EMPIRICAL ANALYSIS OF HOW VISUAL PROPERTIES OF TEXTS AFFECT MANUAL LEGIBILITY

Takugo Y. FUKAYA[*ac], Susumu ONO[b], Minoru MINAKUCHI[b], Gaku SUMINO[b], Koji YOSHIDA[b], Masako HAYASHI[b], and Hiroshi ANDO[ad]

[a] *ATR Media Information Science Laboratories, Japan*
[b] *FUJI PRINTING Co., Ltd., Japan*
[c] *Nara Institute of Science and Technology, Japan*
[d] *National Institute of Information and Communications Technology, Japan*

ABSTRACT

In designing manuals, the visual impression of the text is extremely important in motivating users to read the manual. To empirically clarify how visual properties of text influence the legibility and provide a quantitative guideline for designing user-friendly manuals, we manipulated four visual properties of Japanese text using Universal Design Fonts, i.e., the size of characters, the aspect ratio (width-to-height ratio) of each character, and the space between lines and characters. We experimentally evaluated how these properties affect the legibility of texts. Using a conjoint method and a rating method with a rating scale of 21 steps, we examined various types of visual formats that consisted of these properties. Several thresholds were found that influenced the legibility of visual format. The results of the experiments suggest that if there is no restriction on spatial cost, it is recommended to use a large character size (at least 10 points) with a relative interline spacing of 0.7 and an aspect ratio of 1.0. However, in cases in whicth the overall space should be restricted, it is desirable to use at least a character size of 7.5 point with the relative interline spacing of 0.3 and an aspect ratio of 0.7 in order not to impose a severe visual burden on the users.

Keywords: *character size, interline spacing, letter spacing, character aspect ratio, conjoint method*

---

[*] **Corresponding author**: 2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0288, JAPAN.
E-mail address: tfukaya@atr.jp (T.Y. Fukaya).

1. INTRODUCTION

Do you thoroughly read instruction manuals when you use newly-purchased home electronics, such as mobile phones, video recorders, digital cameras, etc.? As the functions of such electronics become more diverse, the instruction manuals get more complicated and ever larger. Therefore, users tend not to read the instruction manuals carefully. In addition, to reduce the cost of printing, manual makers tend to pack all the instructions into a limited number of pages using small fonts with less spacing, which makes the legibility of manuals even more difficult.

The visual impression of the text in a user manual is extremely important to motivating users to read it. Most of you, when picking up and glancing through a manual, would think, "It looks too difficult to read," or "It looks interesting; I'll read it," before you actually read any of it. The difference in the two responses is the result of the visual appeal of the format.

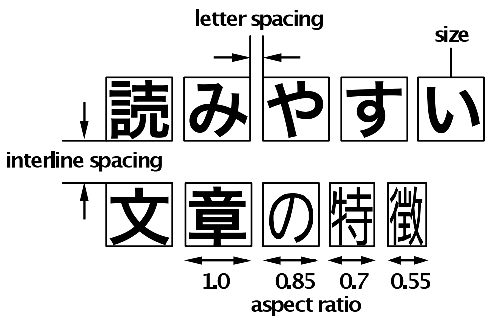

Figure 1: Factors that affect the legibility of text

A number of findings on legibility and text format have been reported in previous research [e.g., 1, 2, 3, 4]. It is well known that font type and size influence legibility. For instance, text written in 14 point type is more legible than text in 12 point type, and sans-serif is more legible than serif in the case of 12 point type, but is not more legible in the case of 14 point type [3]. Also, as Tinker reported, space between lines has a significant influence on legibility when the size of the character is smaller than 12 points [5]. Based on these noteworthy findings, some guidelines for visual formatting have been recommended for designing instruction manuals. For example, ISO recommends 10 point or 12 point type and the use of serif font for the text proper [6]. CPSC indicates that type sizes ranging from 10 to 12 points may be acceptable and type of 14 points or larger is preferred for older and visually impaired users [7].

However, these recommended guidelines do not reflect the current situation of most product manuals. While research on legibility has provided many guidelines, on some issues, there has been no consensus. For example, no one has provided a conclusive answer as to which font, serif or sans serif, provides the best legibility. As for instruction manuals, many manuals are written in sans serif fonts such as Arial, contrary to the guidelines. Moreover, it is not unusual to use characters smaller than 8 point or narrowed characters in a limited area to reduce the cost of printing. Therefore, it is necessary to quantitatively investigate the reasons and the guidelines that are used in the actual manuals in order to reduce the visual burden for users. Furthermore, because the visual impression of text format in one language is different from others, these guidelines should be required for each language and each country. For example, Chinese characters do not have a concept of "x-height", which is common as a baseline of the alphabet, so one cannot simply use the guidelines for the alphabet in place of those for Chinese characters. The same concept is true in other languages.

The purpose of this research is to empirically clarify how visual properties of text influence the legibility and to provide a quantitative guideline for designing user-friendly manuals. In particular, clarifying the most legible formats and the minimum requirements for the manuals written in Japanese is our goal. We focused on four visual properties of Japanese text, i.e., the size of characters, the aspect ratio (width-to-height ratio) of each character, the space between lines, and the space between characters (see, Figure 1), and experimentally evaluated how these properties affect the legibility of texts using Universal Design Fonts. In the first experiment, we employed a conjoint method in which the subjects rearranged text-written cards with different visual properties in the order of legibility. In the following two experiments, we used a rating method with a rating scale of 21 steps and also analyzed by machine learning to investigate in more detail how the visual properties of text affect the legibility.

2. GENERAL METHOD

Twenty-four Japanese subjects including twelve females and twelve males, ranging in age from 35-69, were divided into three groups: Group 1 (ages 35 - 44, average. 40.6); Group 2 (ages 45 - 64, average. 55.4); and Group 3 (ages 65-69, average. 67.4). There were four females and four males in each group and all participated in each of the three experiments. All subjects had normal color vision and over 20/25 vision or corrected vision. Each subject received approximately $10/hour for their participation. Throughout all three experiments, the subjects evaluated the legibility of text in black type printed on white paper, which had a brightness of approximately 200 cd and high contrast on a table at a distance of 50 cm from their eyes under illumination of over 300 lx. All evaluated text was printed in Japanese using Universal Design Font (hereafter "UD Font"), which has become standard among product instructions or user's manuals in Japan. In each text, the following four visual properties were manipulated: 1) size of the characters ("size"), 2) space between lines ("interline spacing"), 3) space between characters ("letter spacing"), and 4) (width-to-height) aspect ratio of each character ("aspect ratio"). The size unit examined is "point" ("pt"). In addition, we also used 1/1000 em as a letter spacing unit, which is commonly used in desk-top publishing. As for interline spacing, the value used is a relative scale of character size; similarly, the aspect ratio is that of width to height of character size.

3. EXPERIMENT 1: PREFERENCE EVALUATION OF TEXT FORMAT

Depending on a number of factors such as the type of product or the user age-group, typical instruction manuals include various types of visual formats of text. These visual formats consist of size, interline spacing, letter spacing, and aspect ratio. In this experiment, the congestion degrees of text in a fixed area were evaluated. To investigate the preferable visual format of texts, we tested various visual formats using a conjoint method.

Table1: Card number and selected factors and levels assigned to L16 orthogonal array

card number	size	interline spacing	aspect ratio	letter spacing	card number	size	interline spacing	aspect ratio	letter spacing
1	7	0.1	1	0	9	9	0.1	0.7	-80
2	7	0.2	0.85	-20	10	9	0.2	0.55	-40
3	7	0.3	0.7	-40	11	9	0.3	1	-20
4	7	0.4	0.55	-80	12	9	0.4	0.85	0
5	8	0.1	0.85	-40	13	10	0.1	0.55	-20
6	8	0.2	1	-80	14	10	0.2	0.7	0
7	8	0.3	0.55	0	15	10	0.3	0.85	-80
8	8	0.4	0.7	-20	16	10	0.4	1	-40

3.1. Method

The four parameters and their ranges in a visual format of text are as follows: size (7 pt, 8 pt, 9 pt, 10 pt); interline spacing (0.1, 0.2, 0.3, 0.4); letter spacing (0, -20, -40, -80); and aspect ratio (1, 0.85, 0.7, 0.55). These variables were assigned to the L16 orthogonal array, and the experimenter made 16 sheets of cards, each of which had printed text corresponding to the assigned orthogonal array. Table 1 shows the contributing factors and levels that were assigned to 16 sheets of cards. Taking into account the possibility that these levels were used in actual manuals, we carefully adopted these levels. Each card was 91 mm in width and 55 mm in height, and also had a 56 mm×50 mm text area in which typical manual-style cautionary statements were printed, such as "Danger of explosion if battery is incorrectly replaced." (see, Figure 2). In the same way, we made another 16 sheets of cards with a wider text area (80 mm×50 mm). For both texts, 56 mm and 80 mm in width, all subjects rearranged 16 sheets of text-written cards with different visual properties in the order of legibility within five minutes.

Figure 2: Examples of Card nos. 5, 6, 7, and 8. Case of text 56mm in width

3.2. Results

Table 2 shows the integrated order of cards rearranged by the subjects in the order of legibility, in both the 56 mm and 80 mm width cases. Scoring the lowest card "1"and the highest card "16," we obtained the values of utility by using quantification method I. Figure 3 is a graph which represents the value of utility in both the cases of text 56 mm and 80 mm in width. As this graph shows, the size affects the user's preference most, and the letter spacing has the least influence. In particular, the utility of 10 pt characters had a greater affect on the subject's preference. Conversely, the text written in 7 pt characters showed a negative effects on their preferences. Similarly, when the aspect ratio is 1.0, the utility is greater, and in the case of 0.55, the effects are considerably negative.

Table 2: Order of cards rearranged by subjects based on legibility

text width 56 mm				text width 80 mm			
order	card number (number of characters)	order	card number (number of characters)	order	card number (number of characters)	order	card number (number of characters)
1	16 (160)	9	9 (378)	1	16 (230)	9	9 (546)
2	15 (220)	10	5 (384)	2	15 (308)	10	5 (544)
3	11 (204)	11	10 (429)	3	11 (300)	11	1 (576)
4	12 (220)	12	1 (396)	4	12 (319)	12	10 (611)
5	14 (264)	13	7 (468)	5	14 (384)	13	7 (663)
6	6 (315)	14	2 (459)	6	6 (450)	14	2 (646)
7	8 (364)	15	3 (495)	7	8 (533)	15	3 (720)
8	13 (377)	16	4 (616)	8	13 (546)	16	4 (882)

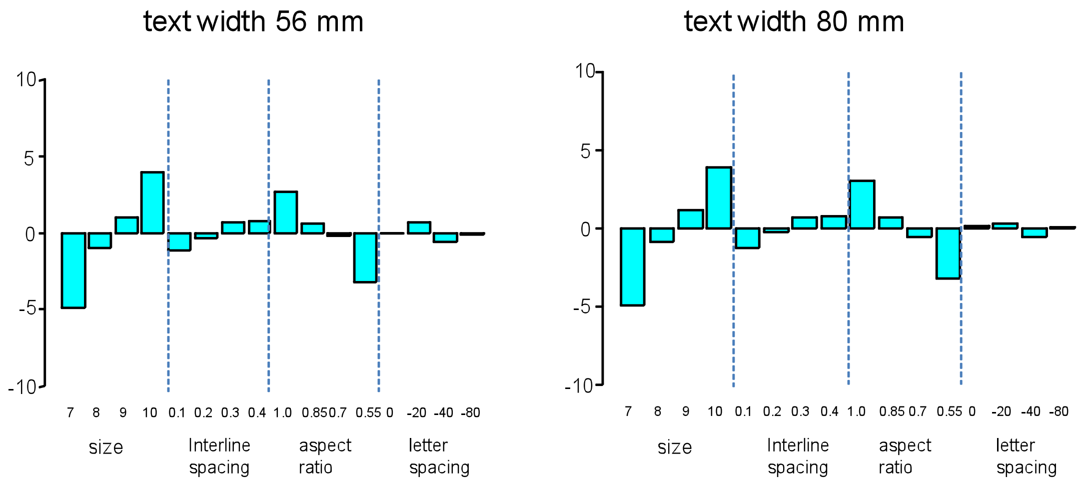

Figure 3: Value of utility to each visual factor of text of width 56 mm and 80 mm widths. The values over 0 indicate positive contributions to preference of subjects.

4. EXPERIMENT 2: EVALUATION OF SIZE × INTER LINE SPACING × LETTER SPACING

The above-described experiment clarified that the size, aspect ratio, and interline spacing affect the subject's preference of visual format compare to letter spacing. In this experiment, a rating method with a rating scale of 21 steps was used to clarify quantitative borders in greater detail, where the visual format of text is classified as legible or illegible because of differences of size, interline spacing, and letter spacing.

4.1. Method

All subjects rated the legibility of texts in 21 ranks. The visual formats of the text were as follows: size (6 pt, 7 pt, 8 pt, 9 pt, 10 pt), interline spacing (0.2, 0.4, 0.6, 0.8), and letter spacing (0, -40, -80). The text samples were printed on B5 paper and had the same content in about 200 characters and were evaluated by the subjects in random order every 8 seconds. In the two cases of text width, 56 mm and 80 mm, these evaluations were performed twice.

4.2. Results

Considering an average of two times per subject for each evaluation, the averages were calculated. Figure 4 shows the averaged evaluations for all text formats. A rating score of "0" means neutral and a positive score indicates a higher legibility. 5×4×3 within-subject ANOVA was used to see if each evaluation actually depended on the visual properties of each text, and to find intervals in which the differences of evaluation tended to be small. In the case of 56 mm width text, the interaction of size×letter spacing ($F(8,184)=2.13$, $p<.05$), size×interline spacing ($F(12,276)=4.33$, $p<.00$), and size×letter spacing×interline spacing ($F(24,552)=1.68$, $p<.05$) were significant, but letter spacing×interline spacing was not. Meanwhile, in the case of 80 mm width text, the interaction of size×interline spacing ($F(12,276)=5.05$, $p<.00$) and size×letter spacing×interline spacing ($F(24,552)=1.87$, $p<.00$) were significant, but size×letter spacing and letter spacing×interline spacing were not. In the interaction of size × interline spacing, simple effects of each level were significant.

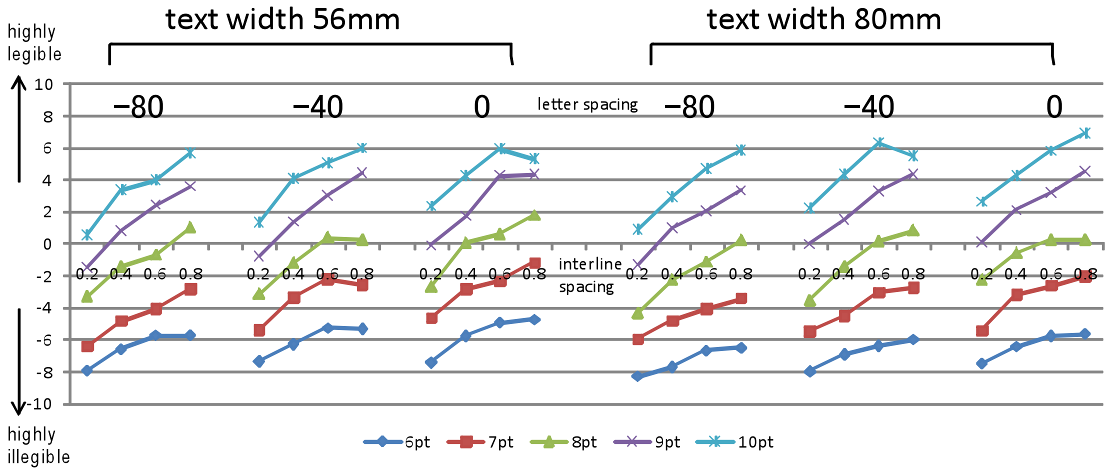

Figure 4: Averaged evaluation by rating scale in each visual format that consists of size, interline spacing, and letter spacing.

Multiple comparisons of simple effects of interline spacing showed that increasing interline spacing from 0.2 to 0.4 significantly improved legibility in all sizes; additionally, little improvement was observed in legibility between interline spacing of 0.6 and 0.8 for all sizes. The difference in legibility between interline spacing 0.4 and 0.6 was not significant when the sizes were 6 pt, 7 pt, and 8 pt. The same was true for text with 80 mm width. These results indicate that as for interline spacing, there is a large gap in legibility between 0.2 and 0.4, but there is little difference in legibility between 0.6 and 0.8. A clear tendency was not found for simple effects of letter spacing despite multiple comparisons.

4.3. Result by decision trees

In order to clarify the priority of factors and levels, which the subjects judged as legible or illegible, machine-learning analysis with C4.5 algorithm was applied to the evaluation results, by using a program whereby "over 0 is legible" or "under 0 is illegible." Figure 5 shows the decision tree which C4.5 algorithm derived from evaluation of all subjects. As the left decision tree for Group 1 (ages 35–44) shows, the most determinative factor for legibility is size over 7 pt among relatively young people, and next factor is the interline spacing over 0.2. Additionally, the right tree shows that the most determinative factor among older people (in Group 3, ages 65-69), is size over 8 pt followed by interline spacing over 0.2, and size over 0.9.

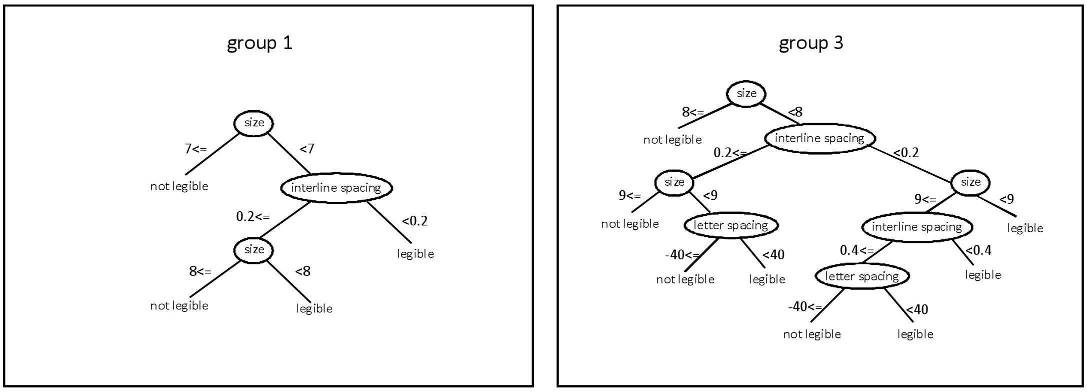

Figure 5: Example of decision trees. The left figure shows the decisions of Group 1 (ages 35–44), and the right figure shows the decisions of Group 3 (ages 65–69). The left tree classified 81% of results and the right tree classified 74% of the results correctly. Both trees used text of 56 mm in width.

5. EXPERIMENT 3: EVALUATION OF SIZE × INTERLINE SPACE × ASPECT RATIO

Similarly to Experiment 2, variations of text format as to size, interline spacing, and aspect ratio were investigated to clarify the borders in which the text was classified as legible or illegible.

5.1. Method

All subjects rated the legibility of text into 21 ranks in the same way as in experiment 2. The visual formats of the text are as follows: size (6 pt, 7 pt, 8 pt, 9 pt, 10 pt), interline spacing (0.2, 0.4, 0.6, 0.8), and aspect ratio (0.55, 0.7, 0.85). The letter spacing was fixed at "0."

5.2. Results

Evaluation scores of all subjects were averaged in the same manner as in experiment 2. Figure 6 shows the averages of all subjects' evaluations for all text formats. (Data of aspect ratio 1.0 were the same as in experiment 2.) The result of 5×4×3 within-subject ANOVA showed that the interaction of size×aspect ratio (56mm:$F(12,276)=3.34$, $p<.00$, 80mm: $F(12,276)=5.21$, $p<.00$), size×interline spacing (56mm:$F(12,276)=5.00$, $p<.00$, 80mm: $F(12,276)=9.92$, $p<.00$), aspect ratio×interline spacing (56mm:$F(9,207)=$, $p<.00$, 80mm: $F(9,207)=7.22$, $p<.00$), and size×aspect ratio×interline spacing (56mm:$F(36,828)=1.62$, $p<.05$) were all significant in texts of both 56 mm and 80 mm in width, except for the interaction of size×aspect ratio×interline spacing in 80 mm width text. Simple effects in interaction of size×aspect ratio were all significant in all combinations of each level. Multiple comparisons showed little difference between aspect ratios of 1.0 and 0.85, when sizes were 6 pt, 7 pt and 8 pt. In the interaction of aspect ratio×interline spacing, multiple comparisons showed no significance for most levels of aspect ratio, when the combination of interline was 0.6-0.8. From these results, we found that the aspect ratio affects legibility between 0.55 and 0.85, regardless of character size, and that the aspect ratio does not affect legibility between 0.85 and 1.0 when character size is small. Moreover, we found that there is no statistical difference of legibility when interline spacing is 0.6 and 0.8, regardless of aspect ratio. As for interaction of size×interline spacing, the results of the multiple comparison shows that interline spacing between 0.6 and 0.8 had no significant difference on legibility for most sizes .

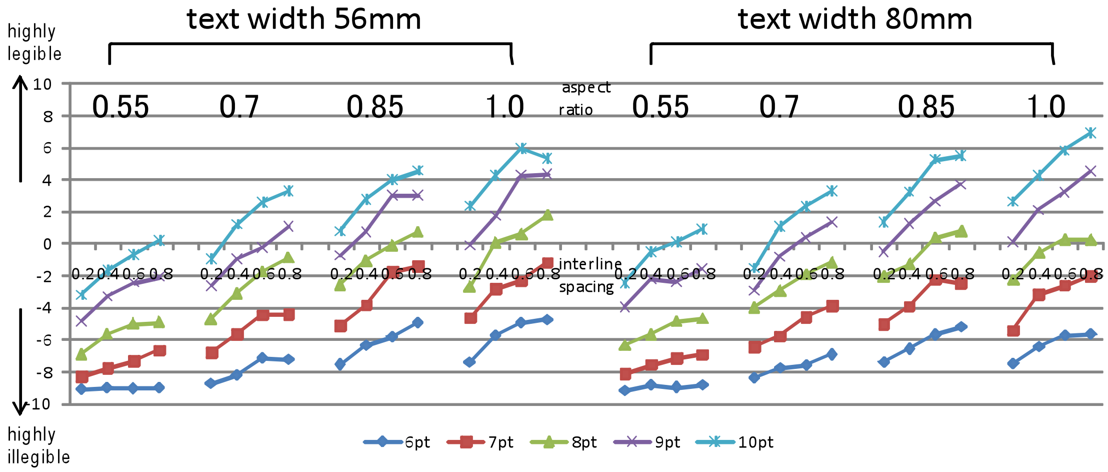

Figure 6: Averages of evaluation scores by rating scale in each visual format that consists of size, interline spacing, and aspect ratio.

5.3. Result by decision trees

Machine-learning analysis was applied to the evaluation results, as in experiment 2. As the decision tree for Group 1 in Figure 7 shows, the most determinative factor for legibility is size over 7 pt, followed by an aspect ratio over 0.55. The right tree in Figure 7 shows that the most determinative factor among Group 3 was an aspect ratio over 0.55 followed by interline spacing of over 0.4.

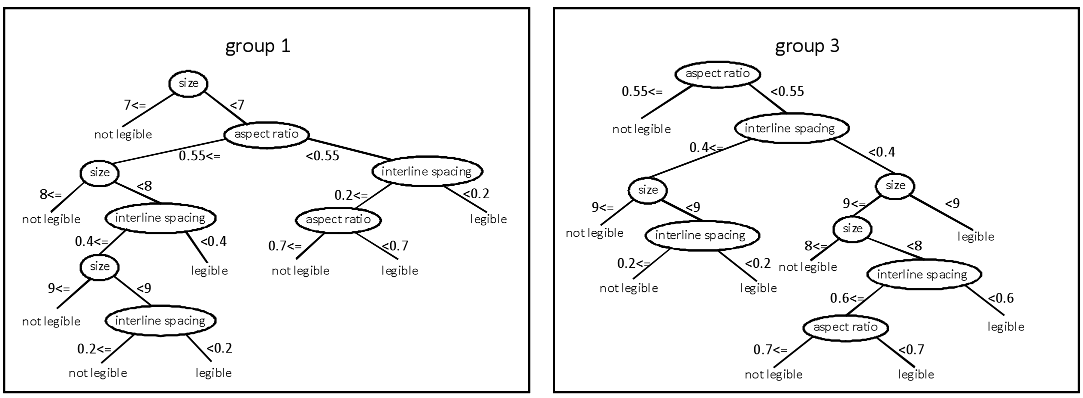

Figure 7: Example of decision trees. The left figure shows the decisions of Group 1 (ages 35–44). The right figure shows the decisions of Group 3 (ages 65–69). The left tree classified 80% of results correctly, and the right tree classified 82% of results correctly. Both trees used text of 56 mm in width.

6. DISCUSSION

In this study, various types of visual factors in Japanese text such as size, interline spacing, letter spacing, and aspect ratio, were empirically examined, and guidelines of legibility of text were found for designing manuals. Through the three experiments, we have quantitatively and qualitatively clarified the relationships between visual format of texts and the impressions that users received.

Concerning the size of character, basically, legibility is high when text is written in larger size type. The value of utility by conjoint method, and evaluated value of legibility by rating scale, as well as the results of the decision trees all suggest that there is a threshold of legibility, between 7 pt and 8 pt in Japanese text with UD Font. In particular, the results by decision trees suggest that character size for aged people should be larger than 8 pt. Compared to other guidelines for designing English manuals, this result is same as the minimum size recommended [8]. Also, the results by decision trees suggest differences of thresholds based on age.

Previous research has reported that approximately 0.7 interline spacing most contributes to legibility [9]. In our experiment, most cases had high scores and no statistical difference was found between 0.6 and 0.8 in legibility. This further suggests that a size near 0.7 best contributes to legibility. The results of ANOVA and the decision trees suggest that there might be a threshold which classifies text into "legible" or "illegible", between 0.2 and 0.4. This is consistent with previous findings using a kind of sans-serif font in Japanese text [9].

This study has revealed a fact about the aspect ratio, that has, hardly been mentioned until now: The impression of text legibility rapidly worsened between the aspect ratios of 0.7 to 0.55. Specifically the results of the decision trees suggest that aspect ratio for aged people should be larger than 0.7. It was also revealed that when the size of the characters is small, an aspect ratio between 0.85 and 1.0 has no significant difference in legibility. Moreover, legibility becomes better from 0.2 to 0.6 of interline spacing, irrespective of the aspect ratio.

The present study adds new empirical evidence about the thresholds that classify text as legible or illegible based on age. Specifically by using machine learning, we could obtain a clear order of preference for legibility. In summary, we have shown integrated guidelines of text legibility in various visual formats. These findings show the possibility that designers of manuals can objectively choose appropriate formats for limited text areas.

7. CONCLUSION

This study empirically investigated how the visual format of text influences legibility, using conjoint method and a rating scale. The experimental results show that the legibility is good if the space between lines relative to the character size is around 0.7, but it worsens rapidly if the space between lines becomes less than 0.4. The aspect ratio also greatly affects the legibility, and most texts are considered illegible if the aspect ratio is less than 0.55. In conclusion, it is recommended that designers use large character size (at least 10 points) with a relative line-spacing of 0.7 and an aspect ratio of 1.0, provided that there are no restrictions on spatial cost. However, in cases where the overall space must be restricted, it is desirable to use characters of at least 7.5 point with a relative line-spacing of 0.3 and an aspect ratio of 0.7 in order not to impose a severe visual burden on the users.

REFERENCES

[1] Bernard, J. B., Scherlen, A. C., Vitu-Thibault, F., and Castet, E., Effect of Line Spacing on Reading Speed in Normally-Sighted Subjects with an Artificial Scotoma, *Journal of VISION*, Vol. 7, No. 9, 518, 518a, 2007.

[2] Chung, S. T., The Effect of Letter Spacing on Reading Speed in Central and Peripheral Vision, *Investigative Ophthalmology & Vision Science*, Vol.43, No. 4, pp1270-1276, 2002.

[3] Bernard, M., Liao, C. H., and Mills, M., The Effects of Font Type and Size on the Legibility and Reading Time of Online Text by Older Adults, *Proceedings of CHI*, WA, USA,pp.175-176, 2001.

[4] Arditi, A., and Cho, J., Serifs and font legibility, *Vision Research*, 45, pp.2926-2933, 2005.

[5] Tinker, M. A., *Legibility of Print*, Iowa State University Press, Iowa, USA, 1963.

[6] International Organization for Standardization, *ISO/IEC Guide 37: Instructions for Use of Products of Consumer Interest*, International Organization for Standardization, 1995.

[7] U.S. Consumer Product Safety Commission, *Manufacturer's Guide to Developing Consumer Product Instruction*, Consumer Product Safety Commission, Washington DC, USA, 2003.

[8] Schoff, G. H., and Robinson, P. A., *Writing and Designing Manuals*, Lewis Publishers, Michigan, USA, 1991.

[9] Sakamoto, R., and Kishida, T., Quantitative Analysis of Spacing between Lines to Make Descriptive Text Legible, *Panasonic Electric Works Technical Report*, Vol.52, No.3, pp.52-58, 2004.