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Paper

Determining the Optimum Font Size for Braille on Capsule Paper for Late Blind People

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Abstract To determine the optimum size of a braille font, we conducted an experiment in which a popular Japanese braille font was printed at various sizes on capsule paper and read and rated by late blind people. The results show that braille printed at 16 to 19-point sizes was read faster and rated higher than that printed at smaller or larger sizes. These optimum sizes mostly coincide with those found for young congenitally blind people. A new finding was that many reading errors that stemmed from mistaking the range of braille cells were observed at larger sizes, 20 to 22-point sizes. This means that enlarging the font size is not necessarily beneficial for late blind people and optimum sizes should be strictly selected when doing so.

Keywords: Late Blind People, Braille Font, Capsule Paper, Tactile Reading, Legibility.

1. Introduction

Capsule paper is a method of producing tactile graphics for blind people. Its surface is coated with microcapsules that swell up when heated to be tangible. Due to its relatively low cost, high speed, and easy production, it is one of the most popular ways to produce tactile maps [1] and educational materials [2].

On capsule paper, braille labels can be easily added to tactile graphics by using braille fonts [3]. In Japan, a braille font developed by Nippon (Japan) Lighthouse [4] (hereinafter referred to as NLB font) is common and used in some braille editors such as t-editor [5] and WinbDic [6] as well as in our tactile map automated creation system, tmacs [7].

Braille fonts can be printed at arbitrary sizes by changing the font size [3]. To find the optimum size for NLB font, we conducted an experiment with young congenitally blind people as participants [8]. The results show that braille printed at point sizes of 17 and 18 was read faster and evaluated higher than that printed at smaller or larger sizes.

However, many studies have demonstrated that late braille learners prefer larger braille. Harada reported that large braille was effective in the instruction of slow braille readers who had become blind later in life [9]. We also reported that sighted people who learned braille in their twenties read enlarged braille faster and rated it higher than the standard size [10]. In fact, there are various braille systems in the world, such as Jumbo Dot, California Braille, and Marburg Large, which are larger than the standard braille for readers who learn braille later in life or who have sensitivity problems [11]. Therefore, it might occur that NLB font should be printed at sizes larger than 17 and 18 points for late braille learners' convenience.

Thus, we designed another experiment with the same stimuli and method as the previous one but with a different participant group, namely late blind people. The experimental results will be compared between different participant groups. On the basis of the findings, we will draw up helpful guidelines for tactile graphics producers.

2. Experiment

2.1 Participants

Thirteen late blind persons (ten males and three females) participated in the study (Table 1). Their ages spanned from 24 to 73, with an average of 47.3. They started using braille on a daily basis between 16 and 43, with an average of 27.4. Eight participants read braille sentences on a daily basis, three sometimes did so, and the other one read only short memos in braille. They were all Japanese.

Prior to testing, they were informed about the intent and protocols of the experiment and gave their consent orally to omit a signature due to blindness.

Six participants were paid for their time. The other

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Table 1 List of late blind participants.

Participants	Sex	Age [years]	Onset of braille usage [years]	Braille usage period [years]	Braille usgae frequency	Dominant hand in readng braille	Used hand in the experiment	Data Analysis
A	F	47	23	24	Sometimes	Right	Right	Done
B	F	44	35	9	Everyday	Left	Left	Done
C	M	33	25	8	Sometimes	Left	Left	No
D	M	24	22	2	Everyday	Left	Left	Done
E	M	24	22	2	Everyday	Left	Left	Done
F	M	65	38	27	Sometimes	Left	Left	No
G	M	73	43	30	Sometimes	Left	Left	No
H	M	56	16	40	Everyday	Left	Left	Done
I	M	60	25	35	Everyday	Left	Left	Done
J	M	35	17	18	Everyday	Left	Left	Done
K	M	41	31	10	Only short memos	Right	Right	Done
L	F	51	25	26	Everyday	Left	Left	Done
M	M	62	34	28	Everyday	Right	Right	Done

seven declined the pay as the experiment was done during their working hours.

2.2 Stimuli

The point size of NLB font [4] was changed from 15 to 22 in 1-point steps in the word processor software Microsoft Word. This stimulus range was identical to that used in our previous study with young congenitally blind people as participants [4] ; the results can be compared between the two participant groups. The dot diameters and dimensions of the braille printed at each size are shown in Table 2.

Several sets of five sheets of braille on capsule paper were prepared for the experiment. Each sheet had eight lines of braille sentences that were printed at eight different points in a random order. Each line had 20 letters that were divided into four five-letter blocks. All blocks were meaningless words consisting of randomly arranged letters so as to prevent participants from reading ahead.

The braille sentences were printed on DIN A4-sized capsule paper (ZY-TEX2, Zychem) by using a laser printer (Satera MF4380d, Canon) (Fig. 1). The paper was heated with a heater (PIAF, Quantum Reading Learning Vision) with a heating parameter of around seven (one: lowest to nine: hottest) to make dots sufficiently high for reading [12].

Table 2 Dimensions of NLB font printed at various sizes.

Size [point]	Dot diameter [mm]	Vertical dot-to-dot [mm]	Horizontal dot-to-dot [mm]	Horizontal cell-to-cell [mm]
15	1.41	1.99	2.17	3.12
16	1.49	2.10	2.34	3.30
17	1.59	2.26	2.48	3.51
18	1.69	2.37	2.61	3.76
19	1.79	2.48	2.75	3.94
20	1.90	2.65	2.92	4.18
21	1.98	2.78	3.08	4.37
22	2.09	2.91	3.19	4.59

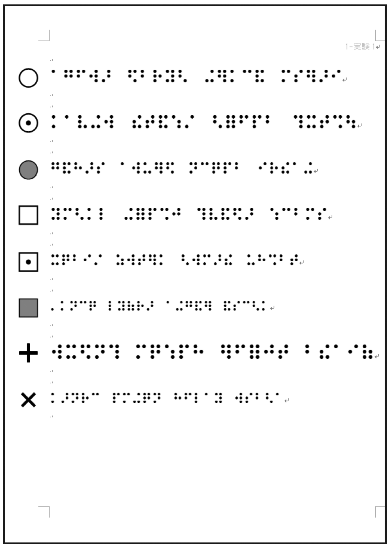

Fig. 1 Sample of stimuli sheet. Eight braille lines are printed at different point sizes. The size of the sheet is DIN A4.

2.3 Procedure

The experiment was carried out in a quiet room. The participants sat on a chair and read materials that were placed on a desk. The participants were asked to read materials with their hands in their usual manner. A raised mark on the left side of each line was assigned as the starting position. They were asked to place their fingers at that position before the start of the experiment. When an experimenter gave the start signal, the participants were asked to begin tactually reading the stimulus lines aloud. The time from start to completion of reading aloud was measured with a stopwatch and recorded as the reading time. After reading a line, the participants were asked to rate the legibility of the braille on a scale of one, least legible, to four, most legible. They were instructed not to make any comparisons with the previous lines.

During the experiment, the actions of each reader's hands were videoed. Reading errors were checked during the experiment and were confirmed from the video after the experiment.

The participants read five stimulus sheets of Braille. The data from the first sheet, which was regarded as the training sheet, were discarded and the data from the remaining four sheets were used for analysis. As each sheet had eight different point sized braille sentences, the participants read braille of the same point size four times in total. The mean of the four trials of the same size was treated as the individual data in each condition for the reading time, legibility rate, and number of errors.

3. Results

Two participants (participants C and G in Table 1) aborted the experiment on the experimenter's decision due to anticipated fatigue from long reading time. (About one to five minutes per line would have amounted to nearly one hour to a couple of hours for a total of 40 lines). Their data were removed from the analysis.

In addition, the data from one participant (participant F) were discarded because he took tremendously long; his reading time was 1.5 to 3.3 times the mean of the other ten participants' data. Thus, his data were regarded as an outlier and excluded from the analysis. Thus, data from ten participants were analyzed.

3.1 Reading Time

Fig. 2 shows the relationship between font size and reading time. The bars represent the means of ten participants' reading times, and the error bars the standard deviations for each point size. The graph looks like a U-shape. The mean reading time was the shortest at 16-point size, and as the size became either smaller or larger than 16 points, the reading time grew longer. This trend was more noticeable when the size became larger.

The assumption of the normal distribution of the data was not violated when using the Shapiro-Wilk test for each font size condition. Thus, we used an ANOVA and found a significant difference in reading time for font size (F (7, 63) = 23.53, p < 0.01). A multiple comparison using Tukey's method (1%) showed significant differences in reading time between font size(s) of 20 and 16 to 18, 21 and 15 to 19, and 22 and 15 to 20 (Table 3).

3.2 Rating of Legibility

Fig. 3 shows the relationship between font size and rating of legibility. The bars represent the means of ten participants' ratings of legibility, and the error bars the standard deviations for each point size. The graph is just an upside-down version of Fig. 2. The rating was the highest at the 16-point size, and as the size became either smaller or larger than 16 points, the rating grew lower. This trend was more noticeable when the size became larger.

As rating of legibility is an ordinal scale, we used a nonparametric Friedman test and found a significant

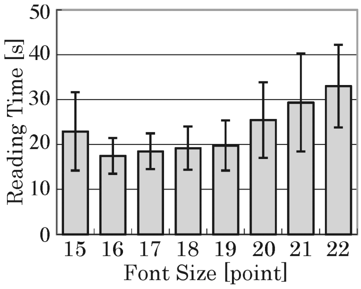

Fig. 2 Relationship between font size and reading time.

Table 3 Significant differences (*: 1%) in reading time.

Size [point]	15	16	17	18	19	20	21	22
15								
16	-							
17	-	-						
18	-	-	-					
19	-	-	-	-				
20	-	*	*	*	-			
21	*	*	*	*	*	-		
22	*	*	*	*	*	*	-	

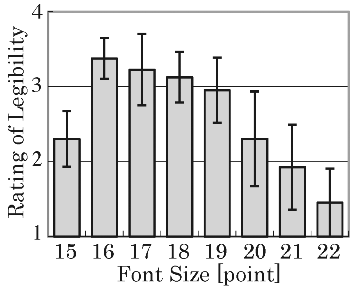

Fig. 3 Relationship between font size and rating of legibility.

Table 4 Significant differences (*: 1%) in rating of legibility.

Size [point]	15	16	17	18	19	20	21	22
15								
16	*							
17	*	-						
18	*	-	-					
19	*	*	-	-				
20	-	*	*	*	*			
21	-	*	*	*	*	*		
22	-	*	*	*	*	*	-	

difference in the rating of legibility for font size (S = 58.63, $p < 0.01$). A multiple comparison using a signed rank sum test (1%) showed significant differences in rating of legibility between font size(s) of 16 to 19 and 15 and 20 to 22, 20 and 21 to 22, and 16 and 19 (Table 4).

3.3 Reading Errors

We observed two types of reading errors. One is "replacing," i.e. one presented braille letter was mistaken for a different letter. Replacing errors had been observed by Nolan and Kederis back in 1960s and divided into several types [13]. The other is "mistaking cell range," which resulted in reading more or fewer letters than the presented letters. As the numbers of presented and read letters differed in many trials, we counted the number of errors in two ways: one is counting the number of letters presented but not read correctly; the other one is counting the number of letters read by the participants but not presented. Fig. 4 shows the relationship between font size and numbers of reading errors counted in the two ways. Only at 15-point size, the former counting method produced more errors than the latter. This means that a few letters were ignored and not read. At the other point sizes, in contrast, the latter counting method produced more errors than the former. This means that more letters were read than presented. This trend was more noticeable when the size became larger.

Five participants made, on the average, less than one error per line throughout all the point sizes whereas the other five participants made one or more, up to nearly nine at the maximum, errors per line (each line consisted of 20 letters). As the normality assumption of the number of errors was violated, we used a nonparametric Friedman test and found a significant difference in the number of errors counted in the latter method for font size (S = 29.35, $p < 0.01$). A multiple comparison using signed rank sum test (1%) showed significant differences in the number of errors between 15 and 16 to 20, 22 and 16 to 19, 17 and 16 and 20 to 21, and 19 and 21 (Table 5).

The numbers of reading errors at each font size summed across ten participants and four trials were above 20 at the minimum and 120 at the maximum. These errors are divided into the two above-mentioned error types (replacing and mistaking cell range) at each font size (Fig. 5 (a)). It was found that replacing errors occurred throughout all font sizes whereas mistaking cell range errors occurred mostly at large font sizes (20 to 22-point).

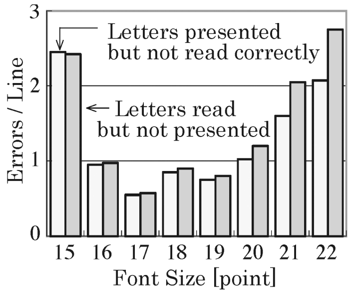

Fig. 4 Relationship between font size and number of reading errors.

Table 5 Significant differences (*: 1%) in the number of reading errors.

Size [point]	15	16	17	18	19	20	21	22
15								
16	*							
17	*	*						
18	*	-	-					
19	*	-	-	-				
20	*	-	*	-	-			
21	-	-	*	-	*	-		
22	-	*	*	*	*	-	-	

Subtypes of replacing errors are one-dot missing, one-dot adding, flip horizontal, rotating, and others (adding or missing more than one dot, and a combination of adding and missing). Examples of these error types are shown in Table 6. The ratios of the subtypes of replacing errors at each font size are shown in Fig. 5 (b), where the first two subtypes that are dominant are shown independently and two other subtypes are categorized in others. As can be seen, one-dot missing errors were the most frequent. This coincides with the report by Nolan and Kederis [13]. Another noticeable feature is that one-dot adding errors were dominant at 15-point size.

The most frequently observed subtype of mistaking cell range errors is one column reading. Only one column of one braille letter that often has two columns was read. This error type is confusable with one-dot missing. When one column of one braille letter has only one dot

Table 6 Typical reading errors.

Main types	Subtypes	Example: Presented letter(s)	Example: Read letter(s)
Replacing	1-dot missing	⠟	⠞
	1-dot adding	⠋	⠏
	Flip horizontal	⠍	⠩
	Rotating	⠅	⠌
Mistaking cell range	One column reading	⠉	(after reading ⠉) ⠁
	Spanning cells	⠺⠥	⠿

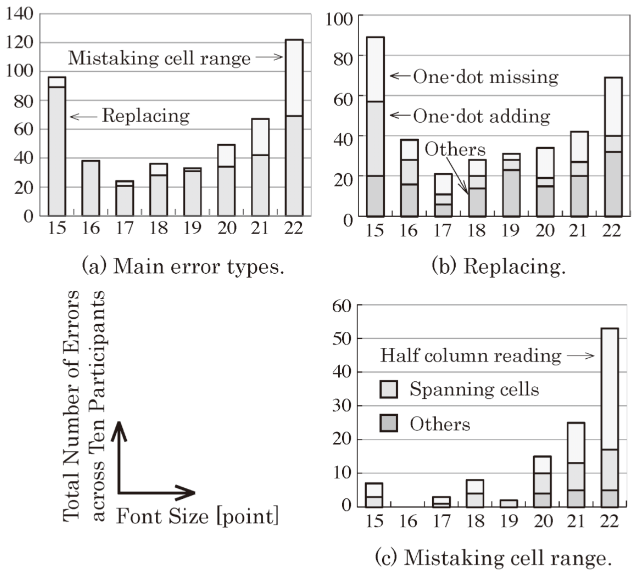

Fig. 5 Relationship between font size and types of reading errors.

and is missed, the error can be categorized as both one column reading and one-dot missing. Thus, we defined this error type by the previous reading. When a braille letter was read correctly and reading one column of the same letter followed it or when the right column of a braille letter was read after spanning cells happened, we categorized the reading as one column reading. Spanning cells error means treating two middle columns of two adjacent braille letters (four columns in total) as one letter. Mistaking cell range errors are unique to the present experimental results. These errors clearly increased as the font size became larger (Fig. 5 (c)).

4. Discussion

4.1 Optimum Font Size for Late Blind People

The results on the reading time, rating of legibility, and numbers of reading errors in which significant differences were found for printed font size revealed that for late blind people, braille made with NLB font was most legible when printed at 16 to 19 points. These sizes mostly coincide with the optimum sizes of 17 and 18 point sizes that were found for young congenitally blind people in our prior research [8]. The reason these sizes were preferred by late blind people can be explained by the fact that 17- to 19-point sizes are already larger than Japanese standard-sized braille (Table 7) [14)-16]. Why, then, do young congenitally blind people prefer larger braille? It would be because the swelling characteristics of capsule paper hinder the legibility of braille printed at 15- and 16-point sizes whose dimensions are close to Japanese standard-sized braille. Smaller dots do not reach the heights that larger dots achieve [12] [17]. Narrower spacing between dots causes them to merge together [18]. As the result, braille larger than the Japanese standard size is evaluated to be legible even for young congenitally blind people.

4.2 Differences between Participant Groups

The average reading time and number of reading errors greatly differed between young congenitally and late blind participant groups. At legible font sizes of 16 to 19 points, young congenitally blind people read within 10 seconds, whereas late blind people read within 20 seconds, about two times longer. This result accords with preceding observations [19)-22].

In our previous experiment, all the young congenitally blind participants made few reading errors across all font sizes. In contrast, half the late blind participants in the present experiment made a few errors per line consisting of 20 letters at less legible font sizes of 15 and 20 to 22 points. The error types included not only conventional letter-to-letter replacing but also mistaking the range of braille cells.

4.3 Reason for Mistaking the Braille Cell Range

It is natural to think that mistaking the range of braille cells is caused by the wide horizontal dot-to-dot spacing at large font sizes. They measure 2.92, 3.08, and 3.19 mm at 20-, 21-, and 22-point sizes, respectively (Table 2), which are close to horizontal cell-to-cell spacing of standard braille size, 3.2 mm (Table 7) [14)-16]. Although enlarging the braille font size is generally thought to be beneficial for late blind people, it may have the opposite effect if the spacing is excessively wide.

5. Conclusion

The present experiment revealed the optimum legible braille font size on capsule paper for late blind people. These sizes coincide with the ones that were found for young congenitally blind people [8]. This experimental result demonstrates the validity of using NLB font at 18 points in our tactile map automated creation system [7]. Tactile graphics producers can make legible braille on capsule paper using our test data.

Table 7 Dimensions of Japanese standard (J. Std), JIS and ISO braille sizes. ISO is shown for reference.

Braille Standard	Dot diameter [mm]	Vertical dot-to-dot [mm]	Horizontal dot-to-dot [mm]	Horizontal cell-to-cell [mm]
J. Std [14]	1.6	2.25	2.0	3.2
JIS[15]	1.3	2.2-2.5	2.0-2.5	5.1-6.3
ISO[16]	1.49	2.10	2.34	3.30

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