Comparison legibility test on Japanese characters and English letters

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Abstract: Legibility thresholds of 210 Japanese characters (56 hiragana, 56 katakana, and 98 kanji) and 52 English letters (26 uppercase and 26 lowercase) were tested by 40 Japanese students (20 male and 20 female). Subjects were asked to identify the characters displayed initially in a minimum size. If the subjects cannot recognize it they required to press "enlarge" key to increase character size by one point until it was legible. The results illustrated that the legibility of the five kinds of characters can be classified into three groups, hiragana/uppercase/katakana, lowercase, and kanji. Increasing one stroke in a kanji should enlarge 0.4 min of arc for legibility complement. For the hiragana and katakana, adding a voiced consonant sign "゛" to a character should enlarge 10.3 min of arc for legibility complement and adding a semi-voiced consonant sign "o" to a character should enlarge 7 min of arc for legibility complement. The results can be a reference for information and interface design.

Key words: legibility, Japanese, Kanji, English letters, hiragana, katakana.

1. Introduction

Both pictorial and text information were used in daily life, however text is still the most common form for storing and conveying message due to its accuracy (Booher, 1975). In general, two kinds of text information are frequently used, the phonogram and ideogram. The most common examples are the English words and Chinese characters. English words are composed of left-to-right alphanumeric letters in one dimension which are belong to phonogram while the Chinese characters are composed of radicals with or without a stem in a two-dimension fashion which are belong to ideogram (Cai, Chi and You, 2001). However, the Japanese is hybrid system of phonogram and ideogram which included three kinds of characters, hiragana, katakana, and kanji. Most kanji were directly used Chinese character and some with little alternation. Hiragana was created according to the script font of kanji and katakana was created according to the Kai font of kanji (Yang, 2001).

Many studies have been conducted to develop ergonomic guidelines for presenting alphanumeric letters (Gould, 1963; Shurtleff, 1967; Smith, 1979; Human Factor Society, 1988, Sanders and McCormick, 1993, pp. 106-107) and for Chinese characters (Cai, Chi, and You, 2001; Chi, Cai, and You, 2003; Cai, Chi, and You, 2008). However it is interesting to test the legibility of the Japanese in its three kinds of characters.

In order to describe the Japanese characters and English letters more precisely with high fidelity presentation, a two-dimension array with 24 x 24 entries was adopted to save stroke images of a character (Cushman & Rosenberg, 1991). Each entry (P_{ij}) in the array can be classified as a stroke entry (presented as "■", entry value= 1) or a blank entry (presented as "□", entry value = 0) to present a stroke pixel or a blank pixel displayed on the screen. For a color display, each pixel is replaced by a coordinate of three integers each valued between 0 (without any color) to 255 (saturated with color) for red, green, and blue, respectively (Eten Information System Co. 1993; Chen 1996). Therefore, a pixel will be displayed in pure white for the tristimulus coordinate values of (255, 255, 255) and in pure black for (0, 0, 0). Each character to be tested can be saved as a picture file with a resolution of 24 x 24 pixels then displayed within a predetermined area. A software computer program written in C language was conducted to extract the tristimulus values of RGB (North and Fairchild 1993) and transform into 0 (blank) and 1 (stroke), respectively, for further analysis. Fig. 1 presents an example pixel matrix for the Japanese character "あ". All black cells presented the stroke have an entry value of 1, while the white cells are blank with a 0 entry value.

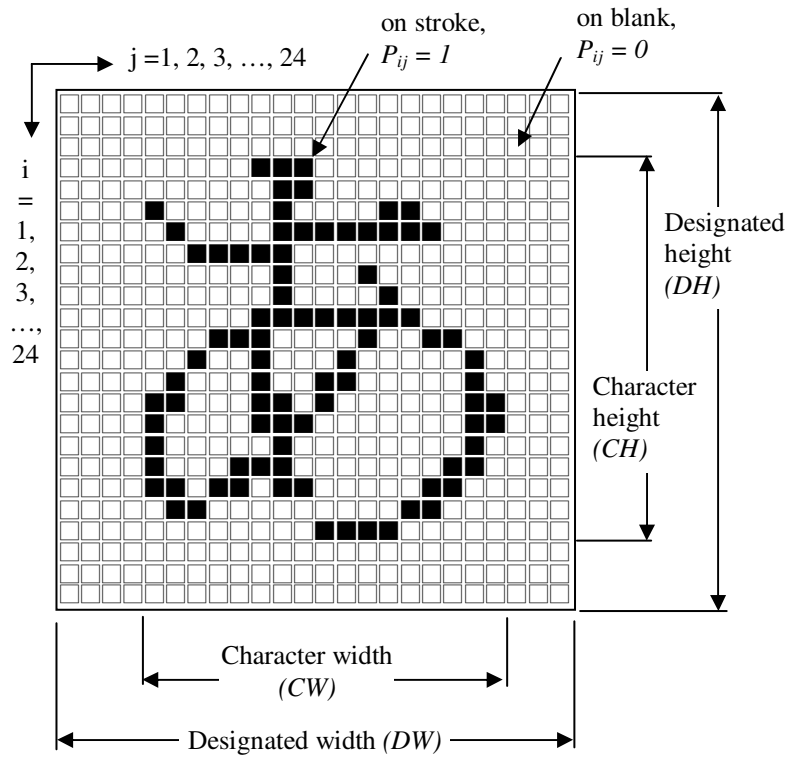

Fig. 1 Illustration of the definition of CH and CW

Similar to Chinese characters, the total number of strokes of a Japanese character is the conventional method for classifying and sorting the Japanese information in dictionary and telephone books, etc., and has proved to be a good predictor for the legibility threshold (Cai, Chi, and You, 2001). The number of strokes of kanji were found by using the kanji dictionary (Takatsuka, 1997). The number of strokes of hiragana and katakana were calculated by using the method for writing Japanese character (Yang, 2001). The number of strokes for the uppercase and lowercase forms of each of the 26 letters was taken from the study of Li and Yeung (1997).

A total of seven descriptors used in a previous study (Chi, Cai, and You, 2003) for Chinese characters, namely, the number of strokes (Stk), total amount of stroke pixels (Ta), character width (CW), character height (CH), character area (CA), width-to-height ratio (WHR), and character density (CD), were assessed from the pixel matrix. Table 1 presents the meaning, scopes, unit, and formulae of the seven descriptors, as well as the values of the seven descriptors for Japanese character "あ".

Table 1. Definitions and formulae for the seven descriptors

Descriptors	Meanings	Scopes	Units	Formulae	Values of descriptors
1. Number of strokes (Stk)	Complexity of characters	$1 \leqq Stk \leqq 20$	stroke		3
2. Total amount of stroke pixels (Ta)	Total amount or length of strokes in pixels	$0 < Ta \leqq 576$	pixel	$Ta = \sum_{i=1}^{24}\sum_{j=1}^{24} P_{ij}$	88
3. Character width (CW)	Maximum width of characters	$0 < CW \leqq 24$	pixel		17
4. Character height (CH)	Maximum height of characters	$0 < CH \leqq 24$	pixel		18
5. Character area (CA)	Maximum area of characters	$0 < CA \leqq 576$,	$pixel^2$	CA = CW x CH	17x18 = 306
6. Width-to-height ratio (WHR)	Square shape of characters	$1/24 \leqq CA \leqq 24$	--	WHR= CW / CH	17/18 = 0.944
7. Character density (CD)	Stroke density in character area	$0 < CD \leqq 1$	--	$CD = \frac{\sum_{i=1}^{24}\sum_{j=1}^{24} P_{ij}}{CA}$	88/306= 0.288

2. Methods

2.1 Subjects

Forty Japanese undergraduate and graduate students (20 male and 20 female) from Nagoya University of Arts and Science, ages 20 to 31 years (M= 23.7 years, SD= 2.1 years) participated in this experiment. All participants were native Japanese speakers and were pretested for at least 0.8 visual acuity, with corrective lenses if needed. Each subject was paid the equivalent of $8 US/hour for participation.

2.2 Materials

All the forty-six common characters and ten special pronunciation characters (voiced consonant and semi-voiced consonant) in both hiragana and katakana were used as experimental materials to test its legibility. Ninety-eight kanji characters were also selected from the most commonly used kanji characters for test. In addition, the 26 English letter in upper and lower case were used for comparing test. A total of 262 characters were tested (Table 2). The Japanese was displayed in Ming font (DFHSMincho-W3) and the English letters were displayed in Times New Roman. The Ming and Times New Roman fonts were chosen because they are the most common fonts used for text on displays (Sanders & McCormick, 1993).

2.3 Apparatus

The main apparatus was an IBM compatible notebook computer. The screen area was 287 x 180 mm with a resolution of 1280 x 800 pixels. Character area for displaying a 72-point character in the screen is 21.4 x 21.4

mm. A computer program was written in C language to control the experimental procedure, display character, and record experimental data for further analysis. A vision tester (OPTEC 2000) manufactured by Stereo Optical was used to measure the visual acuity.

Table 2. The 262 characters used in the experiment

Kinds	Characters
Hiragana	あぃうえお かきくけこ さしすせそ たちつてと なにぬねの はひふへほ まみむめも やゆよらり るれろわを ん ばぱびぴぶ ぷべぺぼぽ
Katakana	アイウエオ カキクケコ サシスセソ タチツテト ナニヌネノ ハヒフヘホ マミムメモ ヤユヨラリ ルレロワヲ ン バパビピブ プベペボポ
Kanji	弓貸詞囲組 図宙肉招臨 要障武縦多 我準発耳側 校巻論班刊 民骨並胸査 令厳湖農表 池重身度化 右悪菜朝人 内科暖専同 防本短君定 共来晴続例 久会調警貴 序顔文吸松 険館酒器衆 拾何連手敗 枝足緑護盛 寺測垂忠百 九塩鉄氷逆 清尊豊
Uppercase	ABCDE FGHIJ KLMNO PQRST UVWXY Z
Lowercase	abcde fghij klmno pqrst uvwxy z

2.4 Procedure

The subjects sat on the front of the screen with a viewing distance of 75cm with chin support with a chin rest. The experimental character was randomly displayed in the center of the screen. A typical psychophysical method called method of limits with ascending stimulus series (Coren et al., 1989) was used to determine the legibility threshold. Participants were asked to identify the displayed character within 0.75 second to avoid unwanted eye accommodation during the experimental process (Stevens, 1975). The characters were initially displayed in 3-point (72 points = 1 inch) which no subject was able to recognize it. If the subject cannot recognize the displayed character, he/she had to press the “enlarge” key on the keyboard to enlarge the letter by 1 point continuously, until the character was legible. When legibility was reached, the participant had to press the “enter” key to record the data pertaining to the tested character and had to write the recognized character on a test sheet to ensure correctness.

The legibility threshold of each character was estimated by averaging the minimum legible size recorded for the 40 participants. Transforming the legibility threshold into visual angle was done to make fair comparisons with other legibility studies. As the character area for displaying a 72-point character in the screen is 21.4 x 21.4 mm, so that the visual angle for the character can be calculated by using the formula: visual angle= character size (point)/72 x 21.4 x 3438/750.

3. Results and Discussion

3.1 The seven descriptors

The statistics of the seven descriptors, number of strokes, total amount of stroke pixels, character height, character width, character area, width-to-height ratio, and stroke density of the five kinds of characters were showed in Table 3.

ANOVA results illustrated that all the seven descriptors of the five kinds of characters were significantly different. Further results of Duncan test for the five kinds of characters were demonstrated in Table 3. For the number of stroke, the kanji was the most, hiragana, katakana and uppercase letter were the second, and the lowercase letter was the least. For the total amount of stroke pixels, the sequence from the most to the least was kanji, hiragana/ uppercase, and katakana/ lowercase. The sequences of both character height and character width, from the most to the least was kanji, hiragana/ katakana, uppercase, and lowercase. The sequence of the area, from the most to the least was kanji, hiragana, katakana, uppercase, and lowercase. For the width-to-height ratio, sequence of the WHR, from the most to the least was katakana/ hiragana/ kanji, uppercase, and lowercase. For the character density, the sequence from the most to the least was lowercase, uppercase/ kanji, hiragana, and katakana.

Table 3. The statistics of the seven descriptors of the five kind of characters

Descriptors	Fonts	N	Min	Max	Mean	Std	Duncan grouping
No. of strokes	Lowercase	26	1	2	1.19	0.40	A
	Uppercase	26	1	3	1.73	0.72	A B
	Katakana	56	1	6	2.55	0.91	B
	Hiragana	56	1	6	2.59	1.28	B
	Kanji	98	2	20	9.43	3.86	C
Stroke pixels	Lowercase	26	29	80	48.35	13.11	A
	Katakana	56	25	89	52.71	11.79	A
	Uppercase	26	38	103	63.65	15.30	B
	Hiragana	56	33	96	66.66	16.60	B
	Kanji	98	49	185	114.95	24.36	C
Character height	Lowercase	26	11	21	13.62	2.87	A
	Uppercase	26	15	19	15.15	0.78	B
	Katakana	56	13	19	16.79	1.59	C
	Hiragana	56	11	20	17.43	1.66	C
	Kanji	98	18	21	19.94	0.69	D
Character width	Lowercase	26	4	16	9.27	2.79	A
	Uppercase	26	6	20	13.69	3.02	B
	Katakana	56	12	19	16.80	1.84	C
	Hiragana	56	11	21	17.43	2.25	C
	Kanji	98	17	21	19.49	0.84	D
Character area	Lowercase	26	64	176	124.00	38.62	A
	Uppercase	26	90	300	207.54	46.79	B
	Katakana	56	195	361	281.95	41.13	C
	Hiragana	56	198	420	304.11	52.72	D
	Kanji	98	340	420	388.57	20.90	E
Width-to-height ratio	Lowercase	26	0.25	1.45	0.72	0.29	A
	Uppercase	26	0.40	1.33	0.91	0.20	B
	Kanji	98	0.81	1.06	0.98	0.05	C
	Hiragana	56	0.61	1.73	1.01	0.18	C
	Katakana	56	0.67	1.46	1.01	0.16	C
Character density	Katakana	56	0.11	0.27	0.19	0.03	A
	Hiragana	56	0.15	0.31	0.22	0.04	B
	Kanji	98	0.14	0.44	0.30	0.06	C
	Uppercase	26	0.23	0.42	0.31	0.05	C
	Lowercase	26	0.26	0.55	0.40	0.07	D

3.2 Legibility thresholds

Table 4 showed the legible thresholds of the five kinds of characters. The hiragana (minimum legible size= 13.03 min of arc.), uppercase (13.28) and katakana (13.28) were the most legible with no differences between them. Followed was the lowercase letters (15.35). The least legible character was kanji (16.68).

Table 4. Legibility thresholds of the five kinds of characters

Kinds	No. of strokes	N	Min	Max	Mean	Std	Duncan grouping	
							Stroke	Kind
	1	11	10.0	12.3	10.98	0.84	A	
	2	19	10.0	18.5	12.07	2.36	B	
	3	15	10.6	22.1	12.98	3.58	BC	
	4	6	10.8	18.4	13.41	2.84	CD	
	5	3	18.6	22.6	20.10	2.15	D	
	6	2	20.7	23.3	21.99	1.90	E	
Hiragana		56	10.0	23.3	13.03	3.60		A
	1	11	12.1	14.8	13.46	0.88	A	
	2	11	12.1	14.0	13.19	0.60	A	
	3	4	11.6	13.9	13.01	1.07	A	
Uppercase		26	11.6	14.8	13.28	0.79		A
	1	3	11.3	13.4	12.04	1.17	A	
	2	28	10.5	19.6	12.18	2.02	A	
	3	19	10.7	23.3	13.54	4.10	A	
	4	4	12.3	21.9	17.10	5.28	B	
	5	1	18.9	18.9	18.94	--	C	
	6	1	22.1	22.1	22.09	--	D	
Katakana		56	10.5	23.3	13.28	3.58		A
	1	21	12.8	19.4	15.31	1.50	A	
	2	5	14.6	17.0	15.53	0.90	A	
Lowercase		26	12.8	19.4	15.35	1.39		B
	2	2	12.3	15.4	13.83	2.21		
	3	2	14.0	15.1	14.53	0.79		
	2-3	4	12.3	15.4	14.18	1.41	A	
	4	4	12.5	13.8	13.37	0.62		
	5	5	13.2	16.4	14.81	1.49		
	6	10	14.1	16.9	15.25	0.92		
	4-6	19	12.5	16.9	14.74	1.24	A	
	7	11	13.5	16.5	15.64	0.93		
	8	11	14.7	18.6	16.26	1.38		
	9	10	15.1	18.8	16.92	1.11		
	7-9	32	13.5	18.8	16.26	1.23	B	
	10	6	14.3	19.1	17.09	1.93		
	11	8	15.6	18.9	17.33	1.08		
	12	10	16.9	20.1	18.03	1.02		
	10-12	24	14.3	20.1	17.56	1.32	C	
	13	6	16.3	19.3	18.07	1.07		
	14	3	17.8	20.3	18.85	1.27		
	15	3	16.3	19.5	17.99	1.56		
	13-15	12	16.3	20.3	18.24	1.18	D	
	16	1	19.2	19.2	19.18	--		
	17	2	18.5	19.2	18.81	0.51		
	18	2	17.9	18.9	18.42	0.72		
	19	1	22.0	22.0	22.00	--		
	20	1	21.7	21.7	21.67	--		
	16-20	7	17.9	22.0	19.62	1.58	E	
Kanji		98	12.3	22.0	16.68	1.93		C

Table 4 also illustrated that the effects of number of strokes on the five kinds of characters. ANOVA results showed that the effects of number of stroke on the legibility of hiragana ($F(5,55)= 11.06$, $p <0.01$), katakana ($F(5,55)= 4.17$, p, 0.01), and kanji ($F(18, 97)= 9.75$, $p < 0.01$) were significant, whereas were not significant of the uppercase ($F(2, 25)= 0,59$, $P= 0.56$) and lowercase letters ($F(1,25)= 0.10$, $p = 0.76$). Duncan test showed that legible thresholds of the hiragana, katakana, and kanji were increased with the total number of strokes on the characters.

3.3 Regression analysis

Table 5 demonstrated the regression equations for predicting legibility thresholds for the five kinds of characters. Coefficient of determination of hiragana, katakana, and kanji showed the linear relationship between number of stroke and legibility thresholds, whereas that of uppercase and lowercase have no linear relationship. For the hiragana, katakana, and kanji, the legibility threshold was increased with the number of strokes. Adding one stroke in a hiragana, katakana, and kanji should enlarge 1.8, 2.0 and 0.4 min of arc respectively for legibility complement. Compared with the slope of regression equations of Chinese character 0.25 (Cai, Chi, and You, 2001), the slopes of the regression equations of all the three kinds of Japanese characters were greater than that of Chinese characters. The stroke effect on legibility of the Japanese characters was greater than on that of Chinese chatacters.

Table 5. Regression equations for predicting legibility thresholds

Kinds	Equations for predicting thresholds	R^2
Hiragana	1.806 Stk + 8.350	0.409
Katakana	1.992 Stk + 8.196	0.258
Kanji	0.397 Stk + 12.936	0.629
Uppercase	-0.238 Stk + 13.688	0.048
lowercase	0.222 Stk + 15.084	0.004

3.4 Special pronounce characters

There are voiced consonants (dakuon) and semi-voiced consonants (han-dakuon) in both hiragana and katakana. The voiced consonant was added a voiced consonant sign “"” to a common character and the semi-voiced consonant was added a semi-voiced consonant sign “o” to a common character. For example, はひふへほ were common characters, ばびぶべぼ were voiced consonants, and the ぱぴぷぺぽ were semi-voiced consonants in hiragana, and ハヒフヘホ were common characters, バビブベボ were voiced consonants, and パピプペポ were semi-voiced consonants in katakana. Table 6 demonstrated that the mean legible threshold for the ten voiced consonant characters was 22.09 min of arc which was 10.3 min of arc greater than that of the ten common characters (11.79), and the average legible threshold for the ten semi-voiced consonant characters was 18.86 min of arc which was 7.07 min of arc greater than that of the ten common characters. We concluded that adding a voiced consonant sign to a common character should increase visual angle of 10.3 min of arc for legibility complement and adding a semi-voiced consonant sign ‘o’ to a character should increase visual angle of 7 min of arc for legibility complement. The results indicated that adding a special sign to a character will increase legibility confusion. This should be seriously considered in the beginning phase of creating a character.

Table 6. Legibility thresholds of common and special pronunciation characters

Kinds	Characters	N	Min	Max	Mean	Std	Duncan grouping
Hiragana	Common	5	10.4	14.1	11.86	1.45	A
	Semi-voiced consonant	5	18.4	19.2	18.62	0.32	B
	Voiced consonant	5	20.7	23.3	21.98	1.06	C
Katakana	Common	5	10.5	13.4	11.72	1.31	A
	Semi-voiced consonant	5	18.4	19.7	19.10	0.55	B
	Voiced consonant	5	21.5	23.3	22.19	0.68	C
Overall	Common	10	10.4	14.1	11.79	1.30	A
	Semi-voiced consonant	10	18.4	19.7	18.86	0.49	B
	Voiced consonant	10	20.7	23.3	22.09	0.84	C

4. Conclusions

This study applied the developed program to analyze the descriptors of Japanese characters and English letters. The materials included 56 hiragana characters, 56 katakana characters, 98 kanji, and 26 uppercase and 26 lowercase English letters. An experiment was conducted to test the legibility of the materials with Japanese subjects. Forty university students (20 males and 20 females) served as subjects participating in this study. Subjects were asked to identify the characters displayed on the screen beginning with a minimal size and enlarged gradually until the subject recognize it. The experimental data was then collected for the further analysis. The results could be summarized as following: 1) The legibility of the five kinds of characters from the most to the least legible could be classified into 3 levels. The first level was hiragana, katakana, and uppercase letters, the second level was lowercase letter, and the third level was kanji. 2) When the difference of the number of stroke was greater than three strokes, the effect of the number of stroke was significant. 3) Increasing one stroke in a Kanji character should enlarge 0.4 min of arc for legibility complement. This was similar to the Chinese characters. 4) For the hiragana and katakana, adding a voiced consonant sign “"” to a common character should enlarge 10.3 min of arc for legibility complement and adding a semi-voiced consonant sign “o” to a character should enlarge 7 min of arc for legibility complement. The results can be used as reference for the information and interface design.

5. Acknowledgement

The authors thank the president Akihiro Igata M.D., Coordinator of International Studies and Exchange Yoshio Ohsumi, Dean and Professor of School of Media and Design Kazuo Kimura, Professor of Department of Design Robin Huang, and the participants at Nagoya University of Arts and Science, Japan for their kind help and participation as well as providing laboratory and facilities for the experiment. We also thank the National Science Council of the Republic of China for the partly finical support under the following projects: NSC-96-2918-I-224-007, NSC-97-2511-S-224-003-MY2, and NSC-97-3114-E-168-002.

6. References

[1] Booher, H.R. (1975) Relative comprehensibility of pictorial information and printed words in proceduralized instructions. Human Factors 17 (2), 266-277.

[2] Cai, D., Chi, C.-F., and You, M. (2001) The Legibility Threshold of Chinese Characters in Three Type Styles, International Journal of Industrial Ergonomics, 27, 9-17.

[3] Cai, D., Chi, C.-F., and You, M. (2008) Assessment of English letters' legibility using image descriptors, Perceptual and Motor Skill, 107, 618-628.

[4] Chen, Y. T. (1996) The format of the character and graphic files in Windows, Taipei: Ru-Lin Book Co. (in Chinese).

[5] Chi, C.-F., Cai, D., and You, M. (2003) Applying Image descriptors to the assessment of legibility in Chinese characters, Ergonomic, 46 (8), 763-779.

[6] Coren, S. Ward, L.M. and Porac, C. 1989, Sensation and Perception (Orlando, FL: Harcourt Brace Jovanovich College Publishers), pp 17 – 19.

[7] Cushman, W.H., and Rosenberg, D.J. (1991) Human Factors in Product Design, New York: Elsevier.

[8] Eten Information System Co., Ltd. (1993) The Technical Handbook of Eten Chinese System, Taipei, Taiwan.

[9] Gould, J.D. (1968) Visual factors in the design of computer-controlled CRT displays. Human Factors. 10. 359-376.

[10] Human Factor Society (1988) American national standards for human factors engineering of visual display terminal workstations. (ANSI/HFS 100-1988) Santa Monica, CA: Author.

[11] Li, X.L. & Yeung, D.Y. (1997) On-line handwritten alphanumeric character recognition using dominant points in strokes, Pattern recognition, 30 (1), 31-44

[12] North, A.D., and Fairchild, M.D. (1993) Measuring color-matching functions: Part I. Color Research and Application, 18, 155-162.

[13] Sanders, M.S., and McCormick, E.J. (1993) Human Factors in Engineering and Design, 7th Ed., New York: McGraw-Hill Book Company.

[14] Shurtleff, A. (1967) Studies in television legibility: a review of the 1iterature.Information Display, 4, 40-45.

[15] Smith, S. L. (1979) Letter size and legibility Human Factors, 21, 661-670.

[16] Stevens, S.S. (1975) Psychophysics: introduction to its perceptual, neural, and social prospects. New York: Wiley.

[17] Takatsuka, T.D. (1997) Dictionary for Writing Japanese, 3rd Ed., Tokyo: Nobarasha.

[18] Yang, M.L., 2001, Learning Basic Japanese, Taipei: Shansitang Publish Co. Ltd.