

Readability of Characters on Mobile Phone Liquid Crystal Displays

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Subject performance in reading characters on mobile phone liquid crystal displays was researched by using (a) English sentences with 3 or 4 different sizes of characters on 2 types of displays with different resolutions ($n = 23$; age = 31.0 ± 6.0 years), (b) Japanese characters in 3 different sizes and 2 types of font ($n = 98$; age = 44.5 ± 18.5 years), and (c) Japanese characters vertically enlarged 1–4 times ($n = 120$; age = 46.9 ± 18.6 years). Subjective evaluation, reading speed, number of reading errors, and viewing distance were recorded. Readability was higher with higher resolution displays, and with Gothic than with Mincho font in Japanese. Young subjects shortened the viewing distance as characters became smaller, whereas elderly subjects increased the viewing distance irrespective of the size of characters. Characters of 3–5 mm are appropriate for the young but inadequate for the elderly. Readability of Japanese characters improved when they were vertically enlarged to approximately twice the width.

VDT small display legibility reading speed viewing distance graphic text

1. INTRODUCTION

In the ubiquitous computing age, opportunities to use character/image information displayed on mobile information terminals such as mobile phones (MPs) are increasing. The use of character information on MPs has expanded applications not only to personal correspondence but also to obtaining business, social, disaster [1], and other types of information.

MP is one of the most important character terminals for business users and also an effective information delivery tool for protecting workers', students', and citizens' safety in disasters or emergencies. Universal designs make the transmission of such important information to everybody, including the elderly, possible.

There have been many studies on the readability or legibility of printed characters and characters on cathode ray tubes (CRT) or liquid crystal

displays (LCD) of computers [1, 2, 3, 4, 5, 6, 7], and recommended character sizes have been standardized in terms of sign displays and video display terminal (VDT) work [8, 9, 10, 11]. The results of these studies are useful in evaluating the qualities of displays and estimating optimal character sizes for each type of display. These standards can be used as a reference in designing characters for MPs. However, MPs have far smaller screens than personal computers (PCs); they also differ markedly from PCs in that they are hand-held. Therefore, reading behavior may be expected to be different than for PCs. The standards for PCs or other devices can not be directly used for MP displays. Some recent standardizations [12, 13] provide methods of estimating ergonomic requirements for new types of visual displays, including flat panel displays such as electroluminescent or field emission displays. However, reading performance of users of individual tools such as MPs is not mentioned in these reports. In recent years, there have also been some studies on the readability of characters on MPs, which have included elderly subjects [14, 15], but research remains inadequate for understanding characteristics of users who read characters on MP screens and for standardization or proposal for guiding principles for a universal design in MPs.

The purpose of this study is not to evaluate the quality of displays but to research the reading performance of users who read sentences on

LCDs in MPs, and to examine character features such as size, shape, and font that are related to readability. The following three detailed experiments were conducted: (a) an experiment using English sentences and two types of MPs, (b) an experiment using two types of Japanese font with subjects including elderly people, and (c) an experiment with vertically enlarged Japanese characters. In each experiment, reading performance was evaluated by measuring viewing distance, reading speed, and the number of errors in reading.

2. METHODS

In this study, graphic characters were displayed on the LCDs of MPs and read aloud by the subjects (Figure 1). Here, graphic characters are characters expressed as image data. For MPs with a camera, which are widely used in some countries such as Japan, it is common to send images attached to e-mails, and character information can also be received and displayed as image data. Graphic characters are useful for the display of special characters such as multilingual characters or pictograms that are unsupported by built-in fonts of ordinary MPs [1]. The use of graphic characters also allows experiments by displaying characters with various fonts and forms not limited to the fonts installed in the product. Graphic characters used in this study were produced with Hasegawa,

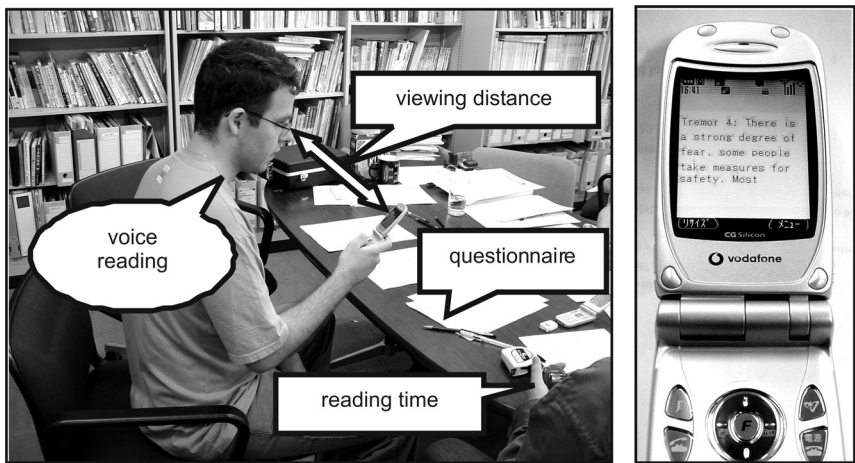


Figure 1. Overview of the experiment. Graphic text was displayed on the liquid crystal displays of mobile phones. Reading time and viewing distance were measured. Subjective evaluation of readability was recorded using a questionnaire after every reading.

Sato, Matsunuma, et al.'s [1] method, in which readability was consistent with that of ordinary binary fonts. Three experiments were performed as described in sections 2.1–2.3. To avoid the influence of the subjects' familiarity with a language [16], subjects whose mother tongue was English took part in the English-sentence reading experiment (experiment 1), while Japanese subjects took part in the Japanese-sentence reading ones (experiments 2–3).

2.1. Experiment 1

Ten English sentences were displayed as graphic characters in the portable network graphics (PNG) format (binary images: black characters on white background) in three different sizes, as shown in Figure 2. The maximum number of characters per line was (a) 16 for large (L), (b) 20 for medium (M), (c) 24 for small (S), and (d) 40 for very small (VS). The font was MS Gothic, in which both stroke width and character width were constant (nonproportional font, no kerning). In the character region, the width-to-height ratio was 1:2. Size L was 12 pt with the height of 4.2 mm; size M: 10 pt, height 3.5 mm; size S: 8 pt, height 2.8 mm; and size VS: 5 pt, height 1.8 mm. For sentences in each character size, the final word on each line was always a full word, never split between two lines (Figure 2). Each graphic character was displayed on one screen of the MP LCDs to avoid scrolling. The two types of MPs shown in Table 1 were used. Each type had a color LCD with a back light. Type H had higher luminosity and higher resolution than type L (Table 1).

TABLE 1. Mobile Phones Used in the Experiment

Type	Product	
	(Manufacturer)	Specification of LCD
L	SH07 (Sharp, Japan)	120 x 160 dots, 2", color TFT
H	SH53 (Sharp, Japan)	240 x 320 dots, 2.4", color CG silicon

Notes. LCD—liquid crystal display, TFT—thin film transistor, CG—continuous grain.

The subjects were 23 people aged 23–51 years ($M \pm SD$: 31.0 ± 6.0) whose mother tongue was English and who had normal naked or corrected visual acuity. Graphic characters, as shown in Figure 1, were prepared in a sufficient variety so that the subjects did not read the same sentence twice. The presentation order was different for each subject to avoid influence from the order of the contents/character size/MP type. The subjects sat in a comfortable posture in a chair in a light room, held a MP in their hand, and read aloud the sentence displayed on the LCD.

Reading time (RT), viewing distance (VD) at the end of reading, and the number of errors (Err) were measured and recorded, and subjective evaluation (SE) was performed every time the reading of one sample was completed by selecting one of the following five choices: 1—*very hard to read*, 2—*hard to read*, 3—*so-so*, 4—*easy to read*, and 5—*very easy to read*.

2.2. Experiment 2

We produced graphic texts of Japanese sentences in three character sizes (L, M, and S) and two fonts (Gothic and Mincho) with 8 characters in

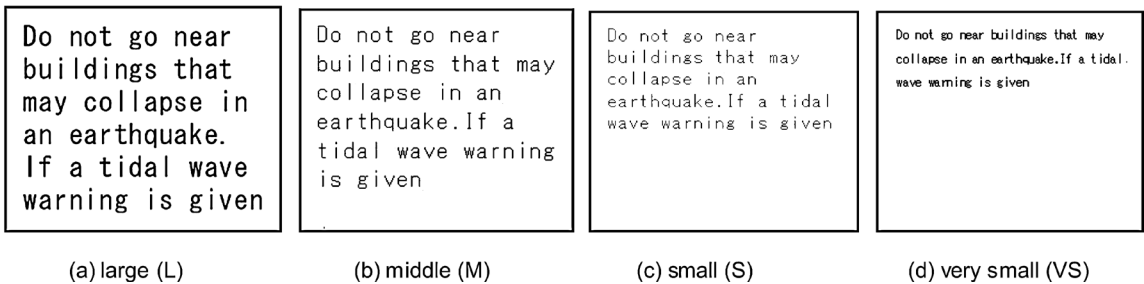


Figure 2. Samples of graphic characters (English). Font characters expressed as binary image data in portable network graphics (PNG) format. Each sample could be displayed on one screen of a mobile phone.

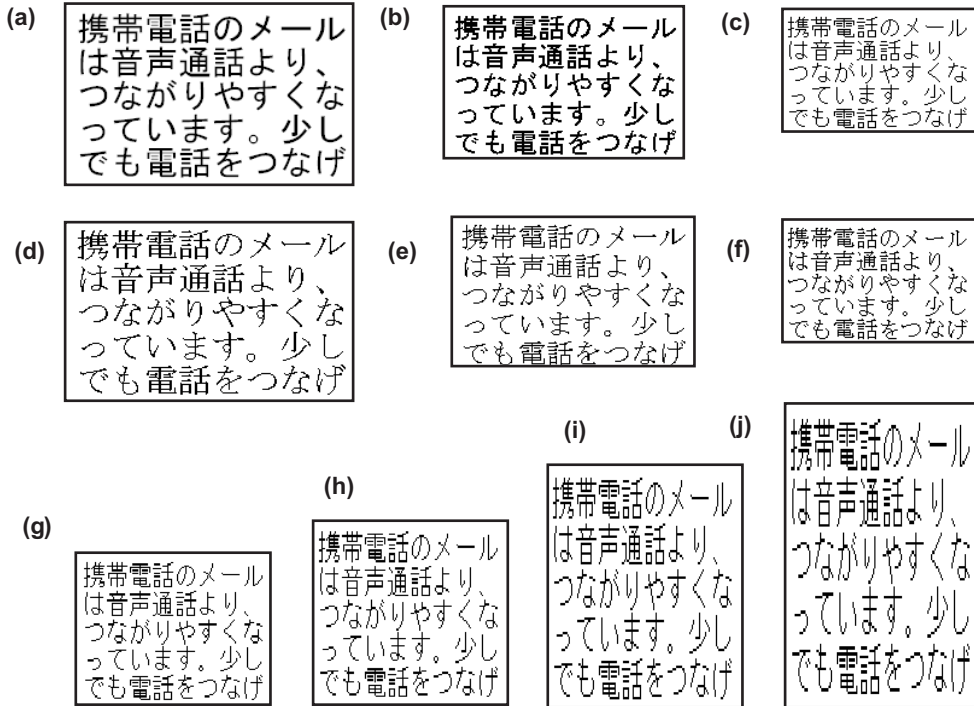


Figure 3. Samples of graphic characters (Japanese). Notes. a, b, c—Gothic font, d, e, f—Mincho font; a, d—L, b, e—M, and c, f—S. L is 1.5 times larger and M is 1.25 times larger than S in width and height. Character in S: 8 pt (2.8 × 2.8 mm). g, j—Gothic font, width is the same as (c) S. The height-to-width ratios are (c) 1, (g) 1.25, (h) 1.5, (i) 2, and (j) 2.5.

one line and the total number of 40 characters (Figures 3a–f). Size S was 8 pt (2.8 × 2.8 mm per character). Size M was 1.25 times size S (10 pt, 3.5 × 3.5 mm per character), and size L was 1.5 times size S (12 pt, 4.2 × 4.2 mm per character).

In this experiment, type H MPs (Table 1) were used. The height of the Japanese characters was the same as that of the English characters used in experiment 1, but their width was twice the height of the English characters (i.e., width = height in both Japanese graphic characters and ordinary Japanese fonts) for sizes L, M, and S. In addition, unlike in the case of English characters, the number of Japanese characters in each line was constant. These character sizes were similar to those frequently used as fonts in MPs. In the experiment with sizes L, M, and S, characters in each size were shown in Gothic and Mincho fonts. Gothic characters had constant stroke width, while Mincho characters did not. Mincho characters were also thinner than the Gothic font in many portions.

The subjects were 98 Japanese people aged 20–78 years ($M \pm SD$: 44.5 ± 18.5). This number

included 55 people aged 20–49 years ($M \pm SD$: 29.6 ± 8.2) and 43 aged 50–78 ($M \pm SD$: 63.6 ± 6.9). The age and height of the subjects were recorded and 30 cm near vision acuity (6 stages in the Landolt ring test: 0.1, 0.3, 0.5, 0.7, 1.0, and 1.2) was measured before the experiment. Mean 30 cm near vision acuity with naked eyes or glasses for distant vision was 0.71 ± 0.42 in all subjects, 1.02 ± 0.29 in subjects aged 20–49 years, and 0.33 ± 0.19 in those aged 50–78 years, and that with naked eyes or glasses for near vision was 0.84 ± 0.39 in all subjects, 1.02 ± 0.29 (the same for distant vision) in subjects aged 20–49 years, and 0.64 ± 0.32 for those aged 50–78 years. The subjects who wore glasses for near vision used them in the experiment.

As with the English sentences, Japanese sentences with different contents, different character sizes (L, M, and S), and different fonts (Gothic, Mincho) were prepared. Sentences were presented so that subjects did not read the same sentence twice, with changes in the sentence presentation order and contents for each subject. The measurement items were the same as those

in the English sentence experiment (RT, VD, Err, and SE).

2.3. Experiment 3

The subjects in experiment 3a were the same as those in experiment 2. Graphic texts (Figures 3g–j) were prepared by increasing the height of size S characters of the Gothic font (8 pt, 2.8×2.8 mm) 1.25-, 1.5-, 2-, and 2.5-fold without changes in width.

Another experiment (experiment 3b) was performed with another 120 Japanese subjects aged 18–77 years ($M \pm SD$: 46.9 ± 18.6) using samples with oblong characters obtained by increasing their height one- (S), two-, three-, and fourfold without changes in width.

The original characters were Gothic with constant stroke width. In the oblong graphic characters, since the original image was vertically enlarged, enlargement was easy, but stroke width was increased by the enlargement rate only for lines in the horizontal direction. Type H (Table 1) MPs were used. The reading methods and measurement items were the same as those in experiments 1 and 2.

3. RESULTS

Among the measurement parameters (RT, VD, Err, and SE), RT and Err were calculated to obtain reading speed (RS) (characters per second), $RS = n/RT$; and error rate (ER) (%), $ER = 100 \times Err/n$, where n is the number of characters displayed on the LCD. SE, RS, VD, and ER were statistically analyzed. The results of experiments 1, 2, and 3 are presented in the following three sections.

3.1. Results of Experiment 1

In experiment 1, English sentences were read. Experiments were performed with illumination of 702.0 ± 3.3 lx on the desk and 679.7 ± 1.2 lx on the MP screens. Luminosity (with black foreground and white background) of the LCD of MPs and contrast (ratio of white background to black foreground) were as follows:

- type H, luminosity: black, 6.1 ± 0.0 (cd/m^2); white, 170.9 ± 0.2 (cd/m^2); contrast, 28.2;
- type L, luminosity: black, 3.1 ± 0.0 (cd/m^2); white, 33.7 ± 0.1 (cd/m^2); contrast, 10.8.

The results of the experiments are shown in Figure 4. Two-way ANOVA using type of MP (H and L) and character size (L, M, and S) as factors showed significant differences in SE both between types H and L ($p < .0001$) and among sizes L, S, and M ($p < .0001$) without interaction effects. No significant difference was observed in RS or VD with the group test. However, the paired t test showed significant differences in RS between sizes L and VS ($p = .0218$), in VD between sizes M and S ($p = .0002$), and between sizes with more marked differences for type H. There were also significant differences in RS between sizes M and S ($p = .0321$), in VD between sizes M and S ($p = .0133$), and between sizes with more marked differences for type L. For size S, significant differences were observed in both RS ($p = .0144$) and VD ($p = .0192$) between types H and L. Size S of type L showed an SE, RS, and VD comparable to or lower than those of size VS of type H. There were few errors during reading.

These results suggest that readability depends on the specification of the LCD and the displayed character size, and readability by SE, RT, and VD decreases with a decrease in character size. This tendency was more marked for the type of LCD with low luminosity and resolution.

3.2. Results of Experiment 2

Experiments using Japanese sentences were performed with illumination of 624.3 ± 7.4 lx on the desk and 294.0 ± 7.9 lx on the screen of MPs. Luminosity and contrast for the type-H LCD used in this experiment were luminosity: black, 5.8 ± 0.2 (cd/m^2); white, 205.8 ± 0.8 (cd/m^2); contrast, 35.7.

The results of analysis are shown in Figure 5. Significant differences were observed in SE among sizes L, M, and S and between the Gothic and Mincho fonts. Though SE did not significantly differ between the two age groups, the differences in SE among sizes L, M, and S

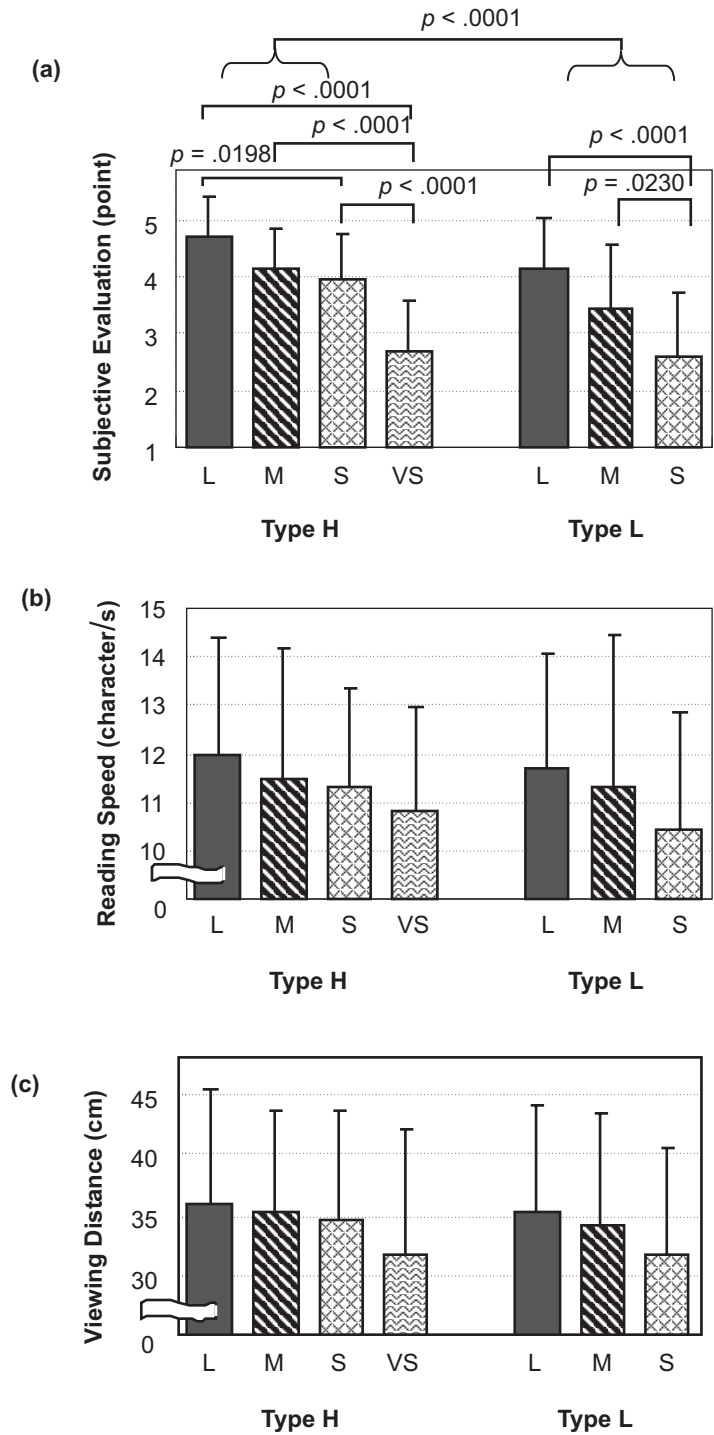


Figure 4. Results of experiment 1; reading English using two types of mobile phones. Notes. Character sizes of L, M, S and VS are as shown in Figure 2. Mobile phone type H and L are as shown in Table 1.

were more marked in the aged group (50–78 years), indicating that they had difficulty in reading small characters (Figure 5a). RS, VD, and ER as objective parameters significantly differed between the two age groups (Figures 5b–d). With a decrease in character size, RS tended to

decrease in the aged group (Figure 5b), while VD tended to decrease in the young group (Figure 5c). Reading errors were rarely observed in the young group, but ER increased with a decrease in character size in the aged group (Figure 5d).

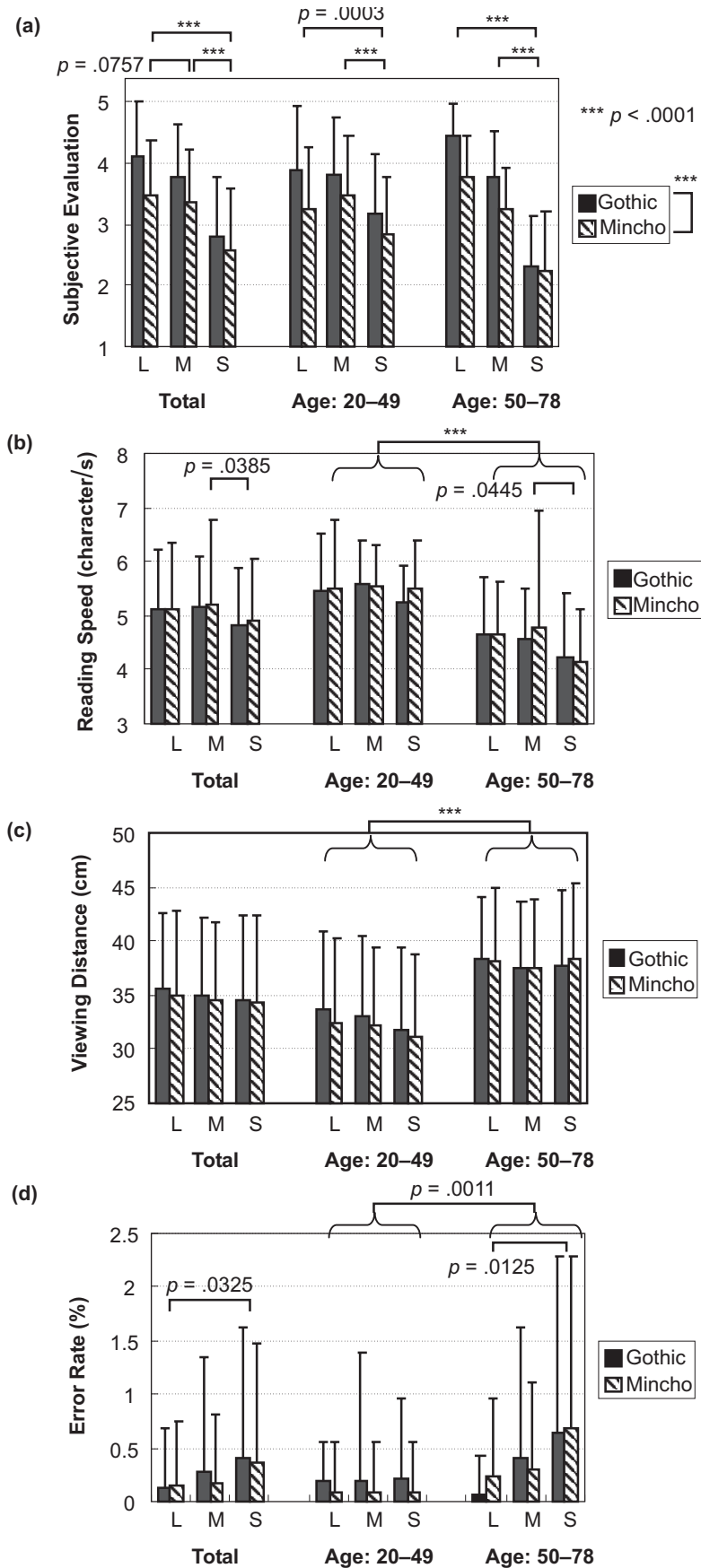


Figure 5. Results of experiment 2; reading Japanese characters. Samples of characters displayed on mobile phone screen are shown in Figures 3a-f.

3.3. Results of Experiment 3

The conditions of experiment 3a comparing characters vertically enlarged 1-, 1.25-, 1.5-, 2-, and 2.5-fold were the same as those in experiment 2. Experiment 3b comparing characters vertically enlarged one-, two-, three-, and fourfold was performed with illumination of 447.3 ± 15.2 lx on the desk and 396.0 ± 16.8 lx

on the MP screen. Luminosity and contrast of the type-H LCD were luminosity: black, 7.4 ± 0.9 (cd/m²); white, 197.6 ± 1.6 (cd/m²); contrast, 26.7.

The results of the experiments are shown in Figure 6. SE showed that characters vertically enlarged twofold were most easily readable, with marked and significant differences from the

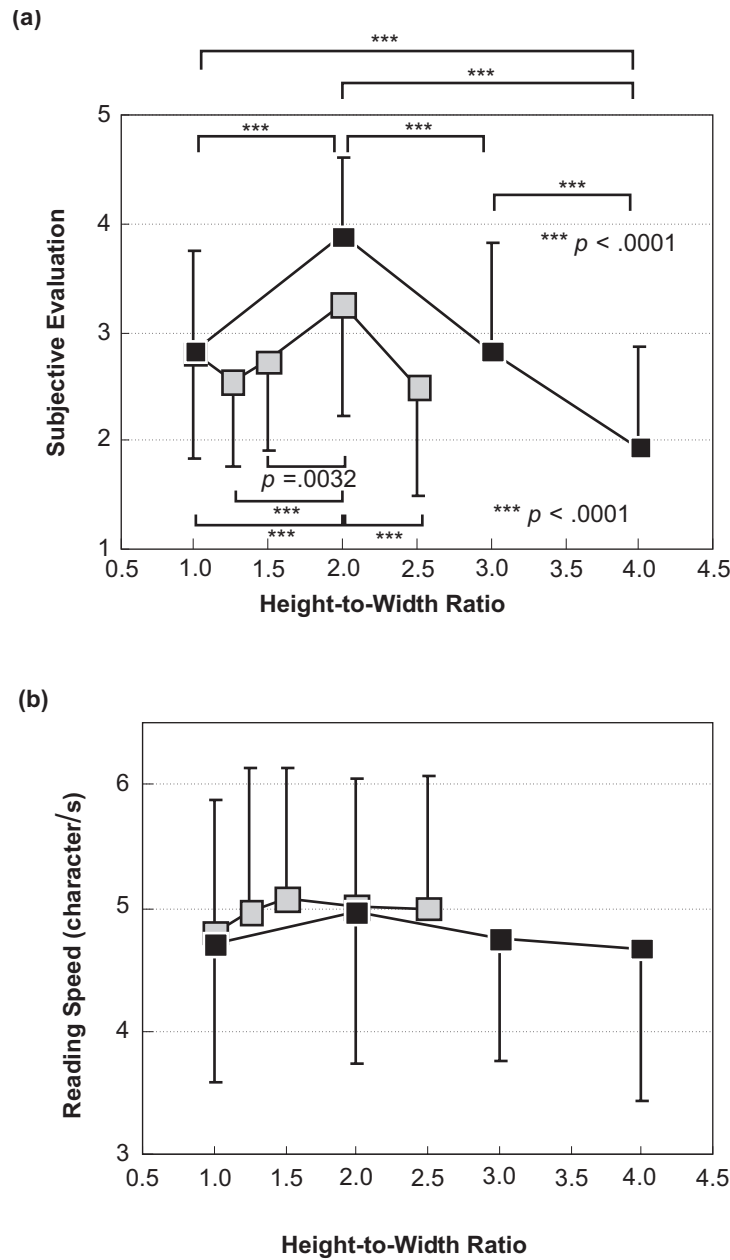


Figure 6. Results of experiment 3; reading vertically long Japanese characters. Samples of characters displayed on mobile phone screen are partly shown in Figures 3g–j. Notes. ■—experiment 3a, ■—experiment 3b.

other sizes (Figure 6a). RS did not significantly differ by the group test. However, the paired *t* test among characters vertically enlarged 1-, 1.25-, 1.5-, 2-, and 2.5-fold showed significant differences in RS between 1- and 1.5-fold characters ($p = .0039$), between one- and twofold characters ($p = .0214$), and between 1- and 2.5-fold characters ($p = .0429$). Comparison among characters vertically enlarged one-, two-, three-, and fourfold showed significant differences in RS between one- and twofold characters ($p = .0009$) and between two- and threefold characters ($p = .0040$) (Figure 6b).

ER was also the lowest for characters vertically enlarged twofold. Thus, objective parameters also showed an improvement in readability through an approximately twofold vertical character enlargement. VD negligibly changed with vertical enlargement.

4. DISCUSSION

The results of the experiment using English sentences in subjects with normal visual acuity (Figure 4) showed that SE, RS, and VD decreased with a decrease in character size. The decrease of those parameters was marked for the MP type with low luminosity and resolution (type L). Size S of type L showed an SE, RS, and VD comparable to or lower than those of size VS of type H (Figure 4). These results suggest that the parameters of SE, RS, and VD measured in this experiment can be used to estimate the readability of characters on LCDs in MPs.

As VDT work criteria, Standard No. ISO 9241-3:1992 [8] recommends that the minimum alphabetical or numerical character height should be 16', with character heights of 20–22' preferred. Miyao, Hacisalihzade, Allen, et al. [3] indicated the need for higher height for CRTs with low resolution. Character readability differs between the CRT and LCD [4, 17]. The visual angle of 20–22' corresponds to an assumed character height of 2.9–3.2 mm at a VD of 50 cm in VDT work. Considering that the VD of MPs is ~35 cm, the height becomes ~2.2 mm. Based on the mean VD in experiment 1 (Figure 4c), the visual angle at a VD of 31.8 (mean value)

for size VS (height, ~1.8 mm) of type H was 19.5', when SE and RS markedly decreased. Therefore, a visual angle of 20' or more may be necessary, which is consistent with the VDT work criteria proposed by ISO [8]. However, the visual angles for sizes S, M, and L of type H similarly calculated using the mean VD were 27.8', 34.1', and 40.1', respectively, and those for sizes S, M, and L of type L were 30.3', 35.3' and 40.9', respectively. Since size S of type L (height, 2.8 mm; averaged visual angle, 30.3') showed readability comparable to or lower than that of size VS of type H (Figure 4), this size can not be recommended for the LCD of MPs. In addition, though the mean point for SE (Figure 4a) was more than 3.0 for sizes S, M, and L of types H and M, and L of type L, even size L was not large enough in terms of SE or RS to cause the saturation of values. These comparisons of visual angle suggest that the optimal character size for comfortable reading on MP displays is considerably larger than the lower limit size in VDT work using PC displays.

When VD is shortened, the visual angle increases, producing enlargement effects on characters with a small display size. However, as definitely shown by size S in Figure 4c, VD was shorter for type L than for type H even when character size was the same. This suggests that VD is not determined by character size alone but decreases with a decrease in visibility in young and middle-aged people with normal visual acuity. Therefore, for not only characters with low readability due to their small size but also those with low readability due to low resolution or luminosity (contrast), people may act to shorten VD (increase the visual angle). However, even if the low readability of characters is compensated for by shortening VD, both SE and RS decrease, as shown in Figures 4b–c. Due to recent technological advances, the resolution and luminosity of LCDs have been increasing. However, the results of this study suggest that the types of MP used in this study (Table 1) still have inadequate resolutions and contrasts (type H: ~30; type L: ~10).

The results of this study also showed high readability with larger characters. However,

since the LCD of MPs is much smaller than that of PCs, when character size is large, the number of words that can be displayed on a line decreases, which may reduce usefulness and readability. In experiment 2 using Japanese sentences, the number of characters in each line was made constant, and the range of practical character size (2.8–4.2 mm) was evaluated in detail. On both VDTs and printed material, character size required for Japanese characters, including Chinese characters, is larger than that for alphanumerical characters [9, 11]. In VDT work, a visual angle of 30–35' is required, which corresponds to 4.4–5.1 mm at a VD of 50 cm and 3.1–3.6 mm at a VD of 35 cm. The results of the experiments showed the following. Readability was higher for the Gothic font with constant stroke width than for the Mincho font. For each font, readability decreased with a decrease in character size. Irrespective of age, SE decreased with a decrease in character size. The decrease in reading performance due to a decrease in character size was objectively reflected by a decrease in RS and an increase in ER in the aged group. VD was not associated with the height of the subjects ($r = .13$, size S). In the young group, VD decreased with a decrease in character size (Figure 5c), which may increase the visual angle, increasing the size of the displayed small characters on the retina for the maintenance of readability. In the young group, even when a decrease in character size reduced SE (Figure 5a), RS did not decrease (Figure 5b).

When the visual angle is increased by shortening VD, the influences of the resolution of the LCD may increase, or the transfer distance of the visual line for reading one line may increase, which may reduce readability. In this study, though glasses for near vision were used as in daily life, VD increased with the age of the subjects ($r = .43$, size S) and was significantly longer in the aged group than in the young group (Figure 5c). In the aged group, VD probably increased because near vision acuity decreased due to the influence of presbyopia in many subjects, but these influences markedly differed among individuals [14, 15]. In any case, mean VD increased irrespective of character size

in the aged group, and RS and ER as objective parameters showed a decrease in readability due to small character size. Therefore, the aged may have difficulty in adjusting VD to optimal VD, at least in the range allowing adjustment by the length of their arm with a MP in their hand.

In this study, the SE points for the young group (age, 20–49 years) were low for size S (~2.8 mm) but did not differ between sizes M (~3.5 mm) and L (~4.2 mm). This result suggests that 3.5 mm is large enough for young people. However, in all the subjects including the aged group, SE showed that size L was more desirable than size M (Figure 5a). In the young group, as described earlier, readability observed using objective parameters (Figures 5b–d) was not always consistent with SE (Figure 5a) due to influences such as those of adjustment of VD (Figure 5c).

Previous studies have suggested marked influence of character height on the readability of English/numerical characters [18]. The results of experiment 3 (Figure 6) show improvement in readability by enlarging the height of Japanese characters to twice their width. In this study, though simple enlargement of characters caused a decrease in vertical resolution and inequality in stroke width between the vertical and horizontal directions, readability improved. These results suggest that an increase only in the height of characters is useful for improving readability when the number of characters displayed in each line is not changed on the small LCDs of MPs with limited width.

5. CONCLUSIONS

We considered subject reading performance with MP character displays to evaluate the readability of characters on the LCDs of MPs in subjective and objective evaluations using English and Japanese sentences.

The LCDs of MPs require higher resolution than those of PCs because MPs are used in the hand at a nearer distance. For Japanese characters, readability was higher for the Gothic font, which has constant stroke width, than for the Mincho font. As character size, 3 mm or more is recommended based on the results of SE by the

young group. However, considering that VD can be freely adjusted within a certain range, when the young with a high 30 cm near vision acuity read short sentences displayed on one screen of the LCD with high luminosity, the readability of 2.8-mm or smaller characters is similar to that of 3-mm characters. However, when aged people are included, even 4.2-mm or larger characters are not adequate.

When the aged with decreased near vision acuity use MPs, adequate VD may not be achieved. There are marked individual differences in the decrease in visual function including contrast sensitivity, extent of the visual field, and cataract cloudiness. Since readability involves many factors in addition to visibility, estimation of the optimal uniform character size is difficult. Further development of studies on reading performance in the aged are awaited [14, 15, 19, 20].

When each character of the LCDs of MPs with limited width is enlarged, the number of characters on one line decreases, which may reduce readability. However, our results suggest that readability can be improved by simple vertical enlargement of characters, even Japanese characters that are not generally vertically enlarged, without reducing the number of characters in one line.

In the near future, character information on ubiquitous terminals such as MPs may be widely used for business by workers, and also for the transmission of various information, e.g., on disasters or emergencies. General MP users should be able to recognize received information that may include public or urgent information, regardless of their age and visual function. In addition, some MP users may use multilingual letters including multi-byte characters such as Japanese for global business. Others may use character information displayed on the small screens of MPs for an occupation for a long time. Users should choose a mobile information terminal that can be adjusted to their purpose, visual functions and other conditions, to their occupational safety and health. Users should request this so that such a mobile terminal is developed in future. This study showed the

necessity of functions that increase character size and height according to users' situation to realize safe universal design. We also aim at the realization of human-centered design through further ergonomic studies on the performance of MP users.

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