A Study on Legibility with Pairwise Comparison in Simultaneous Multilingual Display on Digital Signage

Takashi Kurushima[1], Yoshiki Sakamoto[1], Kimi Ueda[1], Hirotake Ishii[1][a], Hiroshi Shimoda[1][b], Rika Mochizuki[2], and Masahiro Watanabe[2]

[1]*Graduate School of Energy Science, Kyoto University, Yoshida-hommachi, Sakyo-ku, Kyoto, JAPAN*

[2]*Organization of Service Evolution Laboratories, NTT Group , Hikarinooka, Yokosuka-shi, Kanagawa-ken, JAPAN*

{*kurushima, sakamoto, ueda, hirotake, shimoda*}*@ei.energy.kyoto-u.ac.jp,*

{*mochizuki.rika, watanabe.masahiro*}*@lab.ntt.co.jp*

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Abstract: Recently, digital signages are widely utilized to provide information for tourists in plural languages, but it takes longer time to offer information in each language separately. Although simultaneous multilingual display is expected to reduce the time for presentation, there is no guideline for simultaneous multilingual display to keep its legibility. In order to estimate the effect of layout on legibility, the authors prepared contents which have different layout factors and conducted evaluated the legibility of contents with Thurstone's pairwise comparison. Since the number of combinations in layout factors increases exponentially, the number of stimuli was reduced using an orthogonal table. As a result, significant differences were found in some layout factors and it was found that horizontal arrangement of images and sentences, left alignment in sentences, middle margin from screen edge and medium-sized images made contents more legible.

1 INTRODUCTION

Foreign tourism has been getting popular all over the world and the number of foreign sightseers has been increasing. The signs in sightseeing places are therefore often displayed in multilingual these days. Thanks to recent advancement of information and communication technology, the signs are digitalized as digital signage and it is widely used because it is easy to update displayed information and less expensive devices. Especially in Japan, the government is promoting its utilization and function expansion for the coming Tokyo Olympics and Paralympics 2020 (the Ministry of Internal Affairs and Communications, 2015). However, there has been no concrete guidelines for multilingual display of digital signage. At present, although some digital signages changes the displayed information depending on the language, it needs much time to display the information. Other signages show information in multilingual at the same time. It needs less time to show the information, however, it may cause difficulty to read because of lots of texts are displayed in the screen. It is therefore necessary to develop the guideline for legible multilingual display.

The aim of this study is, therefore, to investigate the layout factors which affects legibility of simultaneous multilingual display in order to establish the guideline for multilingual display. In this study, various simultaneous multilingual formats were created with combinations of various layout factors and they were evaluated by a subject experiment. Since there are actually huge number of combinations of layout factors, the number of the display to be evaluated was reduced with experimental design using orthogonal table. In addition, the evaluation was done by Thurstone's pairwise comparison to reduce the burden of the evaluators.

There have been lots of studies which deal with the relationship between display layout and legibility in various research fields. Dyson evaluated the relationship between legibility and text layout on screen and it was found that the number of characters per line affected reading speed (Dyson, 2004). Dobres et al. investigated the legibility in reading at a glance and the result showed that crowded texts required more processing time than isolated texts (Dobres et al., 2018). Grozdanovic et al. assessed the legibility of video display unit depending on charac-

[a] https://orcid.org/0000-0002-5638-4862

[b] https://orcid.org/0000-0002-5231-4955

ter/background color combination and demonstrated that negative contrast was more legible than positive contrast (Grozdanovic et al., 2016). Fu et al. proposed six measurements of legibility on web site using content size, font size, icon, color contrast, density and alignment points and found that these factors gave a significant impact on web page legibility (Fu and Su, 2009). Xie et al. focused on the location of digital signage and found the relationship between maximum viewing distance and observation angle (Xie et al., 2007).

In multilingual contents, on the other hand, there are studies on readability of multilingual websites and they indicated that not only translation but also redesigning were required to improve readability (Miraz et al., 2016) (Hussain et al., 2017). Ogi et al. developed multilingual digital signage which automatically changed its language by the user's smart phone using iBeacon communication and demonstrated that most users felt the effectiveness (Ogi et al., 2016). Alhumoud et al. observed banking interfaces in Arabic and English and showed that the social and cultural aspect influenced the interfaces (Alhumoud et al., 2015). Although there have been some studies on legibility and multilingual contents, there is no study which focuses on the legibility of simultaneous multilingual display for digital signage.

2 EVALUATION METHOD OF LEGIBILITY

As mentioned above, there are various factors which affect the legibility of simultaneous multilingual display and the number of the combinations would be huge. And it is actually impossible to evaluate the legibility of so many combinations one by one. In this chapter, the evaluation method using Thurstone's pairwise comparison and a design method for multifactorial experiment was introduced.

2.1 Thurstone's Pairwise Comparison

Thurstone's pairwise comparison is the method that evaluators select one of two stimuli which are one of the combination pairs of several objects to be evaluated, and they repeat the selection for all the combinations. By analysing the evaluators' response, the scale values of the objects can be quantitatively calculated. As calculation is made from the percentage of selection in each combination instead of evaluators' response, individual inconsistency (e.g. three-way standoff in selection) does not matter in calculation. This method is simple because they watch only a pair of stimuli at a time and intuitively answer the better one. Thurstone's pairwise comparison, therefore, has an advantage of less evaluators' workload comparing the method where they directly evaluate several objects at the same time.

2.2 Experimental Design Method

In the case that objects to be evaluated include several factors, number of the combinations of all the factors increases exponentially and it is difficult to evaluate all the combinations. Assuming that the interrelation of the factors is small, the number of the combination can be reduced using orthogonal table. Table 1 is an example of $L_{16}(2^{15})$ orthogonal table. In arbitrary pair of factor of the orthogonal table, all combinations appear the same number of times. In case of 15 factors with 2 levels each, the number of combinations is originally 32768 (2^{15}), however, it can be reduced to only 16 combinations by using the table. A column of the table expresses two-level factor while four-level factor can be expressed with two columns. By using orthogonal table, although stimuli are multifactoral, the effect of a certain factor can be analyzed with one-way ANOVA as the effects of other factors are canceled.

By employing Thurstone's pairwise comparison and the experimental design method, the evaluation of multilingual display layout with multiple factors which has originally huge number of combinations can be done.

3 OBJECTIVE AND METHOD OF EVALUATION EXPERIMENT

3.1 Objective

The objective of the experiment is to confirm the effectiveness of the evaluation method mentioned in Chapter 2 and to investigate the layout factors which affect the legibility of simultaneous multilingual display. In the experiment, the participants repeated to watch a pair of the contents with different layouts and select more legible one. The scale value of each content was calculated from the answer of the selections and the layout factor which affected the legibility was deduced.

3.2 Layout Factors

There are various layout factors for display of digital signage such as font size and margin. In this

Table 1: $L_{16}(2^{15})$ orthogonal table.

	Column														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
3	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
4	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
5	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
6	0	1	1	0	0	1	1	1	1	0	0	1	1	0	0
7	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
8	0	1	1	1	1	0	0	1	1	0	0	0	0	1	1
9	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
10	1	0	1	0	1	0	1	1	0	1	0	1	0	1	0
11	1	0	1	1	0	1	0	0	1	0	1	1	0	1	0
12	1	0	1	1	0	1	0	1	0	1	0	0	1	0	1
13	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
14	1	1	0	0	1	1	0	1	0	0	1	1	0	0	1
15	1	1	0	1	0	0	1	0	1	1	0	1	0	0	1
16	1	1	0	1	0	0	1	1	0	0	1	0	1	1	0

study, however, the information to be presented was fixed to three images and short explanation text in four languages, Japanese, English, Korean and Chinese (Traditional Chinese). The order of texts was also fixed, Japanese, English, Korean and Chinese because Japanese and Chinese have similar characters and they should be written in isolation. And the layout factors to be considered were also limited to (i) arrangement, (ii) margin, (iii) image block size, (iv) spacing between languages and (v) alignment, as the first trial for the evaluation experiment. Other forms of information and other factors will be considered in further study. The layout factors are explained in following paragraphs.

3.2.1 Arrangement

The arrangement is the factor which expresses the arrangement of images and texts. The arrangement is chosen as a layout factor because it decides the overall layout of content. It has two levels, vertical arrangement and horizontal arrangement. The vertical arrangement means that images are located at the top and texts are below the images as shown in Figure 1. while the horizontal arrangement means that the figures are located on the left and texts are on the right as shown in Figure 2.

3.2.2 Margin

The margin is the factor which expresses the margin between the images and texts, and the margin from the edge of the screen. The margin is chosen as a layout factor because it gives a crowded or uncrowded impression to evaluators. It has four levels, 0%, 2.5%, 5% and 7.5%. For example, 2.5% means that the margin from the right and left edges is 2.5% of the width

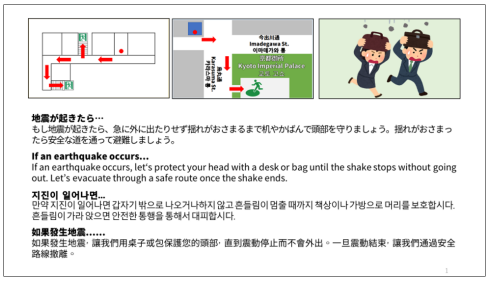

Figure 1: Example of Vertical Arrangement.

Figure 2: Example of Horizontal Arrangement.

of the screen and that that from the top and bottom is also 2.5% of the height. The margin between the images and texts is set as well. The examples of layouts with 0% and 7.5% margin are shown in Figure 3 and Figure 4.

3.2.3 Image block size

The image block size is the factor which indicates the ratio of image area among the whole screen area. The image block size is chosen as a layout factor to assess the impact of images. It has four levels, 20%, 30%, 40% and 50%. When the image block size is 30%, for example, the height of the images is set to 30% of the height of the screen when angement while the width

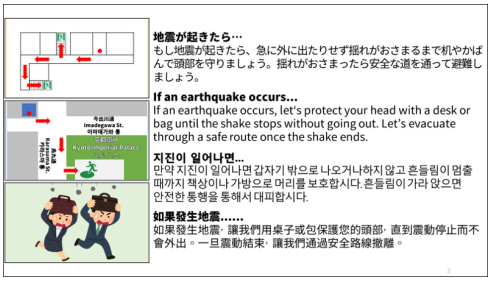

Figure 3: Example of 0% Margin.

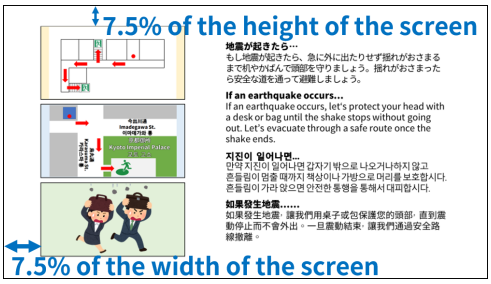

Figure 4: Example of 7.5% Margin.

of the images is set to 30% of the screen when horizontal arrangement. The examples of layouts with 20% and 50% image block size are shown in Figure 5 and Figure 6. In case that the image overlaps the margin mentioned in 3.2.2, it is trimmed or downsized.

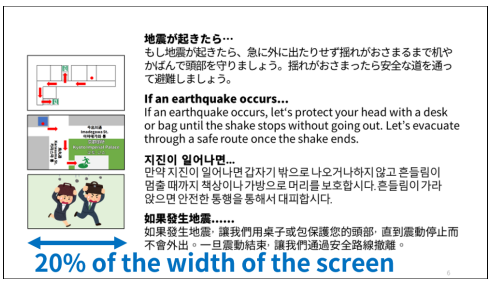

Figure 5: Example of 20% Image Block Size.

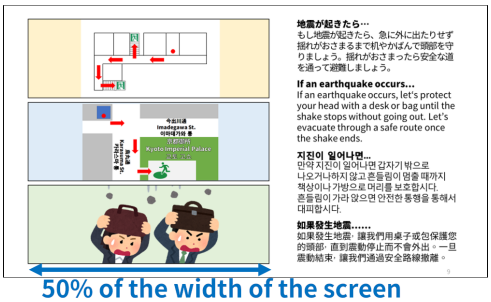

Figure 6: Example of 50% Image Block Size.

3.2.4 Spacing between languages

The spacing between languages is the factor which indicates the margin between the explanation texts in four languages. The spacing between languages is chosen as a layout factor because finding evaluator's language may be important in simultaneous multilingual display. It has four levels, 0%, 50%, 100% and 150%. For example, 50% means that the margin between the texts in Japanese and those in English is set to 50% of font height. The examples of layouts with 0% and 150% spacing between languages are shown in Figure 7 and Figure 8. The font size is automatically set to the maximum size under the limitation of margin, image block size and spacing between languages.

Figure 7: Example of 0% Spacing between Languages.

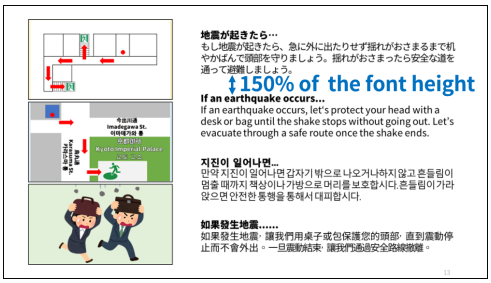

Figure 8: Example of 150% Spacing between Languages.

3.2.5 Alignment

The alignment is the factor which shows the alignment of the texts. The alignment is chosen as a layout factor because it may affect legibility of text. It has two levels, left alignment and center alignment. The examples of layouts with left alignment and center alignment are shown in Figure 9 and Figure 10.

3.3 Presented Information

Three kinds of information were prepared for the experiment, which were (a) sightseeing information, (b) disaster evacuation information and (c) local food culture . They were chosen assuming the case that the digital signage was placed in the sightseeing places for foreign tourists.

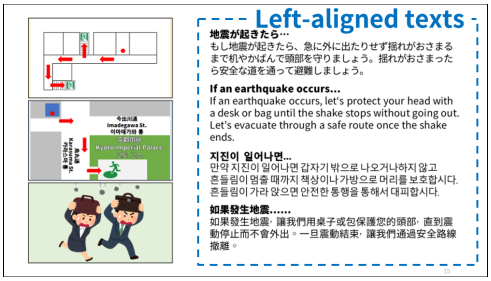

Figure 9: Example of Left Alignment.

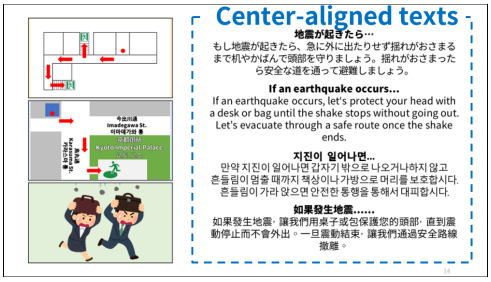

Figure 10: Example of Center Alignment.

In each information, 16 sorts of layout were prepared along with the L_{16} orthogonal table and 5 layout factors above. The layout factors and prepared contents are shown in Table 2. The examples of contents are shown in Figure 11-13.

Figure 11: Example of Sightseeing Information (#13); Pictures are (Co0316co, 2016a) (Co0316co, 2016b) (KENPEI, 2008).

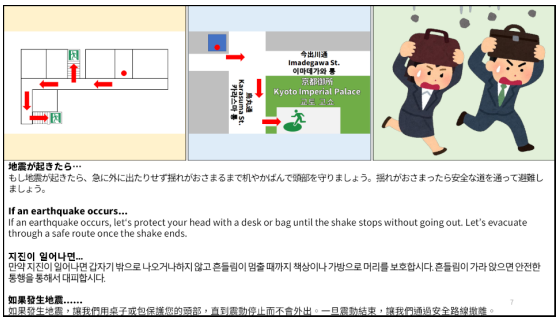

Figure 12: Example of Disaster Evacuation (#8).

Figure 13: Example of Local Food Culture (#11).

3.4 Experimental Procedure

Table 3 shows the experimental procedure. In each evaluation of “Evaluation 1-3”, a pair of layouts were displayed on two monitors (42.5 inches LCD, LG 43UD79-B, resolution: 3840x2160) right and left, respectively, and the participants selected more legible one by using keyboard. Since the number of combinations of 2 layouts among 16 layouts is 120, the selections were repeated 120 times for each presented information. The display time for the selection was set to 6.5 seconds, while the time between the selections was 2.0 seconds. In this experiment, as participants evaluated the legibility at a glance, layout is more effective in legibility than the detail of contents or participants' background. The distance between the monitor and the participants was 2.0m. In “Evaluation 1-3” in Table 3, the order of three information, (a) sightseeing information, (b) disaster evacuation information and (c) local food culture were randomly assigned to each participant in order to cancel the order effect. In “Practice” in Table 3, the participants practiced the selection using different information and layouts from those of “Evaluation 1-3.”

3.5 Participants

25 participants joined the experiment who had normal vision with or without correction and their native language was Japanese. They were 15 males and 10 females and their average age was 21.6 (SD: 1.69).

4 RESULTS OF EVALUATION EXPERIMENT

In order to assess the impact of layout factors, scale value of each content was calculated from participants' response and the effect of each factor was analyzed with one-way ANOVA. In this experiments, there are two analysis methods which are (1) the case

Table 2: The layout of contents.

	Factor (The numbers in round bracket mean corresponding columns in Table 1)				
#	Arrangement (6)	Margin (1, 12)	Image Block Size (4, 11)	Spacing between languages (3, 8)	Alignment (5)
1	Vertical	0%	20%	0%	Center
2	Vertical	2.5%	30%	50%	Center
3	Horizontal	2.5%	50%	0%	Left
4	Horizontal	0%	40%	50%	Left
5	Horizontal	0%	30%	150%	Center
6	Horizontal	2.5%	20%	100%	Center
7	Vertical	2.5%	40%	150%	Left
8	Vertical	0%	50%	100%	Left
9	Vertical	7.5%	30%	150%	Left
10	Vertical	5%	20%	100%	Left
11	Horizontal	5%	40%	150%	Center
12	Horizontal	7.5%	50%	100%	Center
13	Horizontal	7.5%	20%	0%	Left
14	Horizontal	5%	30%	50%	Left
15	Vertical	5%	50%	0%	Center
16	Vertical	7.5%	40%	50%	Center

Table 3: Procedure of experiment.

Time (Min.)	Procedure
10	Introduction and Questionnaire
5	Practice
20	Evaluation 1
5	Break
20	Evaluation 2
5	Break
20	Evaluation 3
10	Final procedure

that the answers of all the participants are analyzed at a time and (2) the case that the order effect of three sorts of information for "Evaluation 1-3" is considered. The analysis results of (1) and (2) are described below;

4.1 Analysis Result for All Participants

In this section, the analysis results of each presented information for all the participants are described. First, the selection of all the participants were accumulated and the scale values of 16 layouts were calculated by Thurstone's pairwise comparison method. Then, the scale values of each level of the layout factors were compared by statistical method and p values were calculated to figure out the significant difference.

4.1.1 Sightseeing Information

For the arrangement, the horizontal arrangement was evaluated more legible than the vertical arrangement, though there is no significant difference ($F(1,14) = 1.42, p = 0.25$). For the margin, the legible order was 5%, 2.5%, 7.5% and 0%, though there is no significant difference either ($F(3,12) = 0.93, p = 0.46$). For the image block size, the legible order was 30%, 40%, 50% and 20% and significant difference was found ($F(3,12) = 5.92, p = 0.01$). A post hoc Tukey test showed that 30% and 40% were significantly more legible than 20% ($p < 0.05$). For the spacing between languages, the legible order was 100%, 150%, 0% and 50%, though there was no significant difference ($F(3,12) = 0.15, p = 0.93$). For the alignment, left alignment was evaluated to be more legible, though there is no significant difference either ($F(1,14) = 1.04, p = 0.33$).

4.1.2 Disaster Evacuation Information

For the arrangement, the horizontal arrangement was evaluated more legible than the vertical arrangement and significant tendency was found ($F(1,14) = 3.16, p = 0.097$). For the margin, the legible order was 5%, 2.5%, 0% and 7.5%, though there was no significant difference ($F(3,12) = 2.56, p = 0.10$). For the image block size, the legible order was 30%, 40%, 50% and 20%, though there was no significant difference either ($F(3,12) = 1.49, p = 0.27$). For the spacing between languages, the legible order was 50%, 100%, 150% and 0%, though there is no significant difference either ($F(3,12) = 0.03, p = 0.99$). For the alignment, left alignment was evaluated to be more legible, though there is no significant difference either ($F(1,14) = 0.12, p = 0.73$).

4.1.3 Local Food Culture

For the arrangement, the horizontal arrangement was evaluated more legible than the vertical arrange-

ment and significant tendency was found ($F(1,14) = 3.20, p = 0.09$). For the margin, the legible order was 5%, 2.5%, 0% and 7.5%, though there is no significant difference ($F(3,12) = 0.75, p = 0.54$). For the image block size, the legible order was 30%, 40%, 50% and 20% and significant difference was found ($F(3,12) = 3.77, p = 0.04$), though a post hoc Tukey test didn't show any significant difference between levels. For the spacing between languages, the legible order was 100%, 150%, 50% and 0%, though there is no significant difference ($F(3,12) = 0.08, p = 0.97$). For the alignment, left alignment was evaluated to be more legible, though there is no significant difference either ($F(1,14) = 1.77, p = 0.20$).

4.2 Analysis Result Considering Order Effect

Three presented information such as (a) sightseeing information, (b) disaster evacuation information and (c) local food culture were randomly assigned to "Evaluation 1-3" in the experiment and the order effect of the evaluation might affect the results. In this section, therefore, the analysis results considering the order effect of the presented information are described. Actually the participants were divided into 3 groups depending on the order and the scale values of each layout were calculated separately. Then, statistical comparison was done using all the scale values.

4.2.1 Sightseeing Information

For the arrangement, the horizontal arrangement was evaluated more legible than the vertical arrangement and significant tendency was found ($F(1,46) = 3.84, p = 0.06$). For the margin, the legible order was 5%, 2.5%, 7.5% and 0% and significant tendency was found too($F(3,44) = 2.72, p = 0.06$), though a post hoc Tukey test didn't show any significant difference between levels. For the image block size, the legible order was 30%, 40%, 50% and 20% and significant difference was found ($F(3,44) = 18.35, p < 0.01$). A post hoc Tukey test showed that 30% and 40% were significantly more legible than 50% and 20% ($p < 0.05$). For the spacing between languages, the legible order was 100%, 150%, 0% and 50%, though there was no significant difference ($F(3,44) = 0.28, p = 0.84$). For the alignment, left alignment was evaluated to be more legible and significant tendency was found ($F(1,46) = 2.88, p = 0.097$).

4.2.2 Disaster Evacuation Information

For the arrangement, the horizontal arrangement was evaluated more legible than the vertical arrangement and significant difference was found ($F(1,46) = 10.39, p < 0.01$). For the margin, the legible order was 5%, 2.5%, 0% and 7.5%, and significant difference was found too ($F(3,44) = 6.45, p < 0.01$). A post hoc Tukey test showed that 5% and 2.5% were significantly more legible than 7.5% ($p < 0.05$). For the image block size, the legible order was 30%, 40%, 50% and 20%, and significant difference was found too ($F(3,44) = 5.49, p < 0.01$). A post hoc Tukey test showed that 30% was significantly more legible than 50% and 20% ($p < 0.05$). For the spacing between languages, the legible order was 100%, 50%, 150% and 0%, though there is no significant difference ($F(3,44) = 0.17, p = 0.92$). For the alignment, left alignment was evaluated to be more legible, though there was no significant difference ($F(1,46) = 0.61, p = 0.44$).

4.2.3 Local Food Culture

For the arrangement, the horizontal arrangement was evaluated more legible than the vertical arrangement and significant difference was found ($F(1,46) = 7.86, p < 0.01$). For the margin, the legible order was 5%, 2.5%, 0% and 7.5%, though there is no significant difference ($F(3,44) = 2.10, p = 0.11$). For the image block size, the legible order was 30%, 40%, 50% and 20% and significant difference was found ($F(3,44) = 10.81, p < 0.01$). A post hoc Tukey test showed that 30% and 40% was significantly more legible than 50% and 20% ($p < 0.05$). For the spacing between languages, the legible order was 100%, 50%, 150% and 0%, though there is no significant difference ($F(3,44) = 0.17, p = 0.92$). For the alignment, left alignment was evaluated to be more legible, and significant difference was found ($F(1,46) = 4.27, p = 0.044$).

5 DISCUSSION

The tendencies of each layout factor and their reasons are discussed in this chapter. As the evaluation result of the arrangement, the horizontal arrangement was more legible and significant difference was found in some analysis results. The reason was supposed that the length of lines in horizontal arrangement was shorter than that in vertical arrangement and it looked easy to read. As the result of the margin, 2.5% and 5% tended to be more legible and significant tendency

appeared in some results. It was supposed that appropriate margin was necessary to make the layout legible. As the result of image block size, 30% and 40% were evaluated more legible and significant difference was often found. In case of multilingual contents, the amount of the text becomes larger. It was therefore supposed that the ratio of image area should be a little smaller than that of text for legible layout. As the result of alignment, the left alignment was more legible and significant difference was found in some results. It was supposed that the start position of reading was always left edge in the left alignment and it gave legible impression.

6 CONCLUSION

Aiming to investigate the layout factors for legible simultaneous multilingual display in this study, the authors have proposed the evaluation method which employs Thurstone's pairwise comparison and experimental design using orthogonal table, and a trial experiment was conducted using only the limited display content with three images and explanation texts in four languages. As the results, horizontal arrangement with images and text, appropriate margin from the edge of screen and left alignment of the text were evaluated to be legible layout factors.

In this experiment, there are some limitations. Since the display contents were limited to three images and explanation texts, the results cannot be expanded to general layout. It is therefore necessary to conduct other evaluation for general display contents. And the native language of all the participants was Japanese in this experiment. It is necessary to conduct the same experiment for other participant with different native language to find the difference depending on the languages. In addition, this study did not take readability or perspicuity into account because the participants evaluated the legibility in a short time. Future works can consider reading speed and comprehension in simultaneous multilingual display.

When revealing the layout factors of legible simultaneous multilingual display in the future, it is expected to realize an automatic layout tools for simultaneous multilingual display can be developed. Using such tools, even the person who has no special knowledge and skill can easily create legible simultaneous multilingual display contents.

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