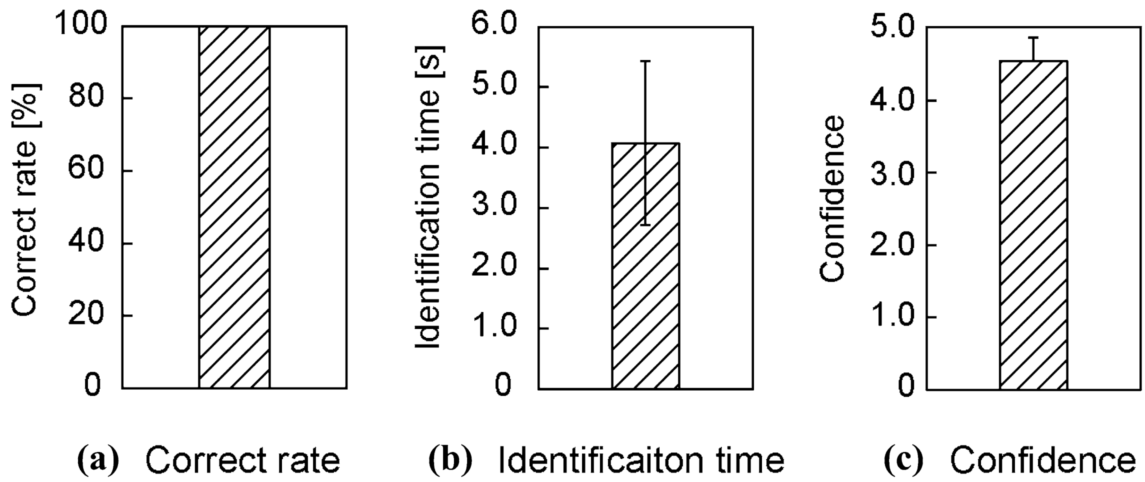


Fig. 9 Results of Braille identification

deviation of 0.3. In all trials, all participants were able to confidently identify the Braille character.

For the tactile legibility of the TRUCT Braille used in this experiment, it is possible to identify the number of missing dots with a correct answer rate of 100%, identification time of 4.1 s, and confidence of 4.6.

3.2 Effectiveness of the pen-type interface

Figure 10 shows the participants' feedback regarding the effectiveness of the pen-type interface for the Braille-to-voice function. The average effectiveness was 4.6, with a standard deviation of 0.7. Six of the nine participants responded that the effectiveness was 5 (extremely effective). Moreover, in the free response section, the participants provided favorable comments, such as "I was able to confirm the result of identifying the Braille easily because of the voice feedback obtained" and "It is effective for learning Braille." There was also a comment on the shape of the interface: "It is necessary to consider its size because the interface may be too big for small-handed children to use." On the other hand, three of the nine participants reported an average effectiveness of 3.7. They commented that the readout function was effective. However, the following comment was provided: "The interface size should be a little smaller." As a reference, there was no significant difference in the discrimination time and confidence between the favorable comments from six participants and the nonfavorable comments from three participants.

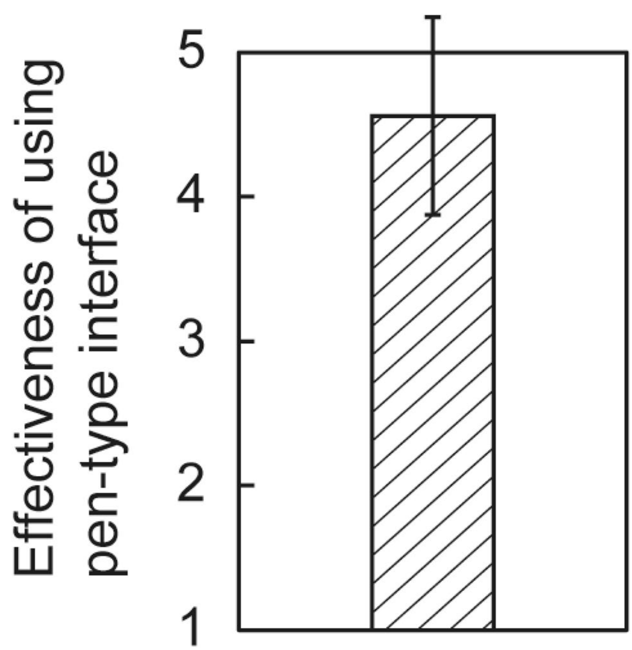


Fig. 10 Participant feedback on the effectiveness of the pen-type interface for the Braille-to-voice function

3.3 Distribution of the pen-type interface touch position

Figure 11 shows the distribution of the pen-type interface touch position. Table 1 lists the centroid coordinates and standard deviation (σ) with the origin at the center of the Braille (midpoint between dotes two and five). The centroid coordinates were 9 mm in the direction of the x-axis and -1 mm in the direction of the y-axis. The standard deviation was 4 mm in the direction of the x-axis and 5 mm in the direction of the y-axis. To obtain a clearer picture of the 2D distribution of the touch position, Fig. 12 shows the frequency distribution of the touch position. As a result, we found that the frequency was high in the x-coordinate range of 5–6 mm and y-coordinate range of -3 to -2 mm, such

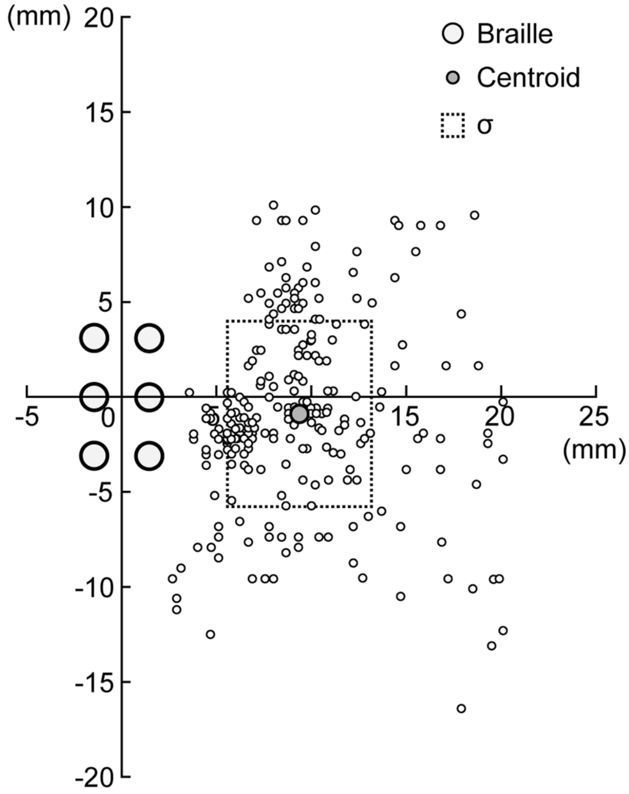


Fig. 11 Touch point distribution with pen-type interface

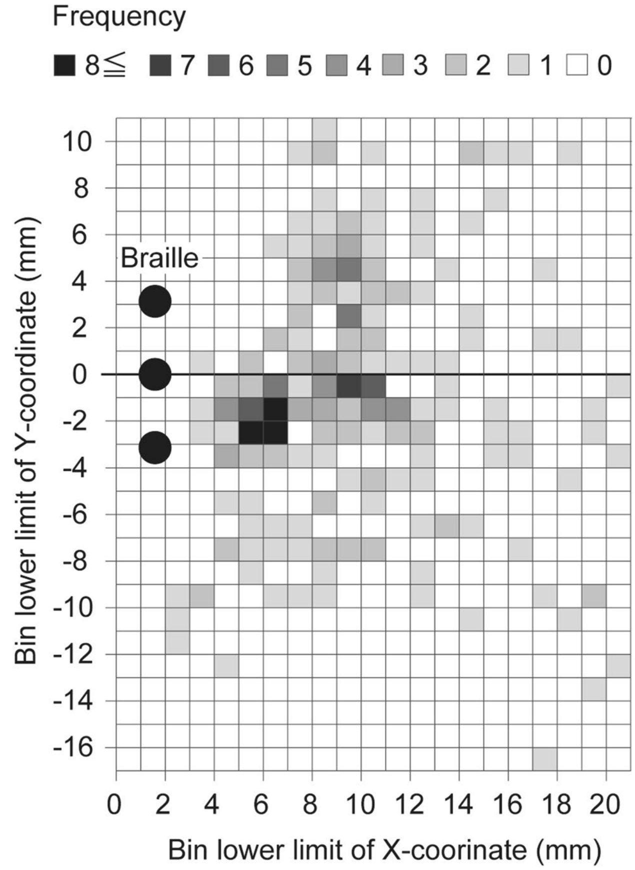


Fig. 12 Frequency distribution of the touch point

Table 1 x- and y-coordinates of the centroid and standard deviation

	x-coordinate (MM)	y-coordinate (mm)
Mean	9	− 1
σ	4	5

that the touch position was slightly offset from the center of the Braille in the lower right direction.

Figures 13 and 14 show the relative and cumulative relative frequencies of the touch position for both the x- and y-axes. Although the sample size was small, the distribution of the touch position obtained in this experiment approximates a Gaussian distribution as shown in Fig. 13, which shows the x- and y-coordinates of the mean together with the cumulative relative frequency. Additionally, when the coordinates are expanded in the $\pm x$- and $\pm y$-axis directions with the x- and y-coordinates of the mean as the center, the cumulative relative frequency exceeds 0.90 for the first time. Specifically, in the x-axis direction shown in Fig. 14a, 90% or more of the total touch position data is included in the x-coordinate range from 3 to 16 (inclusive). Similarly, in the y-axis direction (Fig. 14b), 90% or more of the total touch position data is included in the y-coordinate range from − 10 to 8 (inclusive). The cumulative relative frequency exceeded 0.96 in the x-coordinate range from 2 to 19 and y-coordinate range from − 11 to 10 (inclusive).

3.4 Overall results for TRUCT Braille tactile legibility and pen-type interface effectiveness and touch position distribution

As the TRUCT Braille in this study was created based on the results of our previous studies on the tactile legibility of TRUCT Braille [3, 8], it was possible to identify the number of missing dots with a high correct answer rate and first identification times. Even when the TRUCT Braille was highly readable, we found that the subjects were able to confirm the result of easily identifying the Braille due to the obtained voice feedback. The cumulative relative frequency exceeded 0.96 in the x-coordinate range from 2 to 19 and y-coordinate range from − 11 to 10 (inclusive). If the dot code printing area for the read aloud function of the pen-type interface was selected based on this data, we can improve the success rate of obtaining voice information corresponding to the Braille using the pen-type interface equipped with the Braille-to-voice function.

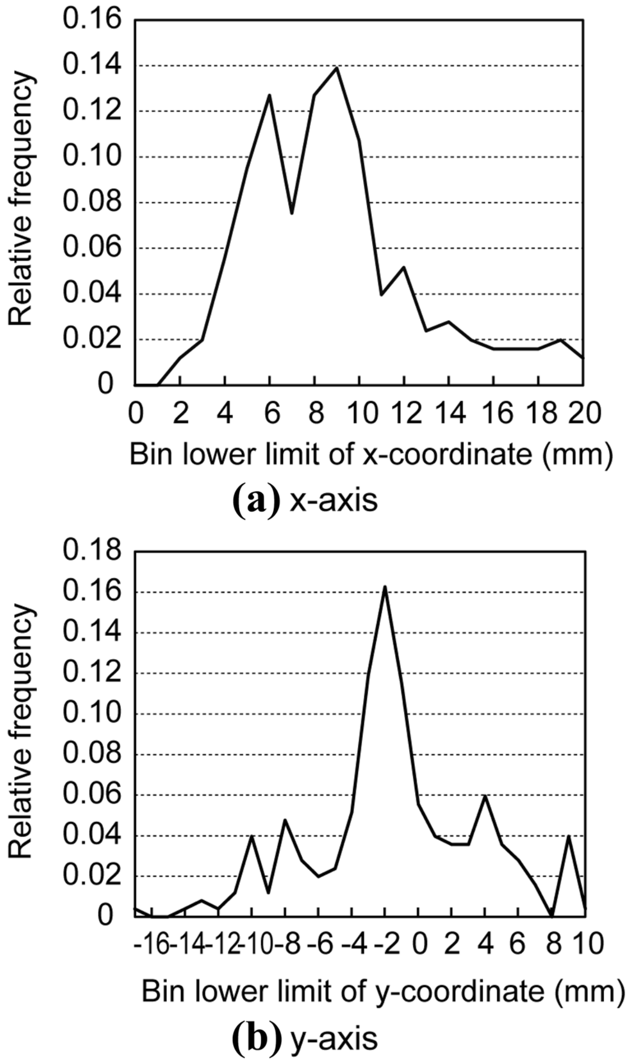


Fig. 13 Relative frequency distribution of the touch position for both axes

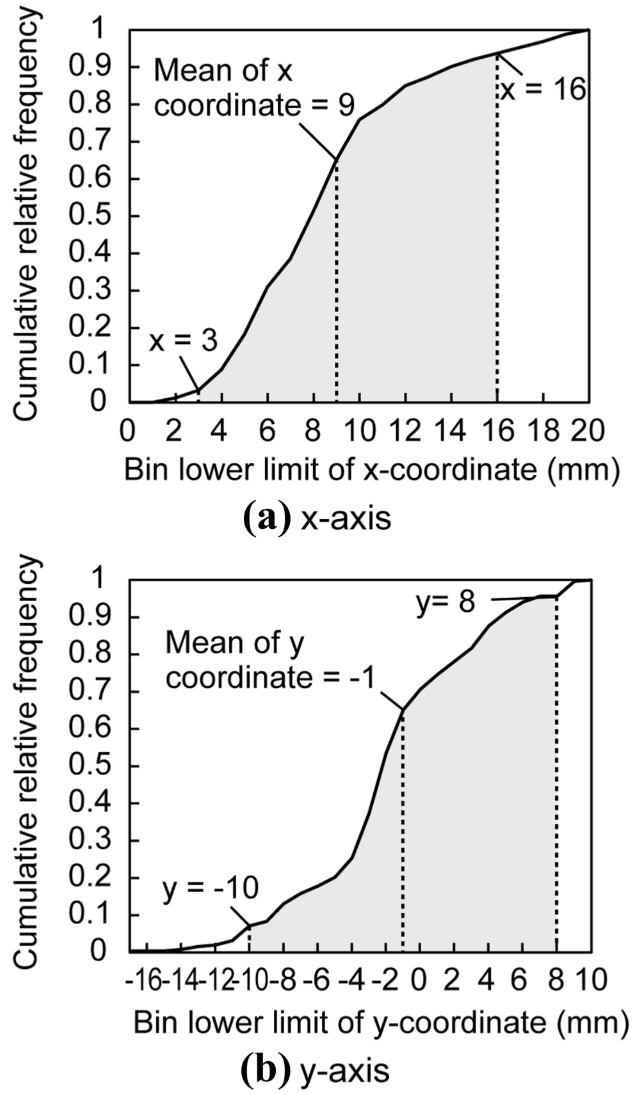


Fig. 14 Distribution of the cumulative relative frequency and coordinate range at a cumulative relative frequency greater than 0.9

3.5 Result of user test by expert Braille teacher

After reading aloud the Braille information from the pen-type interface, the expert Braille teacher verbally evaluated whether the dot code printing area based on the results of this experiment is appropriate and useful for Braille learners. The teacher stated that the dot code printing area is appropriate and also evaluated highly the usability of the Japanese syllabary Braille learning sheet with voice readout function for Braille learners.

4 Discussion

Nine Braille reading novices were able to identify the TRUCT Braille with a 100% accuracy rate. Six out of the nine subjects evaluated the pen-type interface as extremely effective. As Braille requires significant effort to master, numerous people, who are visually impaired, cannot master Braille. Results obtained for the design of Braille size based on quantitative evidence and ensuring voice information demonstrated that Braille can be effectively identified by Braille reading novices. Additionally, the effectiveness of the pen-type interface for its Braille-to-voice function received positive evaluations from Braille reading novices, who were faced with a significant challenge in learning to identify Braille solely by tactile senses. Accordingly, the use of the pen-type interface may be effective for Braille learners as the interface allows them to secure audible information associated with Braille characters that are difficult to recognize solely based on tactile information available through the fingertip.

Furthermore, from the results of the touch position frequency distribution, the touch coordinates were concentrated in a location that was slightly offset from the center of the Braille in the lower right direction. The offset right-of-center for the Braille character can be attributed to the necessity of avoiding the use of the forefinger on the nondominant hand, which is used to touch and read the Braille. We suggest that downward offset from the center of Braille occurred because of the shape of the pen-type interface tip. As shown in Fig. 15, a slight offset occurs between the pen tip contact position and the position read by the image sensor due to the mechanism of the pen-type interface used in this experiment. The touch position was likely detected at a slightly downward position because of such an offset, even though the participant intended to perform a horizontal touch with respect to the center of the Braille. The results of this study indicate that the high frequency range in the y-axis direction was -3 to -2 mm. Therefore, if we include this range in the dot code printing area for the Braille-to-voice function, the offset between the contact position and image processing position does not reduce usability.

In this study, Braille reading novices were evaluated as participants. There is a broad need for Braille learning materials, such that this technology is a potentially significant teaching material for children learning Braille and students with special needs, i.e., visually impaired persons. Accordingly, future studies should consider cases with more diverse users and conduct a usability evaluation with children and elderly people.

Based on the results of the pen-type interface contact position distribution, we can discuss the adequate dot code printing area for Braille reading novices in the early processes of learning Braille. According to the cumulative relative frequency results shown in Fig. 14, 90% of the touch position coordinate data was in the range from 3–16 to –10 to 8 for the x- and y-coordinates, respectively, with the origin at the midpoint of the Braille character (between dots two and five). As an example of another pointing interface for reference, we suggest that the usability of the graphical user interface (GUI) in the touch panels can be improved by designing the size to include 90% or more of the touch position data [10].

Therefore, by designing the dot code printing area such that the cumulative relative frequency is 0.9 or more, we can possibly increase the Braille-to-voice success rate of the pen-type interface. Figure 16 shows an image of the dot code printing area design based on the results of the pointing touch position in this study. Specifically, if the dot code printing area is printed in a direction perpendicular to the Braille, it may be desirable to provide a dot code printing area of 8 and 10 mm above and below, respectively, the

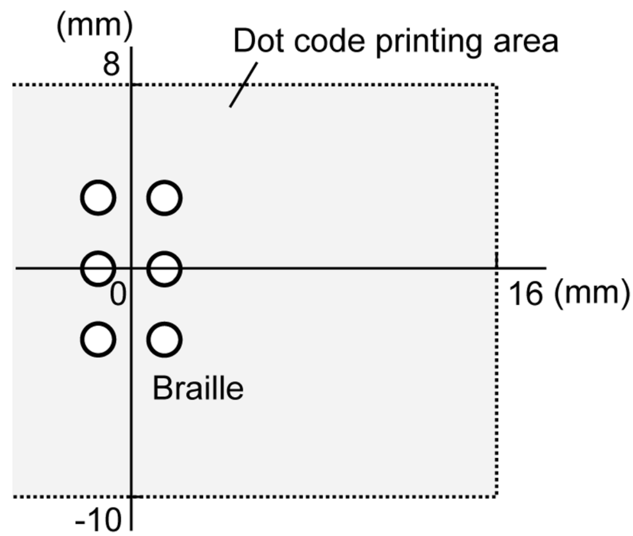
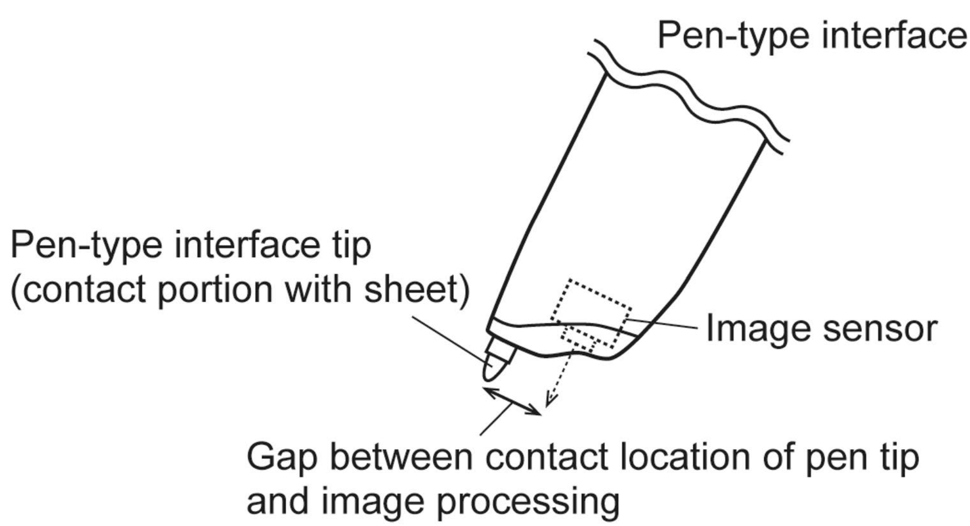


Fig. 16 Appropriate dot code printing area for a pen-type interface as suggested by the experimental results

Fig. 15 Illustration of the pen-type interface's tip used in the experiment



origin of the Braille character (between dots two and five). When the dot code printing area is printed with respect to the Braille character string in the horizontal direction (i.e., the Braille reading direction), printing the dot code area with a width of 16 mm to the right of the midpoint (between dots two and five) of the rightmost Braille may improve the success rate of the pen-type interface touch operation. In this study, we aimed to determine a dot code printing area that is easy to operate for right-handed people with acquired visual impairment and, thus, included right-handed participants in the experiments. A separate investigation is needed to determine whether identical results can be obtained for left-handed experiment participants. However, when applying the knowledge obtained in this study to actual situations, a dot code printing area 16 mm to the left of the Braille character's midpoint at the beginning of the line on the left end of the Braille character string may be realistic, which accounts for a left-handed person with acquired visual impairment.

In this study, we confirmed the standards related to the display method of TRUCT Braille. Standard JIS T925 [7] stipulates that the line spacing of the TRUCT Braille (i.e., the distance between the center of a Braille character and center of the Braille on the line below) is at least five times the vertical dot distance (between dots one and two). The same standard [7] recommends that the vertical dot distance be from 2.2 to 2.4 mm. Therefore, line spacing between 11 and 12 mm is desirable. Here, the width in the vertical direction of the dot code printing area is 8 mm above and 10 mm below the midpoint of dots two and five of the Braille. When Braille is written over two lines, the distance between dots one and two (or between dots two and five) is the same, such that the dot code printing area derived from the results of this study is within the Braille line spacing requirements in the JIS. Accordingly, the dot code area can be printed on the Braille character string without conflicting with this standard. When the participants were taught to perform the hand movements "as quickly and accurately as possible" in a previous study [11], a 96% success rate was assumed as an implicit premise. Based on this knowledge, we can consider the results shown in Fig. 12, i.e., the range when the cumulative relative frequency exceeds 0.96, the x-coordinate ranges from 2 to 19, and the y-coordinate ranges from -11 to 10 (inclusive). When the dot code printing area is examined with the above procedures, a dot code area of 19 mm on the left and right sides, as well as 10 mm above and below dots two and five of the Braille, is sufficient. In this study, the touch object was Braille as the research objective was to obtain an adequate dot code printing area to prevent decreased usability of a pen-type interface with Braille-to-voice functionality for Braille reading novices.

In terms of similar Braille learning materials, Tachibana and Matsutani [12] published a Braille introductory textbook for Braille beginner readers using TRUCT Braille. However, as users must learn while listening to a CD, they cannot easily learn the meaning of the Braille characters in a sequential manner. Therefore, we suggest the proposed method of creating Braille learning material as an alternative using a pen-type interface with Braille-to-voice functionality for Braille reading novices.

Tezuka [13] developed a learning support system using Braille pin display for Braille users. After mastering Braille via this Braille learning material, Braille readers can effectively use the Braille pin display connected to personal computer.

In future studies, we plan to consider the application of the pen-type interface to tactile guide maps, which are considered to recognize by tactile senses alone. Furthermore, we will compare our approach using a pen-type interface with a read aloud function and other tools, which use Braille in combination with QR code recognition and read aloud functions [14].

This study aimed to clarify an adequate dot code printing area for a pen-type interface equipped with Braille-to-voice function for Braille reading novices. We conducted experiments using blindfolded persons without Braille reading experience to eliminate any effect associated with Braille reading experience. In future studies, we will conduct similar experiments with visually impaired Braille learners that wish to master Braille reading, to clarify and verify the adequate dot code printing area with actual visually impaired learners.

5 Conclusions

In this study, we conducted experiments to clarify an adequate dot code printing area to prevent decreased usability of a pen-type interface with a Braille-to-voice function for Braille reading novices. The touch position distribution results suggest that when users interact with the TRUCT Braille via a pen-type interface, the success rate can be improved by designing a dot code printing area to include the space 8 mm above and 10 mm below the midpoint between dots two and five in the vertical direction, as well as a width of 16 mm from the midpoint of the Braille. Based on these results, we determined design guidelines for the dot code printing area to improve the success rate of obtaining voice information corresponding to the Braille. To further confirm the specifications of the printing area, future studies must include more diverse participants, including children, elderly persons, and left-handed persons. Continued clarification of the suitable dot code printing area will further enhance the potential for practical applications of TRUCT Braille reading with the pen-type interface. The specifications determined in this study are particularly applicable to adults with acquired visual impairments who are in the early stages of learning to read Braille. Extensions of this study can contribute to augmented Braille learning methods in various educational settings.

Acknowledgements Masamichi Watanuki of the Design Section in the Development Department of Gridmark Inc. provided invaluable assistance. Funding for this study was provided by JSPS KAKENHI (Grant Number 19H01729).

Compliance with ethical standards

Ethical approval All study participants provided informed consent, and the study design was approved by the appropriate ethics review board. This experiment was conducted in line with the ethical guidelines on research at the National Institute of Special Needs Education.

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