Estimation of legible font size for elderly people

— Accessible design of characters in signs and displays and its standardization —

Ken SAGAWA * and Kenji KURAKATA

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Concept, methodology, and dissemination of outcomes for accessible design research are described in this paper, using vision research as an example. Characteristics of accessible design whose standpoint is different from that of assistive technology are explained in terms of methods for problem solving, objects of design, and public usefulness, and the role of standardization is emphasized from the point of public usefulness. As an example, the process of vision research for estimating minimum legible font size for elderly people is described. To develop a general estimation method for minimum legible font size, we collected fundamental data on visual acuity which changes with age and visual distance. Then, we compiled data on legibility of letters used in actual Japanese, derived a general estimating equation of legible font size, and confirmed the practical utility of the method. We have developed this method as a domestic and international standard. In addition, we have also applied this method to international comparative testing and have confirmed the validity of the results of this research. Finally, the entire process has been clarified by separating it into two procedural cycles: one for basic research and the other for application, and the concept of "*Full Research*" has been addressed in the process.

Keywords : Accessible design, visual acuity, age-related change, minimum legible font size, standardization

1 Introduction

Care for older people and people with disabilities has widely spread in our society due to the rapid aging of society and the adoption of UN Convention of Human Rights on Persons with Disabilities.[1] The issue on older people and people with disabilities encompasses very wide fields of politics, economics as well as society. From a viewpoint of ergonomics which directly concerns with human beings, development and promotion of human-life technology are urgent as the solution to inconveniences that older people and people with disabilities have in their daily lives since such study has been progressing behind other fields.

The inconveniences of older people and people with disabilities have a large variety even in the ergonomic field only. A large variety of problems are found in the reports of surveys conducted by the Cabinet Office, Government of Japan, or the Accessible Design Foundation of Japan.[2] These are classified into (1) physical problems such as body size or movements, (2) perceptual problems such as vision and hearing, and (3) cognitive problems such as attention and memory. These various problems of older people and people with disabilities should be resolved in each of these categories.[3] We reported previously in this journal the technical problem concerning auditory signals together with the concept and design guidelines for older people and people with disabilities.[4]

In this paper, focusing on the age-related change of visual acuity and the legibility problem, our concept and methodology will be described. The problem of legibility is one of the common inconveniences found in the surveys. People pick up information from letters appearing in instructions or warnings attached to household appliances, packages, product-tags, guide pamphlets, and so on. Many difficulties exist here for older people and people with visual disabilities such as low vision. It is vitally important, therefore, to provide easy-to-read letters to those people that would lead to increasing safety and comfort in our social life.

In addition, in this paper, standardization will be picked up as a tool to disseminate the developed method for designing letters and human data. The standardization is regarded particularly important in this study, and the way of thinking and usefulness of it will also be addressed in this paper together with a technical standpoint and a specific feature of standards-related study.

2 Two approaches for solving the problems

There are so many aspects to investigate for solving the problems that older people and people with disabilities have. Two approaches may be addressed as follows from the ergonomic point of view.

One is based on the concept of assistive products or assistive technology. In this approach, the weakened or deteriorated human abilities by aging or disabilities should be compensated by providing special tools or devices that are

Human Technology Research Institute, AIST　Tsukuba Central 6, 1-1-1 Higashi, Tsukuba 305-8566, Japan
* E-mail: sagawa-k@aist.go.jp

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attached or worn on the human body to gain the lost abilities. No change or no modification is required for products, services, and environments for their being used directly as they are. This is the design concept actually employed in the field of "assistive devices" in which human abilities are attempted to be enhanced artificially.

The other one, on the contrary, is to change or modify products, services and environments so that they can be used by those who have weakened or deteriorated human abilities. This is the concept that things should be used without any special tools even if the loss of human abilities exists. This design concept is called "accessible design" and underlies the present study. A similar concept applies to universal design, barrier free, inclusive design etc. Slight differences may exist among exact methods in these designs but the same consideration is shared that products etc. should be designed to fit human abilities without supplying any assistive device.

The difference between the two is elaborated with an example of visibility problem which is illustrated in Fig. 1. On the left side of the figure, which is for the case of assistive devices, it is thought that visibility problem is caused by the weakened visual acuity and improving visual acuity technically is considered. This instantly leads to the development of spectacles or a magnifying lens. Developing suitable spectacles or a magnifying lens enables an older person who has low visual acuity to read small letters on a label of a pharmaceutical bottle. This is the idea to fit human ability of vision to invisible small letters. In this case, spectacles or a lens can be developed to fit one particular person and is of no use to others. This is personal fit, and the basic purpose is to solve the problem of one intended user by providing spectacles or a lens that fits him/her.

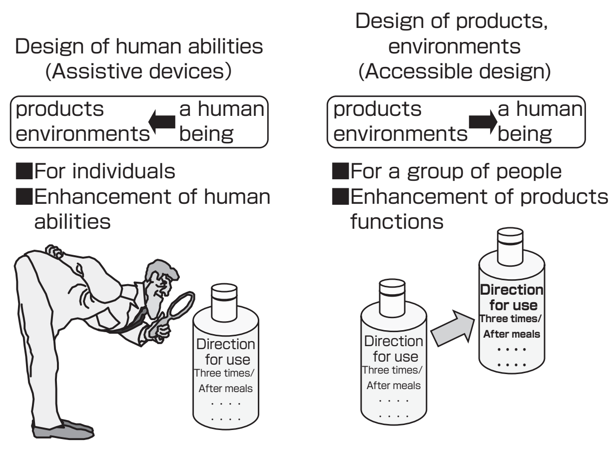

Fig. 1 Basic concept and characteristics for accessible design and assistive devices.
A solution for the legibility problem is shown as an example for each design concept. The left is the concept of assistive devices where design method for an individual like spectacles is shown. On the right, accessible design is shown where the problem is solved by product design like enlarging the letter size.

On the other hand, in accessible design, the problem is regarded as on the side of letters that are designed too small to read. Therefore, enlarging the letters to appropriate size is required. In this case, there is no prerequisite for using spectacles, and designing letters solves the problem. The idea is to fit products to weakened visual acuity. This is not the personal design as previously mentioned but the design for many other people who have similar low visual acuity. It is required to know here prior to designing that what distribution of (the low) visual acuity is found for that group of people. This process highlights the importance of feature extraction of the distribution and also of standardization.

3 Scenario of development and dissemination of the research

In this paper, a concept for the development of an accessible design method and its dissemination through standardization is described with a method for estimating minimum legible font size that takes account of age-related change of visual acuity as an example. As previously mentioned, when we seek for a solution of a problem on the bases of the concept of accessible design, the focus should not be an individual but a group of people. A number of people will see letters in printings or displays once they are designed, and how many or what type of people can see the letters depends surely on the quality of the designing. In the present study, focusing on people in older generation we tried to develop a method that provides legible letters for as wider range of older people as possible. That is, the concept of the widest range of users targeted by accessible design was put in the basics of the present study. It is anticipated that the best fit solution may not be fulfilled, but the publicness by targeting much wider users takes higher priority.

It becomes important here to create the most suitably fitted design to the user group by knowing the characteristics that specify the group, as the accessible design applies to a number of people who have a variety of characteristics individually. It is necessary to know the distribution or a specific feature of the group to obtain a maximum number of users. This idea is shared with standardization. For the standards, it is expected to get as much convenience, efficiency, and effectiveness as possible, and the extent of the commonality of the standards depends on the appropriateness of the design. The same thing is exactly true for the concept of accessible design. The aim is to solve the problems of older people and people with disabilities by design methods that are developed being based on their characteristics. The methods developed like this are intended to disseminate through standardization. To design Braille or display of lifts, for instance, it only becomes useful after a normalized location and indication method is set and the knowledge is shared among people with visual disabilities. The principles of commonality and consistency that standardization has are of particular importance for people with disabilities. This is the most critical reason why the concept and benefit of standardization is adopted in the accessible design.

Figure 2 shows the scenario of the technical development actually taken. Design elements are classified into two parts, viewing conditions and attributes of the letter design, and the former is classified into three design factors (size factor, luminance, and age) and the latter into two such as font type and kind of font. The necessary data are to be collected along with this scheme. The data are then used for the development of an estimation method for minimum legible font size, and this proceeds finally to the goal of standards on the legible font design. This level of development can be addressed as composition and synthesis. Furthermore, it should be noted that, aiming at international standardization as a final goal, the necessary data in oversea countries are to be collected. Based on these data, an international standard on minimum legible font size is to be developed in the end.

The present study was carried out under this scenario and the development process which are based on the concepts of accessible design and standardization.

4 Estimation of minimum legible font size

4.1 Fundamental data collection

The technical point of the present study is to clarify the general relationship between the legibility of letters and visual acuity for a wider range of people including older people. In visual science, visual acuity is defined by a reciprocal of a quantity ($1/\Theta$) of the minimum gap (Θ) expressed in minutes

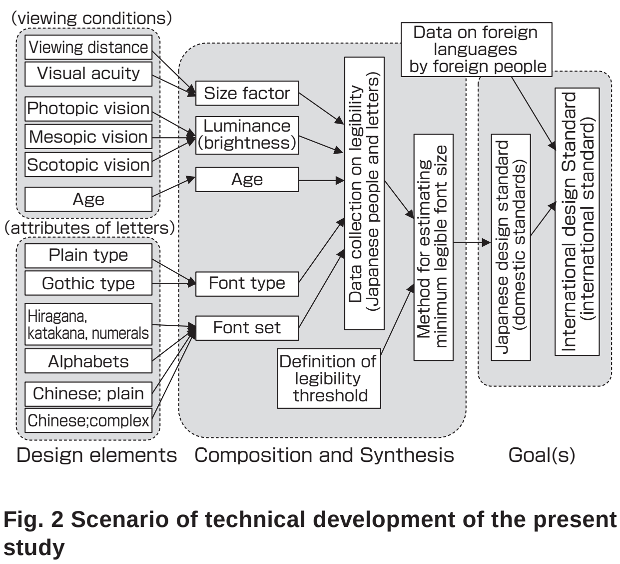

Fig. 2 Scenario of technical development of the present study

Breaking down the legibility problem into design elements and combination of factors and collecting data on legibility, a method for estimating legible font size is to be developed. The method is to be standardized as a national or an international standard. Data on foreign languages are to be collected in their countries for the international standard.

that human eye resolves spatially. Visual acuity 1.0 means to resolve the gap of 1.0 minutes of arc. Although it is well known that the extent of visual acuity affects the size of a legible letter, the quantitative relationship between the two has not been well known. In particular, the feature of age-related change in visual acuity or that of a particular aged group has not been well known. One of the purposes of the present study is to draw the relationship statistically by collecting data that serves to develop a method for estimating minimum legible font size. This relationship could be established in a general form that takes into account the major affecting factors of the viewing condition.

It is well known from the fundamental characteristics of vision that visual acuity changes with various viewing conditions.[5] Three factors such as (1) age, (2) viewing distance, (3) luminance level can be addressed as major ones, and it is required to describe the change of visual acuity as a function of these factors. As previously mentioned, visual acuity is defined by visual angle regardless of viewing distance, but as the accommodation of eye lens depends on age and viewing distance, it becomes important to investigate the effects of age in relation to viewing distance. The effect of each component has been found independently in previous studies but the interactive effects of them have not been clarified yet, and a synthesized study concerning these has been needed.[6]

It is possible to measure in detail visual acuity by means of psychophysical methods. In this study the subject, who served as a monitor of the experiment, was asked whether he/she was able to see and recognize a small cut or open space on a ring pattern or the so called Landolt Ring, which was presented on a display. If the pattern is large enough, the cut is recognized with a probability of 100 %. If it is too small, the cut is hardly recognized and the probability goes down almost to 0 % in which case some chance level of recognition exists as false response and the probability correction is done according to the method adopted by general psychophysical measurement. After deriving a curve with this procedure which is called a probability of correct response curve, a criterion was set on the probability axis (in this study 80 % of correct response) and the corresponding size of a cut on the ring was obtained as a threshold which was regarded as visual acuity of the subject in that viewing condition.

The subjects who participated were a total of 111 people ranging in age from 10s to 70s. The age distribution was as follows: 11 people in the age of 10s, 28 people in 20s, 11 people in 30s, 10 people in 40s, 10 people in 50s, 22 people in 60s, and 19 people in 70s. The subjects dominated in number for the age groups of 20s and for 60s to 70s than others. In this study, the younger and older people mean the ones in ages of 20s and over 60 respectively, but it should be noted that different definitions may exist. The older people in this study have also a limited meaning as people who have no medical disorders in the eyes.

These subjects, from younger to older, were equipped with spectacles to correct their visual acuity so as to get the best acuity at a far point of 5 m. This is called “far point correction.” This correction is of particular importance to obtain basic data at an arranged condition as there is an uncertainty in correctness of spectacles actually used by the subjects.

Five sampling points were selected for viewing distance which were 0.3, 0.5, 1.0, 2.0, and 5.0 m. Considering that visual acuity of older people becomes worse at near distance and the near point of the accommodation of the eye is at about 30 cm, the 30cm distance was set as the nearest measuring point in the present study. On the other hand, the characteristics of the optical lens are described by using dioptre (1/m). Then, accommodative characteristics of human lens at far point can be described at 5 m by regarding this point as a representative. It is reasonably considered that these 5 points from 0.3 to 5 m can be used to describe the overall feature of accommodative ability of the human eye.

As for the luminance level, a wide range from photopic[Term 1] to mesopic[Term 2] vision was covered taking account of the fact that the human eye adapts to such a wide range of luminance. Nine sampling points were actually selected from 0.05 cd/m^2 to 1000 cd/m^2 with almost even steps in logarithmic scale.

Figures 3(a) and 3(b) show the averaged results of the measurement. Figure 3(a) is for the effect of viewing distance on visual acuity and Fig. 3(b) for the effect of luminance. As shown in Fig. 3(a) viewing distance has a remarkable effect on subjects aged over 40 indicating that their visual acuity rapidly decreases as viewing distance becomes shorter. This means we should provide a font larger for older people when it is given in short viewing distance. As for the luminance effect, it can be seen for all the age groups that visual acuity decreases similarly as the luminance level decreases. Although some absolute differences exist, the manner of the relative change of visual acuity is almost the same for any of the age groups and it can be concluded that there is no age effect for the visual acuity change relative to luminance.

While the effects of factors in viewing conditions were figured out, the visual acuity data does not directly relate to the legible letter size. Therefore, the measurement on how much font size is actually needed to read the letters, which appear in Japanese sentences (“Japanese letters” hereafter), was carried out in the same viewing condition as in the visual acuity measurement. The 80 % of correct response was adopted also as the level of legibility which was the same in the case of visual acuity. This makes it possible to directly connect the data on visual acuity to the data on legibility.

Figure 4 shows the data on minimum legible font size in average for three kinds of letters such as hiragana/katakana/numerals, kanji with 5 to 10 strokes, kanji with 11 to 15 strokes. The measurement was carried out under the 8 conditions in combination of two age groups (in 20s and 60-70s), two viewing distances (0.5 and 2 m), and two luminance levels (0.5 and 100 cd/m^2).

The results of the younger 48 subjects (in average) show they were able to read a 4-point-size letter at the most preferred condition, but older people needed at least 12 points of size to read it. This corresponds to the results of visual acuity. It is a priori that longer viewing distance requires larger font size from geometrical reasons, but the need of a larger font at the low luminance level is a requirement from visual characteristics.

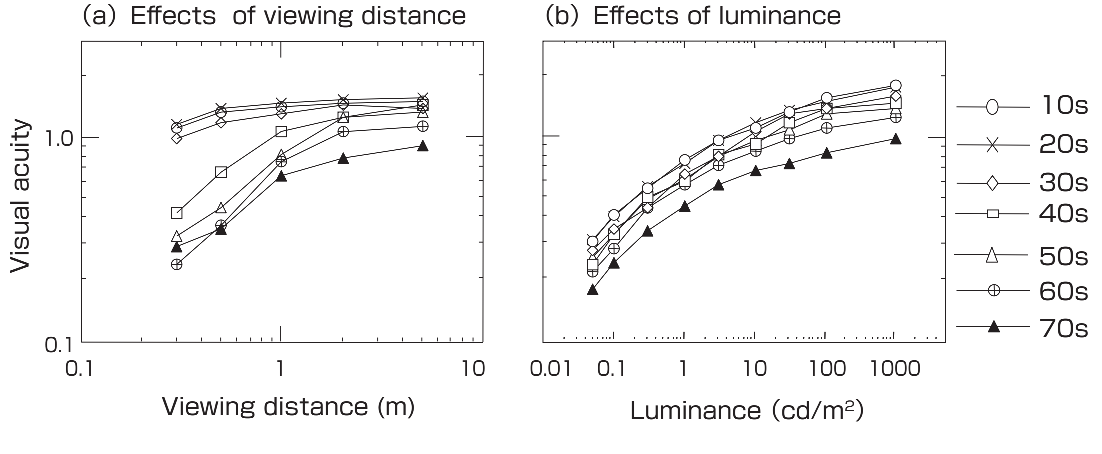

Fig. 3 Effects of viewing distance and luminance on visual acuity
(a) Effect of viewing distance. Visual acuity change for 0.3 to 5 m of viewing distance when the luminance level is fixed at a constant level of 100 cd/m^2. (b) Effect of luminance. Visual acuity change for 0.05 to 1000 cd/m^2 of luminance when viewing distance is fixed at a constant of 5 m. In both (a) and (b) data were taken from 111 subjects and averaged over each age group.

4.2 Estimation of minimum legible font size

Results shown in Fig. 4 are the data only for limited conditions and it is required to generalize these results into other conditions of age, viewing distance, and luminance level. Analysing the data in Fig. 4 we found that a newly introduced quantity namely "a size factor" enables us to describe the whole data in a more simple form. The size factor is a quantity of viewing distance divided by visual acuity as shown in Equation (1).

$$S = D/V \qquad (1)$$

Here, S means the size factor, D viewing distance in meter, and V visual acuity. The size factor implies the visual spatial resolution in a real scale. The visual acuity is defined by the minimum visual angle Θ that the eye resolves, and in the definition it does not depend on the viewing distance. However, for older people who have a limit in accommodative power, visual acuity depends largely on viewing distance in particular for short distance (less than 1 m). Although visual acuity can be known from the data on viewing distance versus visual acuity shown in Fig. 3(a), visual acuity, which only means the resolution of angle but not of actual length, cannot readily be related to font size. Introducing the size factor enables us to know the real length of resolution at the viewing distance which directly relates to font size. That is, minimum legible font size is regarded to be proportional to the actual resolution. Here, some small discrepancy between visual angle Θ and actual distance exists in the conversion from angle to distance ($\tan \Theta = \Theta$) but it is regarded negligible.

In Fig. 5, minimum legible font size experimentally obtained is plotted as a function of the size factor newly introduced here. While some discrepancies are seen, it is found that the whole data on minimum legible font size seem to be expressed well as a function of the size factor. Then, as a most simple case, the following linear equation was applied between the size factor and the minimum legible font size.

Table 1. Coefficients of the equation to estimate minimum legible font size

Kind of letter		*a*	*b*
plain	hiragana, katakana, numerals	8.2	2.6
	kanji 5-10 strokes	9.6	2.8
	kanji 11-15 strokes	9.6	3.6
Gothic	hiragana, katakana, numerals	6.4	3.0
	kanji 5-10 strokes	8.1	3.4
	kanji 11-15 strokes	8.6	4.1

$$P = aS + b \qquad (2)$$

Here, P means the minimum legible font size (in point), a and b mean coefficients that depend on the kind and type of letters such as plain, Gothic, kanji, etc, the values of which are derived from Fig. 4 and summarized in Table 1.

When we consider that font size changes in proportion to the size factor, Equation (2) should be a line that runs through the origin point of the size factor versus the font size plane. However, looking at the experimental data in Fig. 5, it seems appropriate to use the power function that runs from the origin, or to use a linear function with a constant b like Equation (2) to make a fit to the whole range of data. Due to

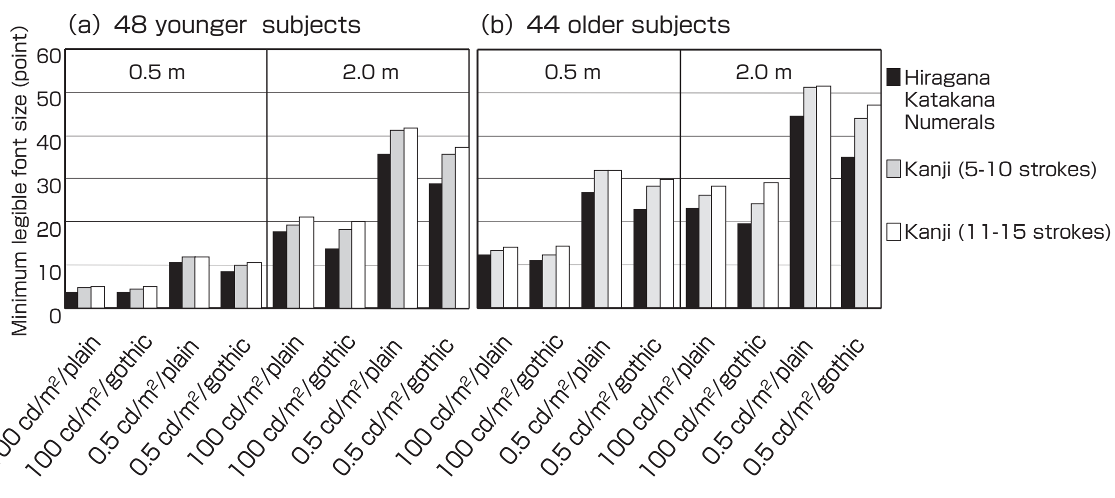

Fig. 4 Font size required to read a Japanese single letter

(a) Minimum font size required to read a Japanese single letter (hiragana/katakana/numerals, kanji 5-10 strokes, kanji 11-15 strokes) at viewing distance of 0.5 and 2 m and at luminance level of 100 and 0.5 cd/m². Results of 48 younger subjects. (b) Same as 4(a) but for 44 older subjects.

the requirement for application of standardization in this study, preference for general easy use rather than high accuracy was emphasized, and a simple linear function and not the power function was selected. Furthermore, it should be realized that Equation (2) should be applied only for the range where the eye can accommodate (from the near point to the infinite far distance) but not for the extreme case that the viewing distance is nearly zero where visual acuity has no actual meaning. This near range is out of scope of Equation (2). It is anticipated that at zero viewing distance Equation (2) gives us $P = b$, meaning that a letter of a certain small size is legible, which is unreasonable, but this situation is regarded as out of range of using Equation (2) and no convergence to $P = 0$ is required.

4.3 An example of calculation

An example of calculating minimum legible font size by using Equation (2) is shown here. Let us assume the viewing condition of a 70 year old, 50 cm of distance, and 100 cd/m^2 of luminance, minimum legible font size calculable for the case of a kanji letter with 5 to 10 strokes of the Gothic font, for example. First, visual acuity at the condition of viewing distance of 50 cm and luminance of 100 cd/m^2 is known as 0.4 from Fig. 3(a), and from this visual acuity the size factor of S (= distance (m)/visual acuity) is obtained as 1.25 (= 0.5/0.4). Then, taking proper coefficients a and b for that condition from Table 1 enables us to calculate the minimum legible font size as follows:

$$P = 8.1 \text{ x } 1.25 + 3.4 = 13.5 \text{ (point)}$$

If we do a similar calculation only for a plain font, a larger font size of 14.8 point will be obtained, which is larger than for a Gothic one. That means the plain font is less legible than the Gothic font. Furthermore, if the luminance condition becomes darker than 100 cd/m^2, the legible font size will be larger because visual acuity will become lower as shown in Fig. 3(b).

It should be noted that the minimum legible font size is a quantity that gives us a basic scale of legibility. It is convenient to have such a common scale by incorporating the affecting factors of age, viewing distance and luminance. It should also be noted that the present minimum legible font size is defined by 80 % of the probability of legibility, that is, a near threshold level, and this size does not necessarily mean “easily legible”. A new scale of legibility extent should be established by conducting relevant studies to obtain the preferable legible font size.[7]

5 Dissemination of the technical outcome through standardization

As previously mentioned, accessible design focuses on the group characteristics of many people rather than on those of an individual person. Being based on the specific feature of the group, the importance is to standardize the technical outcome of the study and to disseminate it into a whole society. As the present study is on the method for estimating minimum legible font size, it is expected to provide easily legible letters to a wider range of people through standardization of the method.

5.1 Establishment of a JIS (Japanese Industrial Standards)

The present study was based on the data collected for Japanese letters and the outcome of it was first established as a Japanese standard. It is generally important in standardization to define the scope clearly. The following items were defined as the scope of the method for estimating minimum legible font size.

(1) A single Japanese letter is applied.
(2) Minimum legible font size is designed as a function of age, viewing distance, and luminance.

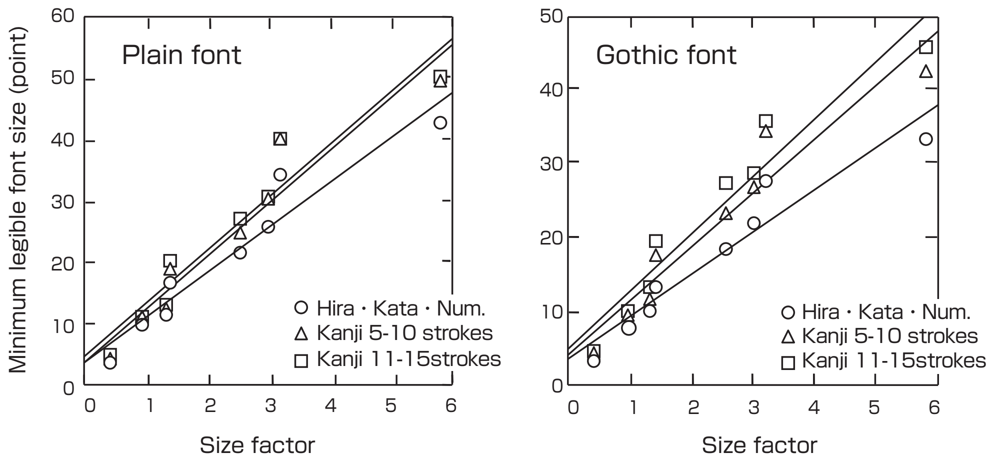

Fig. 5 Relation between minimum legible font size and the size factor
Left: Minimum legible font size as a function of the size factor for three kinds of letters (hiragana/katakana/numerals, kanji 5-10 strokes, kanji 11-15 strokes) of a plain font. Right: Same as the left but for a Gothic font.

(3) It is applicable to a person at any age from 10s to 70s, but not people with visual disabilities like low vision.
(4) Letters with high contrast such as black letters on a white background is considered.

From the viewpoint of accessible design, the design method of the present study is applicable to almost all people at any age. However, it is not applicable to those who have extremely low visual acuity such as low vision and a separate study will be needed for that.

While our actual environment for reading letters is so complicated, main factors such as age, viewing distance, and luminance are considered in the present study. Although another important factor of contrast should be investigated more, the present design method can apply to high contrast letters such as black letters printed on a white background. Care should be taken, however, when applying the present design method to electric displays which have reducing effects of contrast due to the reflection of surrounding light.

Another important point in the present study from a viewpoint of standards is that visual acuity of subjects was corrected by lenses. In the experiment, all the subjects, younger or older, had their visual acuity corrected at the far distance (5 m viewing distance) and then participated in the experiment, which is not the actual situation as visual acuity of older persons are usually corrected by their special lenses to the near point. In such a case they can read letters of much smaller size than those estimated by the present study. Therefore, it should be regarded that the present method is to estimate legible font size at the condition where no special glasses or magnifiers are used.

Under these considerations, the outcome of the present study was standardized as JIS S 0032 "Method for estimating minimum legible font size for a Japanese single character."[8] With this standard it can be said that a scale for legible font size for older people was established. This means it is possible to derive minimum legible font size by taking into account environmental factors (age, viewing distance, and luminance). Taking this size as a criterion, it would be possible to define not only "minimum" but also "legible" letter size.

5.2 Standardization at ISO (International Organization for Standardization)

It is possible to standardize the present design method not only as a domestic standard but also as an international one. As Equation (2) expresses fundamental properties of vision, this may apply to letters of any other language. In particular, legibility of numerals and alphabets should be the same in any other language because of its similar structure as long as human vision is the same. To confirm this, investigation on legibility for different languages and letters was carried out.

In the experiment, test samples of letters printed in high contrast and high resolution on the same plates were sent to 5 research institutes in Korea, China, Germany, Thailand and United States of America and the legibility was compared among them. Hangeul letters in Korea, Chinese letters in China, Thai letters in Thailand, and English in other countries were used respectively both in plain and Gothic fonts. The plain and Gothic fonts are being used in every language as serif and sans serif font respectively. In general, the difference between both types of fonts is whether decorated short lines are attached to the edges of strokes or not. The subjects were about 20 younger and 20 older people in each country. Some differences in the distribution of visual acuity of subjects or illuminance level may exist among countries, but correction using Equation (2) will be possible from the visual acuity data of the subjects measured at the same time for the same experimental condition.

Figures 6(a) and 6(b) show an example for data of percent correct for a plain font and a Gothic font respectively. Due to some differences in viewing conditions such as illuminance or kinds of letters, some deviations were observed for the data in Korea and Thailand but the overall data are almost consistent with each other. This makes it reasonable to assume that there is no basic difference in the human ability for reading and Equation (2) can be applied for estimating minimum legible font size.

Applying Equation (2) to obtain estimated font size, Figure 6(c) was drawn in which the estimated font size is compared with that of experimentally measured. In applying Equation (2), visual acuity measured in the experimental condition in each country was used to know the size factor, and by knowing coefficients from Table 1 the minimum legible font size was estimated. Coefficients for kanji 11-15 strokes and those for hiragana etc. were applied to Hangeul, Chinese, and Thai letters and to alphabets respectively. Although some discrepancies are found for Japanese and Thai data, the estimated font size does fit the one measured (80 % correct legibility). However, it can be said the predictability is not perfect. For example, the coefficients for Hangeul or Thai letters should be different from Table 1 and proper coefficients, if derived correctly, will improve the estimation much.

For the method for estimating minimum legible font size confirmed by the international comparison, discussions for an international standard in ISO have started. It seems reasonable internationally to establish first the use of Equation (2) to alphanumeric letters with appropriate estimation of coefficients because alphabetical letters are frequently used internationally. Coefficients for Chinese, Thai and Korean (Hangeul) letters should also be defined appropriately and may be provided as Annex. If all kinds of letters used in the world are considered, some classification method concerning the visual complexity of the structure of letters will be required. Further studies should be promoted on this point.

Font design is not the only target that should be standardized in accessible design in ISO. Standardization on design methods based on human data of older people and people with disabilities is now being progressed under the initiative of Human Technology Research Institute at AIST for wider ergonomic fields concerning physical, sensory, and cognitive abilities.

Accessible design is a new field in ISO and there were no existing relevant working groups before. There was one Technical Committee (TC) named TC 159 “Ergonomics” which was closely related, and a working group (WG) was established under the TC. Figure 7 shows the structure of TC 159. The fields colored gray in the structure are all WGs established for accessible design, which are WG 2 directly under the TC, WG 10 under SC 4, WG 5 under SC 5, and Advisory Group for Accessible Design (AGAD) which is a coordinating committee for these activities. Establishing such a scheme for standardization was necessary work for disseminating the research outcomes. In accessible design, the concept is running far ahead and the technology is still in the developing stage. Much time and work is needed to form a firm basis for development and promotion such as collection of human data and this is difficult to be done only by industry. Particular knowledge and data on ergonomics will be actually needed to solve the problems with older people and people with disabilities. Studies on accessible design should be carried out with basic research outputs and dissemination of them through standardization being closely coordinated.

6 Summary: *Full research* and standardization

Figure 8 shows the flow of the whole process of the present study. The study is started from the left-bottom of the figure and after it reaches the goal at bottom right, a new research cycle is started to solve a new problem. Normally identifying problems, collection of basic data, and establishing methods for solving problems are done within the first cycle of research shown in the figure, and academic papers are published then. In accessible design, the same steps should be taken in this first cycle but it would be difficult to disseminate the outcome to society if it ends there. This is because research results of a smaller scale based on limited number of

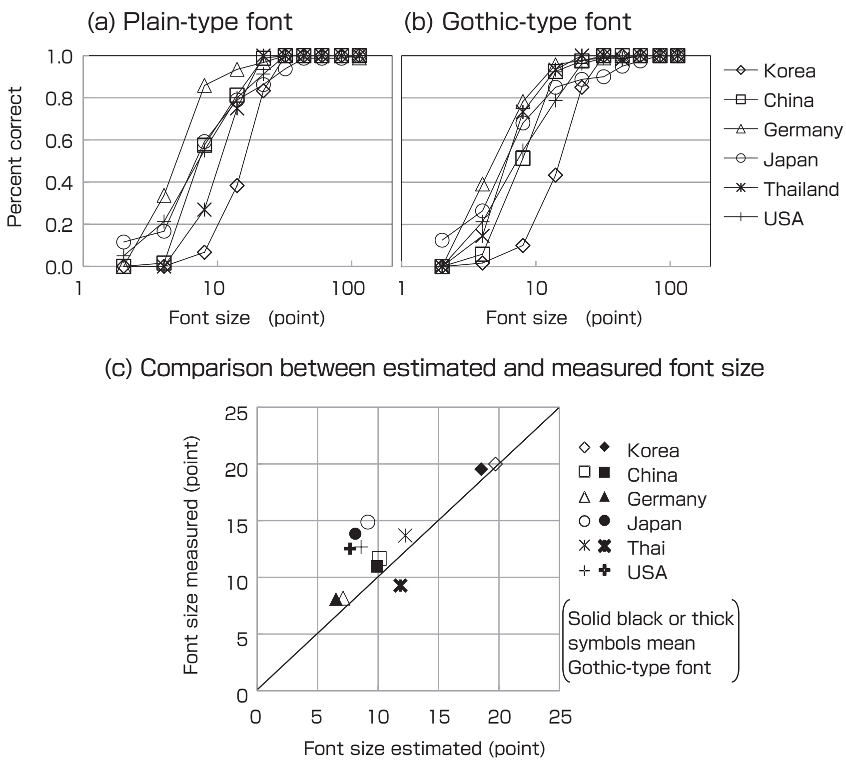

Fig. 6 Minimum legible font size for 6 countries of Korea, China, Germany, Japan, Thailand and USA.
Hangeul for Korea, Chinese for China, Thai letter for Thailand, and lowercase of the alphabet were used for other countries, all in plain and Gothic fonts. Charts (a) and (b) mean the legibility data as percent correct for a single letter with variable size from 2 to 114 point. Data are averaged over 20 older people in each country. Illuminance was from 300 to 500 lx. Chart (c) is the correlation between the data theoretically obtained and the measured ones derived from charts (a) and (b).

samples cannot make it applicable to many people including older people and people with disabilities. Another cycle of research is therefore needed for the study to disseminate the outcome.

In the second cycle, along with the concept of accessible design previously mentioned, data collection is carried out to know the characteristics of older people and people with disabilities. Through analysis of the data as well as investigation on the applicability to products and environments, the technologies developed are elaborated. Those technologies established are finally proposed to international standards for dissemination to society and

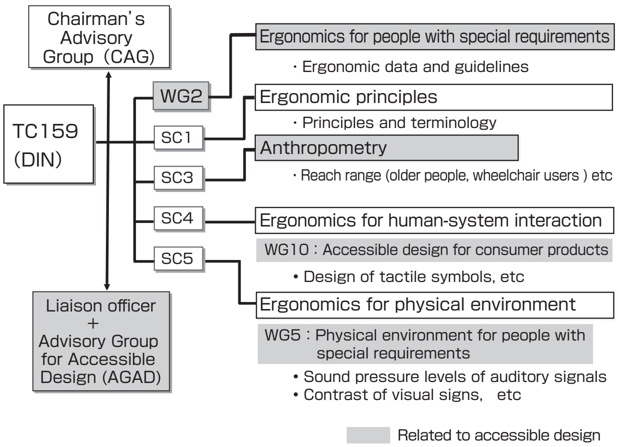

Fig. 7 Structure of TC 159 and working groups related to accessible design.

The boxes colored gray (AGAD, WG 2, SC 4/WG 10, SC 5/WG 5) are new working groups established for the development of accessible design standards. Convenors and secretaries of them are research scientists from AIST.

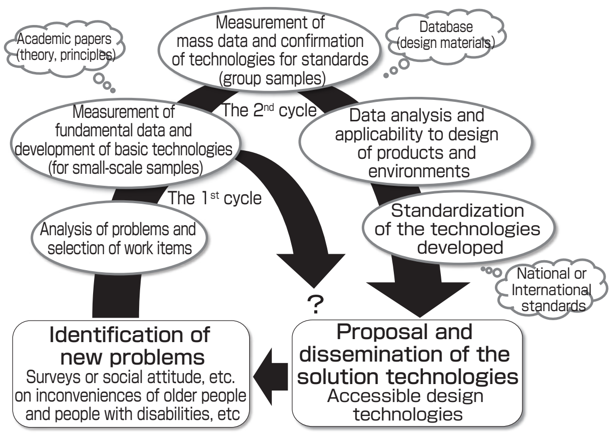

Fig. 8 The flow of the present study from identification of new problems to standardization of outcome.

From identification of new problems to fundamental data and development of basic technologies is addressed as the 1st cycle and results are published as academic papers. Starting from that stage, the 2nd cycle is for collection of mass data and confirmation of technologies to be standardized where database and standards are developed and disseminated.

industry. The whole research process is thus accomplished from identification of needs in the first cycle to developing and disseminating the accessible design methods in the 2nd cycle. When new needs or problems are raised which are not completed in this process, a new second cycle will take place where new methods of development and standards are reconsidered.

The study of minimum legible font size introduced here is now still in the process of standardization; the use and promotion of the method will probably be facilitated through this research cycle together with the experience of domestic standardization.

Terminology

Term 1. Photopic vision; vision in which the eye is adapted to the light over 10 lx of illuminance or a few cd/m^2 of luminance at least. An adaptation state where cone photoreceptors are active in principle.

Term 2. Mesopic vision; Intermediate dim adaptation level of illuminance or luminance between photopic and scotopic vision (below about 10^{-2} lx of illuminance or 10^{-3} lx of illuminance or 10^{-3} cd/m^2 of luminance). An adaptation state where both cone and rod photoreptors are active.

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Authors

Ken SAGAWA

Completed the master's course of the Graduate School of Physical Information Engineering, Tokyo Institute of Technology. Doctor of Engineering. Retired from National Institute of Advanced Science and Technology, AIST, and now a professor in Department of Human Science and Design, Japan Women's University. Emeritus Researcher of AIST. Involved in research fields of visual engineering, photometry and colorimetry, evaluation on visual environments, etc., and studies on visual comfort of environment, evaluation of visual environment for older people, accessible design methods, and worked on standardization, national and international. In the present study, responsible for theoretical framework of accessible design and in experiments on legibility of letters.

Kenji KURAKATA

Completed the doctor's course of the Graduate School of Human Sciences, Osaka University in 1994. Ph.D. (Doctor of Human Sciences). Leader of Accessible Design Research Group, Human Technology Research Institute of AIST. Involved in user-interface design, hearing research of older people, and domestic and international standardization of acoustics and audiology. In the present study, responsible for theoretical framework of accessible design, analysis of the experimental data, and standardization.

Discussions with Reviewers

1 General

Comment (Akira Ono, AIST)

This is an excellent study of *Type 2 Basic Research* where it first clearly selects elemental technologies, synthesizes them, develops a method for estimating minimum legible font size, and finally standardizes the outcome. It was pointed out in chapter 3 that the standardization was useful in disseminating the outcome. However, in addition to that, it seems that setting the standardization as a goal and keeping this always in mind throughout the processes such as the selection of elemental technologies, synthesis, and integration helped to keep the whole study in appropriate control. I would be interested to hear comments from the authors on this point.

Answer (Ken Sagawa, Kenji Kurakata)

As pointed out by the comment, the present research had been carried out keeping the intention and from the viewpoint of standardization. As a matter of fact, this study was conducted with an AIST grant of "Program for Fundamental Research on Standardization." Applying for the grant was a strong requirement itself for us to realize the standardization and to develop standards or something like that as a goal.

A social need to be fulfilled by the standards is set as a goal in the planning stage of the research. In the case of the present study, legible font design for older people was a social need and the study proceeded for standardization as a final goal taking into account the public nature of the study and the difficulty of it being carried out by industry.

2 Reference value for legibility

Question (Akira Ono)

Probability of 80 % was selected as a criterion for legibility to derive minimum legible font size and its standardization. What is the reason for this? Is there any other possibility besides 80 %?

Answer (Ken Sagawa, Kenji Kurakata)

While the 50 % level is usually taken as a threshold, a higher level of probability was selected since with the 50 % level half of the population are able to read but the other half are not, which actually means it is a level which is quite difficult to read. There was an idea to take one standard deviation level (σ) which is the 84.1 % level, but as there was no strong recommendation on this point, the 80 % level was adopted as a rounded value.

The 80 % level still yields one failure of 5 trials and this is also regarded as a difficult level to read, but by using this level as a unit, a scale of legibility could be constructed by multiplying the unit.

Actually in a later study, a scale of legibility was developed with the minimum legible font size as one unit in which "very illegible" for below 0.9, "illegible" for between 0.9 to 1.2, "normal" for between 1.2 to 1.7, "legible" for between 1.7 to 2.2 and "very legible" for over 2.2 were assigned. This scaling is planned to be proposed in the next academic presentation or in the review of the standard.

3 Formula between legible font size and the size factor.

Comment (Motoyuki Akamatsu, Human Technology Research Institute, AIST)

Considering that resolution in absolute value correlates to the minimum actual gap between strokes that is needed to be recognized as a letter, the resolution should be in a linear relationship to the font size. The most simple linear equation to fit is $P = aS$ that is a line that goes through the origin. But there may be some discrepancy which occurs with this fit at the higher value of the size factor. Looking at the data in Fig. 5, a better fit could be obtained with a power function if it is applied. I presume that in the standard document, a linear function with a cross-point of y-axis was used though a power function is known to be better if accuracy is required.

If there is a similar consideration underlying this research, it is worthwhile to clarify it to the readers because it is important to present an easy-to-use equation for the standardization even if it means reducing the accuracy.

Answer (Ken Sagawa, Kenji Kurakata)

There are several ways of thinking and methods for the curve fitting; we finally selected the simplest equation possible. As pointed out in the comment, we have come to the conclusion taking into consideration that dissemination of the research outcome is also an important point.

It is true that detailed and case-separated analysis will give us a better fit. However, keeping in mind the large variability of the data and the no need to go through the origin point, we thought pursuing the accuracy only will give us an unrealistic prediction. Having investigated all possibilities of functions such as a power function or a linear function (with or without a constant), we decided to take a linear function with a constant as the best one. We hope you understand that the conclusion was derived by paying constant respect for the application to standards.

Based on this consideration, the text was revised.

4 Font type and legibility

Question (Akira Ono)

Plain and Gothic fonts were used in this study, both in proper shape and not deformed. Kanji letters used in traffic signs on highways, on the other hand, have missing parts or strokes or are simplified considerably. This seems to mean that deformed Kanji letters are more legible. Is there any relation between this and the present study of legibility?

Answer (Ken Sagawa, Kenji Kurakata)

There exit now several hundreds of font types and a number of fonts that aim for aesthetic appeal more than conspicuity. These are classified into serif (font with decorated short lines at ends of strokes) and sans serif (font without decorated short lines). There are many variations of fonts even in serif and sans serif fonts. In the present study the most frequently used fonts of MS-Mincho and MS-Gothic were used as representatives of the font.

Legibility of fonts can be determined by the distribution of spatial frequency (density or scarceness of lines) of components and visual sensitivity to spatial frequency. Width of strokes is strongly related to the legibility in this sense. The Mincho-font has generally narrower lines and high frequency components, and the Gothic font wider lines and low frequency components. To clarify the difference, it is efficient to study with representative Mincho and Gothic fonts. The relationship between spatial frequency and legibility is one of the fundamental issues, though not studied in detail in this study, and the way and viewpoint of the idea was taken into consideration in setting up the experimental scheme.

As a result, the Gothic font was found to be much easier to read, and this is considered due to the width of strokes. Furthermore, it was found that the minimum legible font size was increased with the change from katakana, kanji (5-10 strokes) to kanji (11-15 strokes) meaning that they are harder to read in this order. Generally speaking, as deformed letters are changed to the simpler, it is regarded that these deformed letters are being used in visual signs.

5 Legibility of letters of foreign languages and Japanese letters.

Question (Motoyuki Akamatsu)

Concerning the results in Fig. 6 where application of the present method to letters of other languages is shown, the worst fit is found to be for Japanese. Although the method was drawn by using Japanese data, the application results for Japanese were the worst. Is there any particular reason?

Furthermore, it was pointed out that using coefficients derived from Japanese data was one problem in applying to other language. Are there any other problems in the application, for example, with the different definitions of the “points” of letters (definition of letter height)? If so, please note these.

Answer (Ken Sagawa, Kenji Kurakata)

There is no essential reason for the worst fit for Japanese letters. The Japanese results were obtained from the new data in the international comparison that was carried out with different subjects and viewing conditions from the ones that yielded the equation. We first thought the bad fit was due to the difference between hiragana (for which coefficients were defined) and the alphabet, but a good fit found in Germany tells us it was not the estimated problem with the alphabet.

Applicability of coefficients derived from Japanese letters is a future problem. It is ideal to draw coefficients suitable to each letter of language, but it may be more feasible to classify according to the complexity of letters and define the appropriate coefficients for each class.

As for the expression of the “points” of letters, it is internationally defined and using the definition is reasonable. For other problems, it should be noted again as previously mentioned that the classification of the complexity of letters will be effectively used in the application of the method.

6 Normative items in standardization.

Question (Akira Ono)

JIS S 0032 “Estimation of minimum legible size for a Japanese single character” was issued as an output of the present research. Please show us what normative items (rules to follow) are defined and what informative items (information to refer) are decided in this standard, and the considerations underlying those decisions as well.

Answer (Ken Sagawa, Kenji Kurakata)

JIS S 0032 standardized the “method” but not the legible font size itself. That is, the method for estimating minimum legible font size is only the normative item [Equation (2) and Table (1)]. The use of the font size derived by the present method is solely dependent on the user of this standard. Informative items include evaluation methods for the sentence readability based on the minimum legible font size etc. which are in the Annex.

7 Strategy for dissemination of research outcome

Question (Motoyuki Akamatsu)

It is well understood that standards documentation is suitable for promotion of accessible design, but the design would not spread widely if designers do not use the standards documents. If there is any action being taken for a wider use of them, please introduce it.

Answer (Kurakata Kenji, Ken Sagawa)

We definitely understand it is important to disseminate the standards documents. At the earlier stage we took things lightly and thought that the design technology would be distributed when it was standardized, but we have clearly found that the dissemination is not so easy. Therefore, in order to let people know widely the idea of accessible design we took some actions such as developing pamphlets or holding symposiums regularly for designers or engineers in industry for the promotion in collaboration with the Ministry of Economy, Trade and Industry or ADFJ (an organization to promote accessible design).

In the future, we think some mechanism to clearly show to consumers the products that incorporate accessible design is needed. One example is a social mechanism concerning conformity assessment of the accessible design standards. With this mechanism, not only consumers are able to easily choose products but also industry will realize the impact of accessible design and the dissemination of the products will be accelerated.

8 Limitations of the methodology using standardization

Question (Motoyuki Akamatsu)

It seems the position of the present study is that a scenario of standardization was adopted to promote accessible design. Please show us the limitations of the methodology using standardization.

Answer (Kenji Kurakata, Ken Sagawa)

1) Leading or innovative research that aims for the “only one” or “number one” does not seem to be suitable for standardization, but the research that is matured and needs one more step for application (*Type 2 Basic Research*) suits standardization. On the other hand, research that needs competitive speed or that aims to develop a new field will be limited by standardization and seems to require a strategic procedure.
2) Standardization of technologies may mean, at the same time, to limit flexibility. The legibility studied in this paper is an estimation of a font size for limited conditions and a type of letters for people in a certain age group, which is something like GCD (greatest common divisor). It might be possible to estimate more accurately the legible size for a person in that condition, taking into account the visual properties of the person and specifying the conditions in more detail. It is one of the characteristics of the standardization research

and a limitation at the same time that it prioritizes speedy promotion of the technologies emphasizing simplification and generalization rather than refinement and the best suitability. There is a large stock of data, however, behind the development with this simplification and generalization. It would be effective to utilize those data for the need of making a best fit for each individual case. To meet the needs of engineers or designers of industry, the authors have started to publicly open the data behind the standardized technologies through the research information database (RIO-DB) at AIST.

3) Concerning the research system, it can be said that a systematic promotion for the standardization research is required. One of the authors (Sagawa) has been involved in international standardization of the light and lighting field in the international organization called Commission Internationale de l'Eclairage (CIE). At first he felt some limitations in conducting research, committee works, and international communication, as he worked completely alone. After reorganizing the institutes to AIST, the industrial standards division was established and the organizational environment for carrying out the program for standardization research was well prepared. With this development, many researchers joined the research intended for standardization and the group studies had been made possible. The situation remarkably progressed. It would be very difficult, on the contrary, to carry out standardization research without such a support system.

4) In relation to answer 3) there is a limitation in bringing research to standardization with projects of short timespan. The standardization work needs at least three years after the proposal (in the case of ISO). If we include the work time for the preliminary stage, it takes 6 to 7 years even if the work proceeds ideally. The projects of about three years is now becoming major, and we are required to do research by connecting these projects. If the connection is terminated, a plan for standardization itself will disappear. Standardization research can never proceed by connecting too short-term projects or new projects.