TECHNICAL REPORT

ISO/TR 22411

Second edition
2021-01

Ergonomics data for use in the application of ISO/IEC Guide 71:2014

Données ergonomiques destinées à être utilisées dans le cadre de l'application du Guide ISO/IEC 71:2014

Reference number
ISO/TR 22411:2021(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 122, *Ergonomics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO/TR 22411:2008), which has been technically revised.

The main change compared to the previous edition is the replacement of ergonomics data on human abilities and capabilities with new or more elaborated data for use in the application of ISO/IEC Guide 71:2014.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is intended to help standards developers by providing ergonomics data related to human characteristics and capabilities to support ISO/IEC Guide 71:2014. This document is supposed to be used mainly by standards developers, but also by those responsible for design. The underlying idea is that products, services and environments encountered in all aspects of daily life and intended for the consumer market and the workplace should be designed to be accessible for people with a widest range of capabilities. This idea, called accessibility, has been spreading all over the world.

ISO/IEC Guide 71 was first published in 2001 to successfully address the importance of being aware of the needs of older persons and persons with disabilities and to direct the attention of standards developers to these needs when they draft or revise standards. In response to the publication of ISO/IEC Guide 71, ISO/TR 22411:2008 was developed to fulfil the gap between the concept and practice with offering ergonomic knowledge and data on human abilities.

After more than 10 years from the publication of ISO/IEC Guide 71 and ISO/TR 22411, together with new knowledge and experience in implementing these documents, ISO/IEC Guide 71 was revised into a more elaborated one and consequently the revision of ISO/TR 22411 was required.

This document provides updated ergonomics data as well as newly available data which are all publicly available and can be used to support standards developers in applying ISO/IEC Guide 71:2014 in their individual standards. These ergonomics data help standards developers to understand characteristics and capabilities of diverse users to be served by requirements and recommendations in a standard. The data provided in this document apply mainly to persons with disabilities and older persons. The intention in using these data is to formulate requirements and recommendations in standards that include the widest possible range of users. It can also be used by designers in order to increase accessibility as part of accessible design or universal design.

While the data covers a wide area of human abilities related to accessibility, data for some part of the area, for example cognitive abilities, is still missing. Furthermore, new data emerged or were updated during the development of this document, which is not included in this document either. This document, due to scientific reasons, does not necessarily adopt the ICF terminology but established terms in ergonomics.

Ergonomics data for use in the application of ISO/IEC Guide 71:2014

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This document provides ergonomics data for standard developers to use in applying ISO/IEC Guide 71:2014 to address accessibility in standards. These data can also be used by ergonomists and designers to support the development of more accessible products, systems, services, environments, and facilities.

The ergonomics data include quantitative data and knowledge about basic human characteristics and capabilities as well as context-specific and task-specific data, all being based on ergonomics research. The data focused on the effects of ageing and/or consequences of various types of human sensory, physical, and cognitive disabilities. It does not contain general ergonomics data that have no direct relation to ageing or disabilities.

The data presented in this document are not exhaustive due to no available data for some aspects of human characteristics and capabilities with regard to ageing and disabilities.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
accessibility
extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals in identified contexts of use

Note 1 to entry: Context of use includes direct use or use supported by assistive technologies.

[SOURCE: ISO 9241-112:2017, 3.15]

3.2
accessible design
design focused on diverse users to maximize the number of potential users who can readily use a system in diverse contexts

Note 1 to entry: This aim can be achieved by (1) designing systems that are readily usable by most users without any modification, (2) making systems adaptable to different users (by providing adaptable user interfaces) and (3) having standardized interfaces to be compatible with assistive products and assistive technology.

Note 2 to entry: Terms such as universal design, accessible design, design for all, barrier-free design, inclusive design and transgenerational design are often used interchangeably with the same meaning.

[SOURCE: ISO/IEC Guide 71:2014, 2.19]

3.3
impairment
problem in body function or structure related to a significant deviation or loss

Note 1 to entry: Impairments can be temporary or permanent; progressive, regressive or static; intermittent or continuous.

[SOURCE: ICF 2001, WHO]

3.4
system
product, service, or built environment or any combination of them with which the user interacts

[SOURCE: ISO/IEC Guide 71:2014, 2.1]

3.5
universal design
design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design

Note 1 to entry: Universal design shall not exclude assistive devices for particular groups or persons with disabilities where this is needed.

Note 2 to entry: Terms such as universal design, accessible design, design for all, barrier-free design, inclusive design and transgenerational design are often used interchangeably with the same meaning.

[SOURCE: ISO/IEC Guide 71:2014, 2.18]

3.6
user
individual who accesses or interacts with a system

[SOURCE: ISO 9241-11:2018, 3.1.5, modified — In the definition, "person" has been changed to "individual", "accesses or" has been added, and "product or service" has been removed.]

4 Supporting ISO/IEC Guide 71 with human data

ISO/IEC Guide 71:2014 provides standards developers with guidance on addressing accessibility in standards through two approaches, as shown in Figure 1:

1) the first approach defines accessibility goals for the product or system under development and the user accessibility needs associated with fulfilling those goals (denoted by Clause 6 in Figure 1);

2) the second approach provides accessibility-related design considerations, based on an understanding of human abilities and characteristics (denoted by Clause 7 in Figure 1).

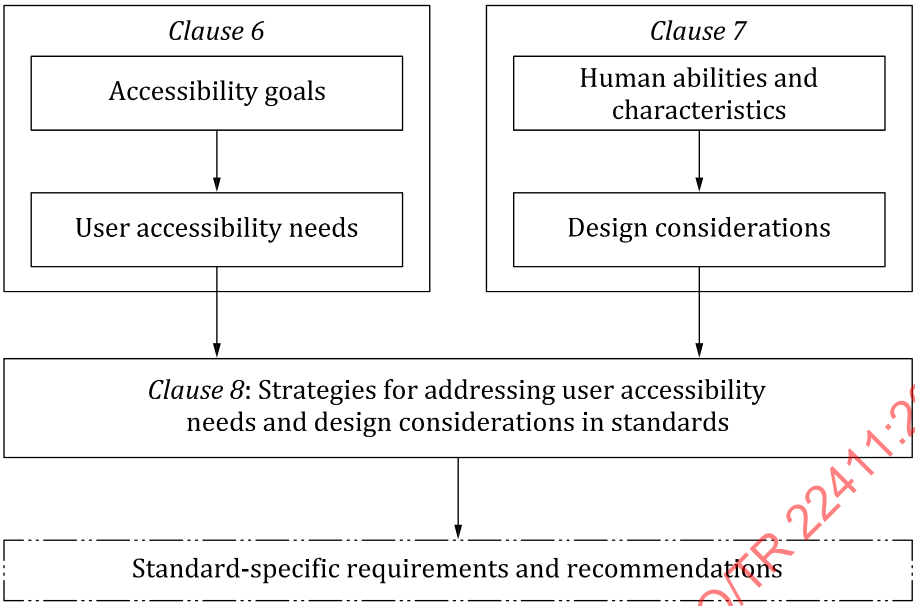


Figure 1 — Two approaches to address accessibility in standards described in ISO/IEC Guide 71:2014

The user accessibility needs (first approach) or design considerations (second approach) can serve as the basis for accessibility requirements and recommendations in standards. Regardless of which approach is used, the accessibility requirements and recommendations in the standards are derived through the appropriate selection of strategies (denoted by Clause 8 in Figure 1) that can meet the accessibility needs or address the design considerations.

Ergonomics data are relevant throughout both approaches and especially important in determining which strategies are the most effective in a situation. In some cases, the data can provide a source of nominal values or numerical specifications which can be included in the requirements and recommendations of standards. In other cases (especially with respect to cognitive variables), the available data are qualitative in nature and/or reflect small sample sizes, but can still be used to evaluate the feasibility of applying particular strategies to meet accessibility needs or to address design considerations.

In addition to the role that ergonomics data play in standards development, these data are directly relevant to the product and system designers, who are attempting to fulfil accessibility requirements and recommendations by developing and implementing technical solutions that make use of the existing data.

One of the challenges for standards developers and designers is that ergonomics data relevant to specific populations is distributed across multiple standards and other guidance documents, as well as in published research reports, papers and books from a variety of academic disciplines. The purpose of this document is to bring the most valid and applicable data together in one document. This will assist standards developers to address accessibility and consider the widest range of user needs when formulating requirements and recommendations. Having a single source of information will also be of value to designers.

5 Data selection and format

5.1 Data selection

The data in this document were selected from various sources existing in scientific books and journals, standards, as well as databases of universities, research institutes or projects. They are all relevant for demonstrating effects of ageing and disabilities and the committee regards valid and worth citing in this document. Most of the data are well-supported in academia and related technical fields or based on a sufficient number of samples to provide statistical meaningful results. Some of the data, especially in cognitive field, have a limited number of samples but the committee regards qualitatively relevant for application.

5.2 Data format of this document

Data in this document are presented in a common format for easy and correct understanding of the data. It contains following items. If no information is available for some items, they are left blank.

— **Title**

This item describes the title of the data. The title has an additional information on the type of data either for the effect of ageing or the effect of some specific disability.

— **General**

This item describes background and outline of data, implications in designing, as well as why the data is important and included in this document. Some scientific information necessary to understand the data is also included.

— **Sampled population**

This item describes samples from which the data have been obtained. Number of people who participated in the experiments or measurements, their age and gender distribution, and any other attributes of samples necessary for understanding the data are presented.

— **Methods and conditions of data collection**

This item describes methods and conditions of the measurement used for data collection. Technical information necessary for understanding the figures and tables in the data section is provided depending on the types of human characteristics and capabilities. Limitations associated with the methods or conditions are also provided.

— **Data**

This item describes typical data given in figures and tables picked up from the data source(s) that would be most suitable for understanding the human characteristics and capabilities expressed in the title of the data. The data is also selected as the most useful one for design considerations.

— **Limitations**

This item describes constrains or cautions for use of the data. As the human data largely depends on the methods and conditions of the measurement, it would be safe and useful to show the limitations in applying the data to actual situations.

— **Application examples**

This item gives a general idea for applying the data and implication of the data for design with some examples. This includes not only specific design examples but also how to use the data in general.

— **References**

This item provides a list of:

— Data sources: sources of information on the data presented in the data item, including relevant literature (standards, academic journals, books, other reports) and website;

— Cross-references: relevant sections in this document for cross-referencing and better understanding of the section;

— Other references: relevant literature and website, not directly related to the data but useful for understanding them.

5.3 How to use the data

This document provides data on a large variety of human characteristics and capabilities that can be applied to product design, as well as some aspects of the design of services and environments.

Clause 6 provides data items on sensory characteristics and capabilities covering modalities of vision, hearing, touch, and the thermal sense. No data is provided on smell and taste as no relevant data source was found, though ISO/IEC Guide 71 does address these senses in a general way.

Clause 7 provides data items on physical characteristics and capabilities, covering body size, fine motor coordination of the hand, movement of upper body structures, movement of lower body structures, and muscle power and muscle endurance. No data is provided on physical characteristics and capabilities related to speech production.

Clause 8 provides data items on cognitive characteristics and capabilities related to attention, information processing and memory. Although cognitive abilities are especially relevant to accessibility, little data of quantitative nature exists because cognitive disabilities vary markedly in their effects and can involve many unique combinations of attentional, information processing, memory, decision-making and affective impairments for any given individual.

The data provided in this document can be used, directly or indirectly, when standard developers and products designers consider accessibility in the context of developing standards or designing products, services or environments. Depending on the nature of experimental data provided, it may or may not be relevant to a specific design issue. Therefore, users of this document should consider whether the data provided in this document can be applied in their specific situation, given how it was collected (i.e. the population tested and the method used), as well as the limitations of the data, as described in subclauses.

In addition, much of the data related to physical and sensory capabilities can be directly applied because numerical values are provided in tables, charts, formulas and graphics. These data may be directly used to set limit values in standards (e.g. weight-lifting limit), or specifications of certain design parameters (e.g. the grip span for a tool). Alternatively, much of the data related to cognitive abilities simply is in the form of task-specific trends, as a function of age and/or disability, and cannot be applied directly. In these cases, designers and standards developers are limited to interpreting the implications of the trends in light of their particular design or standards development situation. It is also extremely important that users of the cognitive data maintain awareness of the significant variance in cognitive capabilities and limitations, generally, and the limited sample sizes involved for some populations for which data is provided.

6 Sensory characteristics and capabilities

6.1 Overview of sensory characteristics and capabilities

Every sensory characteristic and capability can be affected by ageing: abilities to detect, discriminate or perceive sensory stimuli of vision, hearing, touch or thermal sense. How the change occurs varies depending on the sensory function.

Various types of disabilities in sensory characteristics and capabilities are caused by medical disorders or impairments in the structure or the function, which result in low vision, colour defect, hardness of hearing, etc. In addition, disabilities can be caused by environmental factors such as illumination, noise, temperature, etc.

Most of the sensory characteristics and capabilities do not vary depending on the gender or ethnicity. However, in the case of hearing, for example, a large gender difference can be found in the sensitivity of older ears although the reason for that is not known.

Table 1 shows a brief summary of sensory characteristics and capabilities with regard to ageing effects. Details are described in 6.2 to 6.5. The sense of taste and olfaction is missing in this document because of a lack of data useful for ergonomic design.

An online database can be used to investigate the ageing effects and effects of disabilities in sensory characteristics and capabilities (see Reference [77]). Some of the data referenced in this document have been taken from the database.

Overview of ageing effects on vision is also available in Reference [59].

Table 1 — List of major sensory functions and effects of aging

Sensory functions	Particular effects of age
Vision	
Spectral sensitivity	Declines at short-wave region (blue light)
Colour discrimination	Worsened
Colour identification/colour category	Span of colour category reduced
Contrast sensitivity	Declines at high spatial frequencies
Temporal sensitivity (flicker sensitivity)	Declines at high temporal frequencies
Visual acuity	Worsened at high spatial frequencies and at short viewing distance
Legibility (of symbols and letters)	Worsened for complex symbols and letters
Field of view	Narrowed
Dark/light adaptation	Slightly affected
Lighting level	Slightly affected
Glare	Increased
Hearing	
Hearing sensitivity	Declines especially at high frequencies
Sensitivity to extremely high frequency (above 10 000 Hz)	Declines or completely lost
Sensitivity to low frequency (below 100 Hz)	Moderately affected
Loudness	Becomes smaller especially at high frequencies; in some cases, accompanies abnormal growth called “recruitment”
Tone perception	Worsened especially in noisy conditions
Speech perception	Worsened especially in noisy conditions
Touch	
Tactile pressure sense	Sensitivity decreased
Spatial resolution	Declines at high spatial frequencies
Temporal sensitivity (for vibration)	Sensitivity decreased especially for high temporal frequencies
Legibility (for tactile symbols and characters)	Worsened
Thermal sense	
Sensitivity to surface temperature	Decreased
Sensitivity to air temperature	Decreased
Thermal sensation for comfort	Reduced

6.2 Vision

6.2.1 Visual sensitivity to colour (spectral sensitivity of the eye: ageing effect)

6.2.1.1 General

The human eye responds to electro-magnetic radiation of the wavelength range from about 380 nm to 780 nm. The overall sensitivity to the radiation throughout the range is called spectral sensitivity or spectral luminous efficiency. This spectral sensitivity changes with age so that it becomes less sensitive to light in the short-wavelength region approximately from 400 nm to 500 nm (coloured purplish and bluish). Therefore, a bluish as well as a purplish light looks darker to older persons than it does to young persons. Taking account of this ageing effect can increase visibility of signs and displays for older people.

NOTE This ageing effect disappears if an older person has had his/her lens replaced with an artificial eye lens surgically implanted, as the effect is caused mainly by yellowing of the lens.

6.2.1.2 Sampled population

Data were collected from 91 participants ranged in age from 12 years to 78 years. The distribution of ages of the participants were 6 people in 10–19 years, 11 people in 20–29 years, 10 people in 30–39 years, 10 people 40–49 years, 10 people in 50–59 years, 28 people in 60–69 years, and 16 people in 70–79 years. The numbers of male and female participants were nearly equal.

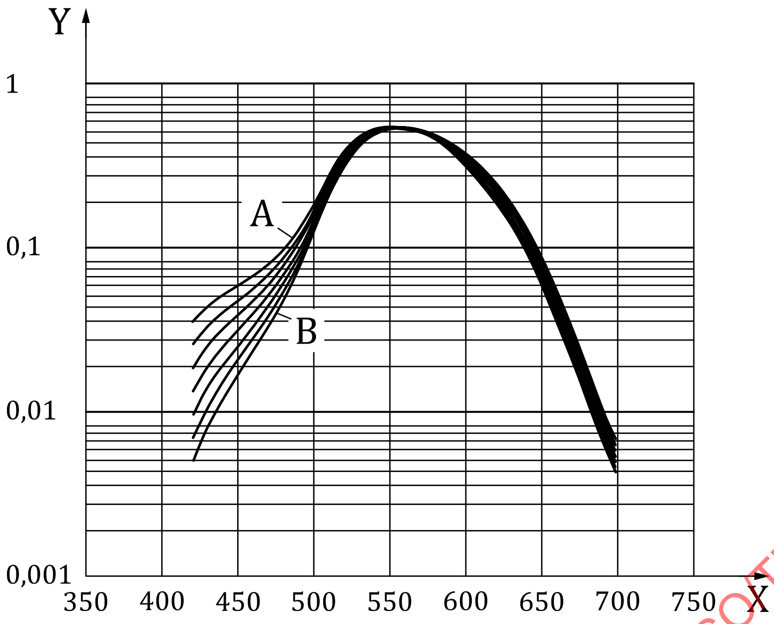
6.2.1.3 Methods and conditions of data collection

The data were measured by the conventional method for visual sensitivity called flicker photometry. In this measurement, a test light and a reference light, both of which were subtended at a visual angle of about 2° at the same location on the retina, were temporally alternated with a fixed frequency of 12 Hz. A non-flicker or a minimum flicker point was determined by adjusting the intensity of the test light, in most cases, while that of the reference light was fixed. The minimum flicker point was regarded as the equal luminance of the test and reference light to the eye. The test light was chosen from a range of 420 nm to 700 nm in 10 nm steps. The amount of each test light needed to reach to the equal luminance level gives the reciprocal of spectral sensitivity data.

6.2.1.4 Data

Figure 2 shows the spectral sensitivity data measured for 91 people by flicker photometry with a foveally fixed 2-degree target field at a photopic level. The data are classified into seven age groups in 10-year steps and the geometric average over all the participants in a decade is expressed as a solid line.

The data shows clear reductions of sensitivity in the short-wave region (blue light) with ageing, while there is almost no change at middle-wave (green light) and long-wave (red light) regions. This means that blue light, which contains a short-wave component, looks darker to older people than it does to young people. This age-related change occurs gradually and smoothly from the youngest age, and the maximum difference reaches about one tenth (or 10 times) when the data of 10–19 years old and 70–79 years old are compared.



Key

X wavelength (nm)

Y relative sensitivity

A average of people in their 10s

B average of people in their 70s

Figure 2 — Spectral sensitivity curves of the human eye for seven age groups from 11 to 78 years

6.2.1.5 Limitations

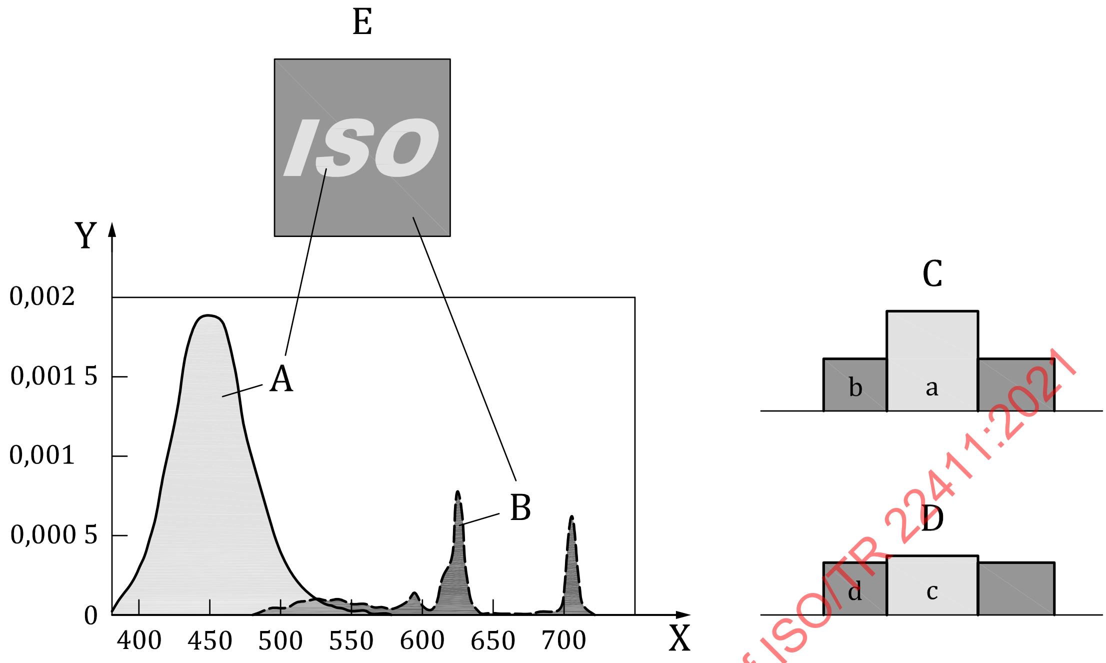
The data presented here are only for people with normal colour vision, and do not apply to people with defective colour vision nor with low vision.

6.2.1.6 Application examples

The main application of human spectral sensitivity is in the measurement of light in terms of visual sensation of lights or objects (photometry or visually meaningful measurement of light), i.e. brighter or darker. The sensitivity data for young people without any visual impairment has been standardized by the International Commission on Illumination (CIE) and has been traditionally used in the measurement of light which is visually meaningful. The age-related change in the sensitivity shown in Figure 2 has not been officially established yet in the field of photometry, but can be practically used in evaluating lights for people in any range of age, in particular for older people, in the same manner as it is used in photometry.

Evaluating the visibility of blue lights for older people in traffic signs, emergency signs and other critical displays, in particular, can increase the accessibility of those signs. Designers should increase light intensity when possible if they use blue lights (blue LEDs, for example) against dark backgrounds in signage used by older people.

Figure 3 shows an example of visual sign composed of blue letters on a dark yellow (brown) background. Using spectral sensitivity curves of people in their 20s and 70s respectively, the contrast ratio of this sign is much lower for older people (1,13 for those in their 70s) than for young people (2,07 for those in their 20s). Nearly twice as much luminance of blue light is needed for older people to achieve the same contrast as young people. This colour combination example is a typical one regarded as hard to see for older people but not to young people. For other colour combinations, this contrast difference may be smaller, but care should be taken for any colour combination when blue light is used in a sign.



Key

X wavelength (nm)
Y spectral radiance (watt/m^2)
A blue letter
B dark yellow background
C contrast for an observer in his/her 20s [2,07 (= 0,003 1 / 0,001 5)]
D contrast for an observer in his/her 70s [1,13 (= 0,001 8 / 0,001 6)]
E sample sign
a luminance of a blue letter to people in their 20s (0,003 1 relative unit)
b luminance of a dark yellow background to people in their 20s (0,001 5 relative unit)
c luminance of a blue letter to people in their 70s (0,001 8 rel. unit)
d luminance of a dark yellow background to people in their 70s (0,001 6 relative unit)

Figure 3 — An application of spectral sensitivity for calculating contrast of a coloured sign

More information on the implication and use of the spectral sensitivity data are presented in ISO 24502.

6.2.1.7 References

— Data source: Reference [31];

— Cross-references in this document: none;

— Other references: Reference [86].

6.2.2 Colour category (spans of fundamental colour, young people, older people, and people with low vision)

6.2.2.1 General

Colour is coded in the central brain, but not in the retina in the eye, as a number of groups of similar colours. This is called categorical colour perception or colour categories. Orangish-red and purplish-red, for example, are both perceived as a colour in the red category in the brain. There are a number of colour categories, 11 or 13 depending on academic studies. Each category corresponds to a fundamental or a basic colour term linguistically, such as red, green or blue.

As the colour category is closely related to colour terms (i.e. language), it is useful to know the span of each fundamental colour in the colour space when colour is used in daily life. Knowing how many colour categories exist, and which colour belongs to which category, is a basic question when selecting and applying colour in any type of design that contains colour.

Knowledge on colour categories is also useful for creating a colour combination in particular. The theory of categorical colour perception says that colours appear distinctive from each other if they are selected from different colour categories. Conversely, colours selected from the same category are likely to be confused.

This clause provides spans of colour categories expressed in the Munsell colour space for different types of people in colour vision: young people, older people, people with defective colour vision and people with low vision. Colour combinations based on colour categories with different distinctiveness are also presented in a tabular form.

NOTE The Munsell colour space is a three-dimensional system to specify colour by hue, chroma (or saturation, meaning how close to or far from grey the colour is) and value (the lightness or darkness of the colour).

6.2.2.2 Sampled population

Data were collected from the following participants groups shown in Table 2.

Table 2 — Participants groups for the measurement of colour category

Participants group	Number of participants	Age (years)	Notes
Young people	50	19–26	
Older people	50	60–76	
People with defective colour vision	59	14–66	Protanope (29) Deuteranope (30)
People with low vision	69	19–79	Retinitis pigmentosa (13) Glaucoma (8) Cataract (8) Optic atrophy (6) Aphakia (3) Others (31)

6.2.2.3 Methods and conditions of data collection

The definition of colour category is based on the subjective judgement of colour similarity. A pair of colours was presented to the participant and he/she judged whether the two colours looked similar or not. Carrying out this similarity judgement, the percentage of similar judgements among the total number of participants was obtained. The similarity data is high when the two colours are close, but low when the two colours are apart from each other.

In the experiment shown in Figure 4 a), a pair of colours consisting of a reference colour and a test colour was presented. The reference colour was selected from one of the thirteen fundamental colours (red 5R5/12, yellow-red 5YR7/14, yellow 5Y8/12, green-yellow 5GY5/8, green 5G5/8, blue-green 5BG5/8, blue 5B5/8, purple-blue 5PB5/8, purple 5P5/10, red-purple 5RP5/10, white N9.5, grey N5, and black N1), and the test colour was randomly picked from a set of 286 test colours distributed in the Munsell colour space while the reference was kept constant. This measurement gave the similarity data against the reference colour, and a contour map was obtained [see Figure 4 b) for the case of red fundamental colour]. This was repeated for all the thirteen reference colours.

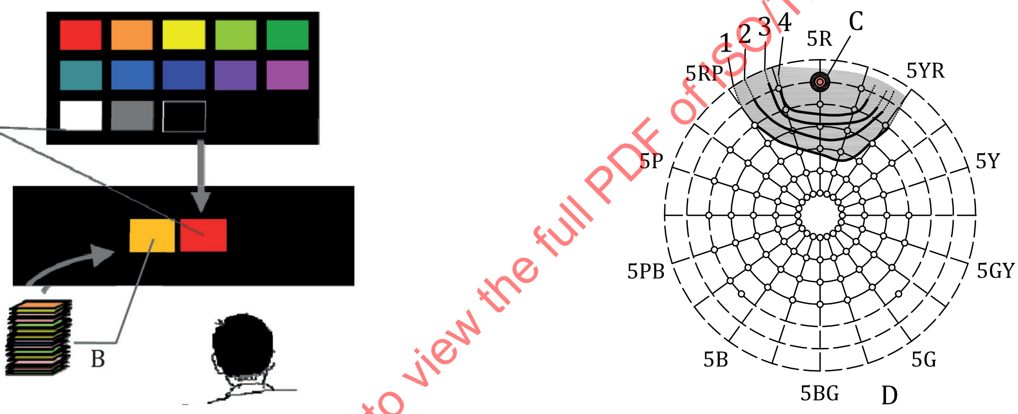
The number of test colours was reduced to 103 for the experiment on low vision taking account of the relatively low colour discrimination ability of those participants.

The similarity data were obtained for each test colour of 286 (or 103 for low vision) samples against the 13 fundamental colours respectively, and a category was defined for each fundamental colour with regard to the similarity data as shown in Figure 4 b). Finally, the 50 % contour [i.e. half of the participants judged as similar (category 3 in Figure 4)], was used as a span of colour category for a fundamental colour.

This span of colour category was measured at 4 different lightness level [value 9 (very light), value 7 (light), value 5 (moderate), and value 3 (dark)] for each fundamental colour and the span is expressed in the four levels.

NOTE Other spans can be defined with a different ratio, e.g. a contour of 70 %, 30 %, or 10 % similarity.

All the colour category data were obtained using Munsell colour chips illuminated at a moderate illuminance level (500 lx) supporting photopic vision. A lower illuminance level of 0,5 lx called mesopic vision was also employed in the study, but the data is not included here (see 6.2.2.7).



a) **Colour similarity measurement** b) **Definition of colour category**

Key

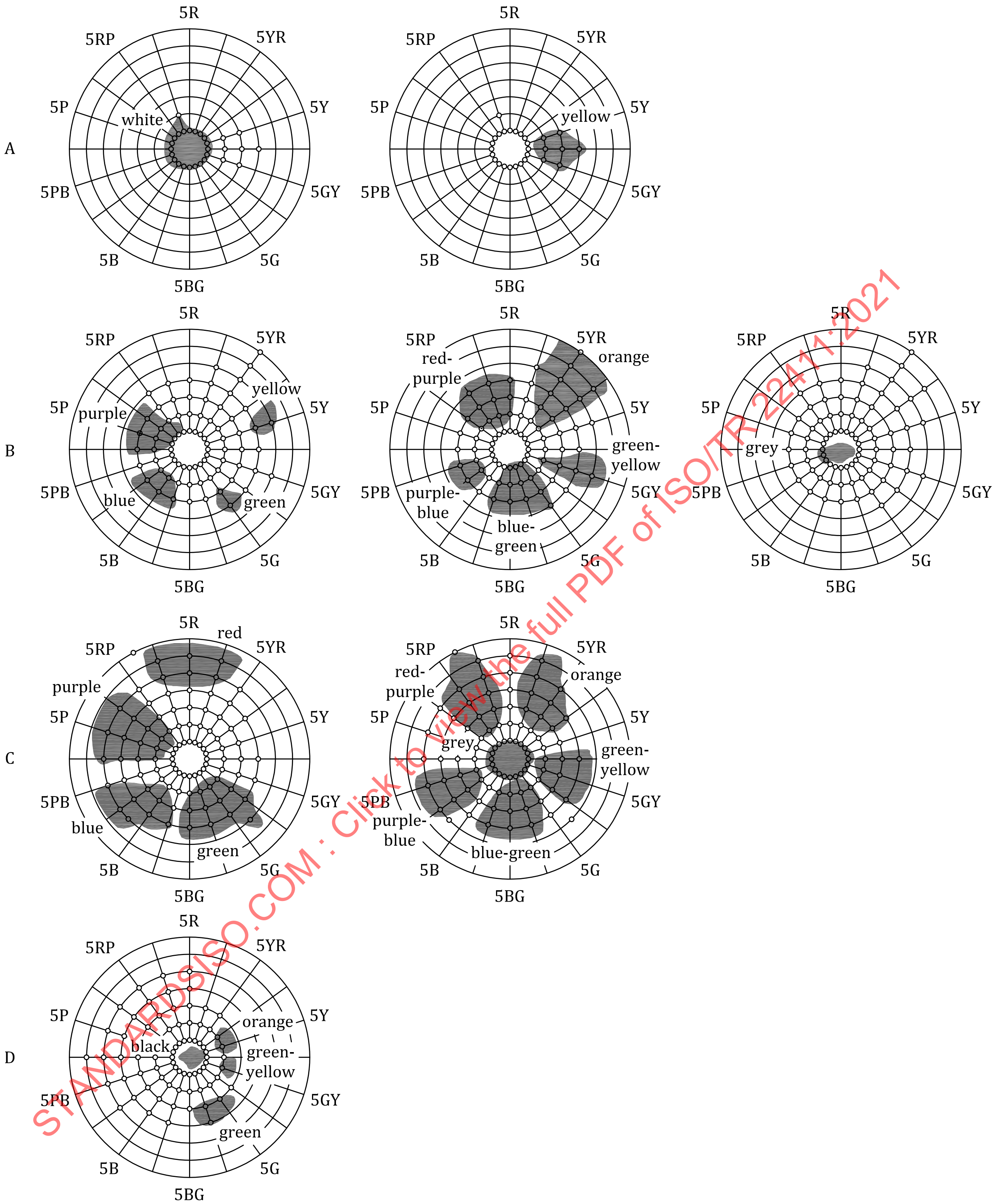
A reference colours (13 fundamental colours)
B test colours (286 or 200 samples)
C red fundamental colour
D Munsell value 5 plane
1 category 1 (10 % similarity)
2 category 2 (30 % similarity)
3 category 3 (50 % similarity)
4 category 4 (70 % similarity)

Figure 4 — Measurements of colour similarity and definition of colour category (in case of red fundamental colour)

6.2.2.4 Data (spans of fundamental colours and colour combination tables)

6.2.2.4.1 Young people

Figure 5 shows the span of colour category for each of the 13 fundamental colours expressed in the Munsell colour space for young people at a moderately bright illuminance level (500 lx). The colour category data were obtained and shown at four different lightness levels in the Munsell colour space of values 3, 5, 7, and 9. The spans coloured grey in the figure show the colour categories of the 13 fundamental colours. In some cases, the spans of two or more fundamental colours overlapped and, in that case, the data are shown in another cross-section separately so that the spans would be visible more clearly. However, contours were still drawn in that case to indicate the overlap. The small open circles in the colour charts mean the test colours used in the experiment.



Key

A Munsell value 9 (very light level)

B Munsell value 7 (light level)

C Munsell value 5 (moderately light level)

D Munsell value 3 (dark level)

Figure 5 — Spans of fundamental colours for young people at photopic level (50 % similarity level)

Table 3 was derived from the data shown in Figure 5 to show possible two-colour combinations and their distinctiveness. The degree of distinctiveness of the colour combination is classified into the three levels (high, moderate and low), depending on the mutual relationship of similarity areas with regard to the situation overlapped or separated. Using the 50 % areas as well as the 10 % ones, the three levels are defined as:

1) both the 50 % areas and the 10 % areas are separated (high distinctiveness);

2) the 50 % areas are separated but the 10 % areas are overlapped (moderate distinctiveness);

3) both the 50 % and the 10 areas are overlapped (low distinctiveness).

Table 3 can be used firstly for the choice of any two fundamental colours depending on the user's preference of the distinctiveness of colour combination. Once the two fundamental colours are chosen from Table 3, a specific colour that belongs to each of the categories of fundamental colours can be selected from Figure 5. For example, a red colour from the red category in Figure 5. Finally, those selected colours are used for the colour combination. When more than two colours are used, this procedure is repeated for any possible two-colour combination.

Table 3 — Colour combinations and their distinctiveness for young people at photopic level

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRE	WHT	BLK
R	—	+	++	+++	+++	+++	+++	+++	++	+	+++	+++	+++
YR	+	—	++	++	+++	+++	+++	+++	++	++	++	+++	++
Y	++	++	—	++	++	+++	+++	+++	+++	+++	++	+	+++
GY	+++	++	++	—	+	++	+++	+++	+++	+++	++	++	++
G	+++	+++	++	+	—	+	++	++	+++	+++	++	++	++
BG	+++	+++	+++	++	+	—	+	++	+++	+++	++	++	++
B	+++	+++	+++	+++	++	+	—	+	++	+++	++	++	++
PB	+++	+++	+++	+++	++	++	+	—	++	+++	++	++	++
P	++	++	+++	+++	+++	+++	++	++	—	+	+	++	++
RP	+	++	+++	+++	+++	+++	+++	+++	+	—	++	++	+++
GRE	+++	++	++	++	++	++	++	++	+	++	—	++	++
WHT	+++	+++	+	++	++	++	++	++	++	++	++	—	+++
BLK	+++	++	+++	++	++	++	++	++	++	+++	++	+++	—

+++ High distinctiveness

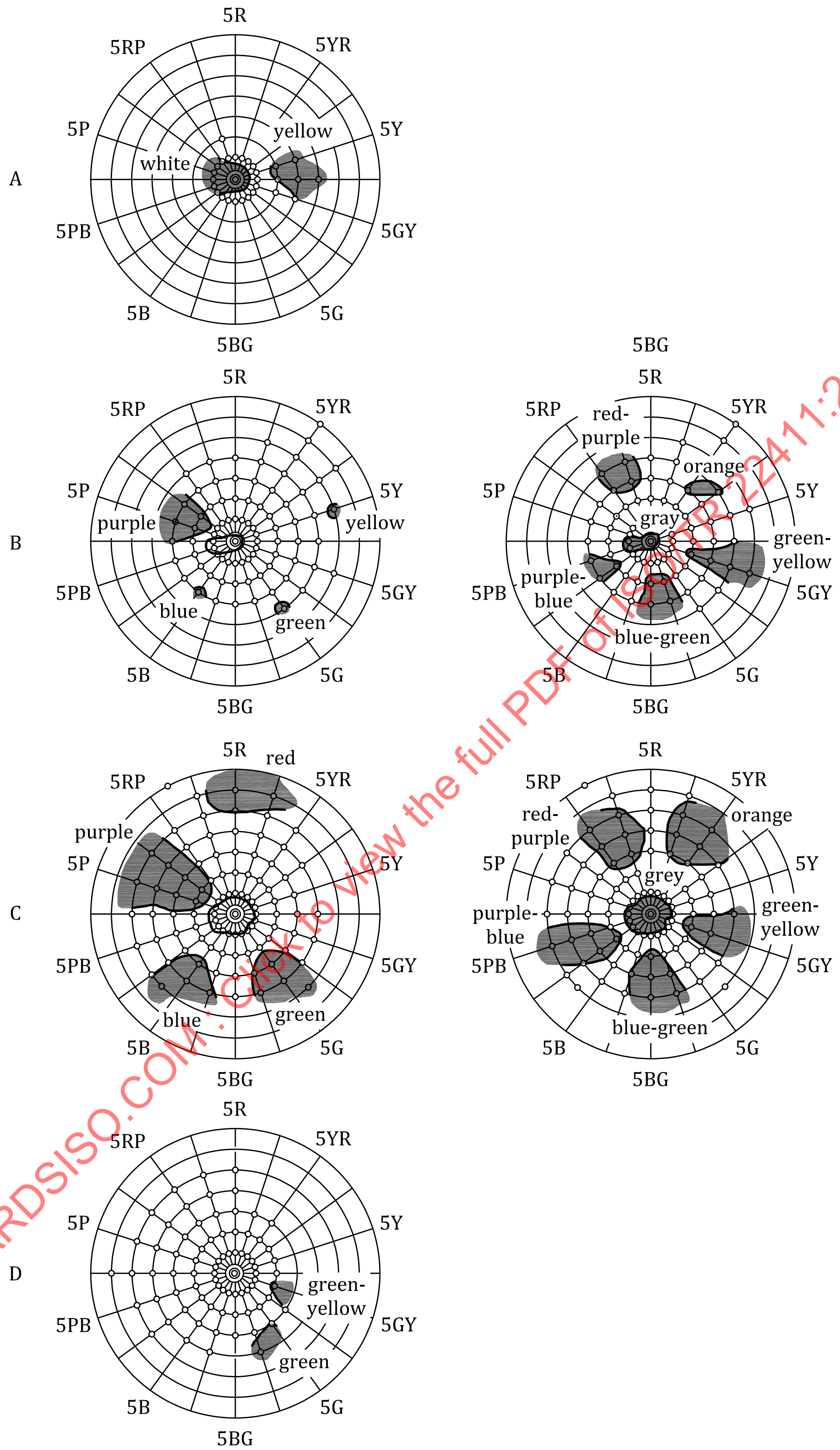
++ Moderate distinctiveness

+ Low distinctiveness

NOTE The names of fundamental colours that define colour categories are: (R) red, (YR) orange or yellow-red, (Y) yellow, (GY) green-yellow, (G) green, (BG) blue-green, (B) blue, (PB) purple-blue, (P) purple, (RP) red-purple, (GRE) grey, (WHT) white, (BLK) black.

6.2.2.4.2 Older people

Figure 6 shows the spans of colour categories for older people expressed in the same way as those for young people (see Figure 5). Most of the spans are smaller than those obtained for young people. This means the choice of a colour for each of the fundamental colours is limited in colour space.



Key

A Munsell value 9 (very light level)

B Munsell value 7 (light level)

C Munsell value 5 (moderately light level)

D Munsell value 3 (dark level)

Figure 6 — Spans of fundamental colours for older people at photopic level (50 % similarity level)

Table 4 shows a colour combination table for older people derived from the colour category data of Figure 6. Note that spans of these categories of older people are different from those of young people. Table 4 should be used in conjunction with the category data of Figure 6.

Table 4 — Colour combinations and their distinctiveness for older people at photopic level

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRE	WHT	BLK
R	—	+	+++	+++	+++	+++	+++	+++	++	++	+++	+++	+++
YR	+	—	++	+++	+++	+++	+++	+++	++	++	++	+++	+++
Y	+++	++	—	++	+++	+++	+++	+++	+++	+++	+++	++	+++
GY	+++	+++	++	—	++	++	+++	+++	+++	+++	++	++	++
G	+++	+++	+++	++	—	+	++	+++	+++	+++	++	+++	++
BG	+++	+++	+++	++	+	—	+	++	+++	+++	++	++	++
B	+++	+++	+++	+++	++	+	—	+	++	+++	++	+++	++
PB	+++	+++	+++	+++	+++	++	+	—	++	+++	++	+++	++
P	++	++	+++	+++	+++	+++	++	++	—	+	++	+++	++
RP	++	++	+++	+++	+++	+++	+++	+++	+	—	++	++	+++
GRE	+++	++	+++	++	++	++	++	++	++	++	—	++	+++
WHT	+++	+++	++	++	+++	++	+++	+++	+++	++	++	—	+++
BLK	+++	+++	+++	++	++	++	++	++	++	+++	+++	+++	—

+++ High distinctiveness

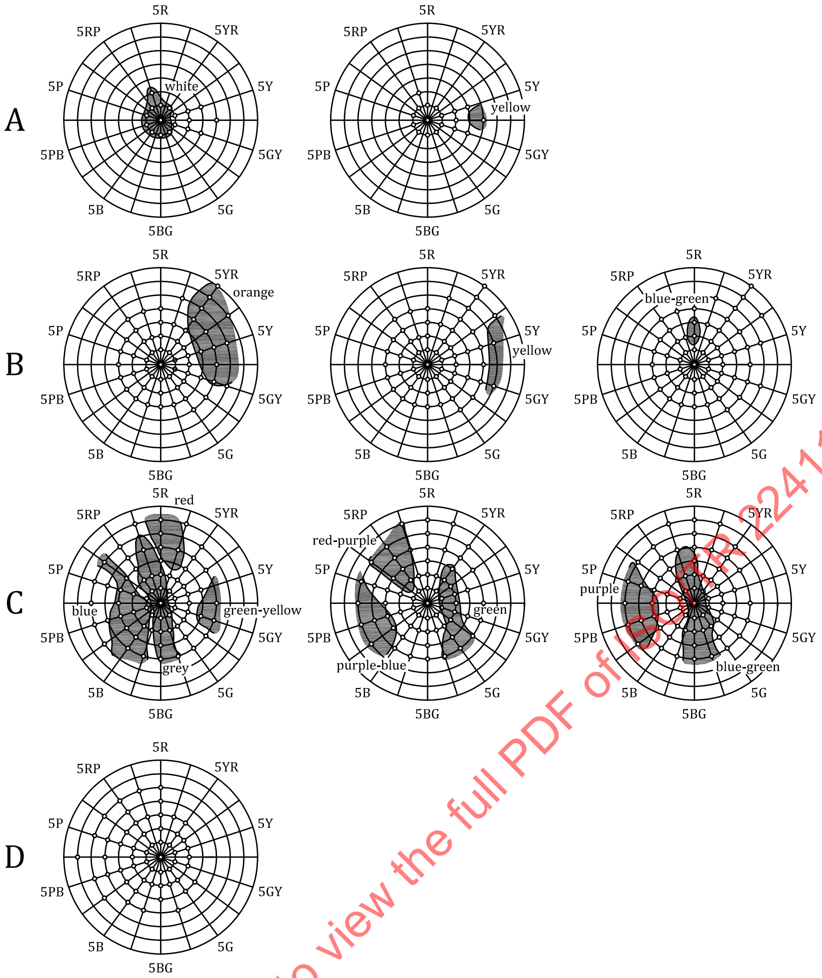
++ Moderate distinctiveness

+ Low distinctiveness

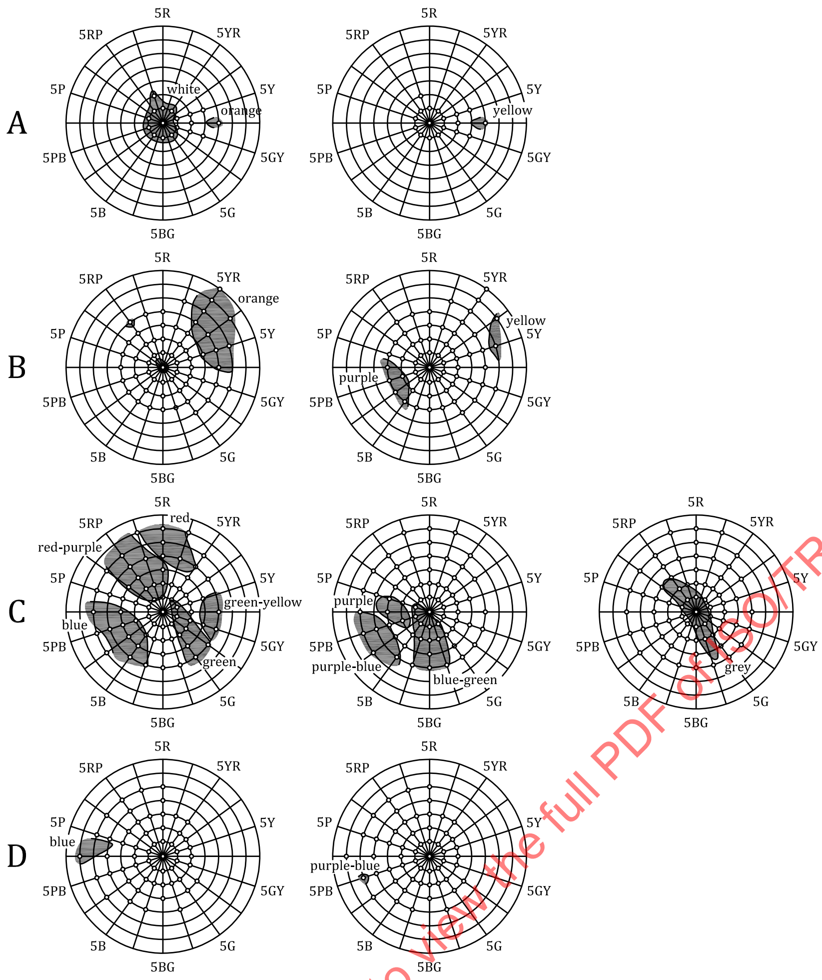
NOTE The names of fundamental colours that define colour categories are: (R) red, (YR) orange or yellow-red, (Y) yellow, (GY) green-yellow, (G) green, (BG) blue-green, (B) blue, (PB) purple-blue, (P) purple, (RP) red-purple, (GRE) grey, (WHT) white, (BLK) black.

6.2.2.4.3 People with defective colour vision

Figure 7 a) and b) shows the spans of colour category for people with defective colour vision, protanope and deuteranope respectively, measured and expressed in the same way as in young and older people. Due to largely different characteristic of colour vision, spans of colour categories are largely different from those of young or older people. Differences are also seen between the data of protanope and deuteranope. The spans of colour categories for both protanope and deuteranope are extended to the direction of red-green colour axis and the distinction of red and green colours become worse for those colour deficiencies.


A
B
C
D
5R
5YR
5Y
5GY
5G
5BG
5B
5PB
5P
5RP
white
yellow
orange
yellow
blue-green
red
blue
green-yellow
grey
red-purple
green
purple-blue
purple
blue-green

a) Protanope



b) Deuteranope

Figure 7 — Spans of fundamental colours for people with defective colour vision at photopic level (50 % similarity level)

Table 5 and Table 6 show colour combination tables for protanope and for deuteranope derived from the colour category data of Figure 7 a) and b), respectively. Note that spans of these categories of older people are different from those of young or older people. Table 5 and Table 6 should be used in conjunction with the category data of Figure 7 a) and b), respectively.

Table 5 — Colour combinations and their distinctiveness for people with defective colour vision, protanope

	R	RY	Y	GY	G	BG	B	PB	P	RP	GRE	WHT	BLK
R	—	++	+++	++	+	+	+++	+++	+++	++	++	++	++
RY	++	—	+	++	++	++	+++	+++	+++	+++	+++	++	+++
Y	+++	+	—	++	++	+++	+++	+++	+++	+++	+++	++	+++
GY	++	++	++	—	++	++	+++	+++	+++	+++	+++	+++	+++
G	+	++	++	++	—	+	+++	+++	+++	++	+	++	++
BG	+	++	+++	++	+	—	++	++	++	+	+	++	++
B	+++	+++	+++	+++	+++	++	—	+	+	+	++	++	+++
PB	+++	+++	+++	+++	+++	++	+	—	+	++	++	++	+++
P	+++	+++	+++	+++	+++	++	+	+	—	++	++	++	+++

Table 5 *(continued)*

	R	RY	Y	GY	G	BG	B	PB	P	RP	GRE	WHT	BLK
RP	++	+++	+++	+++	++	+	+	++	++	—	+	++	++
GRE	++	+++	+++	+++	+	+	++	++	++	+	—	++	++
WHT	++	++	++	+++	++	++	++	++	++	++	++	—	+++
BLK	++	+++	+++	+++	++	++	+++	+++	+++	++	++	+++	—

+++ High distinctiveness

++ Moderate distinctiveness

\+ Low distinctiveness

NOTE The names of fundamental colours that define colour categories are: (R) red, (YR) orange or yellow-red, (Y) yellow, (GY) green-yellow, (G) green, (BG) blue-green, (B) blue, (PB) purple-blue, (P) purple, (RP) red-purple, (GRE) grey, (WHT) white, (BLK) black.

Table 6 — Colour combinations and their distinctiveness for people with defective colour vision, deuteranope

	R	RY	Y	GY	G	BG	B	PB	P	RP	GRE	WHT	BLK
R	—	++	++	++	++	+++	+++	+++	+++	++	++	+++	+++
RY	++	—	+	++	++	+++	+++	+++	+++	++	+++	++	+++
Y	++	+	—	++	++	+++	+++	+++	+++	+++	+++	++	+++
GY	++	++	++	—	++	++	+++	+++	+++	+++	++	+++	+++
G	++	++	++	++	—	+	++	+++	+++	++	+	++	+++
BG	+++	+++	+++	++	+	—	+	++	++	++	+	++	+++
B	+++	+++	+++	+++	++	+	—	+	+	++	++	++	+++
PB	+++	+++	+++	+++	+++	++	+	—	++	++	++	++	+++
P	+++	+++	+++	+++	+++	++	+	++	—	++	++	++	+++
RP	++	++	+++	+++	++	++	++	++	++	—	+	++	+++
GRE	++	+++	+++	++	+	+	++	++	++	+	—	++	+++
WHT	+++	++	++	++	++	++	++	++	++	++	++	—	+++
BLK	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	++	+++	—

+++ High distinctiveness

++ Moderate distinctiveness

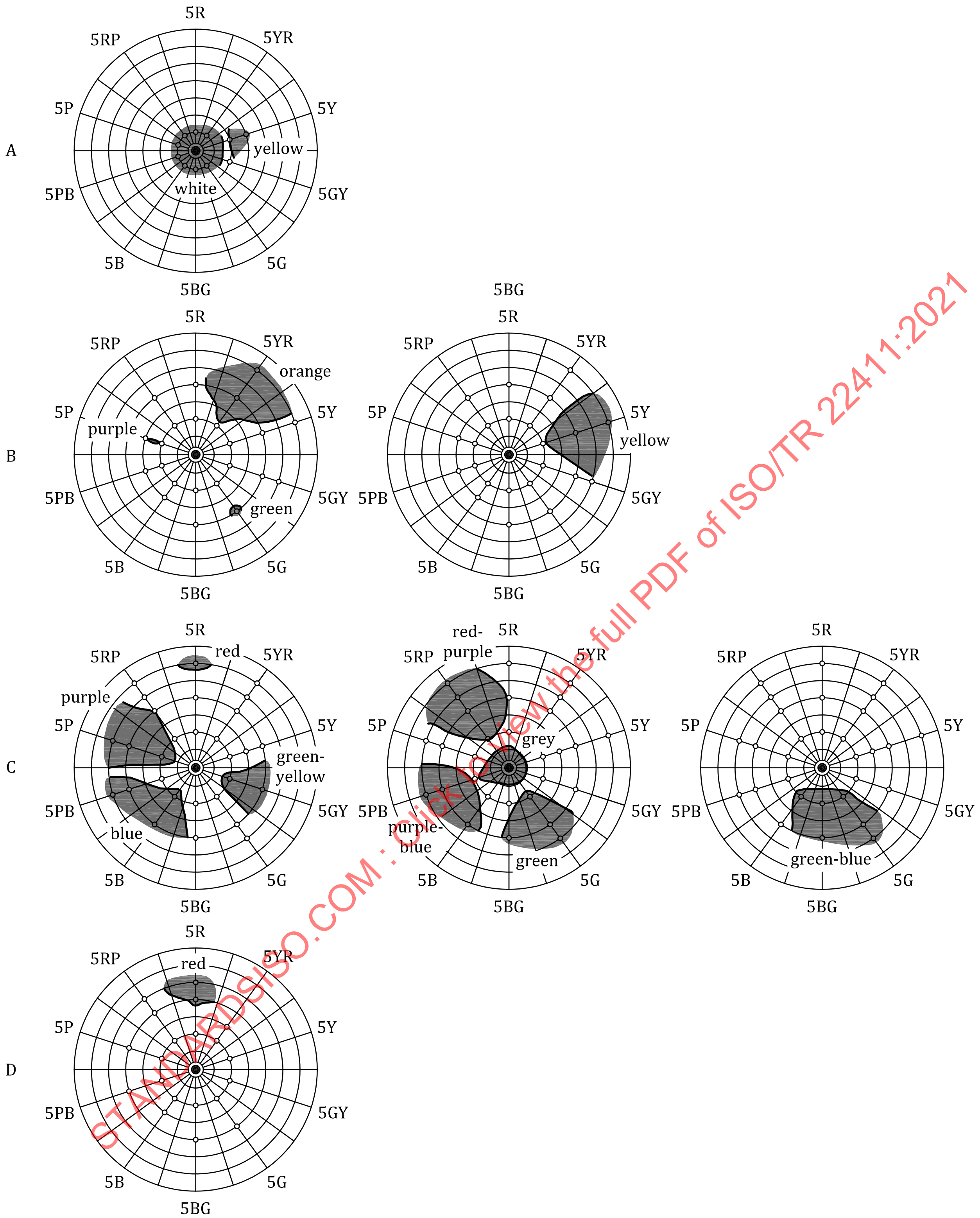
\+ Low distinctiveness

NOTE The names of fundamental colours that define colour categories are: (R) red, (YR) orange or yellow-red, (Y) yellow, (GY) green-yellow, (G) green, (BG) blue-green, (B) blue, (PB) purple-blue, (P) purple, (RP) red-purple, (GRE) grey, (WHT) white, (BLK) black.

6.2.2.4.4 People with low vision

Low vision is physiologically, but not optically, impaired vision with an extremely low visual acuity and/or a restricted visual field, which is caused in most cases by an eye disease or disorder such as cataract, retinitis pigmentosa and glaucoma. Low vision cannot be corrected by spectacles or other optical means of imaging. As colour appearance for people with these visual impairments is different from that of people without any visual impairment, spans of categorical colours also differ for these groups of people. This clause gives data on the span of categorical colours and a colour combination table for people with low vision.

Figure 8 shows the data for colour categories measured for people with low vision. The spans of 50 % level of similarity are rather smaller than those for young people (see Figure 5). However, the spans of the 10 % similarity (not shown here) become larger for almost all fundamental colours, which means colours are perceived as widely spread for low vision and not sharply localized in a colour space.



Key

A Munsell value 9 (very light level)

B Munsell value 7 (light level)

C Munsell value 5 (moderately light level)

D Munsell value 3 (dark level)

Figure 8 — Spans of fundamental colours for people with low vision at photopic level (50 % similarity level)

Table 7 shows a colour combination table derived from the data in Figure 8.

Table 7 — Colour combination and their distinctiveness for people with low vision at photopic level

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRE	WHT	BLK
R	—	++	++	++	+++	+++	+++	+++	++	+	++	+++	+++
YR	++	—	+	++	++	++	+++	+++	++	++	++	++	+++
Y	++	+	—	++	++	++	+++	++	++	++	++	++	+++
GY	++	++	++	—	+	+	++	+++	+++	+++	++	++	++
G	+++	++	++	+	—	+	++	++	++	+++	++	++	++
BG	+++	++	++	+	+	—	+	+	++	++	++	++	++
B	+++	+++	+++	++	++	+	—	+	++	++	++	++	++
PB	+++	+++	++	+++	++	+	+	—	+	++	++	++	++
P	++	++	++	+++	++	++	++	+	—	+	++	++	++
RP	+	++	++	+++	+++	++	++	++	+	—	++	++	++
GRE	++	++	++	++	++	++	++	++	++	++	—	++	++
WHT	+++	++	++	++	++	++	++	++	++	++	++	—	+++
BLK	+++	+++	+++	++	++	++	++	++	++	++	++	+++	—

+++ High distinctiveness

++ Moderate distinctiveness

+ Low distinctiveness

NOTE The names of fundamental colours that define colour categories are: (R) red, (YR) orange or yellow-red, (Y) yellow, (GY) green-yellow, (G) green, (BG) blue-green, (B) blue, (PB) purple-blue, (P) purple, (RP) red-purple, (GRE) grey, (WHT) white, (BLK) black.

6.2.2.5 Limitations

All the data presented in this document are basically applicable to reflected colour samples illuminated at a photopic level at moderately high illuminance levels. Colours appearing in a self-luminous mode such as lamps or displays should be converted into the Munsell colour system, or vice versa, before being applied.

Data in dim lighting condition called mesopic vision are also available (see references in 6.2.2.7).

6.2.2.6 Application examples

6.2.2.6.1 Identification by a single colour

Colour is used to identify a thing or an object by associating it with a specific single colour. For example, a colour is used for the uniform of a sports team to identify this team by the colour. Categorical colours can be used for this purpose effectively, and the choice of colour can be done along with the data on spans of categorical colours.

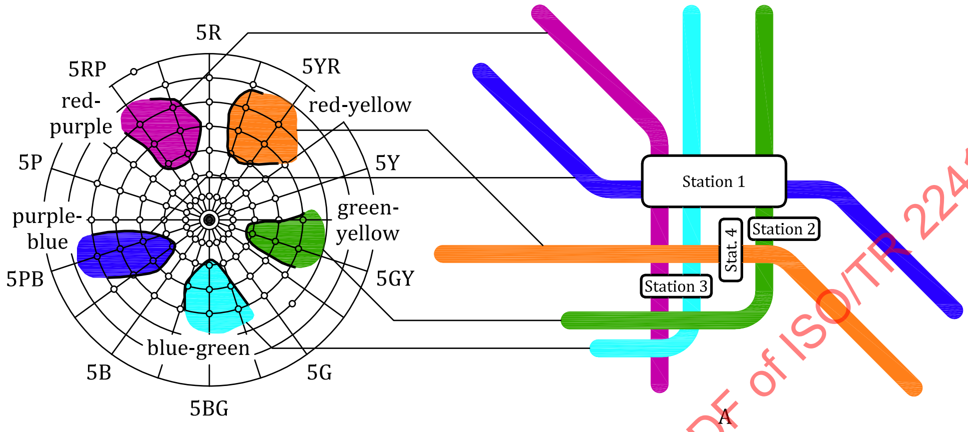
For example, when orange is used for the uniform of a sports team, the colour should be selected from the span of the orange area expressed in one of Figure 5 to Figure 8, depending on the users involved, so that the people can easily identify the uniform colour as “orange” and consequently the group.

6.2.2.6.2 Colour combination

When a set of colours is used to enable identification of different categories of information presented together, the combination is chosen to ensure they can be differentiated. For example, when colouring 5 subway lines on a network map, a set of 5 fundamental colours can be selected by referring to Figure 5 to Figure 8, depending on the users who involved.

In Figure 9, 5 fundamental colours (red-yellow, green-yellow, blue-green, purple-blue, and red-purple) are selected as an example of colour set for older people under photopic viewing condition. Using the 5 fundamental colour groups selected, any 5 colours within the respective span of the colour can be picked to use for colouring the 5 subway lines. This colour combination is distinctive as all 5 colours belong to different categories, not overlapping, and are therefore clearly distinctive.

Different sets of fundamental colours and exact colours for the combination can be created if they belong to a category of those fundamental colours. The choice of colours gives designers freedom and ease of use.



Key

A traffic network

NOTE All the colours used here are at value 5 (moderate lightness level). Other darker or brighter colours can be chosen by selecting colours from the value 3, 7, or 9 level.

Figure 9 — Example of colour combination for older people under photopic condition

6.2.2.7 References

— Data sources: References [43] and [33];

— Cross-references in this document: 6.2.3;

— Other references: Reference [87].

6.2.3 Colour category (international comparison)

6.2.3.1 General

Colour category is considered to reflect cognitive and language-related nature and its span may vary depending on a location in the world. This clause presents data on the spans of categorical colours collected in several countries in the same experimental context to identify regional or language-related differences in the spans of categorical colours.

6.2.3.2 Sampled population

Six countries (China, Germany, Japan, Republic of Korea, Thailand and the USA) participated in the experiment for collecting data on categorical colours. Each country had 20 young (age range 20–29 years) and 20 older (age range 60–79 years) participants. They were all confirmed not having defective colour vision by a test using the Ishihara colour-test chart.

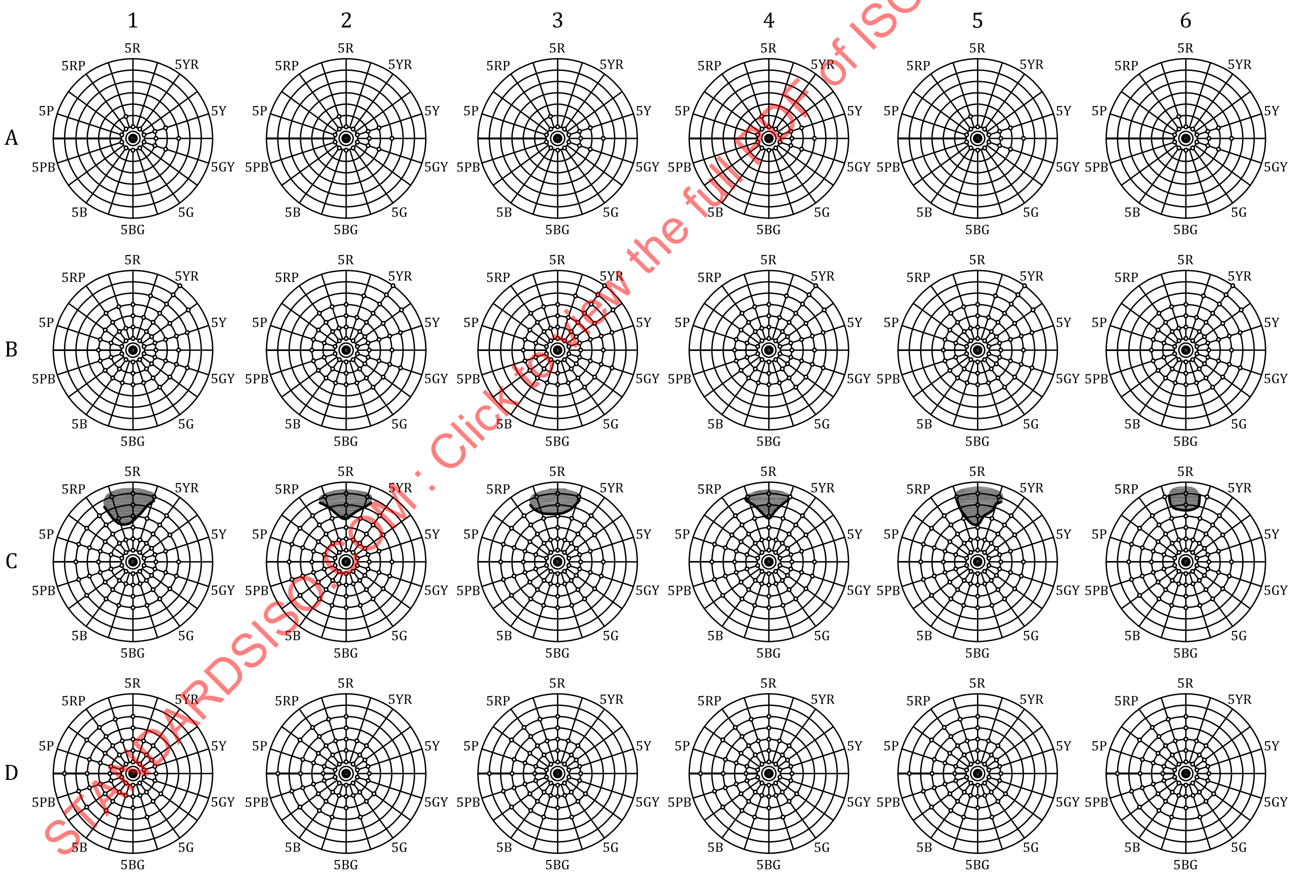
6.2.3.3 Methods and conditions of data collection

The procedure in the experiment was exactly the same as that described in 6.2.2. Colours used 200 test samples evenly distributed in the Munsell colour space and thirteen fundamental colours (red 5R5/12, yellow-red 5YR7/14, yellow 5Y8/12, green-yellow 5GY5/8, green 5G5/8, blue-green 5BG5/8, blue 5B5/8, purple-blue 5PB5/8, purple 5P5/10, red-purple 5RP5/10, white N9.5, grey N5, and black N1). These colour samples were made in Japan and sent to the 6 countries for their experiments.

Illuminance was set at around 500 lx of daylight fluorescent lamp. There was a slight variation in the illuminance setting among countries due to coarse control of the illuminance level, but the settings were all within the photopic range. The effect of the difference was small and negligible.

6.2.3.4 Data

Figure 10 shows an example of a span of colour category for “red (5R5/12)” measured for young people in the 6 countries listed above. The data of each country was plotted together side by side to see national differences at four different value levels of 3, 5, 7, and 9 in the Munsell colour space. It is clear that there are no large differences in size and shape of the span of colour-category of red although slight differences among countries are observable.



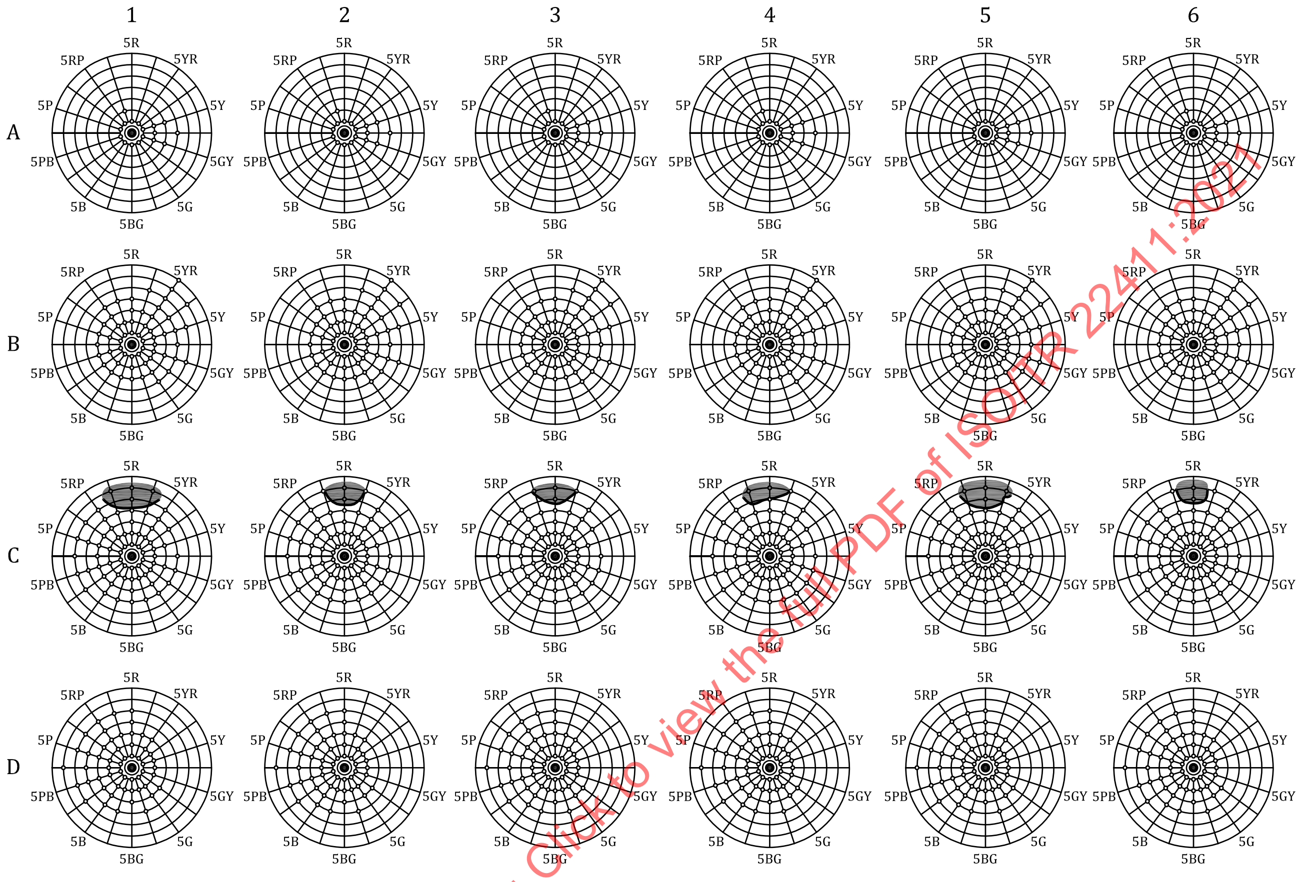
Key

A	Munsell value 9	1	Japan
B	Munsell value 7	2	USA
C	Munsell value 5	3	Germany
D	Munsell value 3	4	Republic of Korea
		5	Thailand
		6	China

Figure 10 — Span of fundamental colour “red (reference 5R5/12)” for young people at photopic vision (moderately bright level) measured in 6 countries (50 % similarity level)

Figure 11 shows similar data but for older people, drawn in the same way as in Figure 10. Again, the span of fundamental colour of “red” is essentially the same for all the 6 countries. Furthermore, the span for older people is smaller than that for young people in all 6 countries.

These data indicate that one standard set of data, if established in one country or area, can be applicable to other countries or areas in the world.



Key

A Munsell value 9
B Munsell value 7
C Munsell value 5
D Munsell value 3

1 Japan
2 USA
3 Germany
4 Republic of Korea
5 Thailand
6 China

Figure 11 — Span of fundamental colour “red (reference 5R5/12)” for older people at photopic vision (moderately bright level) measured in 6 countries (50 % similarity level)

6.2.3.5 Limitations

The data presented here have been collected from people with normal colour vision at photopic level only.

6.2.3.6 Application examples

Summarizing all the data of 6 countries, a common database for the span of categorical colours and colour combination tables were created (see ISO 24505).

6.2.3.7 References

- Data source: Reference [33];
- Cross-references in this document: 6.2.2;
- Other references: Reference [77].

6.2.4 Contrast sensitivity (young people, older people and people with low vision)

6.2.4.1 General

Contrast of luminance is one of the most important variables affecting visibility of visual signs and displays as well as that of small objects like a needle and thread. Sharpness of those visual images depends largely on the contrast, and designers should pay attention to the contrast effect on visibility to make their designed objects clearly visible.

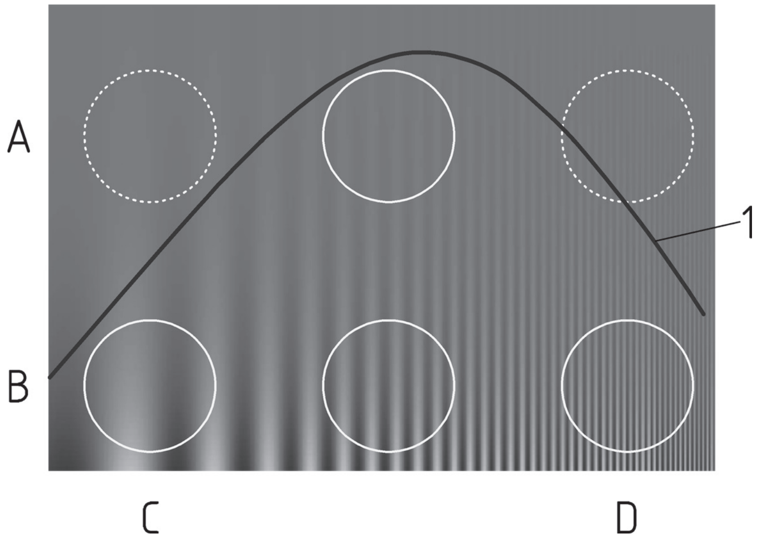
Contrast is defined as a luminance difference between any adjacent areas of a brighter and a darker part. Visual sensitivity to contrast is concerned with how clearly the eye sees the contour. The sensitivity is often measured by having people identify if they can see a black and white stripe pattern (usually of a sine wave grating pattern) when the depth or luminance difference of the brightest and darkest parts is gradually increased or decreased. The observation is done to find a borderline to barely see the stripe pattern.

Scientifically, contrast sensitivity is expressed as so-called contrast sensitivity function (CSF) that shows a borderline expressed on a contrast vs. spatial frequency plane (see Figure 12), where spatial frequency and contrast are shown together with a line that indicates the CSF, i.e. a grating detection borderline. In this example, solid circles mean visible parts and dashed circles invisible parts in the domain of spatial frequency vs. contrast.

The human visual system has a peak of contrast sensitivity at 3 or 4 cycles per degree (cpd). The sensitivity gradually decreases towards the both ends of the spatial frequency spectrum, both for higher frequency regions (i.e. finer gratings) and lower frequency regions (i.e. coarser gratings). This effect can be taken into consideration for designing visual signs and displays.

NOTE Spatial frequency is defined as the number of pairs of dark and light lines per degree of visual angle. Spatial frequency units are expressed in cycles per degree (cpd). A grating with 3 cpd, for example, would have three pairs of dark and light lines per degree of visual angle. One degree of visual angle corresponds to 8,7 mm at the distance of 50 cm from the eye.

The shape of CSF changes with age as well as with visual impairments. This subclause provides CSFs of young people, older people and people with low vision.



Key

A low contrast

B high contrast

C low spatial frequency (coarse pattern)

D high spatial frequency (fine pattern)

1 grating detection border line (CSF)

Figure 12 — Contrast sensitivity function plotted on the spatial frequency vs. contrast plane

6.2.4.2 Sampled population

The CSF data were taken from the following three different groups:

— young people: 24 young people without visual impairment, ranging in age from 20 years to 28 years;

— older people: 20 older people without visual impairment, ranging in age from 70 years to 77 years;

— people with low vision: 72 people with low vision (medically diagnosed), ranging in age from 18 years to 70 years.

6.2.4.3 Methods and conditions of data collection

Contrast sensitivity functions for young people, older people and people with low vision were measured at a photopic (moderately bright) level. A sine-wave grating pattern was presented on a flat CRT screen which was set at the distance of 2 m for young and older people and 50 cm for people with low vision. The grating was presented at one of the four orientations of 0°, 45°, 90°, and 135° from the horizontal axis at a random order. Participants reported the orientation by a four-alternative forced-choice method. Average luminance of the grating patterns was 50 cd/m^2.

Younger and older people wore correction lenses to adjust their accommodation power to be best at a far point (5 m). No correction was made for people with low vision.

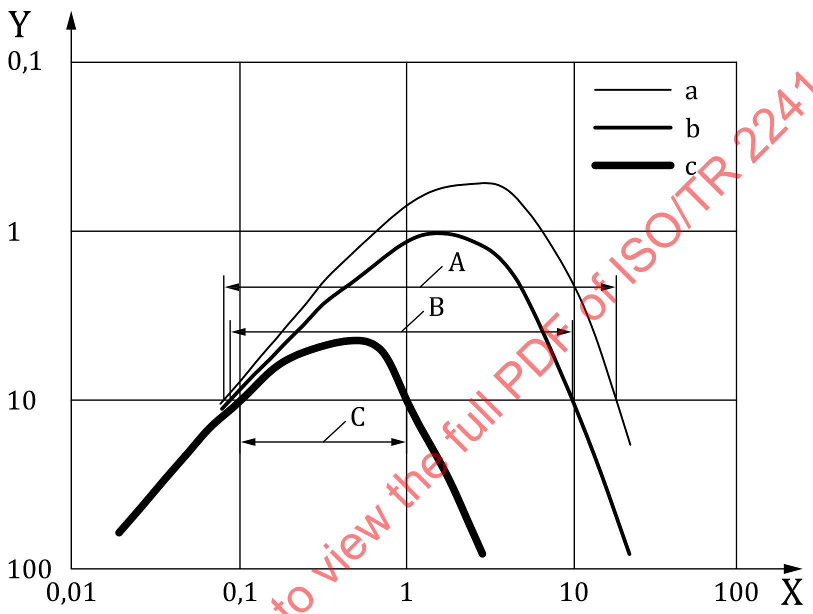
6.2.4.4 Data

Figure 13 shows average contrast sensitivity of the three groups, young people, older people and people with low vision, as a function of spatial frequency, called CSF. The contrast is defined by Michelson contrast here (see NOTE).

The older people were less sensitive at higher frequencies above a few cycles per degree than young people were. This means it is more difficult for older people to discriminate or recognize the fine grating in the higher frequency region.

For persons with low vision, the sensitivity was much lower in middle-to-high frequency regions compared to younger or older people. Care should be taken when designing visual signs for people with low vision because they are often unable to discriminate patterns that are easily discriminable for young or older people.

NOTE Michelson contrast (modulation contrast) is defined as $(L_{max} - L_{min})/(L_{max} + L_{min})$, where L_{max} and L_{min} are the maximum luminance and minimum luminance, respectively, per cycle of the dark and light grating pattern.



Key

X spatial frequency (cycles per degree)

Y contrast at threshold (%)

a young (average, 20–29 years)

b older (average, 70–79 years)

c low vision (median, 18–70 years)

A visible range at 10 % contrast for younger people

B visible range at 10 % contrast for older people

C visible range at 10 % contrast for people with low vision

Figure 13 — Contrast sensitivity function of human visual system for young people, older people and people with low vision

6.2.4.5 Limitation

The data presented here are only for a photopic (moderately bright) level which is above about 10 lx of luminance or a few candela per square meter of luminance. The shape of CSF changes at a lower or an extremely higher illuminance level and different CSFs for those conditions are expected. A band-pass shape with a reduction of sensitivity at the lower spatial frequency region and a low-pass shape with a reduction at the higher frequency region is expected for a higher luminance level and for a lower luminance level respectively.

The CSF shows the sensitivity to a grating pattern of a single spatial frequency. In a complex pattern or a natural scene having multiple components of the frequency, the overall sensitivity to that complex pattern cannot be estimated easily from the CSF.

6.2.4.6 Application examples

The CSF data can be used to estimate a visible range of spatial frequency where an individual can detect a grating whose contrast is known. For example, for a visual image with a 100 % contrast (the ideal contrast of black and white images as used in the Landolt ring or Snellen chart), the range of visible spatial frequencies are 0,01 cpd to 30 cpd for young people, 0,01 cpd to 20 cpd for older people, and 0,01 cpd to 3 cpd for people with low vision (Figure 13). A pattern containing frequency components beyond those ranges is difficult to see with extremely low or no contrast.

At a lower contrast of 10 %, for example, the range of visible spatial frequency can be very narrow. For a person with low vision, the range is only about 0,1 cpd to 1 cpd (C in Figure 13), while it is 0,1 cpd to 10 cpd (B in Figure 13) for older people and 0,1 cpd to 20 cpd (A in Figure 13) apply to younger people.

When designing visual signs that contain fine details such as small letters or low contrast such as pictures of pale colours, special care should be taken to accommodate the visible range in the plane of spatial frequency vs. contrast for older persons and persons with low vision. When the image contains fine details, the image should be enlarged or contrast should be increased to make it more visible.

Contrast reduction usually occurs for visual electronic displays seen in a lit condition. Reflected light from the display surface can reduce the contrast of images. In this case, the lighting direction or the display angle should be arranged so that it reduces the reflected light.

6.2.4.7 References

— Data source: Reference [67];

— Cross-references in this document: 6.2.1, 6.2.5;

— Other references: References [80] and [62].

6.2.5 Contrast for legibility (ageing effect)

6.2.5.1 General

Contrast between a character and a background is one of the critical factors that affect the legibility of a character. Figure 14 illustrates different contrast of a character on a fixed grey background as an example. As shown in the figure, increasing the brightness of the character from dark to bright changes the contrast from high positive to high negative contrast in between low positive and negative contrast is seen. Similar contrast change occurs for a fixed brightness of a character on a variable brightness of background. Characters printed on a highly reflective paper or an electronic display with highly reflective surface usually have low contrast when illuminated by a strong light source due to an increase of background brightness that consequently reduces the contrast and legibility. Coloured characters or coloured backgrounds also have a large variety of contrast depending on the colour used. For example, a yellow character on a white background usually has a low contrast and is difficult to read. To provide good legibility contrast is an important factor that designers should pay attention to.

This subclause provides data on the effect of contrast (i.e. luminance contrast) on the legibility of characters for young and older people.

a) High positive contrast | b) Low positive contrast | c) Low negative contrast | d) High negative contrast

Figure 14 — Character on a grey background with variable contrast

NOTE 1 Positive contrast means a character or symbol that is darker than the background. Negative contrast means a character or symbol brighter than the background.

NOTE 2 Contrast is usually defined for luminance and colour separately, even for a coloured sample using its luminance or chromaticity value. The luminance contrast has much more effect than the colour contrast on the sharpness of an image. Therefore, contrast means the luminance contrast, unless stated otherwise.

6.2.5.2 Sampled population

The data on legibility with variable contrast were obtained from the following two groups of different ages:

— 56 young people without visual impairment, ranged in age from 18 years to 28 years (mean = 21,9 years, sd = 2,16 years);

— 55 older people without visual impairments, ranged in age from 60 years to 77 years (mean = 67,1 years, sd = 3,93 years).

6.2.5.3 Methods and conditions of data collection

The legibility data were taken by presenting a character on a CRT monitor at various contrasts against a background of a mean luminance of 40 cd/m^2. The contrast was either positive or negative. Participants evaluated legibility, after seeing a character presented for one second, using a 5-point scale of legibility with an additional response of "not visible" as shown below:

— 5: very legible;

— 4: slightly legible;

— 3: moderate (neither legible nor illegible);

— 2: slightly illegible;

— 1: very illegible;

— 0: not visible (at or under the visibility threshold).

Viewing distance was fixed at 70 cm. All the young and older participants wore correction lenses to adjust their accommodative power best at the far-point (5 m). For older participants, further correction lenses were attached to bring their best accommodation point to a viewing distance of 70 cm.

Three kinds of characters were used. Each set contained a total of 86 different characters picked up at random for the experiment.

— Simple characters in sans-serif font of positive polarity (alphabets, numerals, and alphabets, numerals Japanese phonetic signs.

— Complex characters in serif font of positive polarity (Japanese Kanji, i.e. Chinese characters).

— Simple characters in sans-serif font of negative polarity (alphabets, numerals, and alphabets, numerals Japanese phonetic signs).

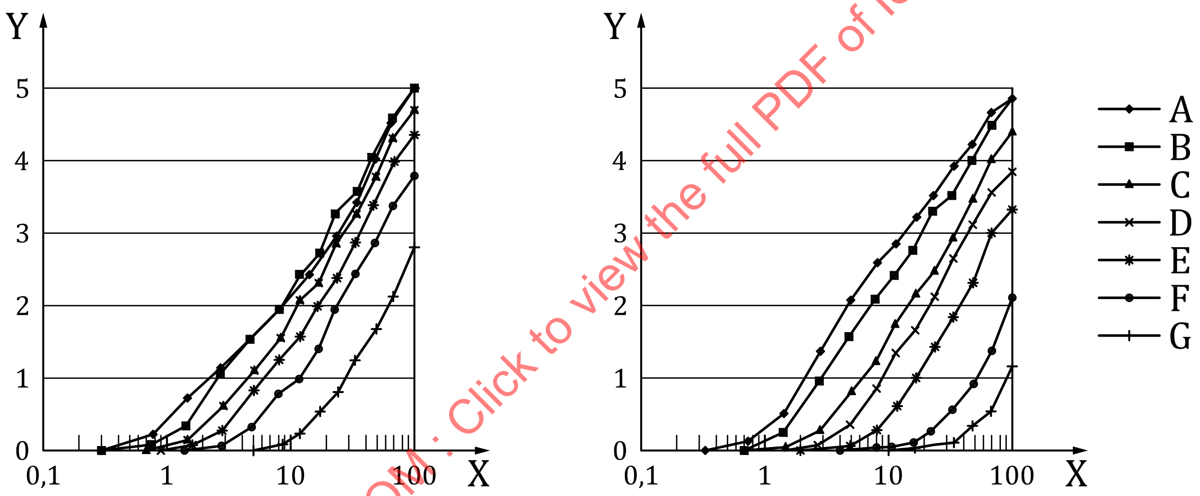
The data on negative polarity are not shown here but can be found in 6.2.5.7. The data were taken for seven sizes of a character from 8 pt to 160 pt to examine the effect of font size on the contrast.

6.2.5.4 Data

Figure 15 a) and b) shows the legibility evaluation data for simple characters of positive polarity as a function of contrast, for young and older people, respectively.

The evaluation score for legibility became higher for all font sizes and for both age groups as contrast increased. The legibility was also determined by the font size (i.e. the larger the font size, the higher the legibility). To keep a certain level of legibility, a higher contrast was needed for a smaller character. Age-related difference was observed for all the font sizes. The difference was relatively large for a smaller font size below 18 pt, for which older people show much lower legibility than young people do.

There was an effect of font type, serif or sans-serif, though it is not shown here. Sans-serif fonts gave better legibility than serif fonts even when the contrast was the same. The effect was more pronounced for a smaller font size than for a larger one.



a) **Young people**

b) **Older people**

Key

X contrast (%)

Y legibility evaluation score

A 160 pt

B 80 pt

C 40 pt

D 28 pt

E 18 pt

F 12 pt

G 8 pt

Figure 15 — Legibility of simple characters of seven different font sizes with positive polarity as a function of contrast

6.2.5.5 Limitations

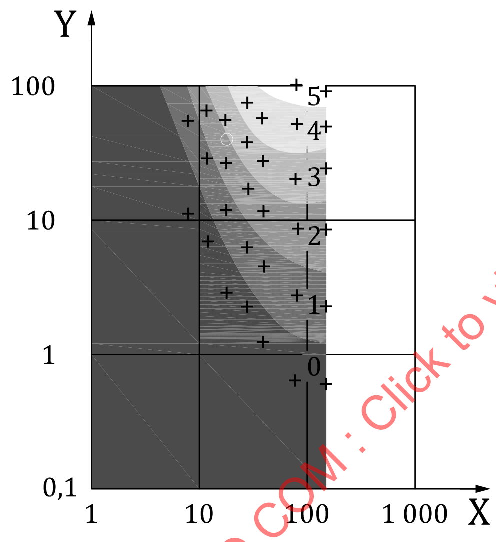
The data are directly applicable for a moderately bright level supporting photopic vision, which is beyond about 10 lx of illuminance or a few cd/m^2 of luminance. It is also applicable to a positive contrast where a black or darker character is presented on white or brighter background.

The font size in this data is defined only for a viewing distance of 70 cm. For other viewing distances, the size should be changed proportionally to the reference distance of 70 cm. For older people, the visual acuity change with viewing distance should be taken into account (see 6.2.6).

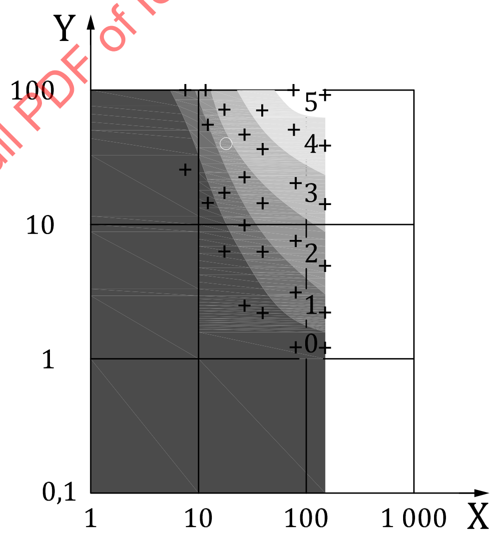
6.2.5.6 Application examples

The present data can be replotted as equal legibility contours on a two-dimensional plane of font size (in pt) and contrast. Figure 16 shows this two-dimensional representation. The different grey-coloured zones indicate each of the 5 legibility levels and the below threshold (not visible) level. For a given combination of contrast and font size, the legibility level score can be estimated directly from Figure 16.

For example, a character (alphabet or numeral) of 18 pt with 40 % contrast seen at the distance of 70 cm (an open circle in Figure 16) is at the legibility level of 3 (moderate) for young people, and level of 2 (slightly illegible) for older people.



a) Young people



b) Older people

Key

X font size (pt)

Y contrast (%)

NOTE A small white dot shows an example of legibility estimation described in the text.

Figure 16 — Map of legibility level as a function of font size (in pt) and contrast for simple characters for young and older people

6.2.5.7 References

— Data source: Reference [79];

— Cross-references in this document: 6.2.4, 6.2.7;

— Other references: none.

6.2.6 Visual acuity (effects of age, viewing distance and luminance)

6.2.6.1 General

Visual acuity is an ability to discriminate fine details of images or objects that relates to sharpness or distinctness of a visual image. This is a matter of concern when people read letters or see pictures. When visual acuity is low, sharpness and distinctness of visual images become worse or blurred, and a larger size of a letter or a picture is required to see them more clearly.

It is well known that visual acuity changes with viewing conditions such as luminance level, contrast, viewing distance and other factors like position in a visual field. Among these factors, viewing distance is one of the factors with the greatest effect where the age of viewer is concerned. It is therefore important to consider the viewing distance when designing visual images seen by older people.

Luminance, which means the background luminance on which the test image is displayed, is another important factor affecting visual acuity, but this effect occurs consistently for both young and older people.

In this subclause, the visual acuity data are presented as a function of viewing distance and luminance with age of a viewer as a parameter.

6.2.6.2 Sampled population

Visual acuity data in this subclause were taken from 111 participants and divided into 7 age groups as follows:

1) 10–19 years old (average 14,9 years), 11 participants;
2) 20–29 years old (average 22,8 years), 28 participants;
3) 30–39 years old (average 33,0 years), 11 participants;
4) 40–49 years old (average 46,5 years), 10 participants;
5) 50–59 years old (average 52,4 years), 10 participants;
6) 60–69 years old (average 65,3 years), 22 participants;
7) 70–79 years old (average 72,8 years), 19 participants.

Male and female were nearly balanced for each age group, except for the group of 40–49 years in which most of the participants were female. All the participants had no eye disease and no history of eye surgery.

6.2.6.3 Methods and conditions of data collection

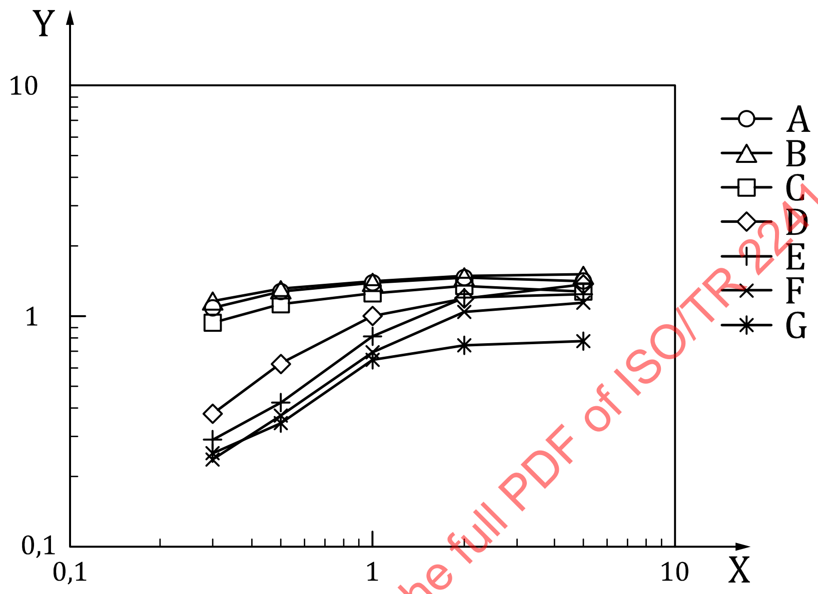
The data were obtained with a test chart based on the Landolt ring, which was printed on a white sheet with a gap in the ring in one of 8 directions. In investigating the effect of viewing distance, the luminance level of the white background sheet was set at 100 cd/m^2 and the viewing distance was changed from 0,3 m to 5 m. In investigating the effect of luminance, the distance was fixed at 5 m and the luminance was changed from 0,05 cd/m^2 to 11 000 cd/m^2.

The participants were asked to report the direction of the gap in the ring by choosing one from 8 directions. With reducing the size of the ring, the minimum size at which 50 % of correct responses was obtained. The visual angle of the gap at this minimum size gives the critical resolution of the eye, and the reciprocal of the visual angle (expressed in minutes of arc) finally gives the visual acuity.

All the participants wore correction lenses prepared for the measurement so that their best acuity was obtained at a far viewing point of 5 m.

6.2.6.4 Data

Figure 17 shows the visual acuity as a function of viewing distance for seven age groups. The luminance level was fixed at 100 cd/m^2. For participants of 10–19 years old, the visual acuity remained almost constant at around 1,0 although it reduced slightly at shorter viewing distance of 0,3 m. On the other hand, for participants of 40–49 years old or older than this, the acuity clearly decreased at shorter distances of 1 m and below. Visual acuity at shorter distance is quite low for older people, and enlarged letters or signs are necessary for them to see clearly.



Key

X viewing distance (m)

Y visual acuity

A 10–19 years old

B 20–29 years old

C 30–39 years old

D 40–49 years old

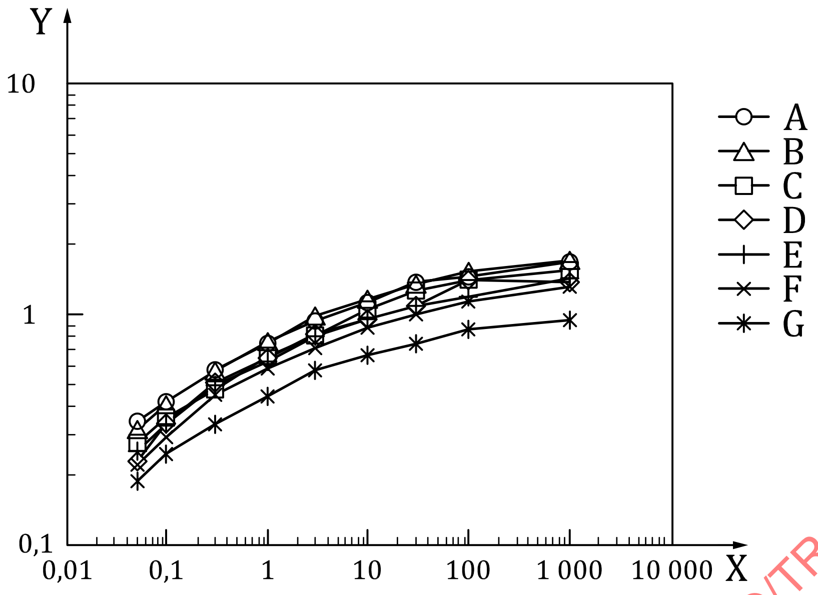
E 50–59 years old

F 60–69 years old

G 70–79 years old

Figure 17 — Visual acuity as a function of viewing distance for seven age groups

Figure 18 shows visual acuity as a function of luminance for seven age groups. The viewing distance was 5 m. Visual acuity for all age groups decreased in a similar rate as the luminance level decreased. This result suggests that the effect of luminance on visual acuity has no age dependence and can be expressed as a single formula for all ages. It also shows that a visual task that needs fine resolution of images is not appropriate to do in dark conditions for both young and older people generally.



Key

X luminance (cd/m[2])
Y visual acuity
A 10–19 years old
B 20–29 years old
C 30–39 years old
D 40–49 years old
E 50–59 years old
F 60–69 years old
G 70–79 years old

Figure 18 — Visual acuity as a function of luminance for seven age groups

6.2.6.5 Limitations

Data were taken with corrected lenses to measure every participant under the same visual condition (best corrected vision to a far viewing point). People wearing glasses of their own choice do not necessarily show the same change of visual acuity as shown in Figure 17. However, the relative change of visual acuity with luminance level generally applies to most of the viewing conditions.

6.2.6.6 Application examples

Visual acuity is expressed as the reciprocal of minimum discriminable visual angle. Therefore, when visual acuity is reduced by half, for example from 1,0 to 0,5, the size of a letter or a picture needs to be doubled to maintain the same level of visual resolution. This inverse relationship is basically applicable to most of the viewing conditions.

However, it is noted that visual acuity does not directly relate to the legible font size. For the relationship between visual acuity and font size, see 6.2.7.

6.2.6.7 References

— Data source: Reference [42];

— Cross-references in this document: 6.2.7, 6.2.8;

— Other references: Reference [88].

6.2.7 Minimum font size for legibility (effects of age, viewing distance and luminance)

6.2.7.1 General

Characters are used frequently and widely in our daily life. Font size for better legibility is always a matter of concern for designers of displays, pamphlets, and booklets like instruction manuals. However, ergonomics data and a method to estimate a legible font size have not been available because the legible font size is affected by so many factors such as font types, viewing conditions or human cognitive factors.

This subclause provides a set of data for legibility on Japanese and Chinese characters that were taken for young and older people in some typical reading conditions to provide the basic data showing the effects of age, viewing distance, and luminance.

6.2.7.2 Sampled population

Forty-seven young people ranging in age from 20 years to 27 years (average 22,7 years), and 46 older people ranged in age from 60 years to 78 years (average 68,3 years) participated in the experiment.

Males and females were nearly balanced for both the young and older group. All have or have had no eye disease and no history of eye surgery.

6.2.7.3 Methods and conditions of data collection

The legibility was measured as the minimum size of a character that gave the 80 % correct character identification by presenting a single character at a time. The test character was printed in black on a transparent sheet giving high contrast when illuminated from the rear. Three different types of characters were used as follows:

— simple characters: a mixture of Japanese phonetic signs called Hiragana, Katakana, and numerals;

— complex characters 1: Kanji characters (or Chinese characters) with 5–10 strokes;

— complex characters 2: Kanji characters (or Chinese characters) with 11–15 strokes.

For each group, two font-types, serif and sans-serif, were used.

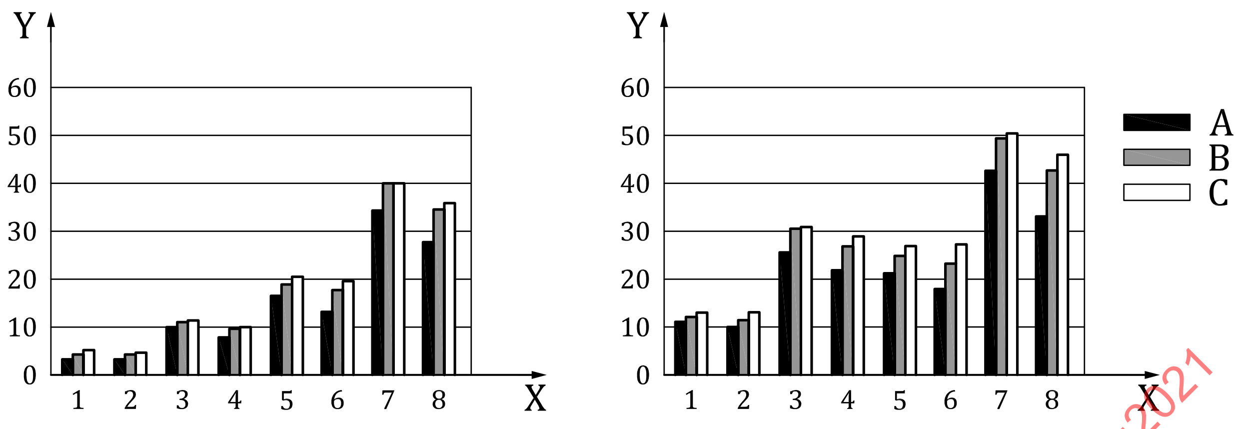
Four viewing conditions were used which consisted of combinations of two viewing distances, 0,5 m and 2,0 m, and two luminance conditions, 0,5 cd/m^2 (dark) and 100 cd/m^2 (bright).

Results were calculated as a probability of correct identification of characters for a font size in given viewing conditions. For this, a total of 12 consecutive trials were carried out by a participant with the same font size but different characters. The probability of 80 % of correct response was used to define minimum font size for legibility.

All the participants wore corrected lenses prepared individually for the experiment to keep a common accommodative power among participants which gave a best corrected vision to a far viewing point of 5 m.

6.2.7.4 Data

Figure 19 a) and b) shows the minimum font size for legibility as a function of viewing conditions for young and older people respectively. The X-axis represents the 8 viewing conditions including the different font-types (serif and sans-serif). For each condition, minimum font size for legibility for 3 groups of characters (simple characters, complex characters 1, and complex characters 2) was given. Minimum font size for legibility is smaller for the shorter viewing distance and for the brighter condition in general. Marked differences between younger and older people are found at the short distance (0,5 m) in which about 3 times as large a font size is required for older people compared to that for young people. This is consistent with the visual acuity data shown in Figure 17.



Key

X viewing conditions

Y font size (pt)

A simple characters (Japanese Kana, numerals)

B complex characters 1 (Chinese with 5–10 strokes)

C complex characters 2 (Chinese with 11–15 strokes)

1 0,5 m, 100 cd/m^2, serif font

2 0,5 m, 100 cd/m^2, sans-serif font

3 0,5 m, 0,5 cd/m^2, serif font

4 0,5 m, 0,5 cd/m^2, sans-serif font

5 2 m, 100 cd/m^2, serif font

6 2 m, 100 cd/m^2, sans-serif font

7 2 m, 0,5 cd/m^2, serif font

8 2 m, 0,5 cd/m^2, sans-serif font

Figure 19 — Minimum font size for legibility of single characters for young and older people

Regarding the effect of font type, i.e. serif and sans-serif, the serif font needs slightly but consistently larger size than the sans-serif font for all the viewing conditions, which indicates that sans-serif is slightly more legible than serif font.

6.2.7.5 Limitations

It is noted that the data were taken with correction lenses to keep a common accommodative condition (best corrected vision to the far viewing distance of 5 m) among the subjects. People wearing their own preferred glasses do not follow the data trend expressed in Figure 19. However, relative changes of the font size with different viewing conditions such as darker or lighter condition can generally apply.

The data were collected for some fixed conditions i.e. luminance, distance, font type, etc. To apply the present data in different condition an estimation method that takes into account the effects of those conditions is required (see JIS S 0032).

As already mentioned in 6.2.7.3, the minimum font size for legibility here was defined by 80 % correct identification of characters. This means that the font size is still at threshold level and not at the level of ease of reading. If font designers are concerned with the comfortable level of legibility, the size should be enlarged. The factor of enlargement can be defined relative to the minimum font size for legibility consistently for all the viewing conditions (see Reference [84]).

6.2.7.6 Application examples

Minimum font size for legibility in specific conditions can be estimated directly from the data shown in Figure 19. The effects of viewing conditions and font types are also shown by the data and can apply to other conditions. One example of the estimation method is given in JIS S 0032.

6.2.7.7 References

— Data source: Reference [42];

— Cross-references in this document: 6.2.6, 6.2.8, 6.2.9;

— Other references: References [88], [84] and [35].

6.2.8 Minimum font size for legibility (international comparison)

6.2.8.1 General

Different fonts are used in different countries and legibility can differ among fonts. Therefore, it is worth testing the legibility of different fonts in different countries to recommend a standard font size across the countries.

This subclause provides data on the legibility of a single character for 6 different countries using the same experiment and the same viewing condition for groups of younger and older people.

6.2.8.2 Sampled population

The legibility experiment was carried out in each of six countries: China, Germany, Japan, Republic of Korea, Thailand and the USA. Each country recruited 15 to 20 people in their 20s and also 15 to 20 people in their 60s and 70s as participants in the experiment. They all had no impairment and no experience of surgery of the eye.

6.2.8.3 Methods and conditions of data collection

Legibility was investigated with a number of single characters in different sizes, printed in black on white paper. Ten font sizes from 2 pt to 114 pt were used. For each size, twelve different characters were tested. The participant was asked to read characters in their natural viewing manner, i.e. with glasses if they are used in their daily life, at fixed viewing distances of 0,5 m and 2,0 m. The illuminance at the viewing position was set at 500 lx approximately.

Under the same experimental conditions, the participants' visual acuity (spatial resolution ability) was measured using a Landolt-ring test chart.

Three types of characters, 4 languages, and 2 font types were used in the experiment as shown in Table 8. Japan used alphabets to investigate an effect of non-native language. The legibility data for Japanese characters is presented in 6.2.7.

Table 8 — Experimental conditions used for the international comparison for legibility

Type of characters	Language	Country	Font type
Numerals	Arabian numerals	China Germany Japan Rep. of Korea Thailand USA	Serif Sans-serif

Table 8 *(continued)*

Type of characters	Language	Country	Font type
Simple characters	Alphabet uppercase	Germany Japan USA	Serif Sans-serif
	Chinese simple	China	
	Hangeul simple	Rep. of Korea	
	Thai simple	Thailand	
Complex characters	Alphabet lowercase	Germany Japan USA	Serif Sans-serif
	Chinese complex	China	
	Hangeul complex	Rep. of Korea	
	Thai complex	Thailand	

6.2.8.4 Data

Figure 20 and Figure 21 show the minimum font size for legibility, for a serif font and for a sans-serif font respectively, measured in six countries, for young people (the left panel in Figure 20 and Figure 21) and for older people (the right panel in Figure 20 and Figure 21). The minimum font size for legibility was defined as the 80 % level of correct identification. Data in Figure 20 and Figure 21 are for a viewing distance of 0,5 m.

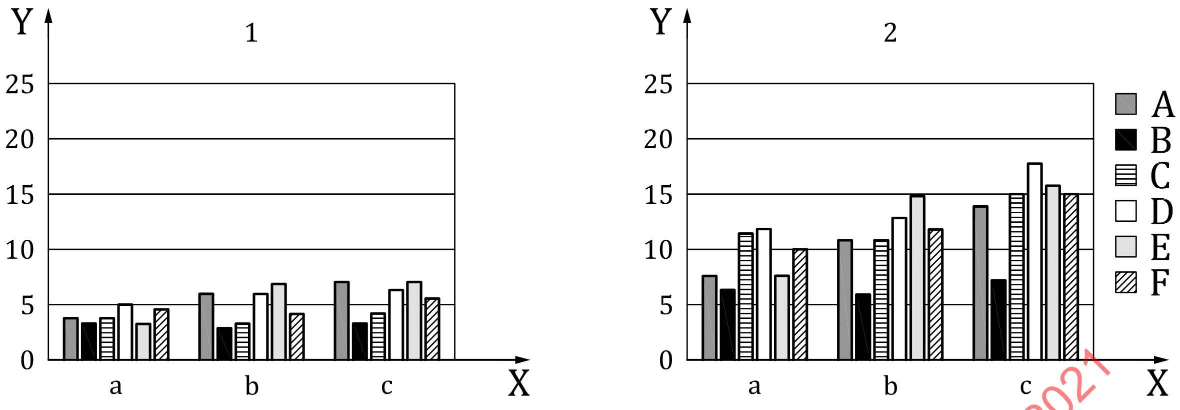
Visual acuity data of the participants were also measured in the same experimental condition, which are provided in Table 9 for reference.

The minimum font size for legibility of young people ranged from 3 pt to 7 pt (at the 0,5 m distance), which is similar to that in shown in 6.2.7.4. For older people the legible font size became larger in a range from 6 pt to 17 pt. This result was reasonably expected based on the decrease in visual acuity with age at a short viewing distance generally, and also from the visual acuity data actually measured for younger and older people in each country (see Table 8).

The effect of different languages on the minimum font size for legibility is not clearly seen in Figure 20 and Figure 21. This can be due to some un-controlled factors such as the individual acuity of participants. Correction of data by visual acuity may be necessary for comparing the differences among the fonts in different countries more precisely.

Rough estimation using the simple inverse relationship of visual acuity in Table 8 and font size data in Figure 20 and Figure 21 revealed that there was no remarkable effect of the different fonts of different languages used.

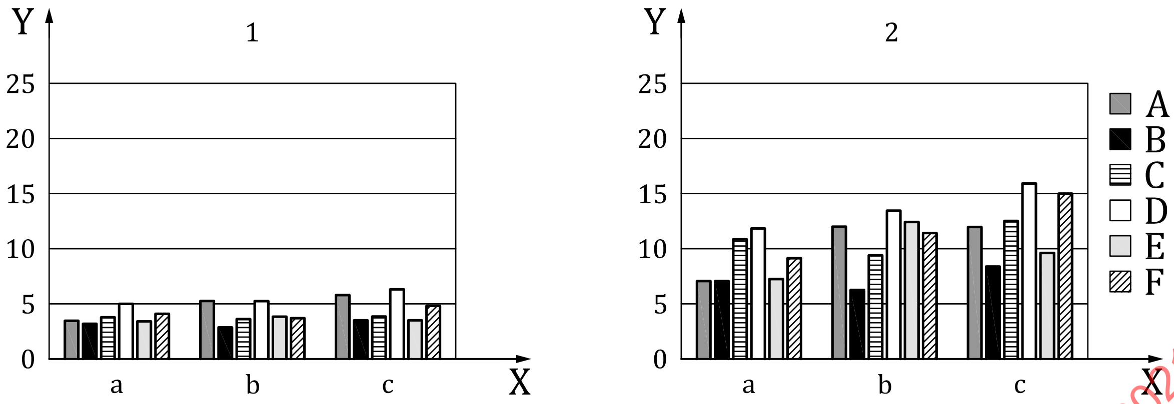
The sans-serif character shows smaller font size than the serif font for most of the conditions meaning that sans-serif is more legible. For older people in Thai language, minimum legible font size for sans-serif is much larger than that for serif-font.



Key

X type of characters
Y font size (pt)
1 young people
2 older people
A China
B Germany
C Japan
D Rep. of Korea
E Thailand
F USA
a numerals
b simple characters
c complex characters

Figure 20 — Minimum font size for legibility for single characters for six different countries and serif font



Key

X type of characters
Y font size (pt)
1 young people
2 older people
A China
B Germany
C Japan
D Rep. of Korea
E Thailand
F USA
a numerals
b simple characters
c complex characters

Figure 21 — Minimum font size for legibility for single characters for six different countries and sans-serif font

Table 9 — Averaged visual acuity of people who participated in the legibility experiment in each country

Country	Young people	Older people
Rep. of Korea	1,47	0,37
China	1,92	0,74
Germany	2,14	0,91
Japan	1,27	0,63
Thailand	2,18	0,55
USA	1,69	0,68

6.2.8.5 Limitations

Figure 20 and Figure 21 present font sizes at the minimum legible level defined as 80 % correct identification in the different conditions. The font size should not be smaller than this. The font size for comfortable seeing and reading may be much larger than the minimum legible size.

6.2.8.6 Application examples

The minimum font size for legibility at short viewing distance of 0,5 m can be estimated directly from the data shown in Figure 20 and Figure 21. For other conditions, the inverse relationship between visual acuity and font size can be roughly applied to estimate the minimum font size for legibility (see 6.2.6).

6.2.8.7 References

- Data source: Reference [77];
- Cross-references in this document: 6.2.6, 6.2.7, 6.2.9;
- Other references: Reference [35].

6.2.9 Minimum font size for legibility (low vision)

6.2.9.1 General

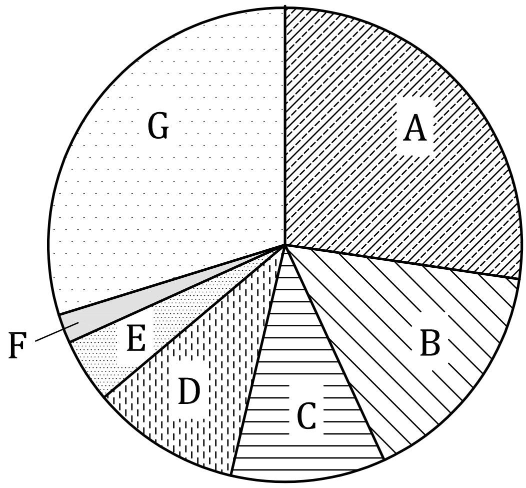
Persons with low vision have extremely low visual acuity due to retinal and/or neural disorders in visual pathways, and the visual acuity cannot be corrected even with correction lenses. They need fairly large font size when they read characters and pictures. The extent to which persons with low vision can read characters is different depending on the impairment of retina or visual pathways.

Luminance level and luminance contrast of characters are also significant factors affecting legibility for people with low vision. Higher luminance level and high contrast are usually preferable for them, but these conditions sometimes cause glare and consequently degrade the legibility.

This subclause provides data about how big the font size needs to be to read characters in a typical viewing condition for people with low vision.

6.2.9.2 Sampled population

The data were obtained from 59 persons who were medically diagnosed as having low vision. Details of their diseases and distribution are shown in Figure 22. This reflects a typical distribution in Japan, but can differ in other countries.



Key

A retinitis pigmentosa
B cataract
C glaucoma
D optic nerve atrophy
E aphakic eye
F retinal detachment
G others

Figure 22 — Eye diseases distribution of 59 people with low vision participated in the experiment

6.2.9.3 Methods and conditions of data collection

For each participant, the minimum font size for legibility for a single character was measured. The character was presented on a CRT display at the highest positive or negative contrast (i.e. a black character on a white background or vice versa) that the CRT can generate. The luminance level of the background was set at 70 cd/m^2 for positive contrast and nearly zero (below 0,5 cd/m^2) for negative contrast.

The minimum font size for legibility was measured for the following four types of characters:

a) alpha-numerals with serif font;

b) Chinese characters with serif font;

c) alpha-numerals with sans-serif font;

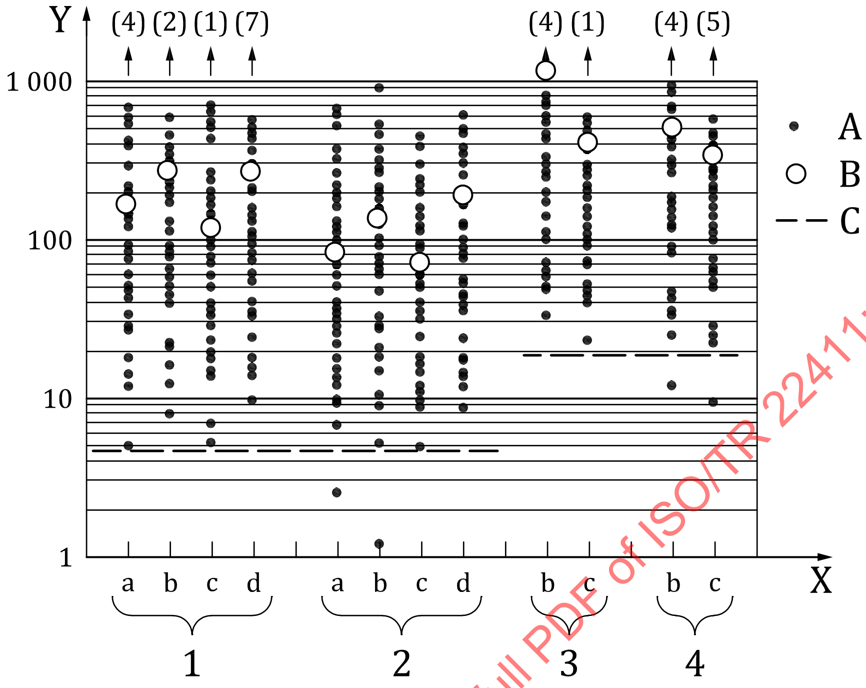
d) Chinese characters with sans-serif font.

All the characters in these 4 conditions were presented both in positive and negative contrast, and were viewed at a distance of 0,5 m and 1,5 m.

6.2.9.4 Data

Figure 23 shows the minimum font size for legibility for a total of 59 people with low vision who participated in the experiment. The data show the font size for 4 kinds of characters (denoted as a, b, c, and d in Figure 23) and in 4 conditions (combinations of 2 distances and positive and negative fonts).

The data show a large variation for legibility for almost all the conditions tested, ranging from below 10 pt to above 1 000 pt. The median level was at around 100 pt to 200 pt which is about 10 times larger than that of normally sighted young people. Fonts with negative contrast (a white character on dark background) were more legible than fonts with positive contrast for people with low vision, and sans-serif fonts were slightly more legible than serif fonts.



Key

X type of characters and viewing conditions
Y minimum legible font size (pt)
A individual data
B median data of 59 individuals (29th of measured data)
C mean level of young people with no impairment
a alpha-numerals with serif font
b Chinese characters with serif font
c alpha-numerals with sans-serif font
d Chinese characters with sans-serif font
1 positive font at 0,5 m viewing distance
2 negative font at 0,5 m viewing distance
3 positive font at 1,5 m viewing distance
4 negative font at 1,5 m viewing distance

Figure 23 — Minimum font size for legibility for people with low vision viewed at a distance of 0,5 m and 1,5 m

6.2.9.5 Limitations

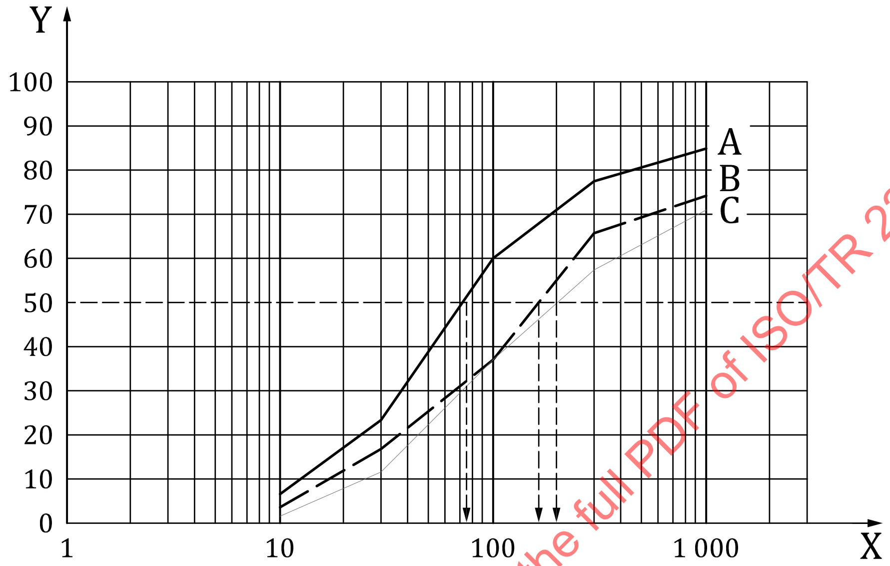
The data can be used for near sight at a moderately bright level only.

6.2.9.6 Application examples

Figure 24 shows cumulated percentage of participants who could read characters of a given font size, as a function of the size. Three curves are drawn as examples from the data in Figure 23 for alpha-numerals for 1) serif and positive font, 2) sans-serif and positive font and 3) sans-serif and negative font, all at the 0,5 m viewing distance. Similar curves can be drawn for other viewing conditions.

Designers of font type and size can see from this figure how many people (in % of the low vision people) can read an alpha-numeric font when they design it at a given size. Alternatively, once they set a percentage of low vision people whose needs are to be satisfied, for example 30 %, they would be able to find a font size that meets the criterion.

In Figure 24, the 50 % level has been set as a legible level of low vision as an example. At this level, the minimum font size of alpha-numerals with sans-serif in a negative font, sans-serif in positive font, and serif in positive font are 75 pt, 170 pt and 200 pt, respectively. The sans-serif in a negative font is the most legible one among these three conditions.



Key

X font size (pt)

Y cumulated percentage of people who can read a character

A sans-serif font in negative polarity

B sans-serif font in positive polarity

C serif font in positive font

NOTE The curves were derived from the data in Figure 23.

Figure 24 — Cumulated percentage of people with low vision who can read alpha-numeric characters as a function of font size

6.2.9.7 References

— Data source: Reference [65];

— Cross-references in this document: 6.2.7, 6.2.8;

— Other references: none.

6.2.10 Disability glare (ageing effect)

6.2.10.1 General

Glare is the condition of vision in which light sources cause an undesirable or annoying effect on visual perception due to scattering of light in the eye. The effects manifest itself in different ways as generally described by disability glare and discomfort glare, the two types of glare.

Disability glare makes it difficult, even impossible, to perceive certain objects in the visual field. This glare results in a decrease in detectability of light signals or readability of visual signs when very bright light exists near the line of sight (e.g. at night driving in the presence of headlights or street lights, or when looking at traffic signals near the sun in the daytime).

Discomfort glare causes a sense of annoyance or pain without impairing vision. This can decrease the comfort of the visual environment such as workplaces or living rooms.

Ageing affects both types of glare as scattering of light in the eye increases with age. This subclause describes ageing effects of disability glare as a function of age, taking the young eye as a reference.

Regarding the discomfort glare, the CIE has provided a method to measure discomfort glare which is known as the CIE unified glare rating (UGR) and has recommended values (upper limits) for various work places which have been presented in their standards[1]. However, ageing effects are not addressed in these standards.

6.2.10.2 Sampled population

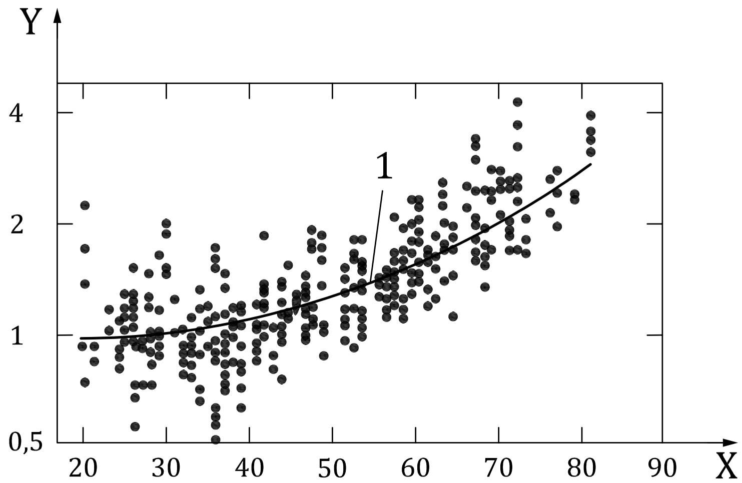
The data were obtained from 129 people ranging in age from 20 years to 70 years. They had no eye pathology and their visual acuity was equal to or better than 1,0.

6.2.10.3 Methods and conditions of data collection

Disability glare was measured as the veiling light that fell on the centre of the eye (1° field size) caused by a glare source which was presented in the periphery of the visual field. The glare source was intermittently presented at 8 Hz. This generated a flicker sensation at the centre of the eye due to the scattering of the glare source. Counter-phased flickering light was presented at the centre of the eye so that it could compensate the flicker sensation caused by the glare source. The participant's task was to report the existence of flicker sensation every time when the variable amount of compensating light is presented. The amount of light required for compensating the flicker gave the amount of scattered light from the glare source.

6.2.10.4 Data

The data summarized as the relative age factor for disability glare are shown in Figure 25. This age factor indicates the increase of veiling light inside the eye, which was caused by a light source relative to the eye of a young person for whom the veiling light is assumed to be nearly absent. At the age of 70 years, this factor reaches about 2,0, indicating that twice as much veiling light falls on the retina in the eye of an older person as compared to a young person. Therefore, disability glare is much more troublesome for older people.



Key

X age (years)

Y age factor

1 1+(A/70)^4 where A is age

Figure 25 — Relative age factor for disability glare (scattering effect in the eye as a function of age)

6.2.10.5 Limitations

The data shows the scattering effect in the eye only, but not the subjective scaling of the glare sensation or glare perception. It should be noted that twice the scattering light in the eye does not necessarily mean twice of glare sensation. The data can be used to estimate the glare effect on older people relative to that of young people as the intensity of a glare light source increases. For example, doubling the intensity of light source can generate the same amount of glare effect on a young person as a 70-year-old person would perceive.

The data presented here is about disability glare, but not about discomfort glare. There is no good data source for discomfort glare. For general information on discomfort glare, see CIE S 008.

6.2.10.6 Application examples

When designing light signals, visual signs and markings of interior or exterior workplaces for older people, the glare effect should be taken into account.

Reflective surface such as a display panel or a glossy paper for printed information can reduce the legibility because of the glare effect of a reflected light source. However, the existence of a disability glare depends on environmental factors and the solution depends on the environmental design. Care should be taken in designing products for the environment in which the products are used and possible ways for avoiding the glare effect.

6.2.10.7 References

— Data source: Reference [2];

— Cross-references in this document: none;

— Other references: Reference [1].

6.2.11 Useful field of view (ageing effect)

6.2.11.1 General

The human eye has a wide range of visual field (more than 90° for the left and the right side from the central visual axis) for detecting, discriminating, understanding lights and objects in front of the eye. The visibility of a visual sign, a signal or an object depends on the position of the visual field in which it appears mainly due to the inhomogeneous nature of the retina of the eye.

Generally, the central visual field at around the visual axis is best for most of the visual functions. However, those functions are less effective in the periphery of the field. Colour perception, for example, changes its function less effective with increasing eccentricity in the visual field because the density of colour sensitive photoreceptors (cones) in the retina is reduced apart from the centre of it. Colour identification and colour discrimination become worse at peripheral vision.

It is noted that sensitivity to temporal changes of light stimuli is higher in peripheral vision than in central vision. A flickering or blinking light in a peripheral visual field (off visual axis) is detected better and, therefore, useful in visual signalling.

Important visual signs such as emergency signs should be placed at the centre of visual field, otherwise the sign cannot be detected at all in the worst case. Therefore, it is a critical issue for any visual sign or signal where it is presented and detected in the visual field.

Useful field of view (UFOV) is a range of visual field where good performance is expected for a specified visual task such as colour identification or object recognition. UFOV can be determined for various visual functions or tasks, e.g. detection, spatial or temporal discrimination, object recognition, flash or movement detection, etc. The most basic UFOV is measured by a simple detection task, in which a person is required to detect a target presented in the periphery while his/her eye is fixated to the centre of visual field.

This subclause presents the data on detectability of a simple target (a circular light spot) presented in the periphery of visual field with variable eccentricity.

6.2.11.2 Sampled population

The data were taken from 46 young persons (20–28 years old) and 52 older persons (62–81 years old) who had no visual impairment.

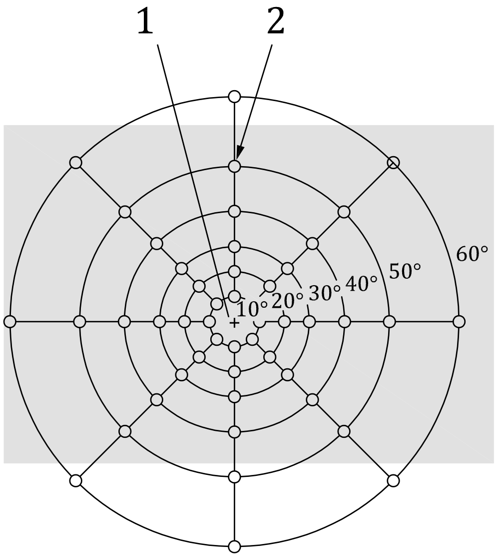
6.2.11.3 Methods and conditions of data collection

A uniform grey background field extended 60° to the left and right, 50° up and 40° down from the centre of visual axis, was used. A disk target of 2° in diameter was presented on the background at one of the 43 positions distributed in eight directions in 45° steps and in four to six eccentricities from 10° to 60° in 10° steps. This is illustrated in Figure 26 a).

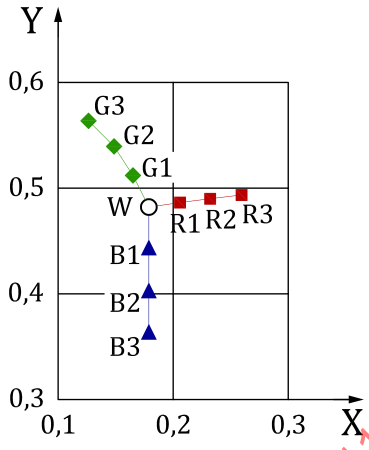
Visual field was measured for a luminance difference and for a colour difference. For the luminance difference, the target had a higher luminance than the background with one of the three luminance ratios of 1,2, 1,4 and 1,8 (20 %, 40 % and 80 % brighter, respectively). For the colour difference, the target had a different colour from the grey background as specified in Figure 26 b), with no luminance difference (equal luminance condition). In Figure 26 b), R1, R2, R3, G1, G2, G3, B1, B2 and B3 represent red targets of low, middle, high saturation, green targets of low, middle, high saturation, and blue targets of low, middle, high saturation, respectively

The target was presented as a flash with a 250 ms duration at one of the 43 positions. Participants were asked to fixate their right eye at the central fixation point and, after the presentation of a test target, to respond whether they could detect the target and which direction it appeared if detected.

The visual acuity of the participants was corrected with a special lens covering a wide visual angle for this measurement and the best visual acuity was obtained at the centre of the visual field at 1,0 m viewing distance.



a) Target positions



b) Chromaticity of coloured targets

Key

X CIE1976LUV chromaticity coordinate (*u*′)

Y CIE1976LUV chromaticity coordinate (*v*′)

1 fixation point

2 test target position

R1, R2, R3 red targets

G1, G2, G3 green targets

B1, B2, B3 blue targets

W white point

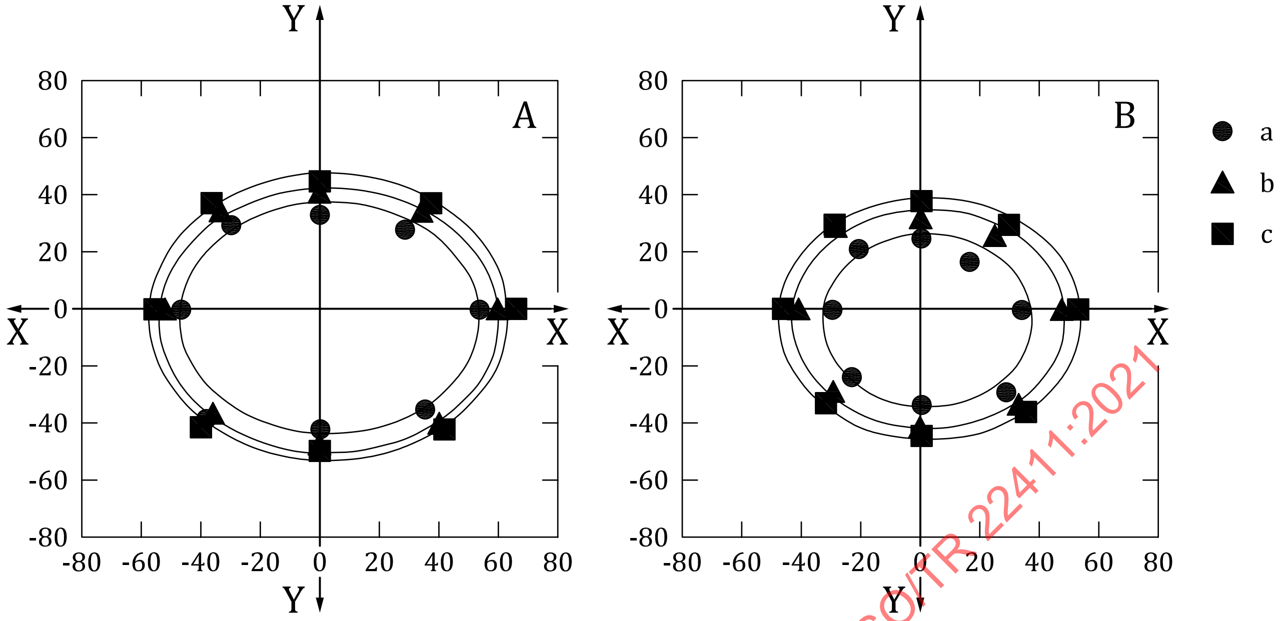
NOTE The terms *u'* and *v'* are the colour coordinates of the uniform colour space, LUV, defined by the CIE.

Figure 26 — Target positions and chromaticity coordinates of coloured targets used for the measurements of UFOV

6.2.11.4 Data

Figure 27 and Figure 28 show UFOV data of 50 % detectability for a disk target with a luminance difference and with a colour difference, respectively. The colour difference data are shown only for the most saturated colours for red, green and blue stimuli [i.e. R3, G3 and B3 in Figure 26 b)].

This data clearly shows that the UFOV is smaller for older people than for young people for both conditions. The ageing effect is more pronounced for the colour difference than for the luminance difference. This result can be expected from the effect of cataract or scattering of light in the eye which increases with age. Desaturated colours reduce colour differences and make the UFOV smaller.



Key

X horizontal eccentricity (degree)

Y vertical eccentricity (degree)

A younger people

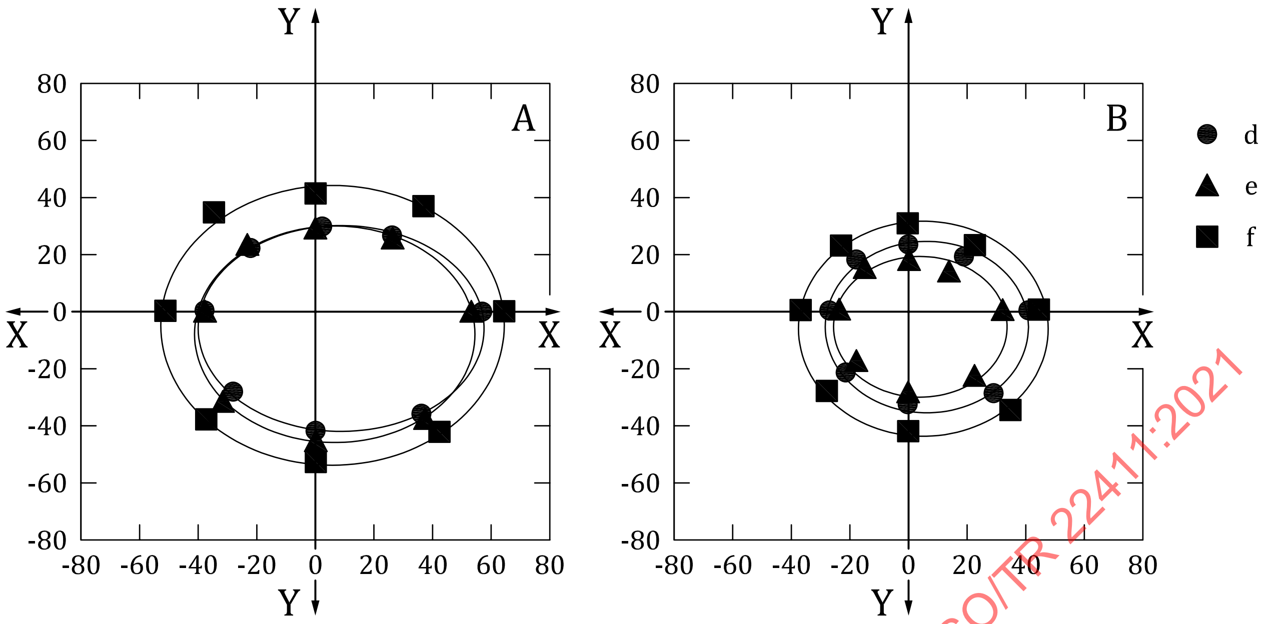
B older people

a luminance ratio 1 : 1,2

b luminance ratio 1 : 1,4

c luminance ratio 1 : 1,8

Figure 27 — Useful field of view for a target only with luminance difference (50 % detectability contour) of young and older people



Key

X horizontal eccentricity (degree)
Y vertical eccentricity (degree)
A younger people
B older people
d coloured target, red
e coloured target, green
f coloured target, blue

Figure 28 — Useful field of view for a coloured target on white background (50 % detectability contour) of young and older people

6.2.11.5 Limitations

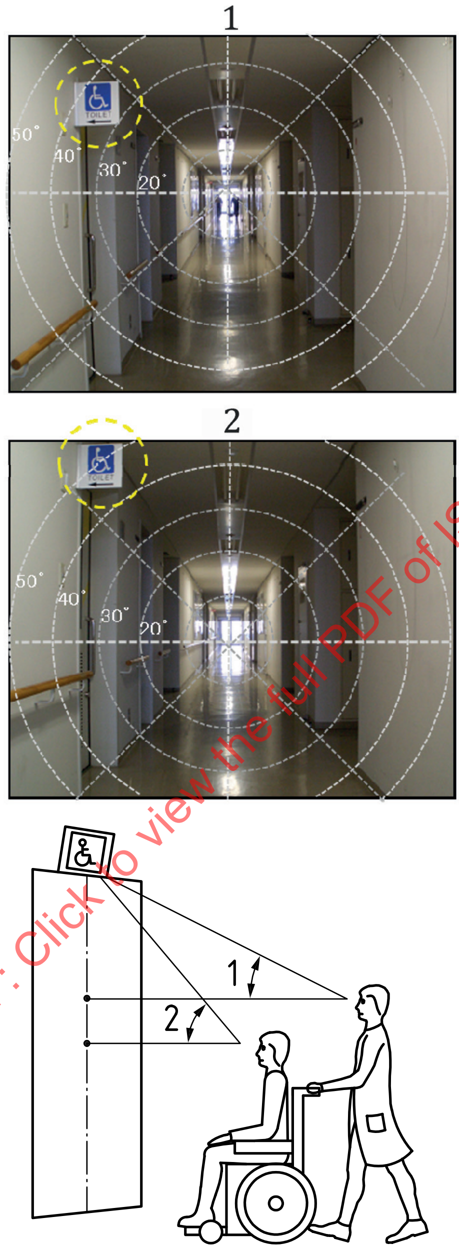
The data shows a UFOV for a uniform background which is the simplest case and, therefore, the widest case for UFOV. Complex background stimuli are seen in a natural viewing condition for which the UFOV can be smaller due to cognitive effects such as attention, searching, familiarity for detecting a target.

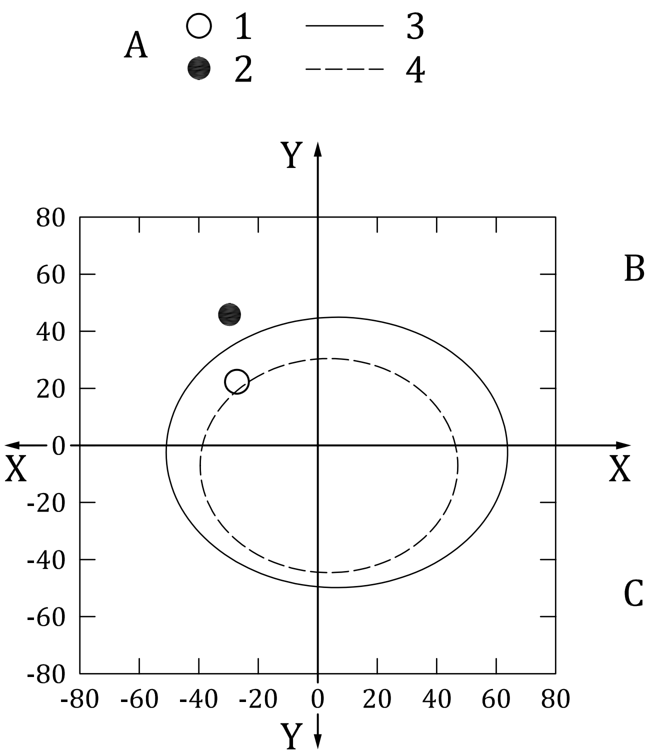
6.2.11.6 Application examples

Present data on UFOV can be used in designing layout of a visual sign or a display with regard to the detectability of it when it appears in the peripheral visual field. Applications include designing a traffic sign, a public emergency sign for evacuation, an information sign in a station, the labelling of ATMs in banks or public spaces. The UFOV is also a matter of concern for designers when considering the location of switches and buttons in control panels or home appliances. Their layout is a critical problem even if each part of panel is designed for good visibility at the central part of visual field. Positioning of an indicator lamp is such an example.

Figure 29 shows another example for estimating detectability of a restroom sign coloured in blue. Simplifying the viewing condition as a blue target in a uniform grey background, the data on a blue target in Figure 28 can be referred to estimating the detection probability of the sign for a person who is standing and for a person in a wheelchair, both of them being young for instance.

By plotting the location of the sign viewed by those two persons (see the inset figure of useful visual field data in Figure 29), it can be found that the sign is within the 50 % detectability area of useful field of view (the solid circle) for the young person who is standing. However, it is outside of the 50 % area for the person in a wheelchair. In the case of older persons, the sign is outside of UFOV of a person who is standing (the dashed circle in Figure 29). The sign can be overlooked by a young person in a wheelchair, and it is more difficult to detect by an older person even he/she is standing.





B

Viewing distance:	3 m (approx.)
Target size:	4 degree (approx.)
Luminace contrast:	1 : 0,1
Color difference:	white-blue
Target eccentricity:	36 degree (at standing)
	50 degree (in a wheelchair)
Orientation:	left-upper

C

	3	4
1	> 50%	< 50%
2	< 50%	< 50%

Key

1 view standing
2 view in a wheelchair
3 for a young person
4 for an older person
X horizontal eccentricity (degree)
Y vertical eccentricity (degree)
A data used for estimating detectability (the 50 % detection contour for a blue target on white background)
B viewing conditions
C evaluation of detectability of a toilet sign (estimated from the colour detection data)

Figure 29 — Example of estimating visibility of a blue restroom sign for a person standing and a person in wheelchair

It is noted that sensitivity to temporal changes of light stimuli is higher in peripheral vision than in central vision, though the data is not shown here. A flickering or blinking light in a peripheral visual field (off visual axis) is detected better and, therefore, useful in visual signalling.

6.2.11.7 References

— Data source: Reference [46];

— Cross-references in this document: none;

— Other references: Reference [66].

6.2.12 Lighting level and visual performance (ageing effect)

6.2.12.1 General

The appropriate level of lighting level is a critical issue in lighting design both for workplaces and living spaces. It depends on the visual tasks which people are engaged in, and on their visual abilities too.

This subclause presents data on a required time for doing some typical visual tasks as a function of lighting level for younger and older people. The following three different tasks were employed as representatives of a visual task:

a) pegboard operation (key insertion);

b) colour sorting;

c) reading printed sentences.

6.2.12.2 Sampled population

Data were obtained from 55 young people (33 male and 22 female) ranging in age from 18 years to 26 years (21,6 years on average), and 55 older people (34 male and 21 female) from 60 years to 83 years (67,3 years on average). They all had no visual impairment and no colour defect.

6.2.12.3 Methods and conditions of data collection

The pegboard task was an eye-hand coordination task in which the participants had to insert each of 25 keys into holes in a 5 × 5 matrix in different locations.

The colour sorting task was to sort out in the right colour order for 16 pieces (4 for each of red, yellow, green, and blue) of slightly different colour chips. The colour chips were taken from the Farnsworth 100 hue test.

The reading task was to read out sentences of 10 lines printed in black on a white paper with a viewing distance of 50 cm. Serif and sans-serif fonts of 18 pt were used.

For each task, the time required for a participant to complete the task was measured. The maximum time was set at 3 min, beyond which the participant had to stop the task. The number of participants who completed the task correctly and the time required to conduct the task were recorded.

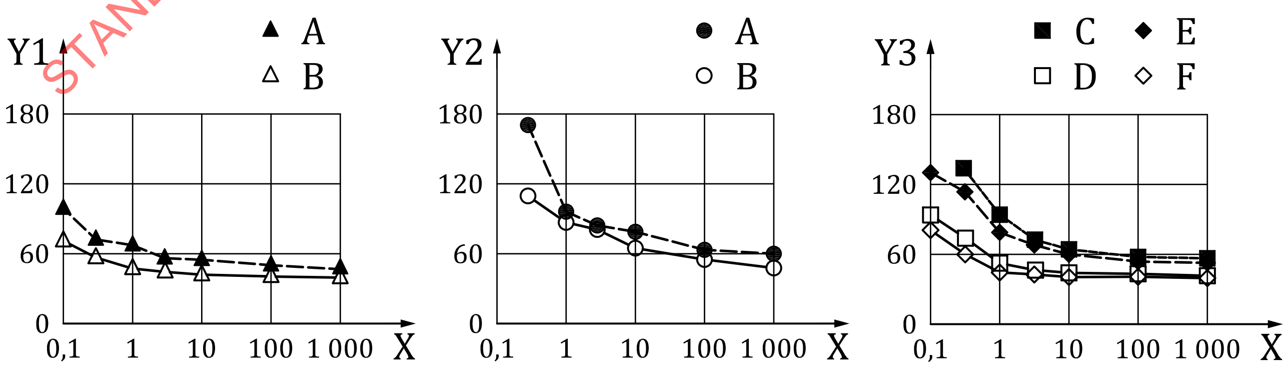
Illuminance was set at one of seven levels: 0,1 lx, 0,3 lx, 1 lx, 3 lx, 10 lx, 100 lx or 1 000 lx. Daylight fluorescent lamp was used to illuminate the working area in a uniform way.

The participants wore correction lenses to obtain their best visual acuity at the working plane.

6.2.12.4 Data

Figure 30 shows the time required for completing three visual tasks of a) pegboard, b) colour sorting and c) reading, respectively, in which the time was averaged for both young and older people separately.

The time increased gradually as the illuminance lowered for every task in general. Illuminance lower than 1 lx made the tasks more difficult and the time increased as the illuminance decreased.



a) **Pegboard** b) **Colour sorting** c) **Reading**

Key

X illuminance level (lx)
Y1 pegboard manipulation time (s)
Y2 colour chips sorting time (s)
Y3 reading time (s)
A older people
B young people
C older people (for serif font)
D young people (for serif font)
E older people (for sans-serif font)
F young people (for sans-serif font)

Figure 30 — Time required for completing a visual task as a function of illuminance

Older people were affected more severely than young people in colour discrimination. The reading task was affected when the illuminance was lower than 10 lx for both serif and sans-serif fonts.

To summarize all these results, it can be said that illuminance above 10 lx should be maintained in general for keeping the task easy.

Considering the general functioning of the human eye, the working range of the eye in relation to illuminance change can be divided into 3 parts:

1) photopic vision at above about 10 lx, where shapes and colours of objects are clearly seen;

2) mesopic vision at about 0,01 lx to 10 lx, where shapes and colours are slightly seen depending on the illuminance level;

3) scotopic vision at below 0,01 lx, where only vague shapes of objects can be seen.

The data shows that visual tasks become harder to complete in general when the illuminance becomes lower than that needed for photopic vision, i.e. below about 10 lx.

6.2.12.5 Limitations

The present data is available for three representative visual tasks (eye-hand coordination, colour sorting and reading). For other different types of visual task such as searching or motion perception, the illuminance effect can be different. The ageing effect can also vary depending on the difficulty of the task.

6.2.12.6 Application examples

The present data can apply to three major types of visual tasks:

1) a task that needs eye-hand coordination;

2) a task that needs colour identification and discrimination; and

3) a task that needs fine spatial resolution.

The data on pegboard insertion [Figure 30 a)] can apply to eye-hand coordination tasks. The data on colour sorting [Figure 30 b)] can apply to tasks that involve colour identification and discrimination. For visual tasks that need fine spatial resolution, the data in Figure 30 c) can be used.

6.2.12.7 References

— Data source: Reference [77];

— Cross-references in this document: none;

— Other references: none.

6.2.13 Visibility of an indicator lamp: Context and task specific data (effects of ageing and low vision)

6.2.13.1 General

Visibility of an indicator lamp becomes better in general as the luminance of the lamp increases. However, extremely high luminance can cause glare, and too bright a sensation of light reduces the visibility. Therefore, visibility and glare should be taken into account when determining the luminance level of an indicator lamp.

This subclause provides data on the visibility of indicator lamps when changing their luminance level.

6.2.13.2 Sampled population

Data were collected from three different groups, younger people without any visual impairment (average age 22,2 years ± 2,2 years), older people (average age 68,4 years ± 3,4 years), and people with low vision (average age 57,8 years ± 8,3 years). The number of participants in each group was 20.

6.2.13.3 Methods and conditions of data collection

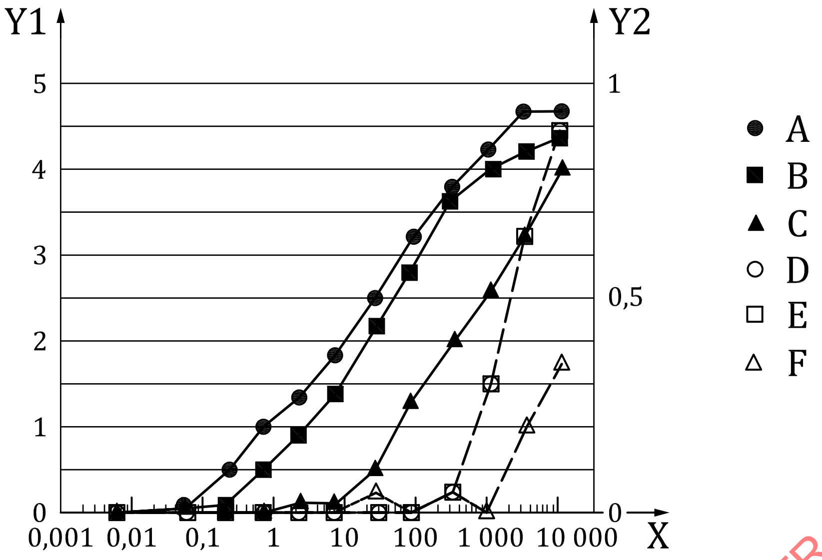
Visibility of indicator lamps was measured using a subjective evaluation method. A visibility scale of six points was used: 0: not visible, 1: very difficult to see, 2: slightly difficult to see, 3: neither difficult nor easy, 4: slightly easy to see, and 5: very easy to see. For glare evaluation, a two-point scale was used; 1: glaring, 0: no glare.

6.2.13.4 Data

Figure 31 and Figure 32 show results of subjective evaluation of visibility and glare feeling of an indicator lamp of 3 mm diameter as a function of luminance for a photopic condition (500 lx; moderately bright) and for a mesopic condition (0,5 lx; dark), respectively. The visibility evaluation is shown by closed symbols for the Y1-axis, and the glare feeling by open symbols for the Y2-axis. The visibility data were averaged over 20 participants for each of three groups (young people, older people and people low vision). The variance of the data, not shown here, was large for older people and much larger for people with low vision, compared to that of young people.

Both the visibility score and glare feeling increased with luminance level. However, since the glare has a negative effect on visibility, there is a trade-off between the visibility and the glare feeling along with the luminance level. This effect is important particularly for the dark (mesopic) condition where the glare feeling is much higher than that for the bright (photopic) condition.

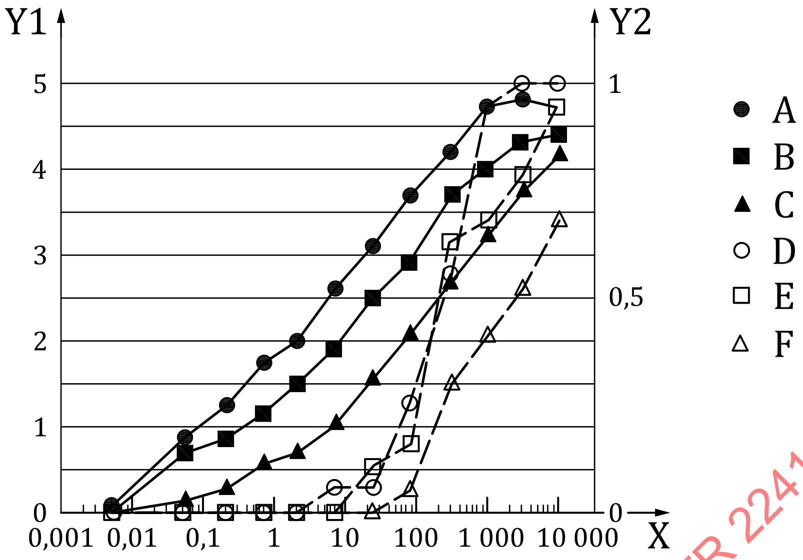
The visibility score is not much affected by the lighting environment, dark or bright.



Key

X luminance (cd/m^2)
Y1 visibility score
Y2 probability of glare feeling
A visibility of young people
B visibility of older people
C visibility of people with low vision
D glare feeling of young people
E glare feeling of older people
F glare feeling of people with low vision

Figure 31 — Visibility and glare evaluation for an indicator lamp at photopic vision (500 lx) – White colour, diameter of 3 mm, and black surrounding



Key

X luminance (cd/m^2)
Y1 visibility score
Y2 probability of glare feeling
A visibility of young people
B visibility of older people
C visibility of people with low vision
D glare feeling of young people
E glare feeling of older people
F glare feeling of people with low vision

Figure 32 — Visibility and glare evaluation of an indicator lamp at mesopic vision (0,5 lx) – White colour, diameter of 3 mm, and black surrounding

6.2.13.5 Limitations

Since the data presented here are for a small indicator lamp (3 mm in diameter), they cannot be applied to designing a lamp with a larger size such as an alarm lamp or a lamp for machinery in a special use for industry, professional or technical. Nor are data available for a display presenting characters and graphics with complex spatial information.

The data presented here do not apply to people with a colour deficiency.

6.2.13.6 Application examples

These data are useful for designing indicator lamps or LEDs of household appliances used as a means of indicating operating conditions of devices and making operations of consumer products easier.

6.2.13.7 References

— Data source: Reference [64];

— Cross-references in this document: none;

— Other references: Reference [36].

6.3 Hearing

6.3.1 Hearing-sensitivity decrease as a function of age

6.3.1.1 General

The data in this subclause show how our hearing sensitivity changes, as a function of frequency, as the age advances. Gender effects and individual differences are taken into consideration.

As age-related hearing loss develops more rapidly at high frequencies than at low frequencies, older people experience more hearing problems in relation to high frequency sounds.

6.3.1.2 Sampled population

Men and women living in France, Germany, Japan, Norway, the UK and the USA who had otologically normal hearing and were aged from 15 years to 96 years. The number of participants was more than 20 000.

6.3.1.3 Methods and conditions of data collection

Monaural pure-tone audiometry (a hearing test using an earphone) was performed for individual participants. Audiometers and measurement methods conformed to relevant international or domestic standards.

6.3.1.4 Data

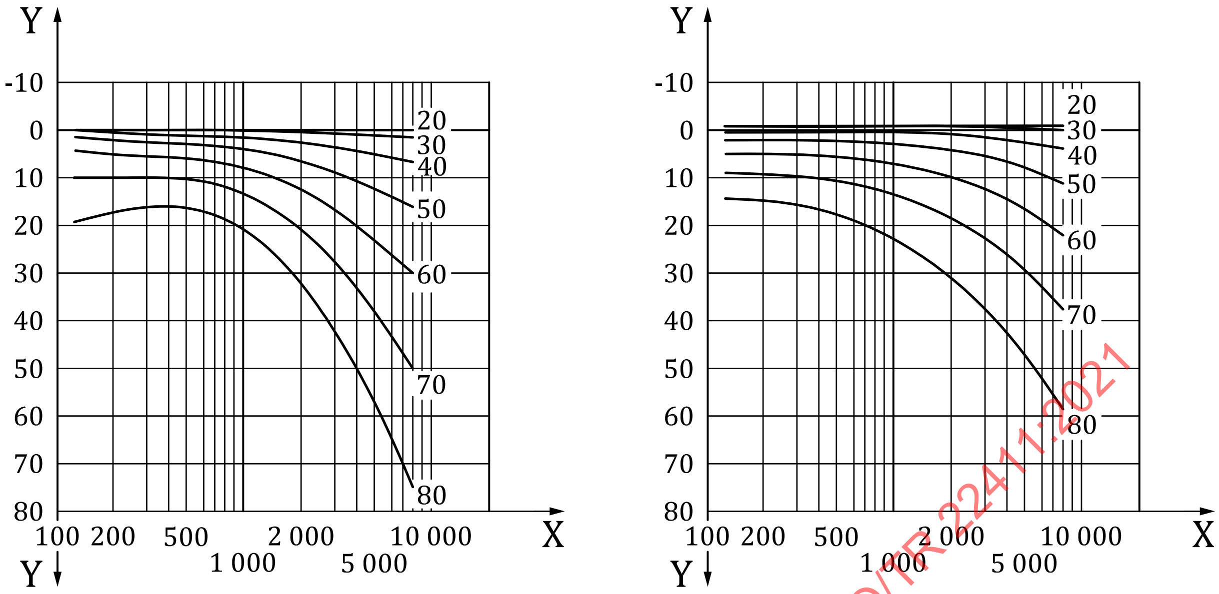
The data were analysed statistically for populations within the age range from 18 years to 80 years for the range of audiometric frequencies from 125 Hz to 8 000 Hz, and produced the following:

a) the expected median value of hearing thresholds relative to the median hearing threshold at the age of 18;

b) the expected statistical distribution of individual thresholds above and below the median value.

Figure 33 and Figure 34 display some examples of the hearing threshold deviation as a function of frequency, the listener's age being a parameter. The 10th percentile in Figure 34 indicates the hearing threshold deviation above which 10 % of hearing threshold deviations of individuals sampled from the population of the same age and gender are expected to fall. In other words, 90 % of the population has better hearing than the curve indicates.

The figure shows, for example, that the sound level of a 2 000 Hz tone, which is just audible for 20-year-old males having the median (50th percentile) threshold, needs to be increased by as much as 40 dB in order for it to be just audible by 90 % of 70-year-old males.



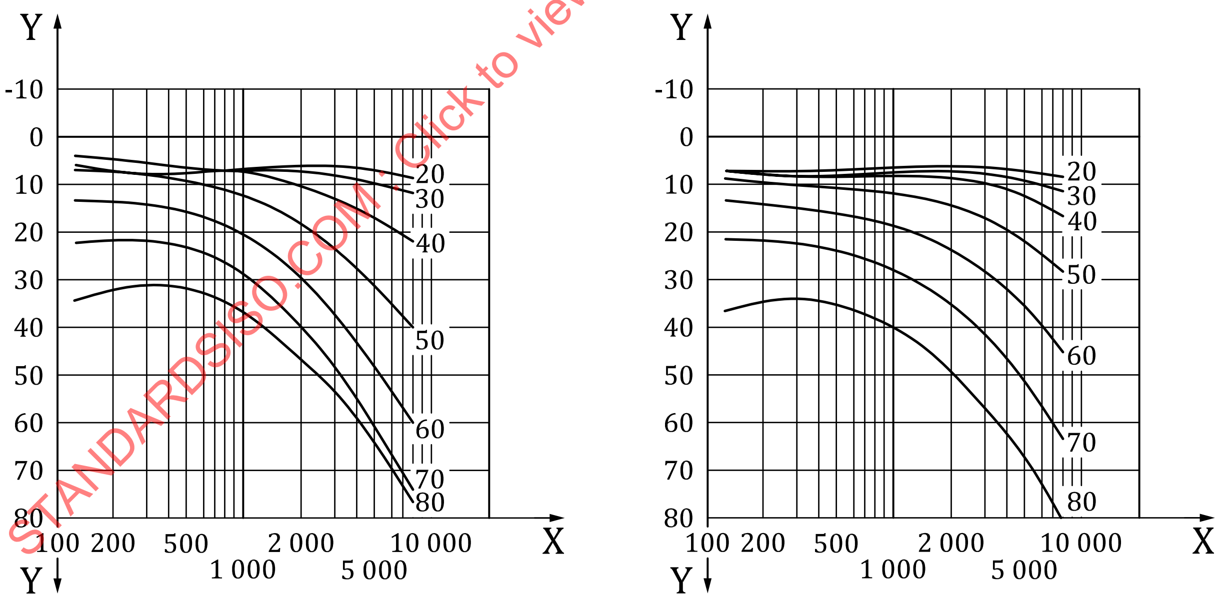
a) **Males** b) **Females**

Key

X frequency (Hz)

Y hearing threshold deviation (dB, relative to 18-year-old threshold)

Figure 33 — Hearing threshold deviations as a function of age, 50th percentiles (medians)



a) **Males** b) **Females**

Key

X frequency (Hz)

Y threshold deviation, dB relative to 18-year-old threshold

Figure 34 — Hearing threshold deviations as a function of age, 10th percentiles

6.3.1.5 Limitations

The data in Figure 33 and Figure 34 are presented in a form of audiograms to show the hearing-sensitivity decline in relation to the reference value of 0 dB, the median threshold of 18-year-old population of the same gender. For the thresholds expressed in sound pressure levels, see 6.3.2.

The thresholds presented here are related to the hearing sensitivity to single pure tones (sounds composed of a single frequency component) in quiet. These data need to be examined carefully when applied to pure tones in noisy conditions or to sounds composed of multiple frequency components such as beeps or speeches. In most cases, those complex sounds are easier to detect than single pure tones because the listener has more chances to detect it by hearing any of the sound components. Complex sounds are also beneficial for persons with hearing loss at a specific frequency region (e.g. around 4 kHz in the case of noise-induced hearing loss) for the same ground. The listener has a chance to detect the sound in noise by hearing any of the frequency component(s) that fall(s) in his/her audible frequency range.

For tone perception in noise, see 6.3.5. For the perception of multiple-frequency sounds, see 6.3.6.

The data in Figure 33 and Figure 34 have been obtained from persons with otologically normal hearing. Persons with hearing impairment that is not attributable to ageing (e.g. impairments caused by injury, disease or exposure to intensive noise) show a different threshold profile than those presented in this subclause. The threshold varies depending on the type and severity of impairment.

6.3.1.6 Application examples

Choice of the frequency of auditory signals: auditory signals used in consumer products and public facilities can be made easier to hear for older listeners if the signals have a moderately low frequency component.

6.3.1.7 References

— Data source: Reference [12];

— Cross-references in this document: 6.3.2, 6.3.5, 6.3.6;

— Other references: Reference [30].

6.3.2 Tone perception in quiet conditions (ageing effect)

6.3.2.1 General

A pure tone (a sound with a single frequency component) is audible for the listener in quiet when the sound pressure level of tone is higher than the listener's absolute hearing threshold.

6.3.2.2 Sampled population

Two populations of various ages were adopted as an example: 1) rigorously screened, otologically normal persons from the same population as in 6.3.1.2 and 2) unscreened persons, including hearing-aid users. The number of persons in the latter population was 4 942. In principle, calculation for any age groups is executable by taking the same procedure and using the same data sets as shown in 6.3.2.3 and 6.3.2.4.

6.3.2.3 Methods and conditions of data collection

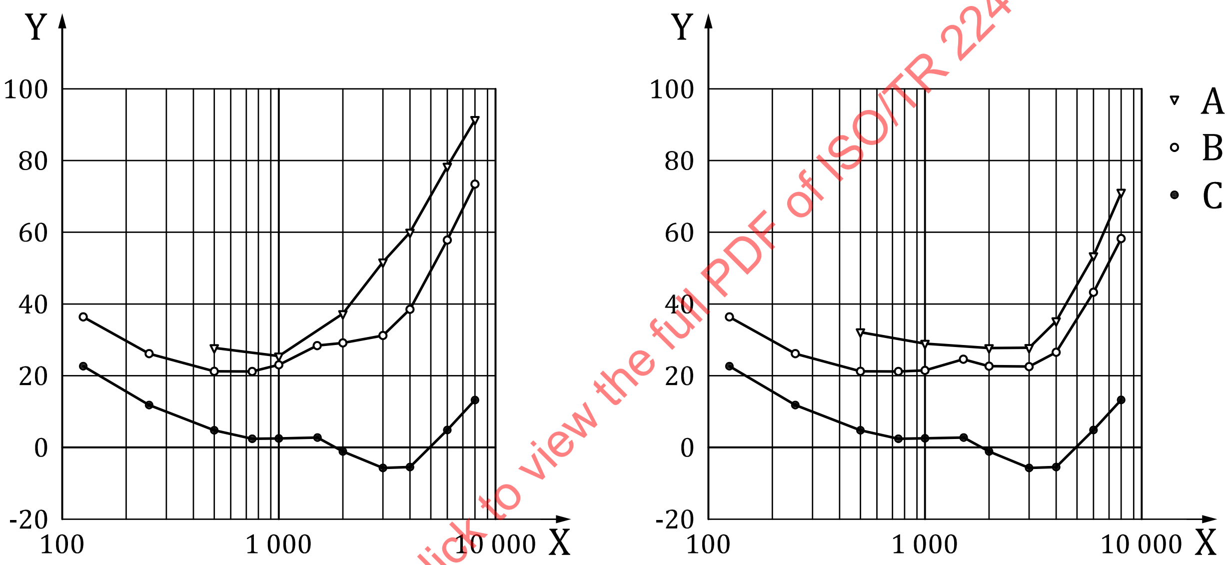
Monaural pure-tone audiometry (a hearing test using an earphone) was performed for individual participants. Audiometers and measurement methods conformed to relevant international or domestic standards. Only the "better ear" threshold was retained for the unscreened population.

6.3.2.4 Data

Figure 35 shows the 10th percentile thresholds estimated for 60-year-old persons from the screened and unscreened populations. 90 % of the population is expected to be able to detect the tone in quiet conditions if the sound pressure level exceeds the respective curve at the tone frequency. These curves were obtained by combining the normative hearing threshold for young population[9] and the age-related threshold shift for a screened population[12] and an unscreened population (see ISO 1999:2013, database B4), respectively. Thus, the hearing thresholds in Figure 35 represent those in free field where a sound comes directly from the front although the thresholds of the two groups had been measured using an earphone.

NOTE 1 The normative threshold is obtained from otologically normal persons aged from 18 to 25 years.

NOTE 2 A free field is a sound-wave field devoid of obstacles causing reflection, refraction or diffraction, such as an open-air space.



a) Males b) Females

Key

X frequency (Hz)
Y sound pressure level (dB)
A 60 years old, unscreened
B 60 years old, screened
C normative threshold

NOTE The normative threshold is shown for comparison.

Figure 35 — 10th percentile hearing threshold curves of screened or unscreened population aged 60 years

6.3.2.5 Limitations

The thresholds show the hearing sensitivity for single pure tones (sounds composed of a single frequency component) in quiet. The data need to be examined carefully when applied to sounds composed of multiple frequency components such as beeps or speech. In most cases, those complex sounds are easier to detect than single pure tones because the listener has more chances to detect it by hearing any of the sound components. Complex sounds are also beneficial for persons with hearing loss at a specific frequency region (e.g. around 4 kHz in the case of noise-induced hearing loss) for the same ground. The listener has a chance to detect the sound by hearing the frequency component(s) that fall(s) in his/her audible frequency range. For speech sounds, see 6.3.6.

External noise can increase the threshold for tones. For the effect of noise on hearing threshold, see 6.3.5.

6.3.2.6 Application examples

Auditory-signal design: The absolute hearing threshold can be a reference for determining a minimum sound pressure level of auditory signals. A signal having a sound level higher than the threshold is expected to be audible to the population from which the threshold was obtained.

When the auditory signal is designed for a generic population, the threshold of unscreened males should be used because they have worse hearing than unscreened females and, thus, the designed signal would be audible for both males and females.

When the signal is of multiple frequency components, the component having the highest level relative to the threshold determines the audibility in most cases.

NOTE 1 When the frequencies of components are close enough to fall in a certain frequency band (called critical band), the threshold becomes lower than that for a single frequency tone.

NOTE 2 The threshold can vary depending on the duration of sound. The threshold becomes higher for short tones, for example.

6.3.2.7 References

— Data sources: References [9], [12] and [11];

— Cross-references in this document: 6.3.1, 6.3.5, 6.3.6;

— Other references: Reference [30].

6.3.3 Sensitivity to low-frequency tones (ageing effect)

6.3.3.1 General

The data in this subclause show how our hearing sensitivity at low frequencies below 100 Hz is affected by ageing. Gender effects and individual differences are taken into consideration.

Since the age-related decrease in hearing sensitivity at low frequencies is small compared to that at high frequencies (see 6.3.4), some older persons can hear a low-frequency tone at a very low sound level. Therefore, they can be annoyed by low frequency noise just as young persons do.

6.3.3.2 Sampled population

Young listeners were a sample of 33 men and 18 women aged 19–25 years, screened for hearing abnormalities. Older listeners were a sample of 20 men and 21 women aged 61–83 years. The older listeners were not screened for hearing abnormalities (see below), but all of them reported that they did not have serious problems with hearing in daily life.

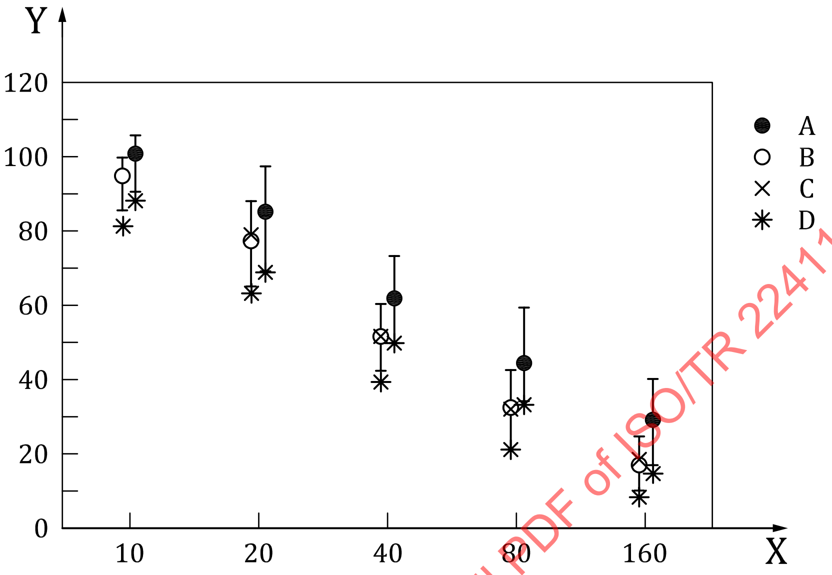
6.3.3.3 Methods and conditions of data collection

Binaural listening (listening with both ears) for a single pure tone in a pressure field (i.e. the volume of the chamber was varied to produce low frequency sounds). The hearing threshold was measured using a bracketing method (up-and-down method) as specified in ISO 8253-1.

6.3.3.4 Data

Figure 36 shows the hearing thresholds of two age groups. The older listeners had a threshold that was higher by about 5 dB than that of young listeners at every frequency measured. The threshold difference between the two listener groups was much smaller than that at higher frequencies (see 6.3.1 and 6.3.2).

Their threshold did not change before and after screening for hearing abnormalities. This fact suggests that the hearing sensitivity at low frequencies is not affected substantially by the hearing abilities at higher frequencies.



Key

X frequency (Hz)

Y sound pressure level (dB)

A older listeners

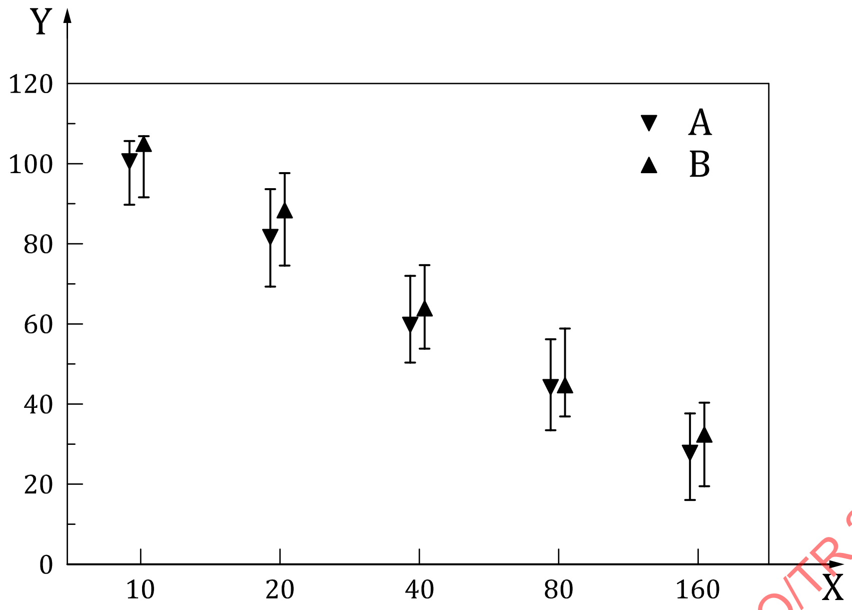
B young listeners

C normative hearing threshold (see ISO 389-7:2005)

D minimum threshold in the listener group

Figure 36 — Hearing threshold at low frequencies for young and older listeners – Median values with the 90 % range (the interval between the 5th and 95th percentiles)

Figure 37 shows the effect of gender on the hearing thresholds of older listeners. Older women had slightly lower thresholds (better hearing) at low frequencies as is expected from their better hearing abilities at high frequencies.



Key

X frequency (Hz)

Y sound pressure level (dB)

A older men

B older women

Figure 37 — Hearing threshold at low frequencies of older men and women

6.3.3.5 Limitations

Single pure tones were used in the measurement. Other types of sounds such as complex tones (composed of multiple frequency components) and time-varying sounds may have a different effect on the threshold.

6.3.3.6 Application examples

Noise evaluation in environment: Since the ageing effect on hearing sensitivity at low frequencies is not large, it should be noted that older people can perceive low frequency noise and can suffer from annoyance caused by the noise, as young people do. Environments for living and working should be designed to make them quiet enough regardless of the age of occupants so that low frequency sound would not cause noise problem.

6.3.3.7 References

— Data source: Reference [71];

— Cross-references in this document: 6.3.1, 6.3.2;

— Other references: none.

6.3.4 Equal-loudness-level contours (ageing effect)

6.3.4.1 General

The data in this subclause show how our hearing sensitivity at above-threshold levels is affected by ageing. Gender effects are taken into consideration.

6.3.4.2 Sampled population

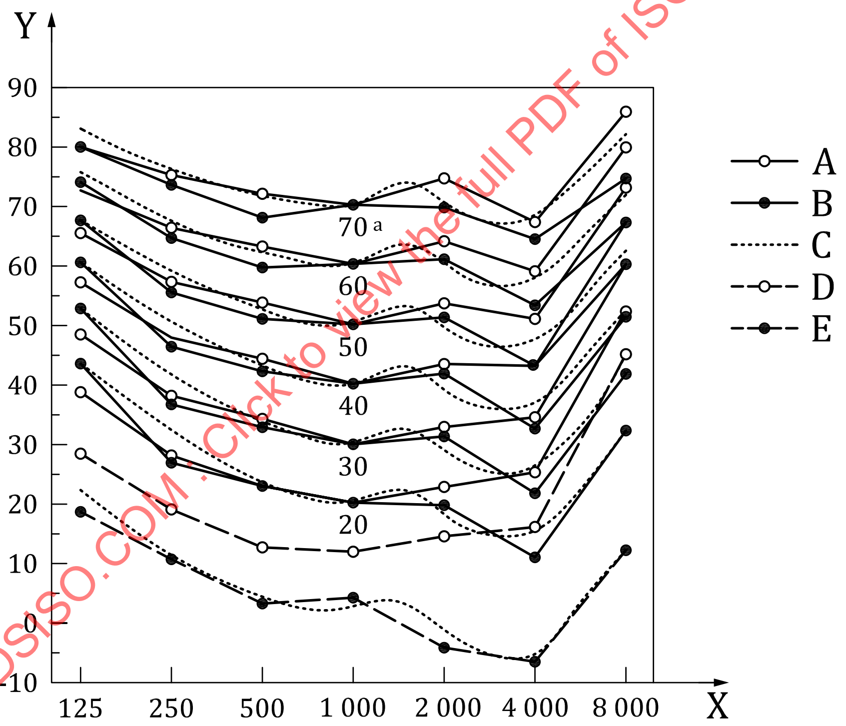
Young listeners were 33 men and 24 women aged 18–25 years. Older listeners were 24 men and 26 women aged 60–69 years. All the listeners were screened for hearing abnormalities and had otologically normal hearing for their age.

6.3.4.3 Methods and conditions of data collection

Binaural listening (listening with both ears) for a single pure tone of frontal incidence (the tone is coming to the listener directly from the front) in free field (a space with no obstructions or reflections). Listeners judged the perceived loudness of tones that varied in frequency and sound pressure level, following the procedure of the magnitude estimation method.

6.3.4.4 Data

Figure 38 shows the equal-loudness-level contours of two age groups. The older listeners had raised contours at frequencies of 2 000 Hz and above, whereas the contours at lower frequencies did not show a large difference from those of young listeners. That means that older listeners need a higher level of tone at high frequencies so that it would be perceived as loud as that at low frequencies.



Key

X frequency (Hz)

Y sound pressure level (dB)

A equal-loudness-level contours for older listeners

B equal-loudness-level contours for young listeners

C normative equal-loudness-level contours and hearing threshold (see ISO 226:2003)

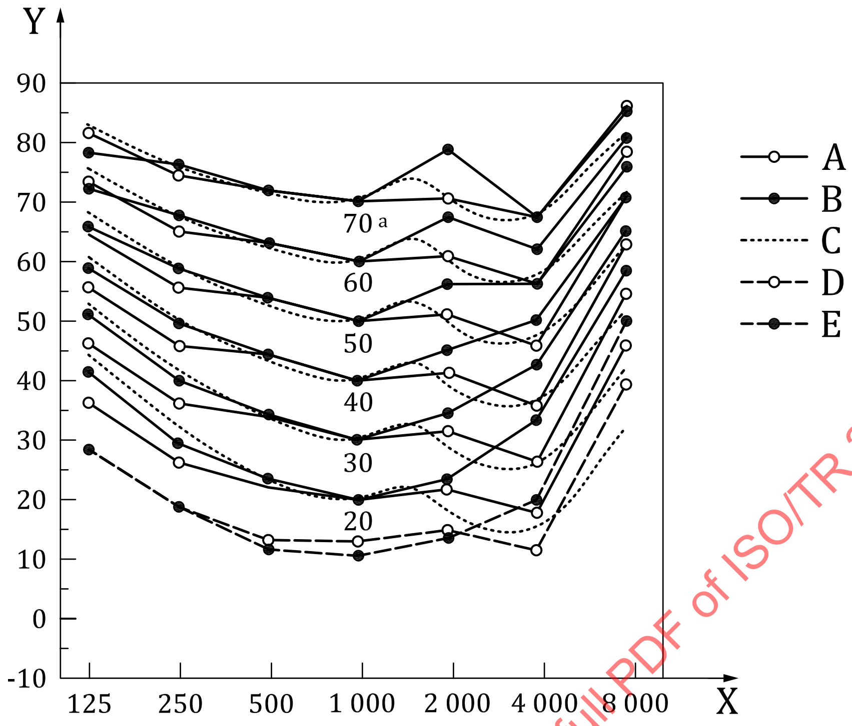
D hearing threshold for older listeners

E hearing threshold for young listeners

a Phons.

Figure 38 — Equal-loudness-level contours for young and older listeners

Figure 39 shows the effect of gender on the contours of older listeners. Older men showed even larger ageing effect at high frequencies.



Key

X frequency (Hz)

Y sound pressure level (dB)

A equal-loudness-level contours for older men

B equal-loudness-level contours for older women

C normative equal-loudness-level contours (see ISO 226:2003)

D hearing threshold for older men

E hearing threshold for older women

a Phons.

Figure 39 — Equal-loudness-level contours for older men and women

6.3.4.5 Limitations

Single pure tones were used in the measurement. Other type of sounds such as complex tones (composed of multiple frequency components) and time-varying sounds can have a different effect on the loudness perception.

6.3.4.6 Application examples

Noise evaluation in environment: Since the ageing effect on hearing sensitivity at low frequencies is not large compared to that at high frequencies, it should be noted that older people can perceive low frequency noise and can suffer from annoyance caused by the noise, as young people do. Environments for living and working should be designed to make them quiet enough regardless of the age of occupants so that low frequency sound would not cause noise problem.

6.3.4.7 References

— Data source: Reference [69];

— Cross-references in this document: 6.3.1, 6.3.2;

— Other references: none.

6.3.5 Tone perception in noisy conditions (ageing effect)

6.3.5.1 General

In noisy conditions, a signal-to-noise ratio (SNR) determines the audibility of signals. In the case of pure tone–like signals, the signal is audible against noise when the level of the dominant component of the signal is higher than that of the noise in the same frequency band by a certain amount.

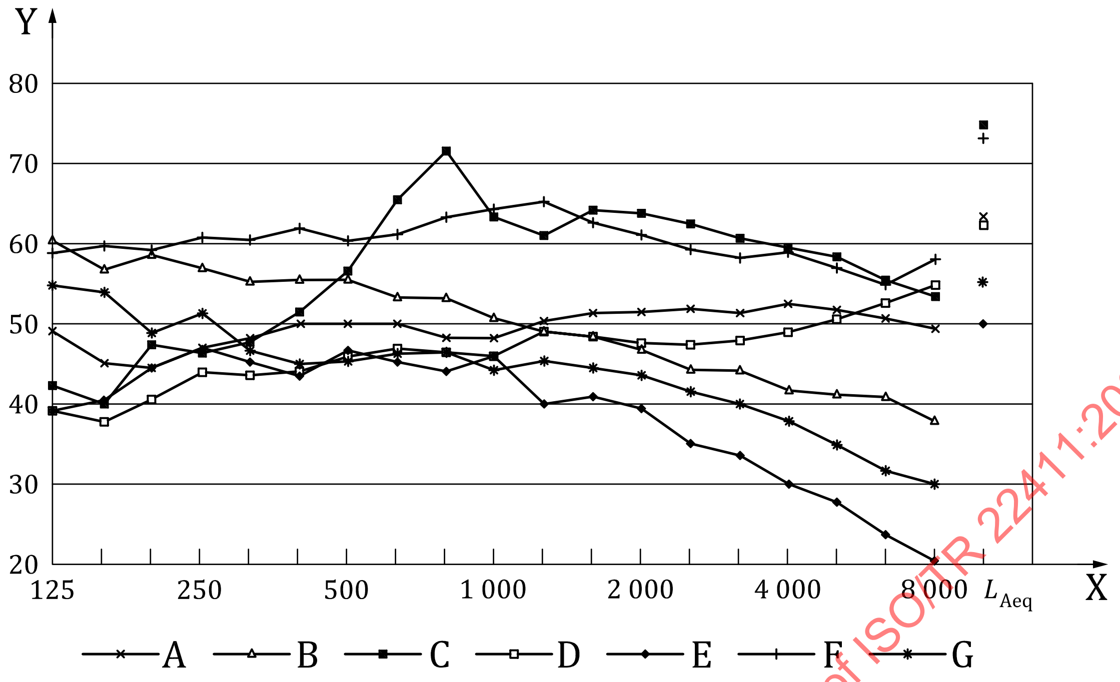
When the signal has multiple frequency components, its audibility is determined by the frequency component that has the largest power in relation to the interfering noise in most cases.

6.3.5.2 Sampled population

Young listeners were 16 men and 14 women aged 18 to 24. Older listeners were 25 men and 29 women aged 55 to 79. All the listeners were screened for hearing abnormalities and had otologically normal hearing for their age.

6.3.5.3 Methods and conditions of data collection

The signal was a 1 s pure tone repeated three times with a 1 s silent interval. The frequency and sound pressure level were varied from trial to trial. The background noises were typical domestic noises. Frequency characteristics of the noise used are shown in Figure 40. Both the signal and noise were presented to individual listeners via a loudspeaker in a soundproof room. Listeners judged the audibility of signal, using a five-point scale from "1: not audible" to "5: too loud".



Key

X centre frequency of one-third octave band (Hz)
Y sound pressure level (dB)
A dish washing
B washing machine
C hair dryer
D shower in bathroom
E TV sound
F vacuum cleaner
G ventilation fan

NOTE L_{Aeq} is the A-weighted equivalent continuous sound pressure level.

Figure 40 — Frequency characteristics of the background noise used

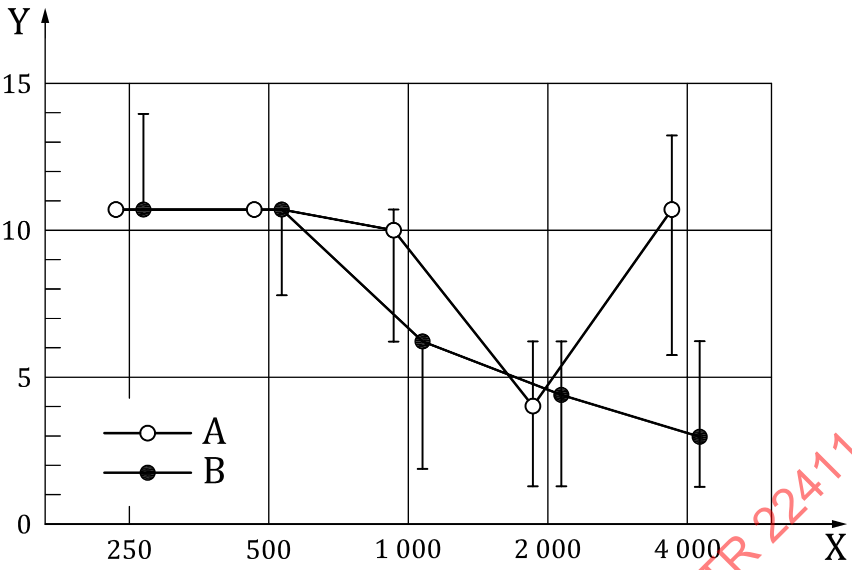
6.3.5.4 Data

Table 10 and its graphical presentation in Figure 41 show the minimum difference level between signal and noise. When the signal level was higher than the noise level by the shown amounts, 90 % of listeners in each age group responded that the signal was "2: barely audible".

In the same experiment, both listener groups responded that the signal was "4: loud" when the sound pressure level of signal reached 70 dB to 80 dB. The level varied depending on the tone frequency.

Table 10 — Medians of the minimum level difference between signal and noise in order for the signal to be "barely audible" against the noise

Centre frequency of one-third octave band (of tone and noise), Hz		250	500	1 000	2 000	4 000
Minimum level difference, dB	For young adults	11	11	6	5	3
	For older adults	11	11	10	4	11



Key

X centre frequency of one-third octave band (Hz)

Y minimum level difference (dB)

A older adults

B young adults

NOTE Arrow bars indicate the interquartile range (the range between the 25th and 75th percentiles) of listeners' ratings.

Figure 41 — Graphical representation of the medians of the minimum level difference between signal and noise in Table 10

6.3.5.5 Limitations

The thresholds show hearing sensitivity to single pure tones (sounds composed of a single frequency component) in noise. The data need to be examined carefully when applied to multiple-frequency sounds such as beeps or speeches.

The level difference required for tone detection depends on the signal and noise used. Another factor that can affect the detectability of tone in noise is the duration of tone. The threshold becomes higher in general as the duration of tone becomes shorter. Although the data presented above show general characteristics of ageing effect, readers of this document are encouraged to determine the level of signal required for its audibility, using the signal and noise in which they are interested. For a standardized procedure, see ISO 24501.

6.3.5.6 Application examples

Auditory-signal design: the hearing threshold in noise can be a reference for determining a minimum sound pressure level of auditory signals; a signal having a sound level higher than the threshold is expected to be audible to the population from which the threshold was obtained.

When the signal is of multiple frequency components, the component having the highest level relative to the threshold determines the audibility in most cases. When the frequencies of components are close enough to fall in a certain frequency band (called critical band), the threshold becomes lower than that for a single frequency tone.

6.3.5.7 References

— Data sources: References [70] and [30];

— Cross-references in this document: 6.3.1, 6.3.2, 6.3.6;

— Other references: References [17], [18] and [25].

6.3.6 Sound pressure level of spoken announcements in public space (ageing effect)

6.3.6.1 General

Spoken announcements should be presented sufficiently loudly so that listeners can comprehend them with ease. When the sound level of announcements is too high or too low, speech recognition generally decreases.

The data in this subclause show the effect of ageing on the preferred sound pressure level of spoken announcements in noisy conditions.

6.3.6.2 Sampled population

Young listeners were 17 men and 9 women aged 19–23 years. Older listeners were 31 men and 29 women aged 64–82 years. All the listeners were screened for hearing abnormalities and had otologically normal hearing for their age. Their first language was Japanese.

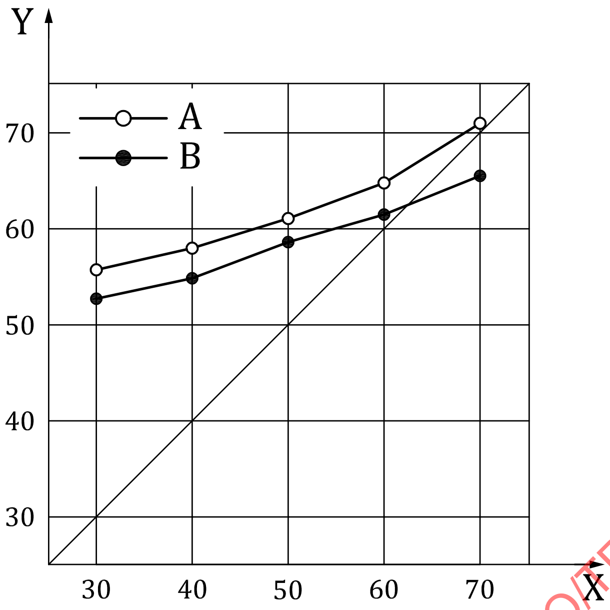
6.3.6.3 Methods and conditions of data collection

Announcements consisted of four-mora (syllable) Japanese words. Eight different words were successively presented, with an 800 ms silent interval, to listeners via a loudspeaker in a soundproof room. Noise that simulates the sound frequency of multiple talkers was also presented via another loudspeaker at various sound levels. The task of listeners was to adjust the sound level of announcement to a level that was comfortable to hear and provided easy comprehension of the announcement.

6.3.6.4 Data

Figure 42 shows medians of adjusted levels of announcement as a function of noise level. The difference in preferred levels between young and older listeners was 5 dB or less at any noise level. This difference is much smaller than that expected from the threshold difference in quiet as shown in 6.3.1.

Note also that the level difference between speech and noise is not constant for both listener groups. The preferred level of speech does not increase proportionately as the level of interfering noise becomes higher.



Key

X level of interfering noise (dB, A-weighted)

Y level of spoken announcement (dB, A-weighted)

A older adults

B young adults

Figure 42 — Preferred level of spoken announcement as a function of interfering noise level

6.3.6.5 Limitations

The data are based on experiments, using Japanese words and employing Japanese listeners. The effects of language are not large, as shown in ISO 24504 which specifies methods to determine an appropriate sound pressure level range for spoken announcements in noisy environments.

Other factors such as acoustic characteristics of speech and noise and complexity of speech information can affect the preferred speech levels. Usually, older listeners are susceptible to worse conditions of listening. They can want to hear the speech at an even higher level.

Effects of the context of speech is not taken into consideration. If that information was available, older listeners could have attained as good a recognition level as young listeners.

6.3.6.6 Application examples

Spoken announcements in a public space: Announcements are expected to be sufficiently loud in noisy conditions if they are presented at the level shown in Figure 42.

6.3.6.7 References

— Data source: Reference [76];

— Cross-references in this document: 6.3.1, 6.3.2;

— Other references: References [32] and [37].

6.3.7 Audible conditions for speech communication in a noisy environment (ageing effect)

6.3.7.1 General

The auditory conditions necessary to keep speech communication understandable and to prevent listening difficulty are provided in Reference [91]. The conditions are presented in dB, taking into account the age-related decrease of hearing ability (see 6.3.1).

NOTE 1 Signal-to-noise ratio (SNR) is the numerical difference between the sound pressure levels of speech signal and that of noise.

NOTE 2 The speech transmission index (STI), which is standardized in IEC 60268-16, is also frequently used for designing acoustical condition in an environment.

6.3.7.2 Sampled population

Listeners listed in Table 11 were used as subjects. They are otologically normal young listeners (20s), middle aged listeners (30s–40s) and older listeners (aged 60 or older) with various hearing threshold levels. The hearing threshold level is represented by a pure tone average (PTA), which is the arithmetic average hearing threshold level at 0,5 kHz, 1 kHz, 2 kHz and 4 kHz, where a signal contributes toword recognition.

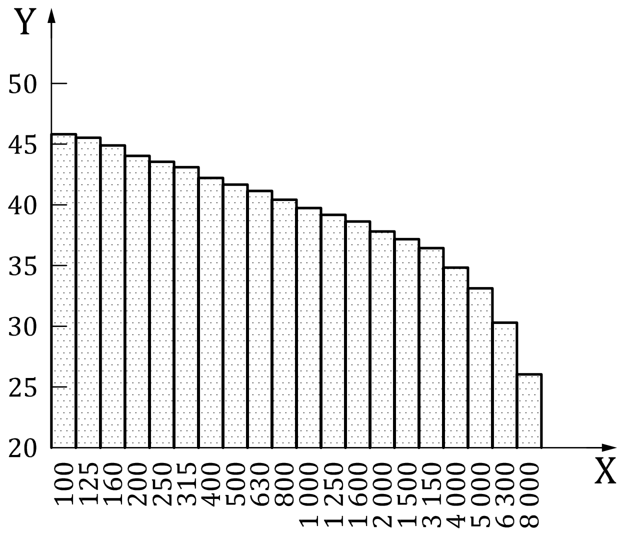
NOTE Otologically normal persons were defined as "persons in a normal state of health who are free from all signs or symptoms of ear disease and from obstructing wax in ear canals and who have no history of underexposure to noise" in ISO 7029:2000.

Table 11 — Specification of three groups of listeners: young (Group A), middle-aged (Group B) and older listener (Group C) groups

Group	Number of subjects (male/female)	Mean age	PTA range	PTA mean
A	34/21	21,3	−5 to 10	2,6
B	1/6	38,5	−2,5 to 10	4,5
C	27/24	70,7	7,5 to 54	23,6

6.3.7.3 Methods and conditions of data collection

Word recognition scores were measured under ambient noise (equivalent continuous sound pressure level with a standard frequency weighting A of 50 dB) with the Hoth spectrum. Figure 43 presents sound pressure level in each 1/3 octave band of Hoth spectrum noise, which is the typical spectrum observed in rooms specified in ITU-T P800.



Key

X frequency (Hz)

Y sound pressure level (dB)

Figure 43 — Sound pressure level of Hoth spectrum noise in each 1/3 octave band

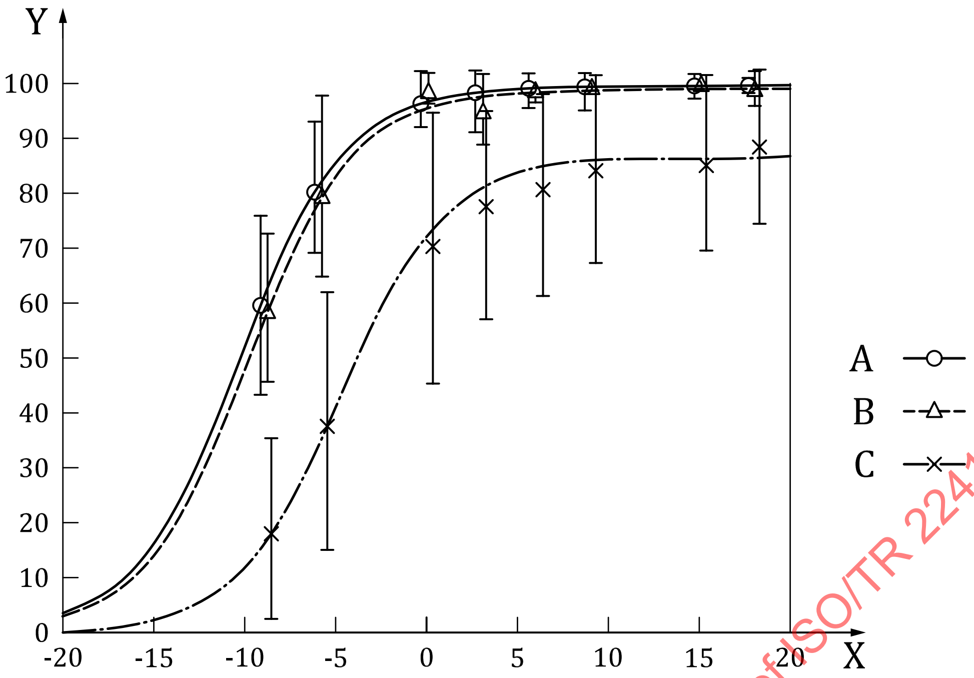
6.3.7.4 Data

Figure 44 presents the relation between the SNR and single-word recognition scores. The signal-to-noise ratio is the sound pressure level of a spoken announcement measured relative to ambient noise. Mean scores and standard deviations for each SNR and each listener group are also presented in Figure 44.

For young listeners, a −2,0 dB SNR is necessary to achieve 95 % of their maximum score. The older listener group with PTA of 23,6 dB requires 5,5 dB improvement of SNR, on average, under anechoic conditions.

Curves are shifted 0,26 dB to a higher SNR when PTA increases by 1 dB. The SNR required for persons with severe hearing loss can be estimated using this relationship.

Scores of middle-aged listeners are not different from those of younger listeners.



Key

X signal-to-noise ratio in dB

Y percentage of correct of word recognition scores

A mean scores with error bars for S.D. of young listeners (Group A)

B mean scores with error bars for S.D. of middle-aged listeners (Group B)

C mean scores with error bars for S.D. of older listeners (Group C)

Figure 44 — Word recognition scores and their standard deviations of young (Group A), middle-aged (Group B) and older listener (Group C) groups for each signal-to-noise ratio

6.3.7.5 Limitations

Presented data was based on Japanese listeners with loudspeakers in an anechoic chamber. Variations of speech recognition performance is expected depending on nature of the measurement: differences of languages, clarity of voice, gender of talker, and transducers used for presentation of spoken announcements. The expected variation range is around 10 dB in SNR for 50 % correct word recognition. Variations in the differences are caused by the variation of listener age and their hearing ability.

The effect of language is not large, as shown in ISO 24504 which specifies methods to determine an appropriate sound pressure level range for spoken announcements in noisy environments.

6.3.7.6 Application examples

Determination of presentation level of spoken announcement: Older persons who have 20 dB higher hearing threshold than normal young person in PTA require 5,2 dB higher SNR for their listening condition. When a target percentage of correct word intelligibility score is set as 70 % for example, −8 dB of SNR for younger person and −2,8 dB SNR for older person are required.

When the measured noise level is 50 dB, the presentation level of spoken announcement for young person is determined as 42 dB and that for older person is 47,2 dB. A higher level of spoken announcement is desirable if the SNR would result in a value under the preferred sound pressure level described in 6.3.6.

6.3.7.7 References

- Data sources: References [92], [32] and [91];
- Cross-references in this document: 6.3.1, 6.3.6;
- Other references: References [41], [24], [3], [8] and [37].

6.4 Touch

6.4.1 Tactile pressure sense and spatial resolution (ageing effect)

6.4.1.1 General

Tactile pressure sense and spatial resolution are basic characteristics and capabilities of touch sense. Designing any tactile markings should take account of these basic characteristics for comfort and correct recognition of the markings.

Spatial resolution, which is the ability to discriminate details of the markings, is one the most important tactile characteristics in designing tactile symbols and letters. Resolution is generally measured by the closest distance of two stimuli that can be perceived as two separate stimuli.

These basic tactile characteristics change with age and this should be considered when designing tactile marking that will be used by older people. This subclause presents a set of data that shows how the sensitivity of tactile pressure sense and spatial resolution change with age.

6.4.1.2 Sampled population

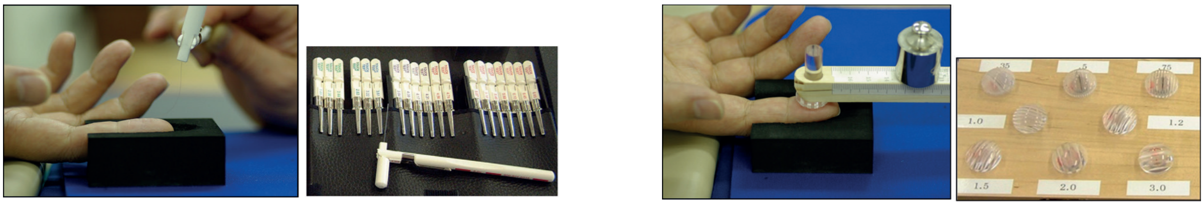
A total of 48 young people with the mean age of 21,0 years (standard deviation sd = 1,7 years) and 45 older people with the mean age of 66,5 years (sd = 3,8 years) participated in two experiments on 1) pressure sensitivity and 2) static spatial resolution. All participants were sighted and their eyes were covered during the experiments in order not to use visual information.

6.4.1.3 Methods and conditions of data collection

Tactile pressure sense was measured by a conventional method using an instrument called von Frey hair. Figure 45 a) shows this method. By stimulating the tip of a forefinger vertically with a thin nylon string of variable thickness (i.e. diameter of the string) until it bends and asking the participant whether the participant felt it or not, a minimum thickness of a string needed for the participant to perceive the touch is obtained. The thickness of the string gives the pressure strength which is calibrated previously.

Spatial resolution was measured by another conventional method using an instrument called JVP dome which has a number of grooves on the rounded surface, from coarse grating to fine grating as illustrated in Figure 45 b). The face of the dome is pressed softly with a constant pressure on the tip of forefinger and the participant should answer the direction of the grooves, horizontal or vertical (to the finger direction). The threshold spatial resolution can be obtained from the groove that gives a 50 % correct response for the repeated trials.

These methods give us the static characteristics of touch sense called passive sense. There is another method to measure touch sense with using moving stimuli or moving fingers which is called active touch. Because there is a variety of experimental conditions for measuring active touch such as moving speed, the basic data is mostly measured in a static condition.

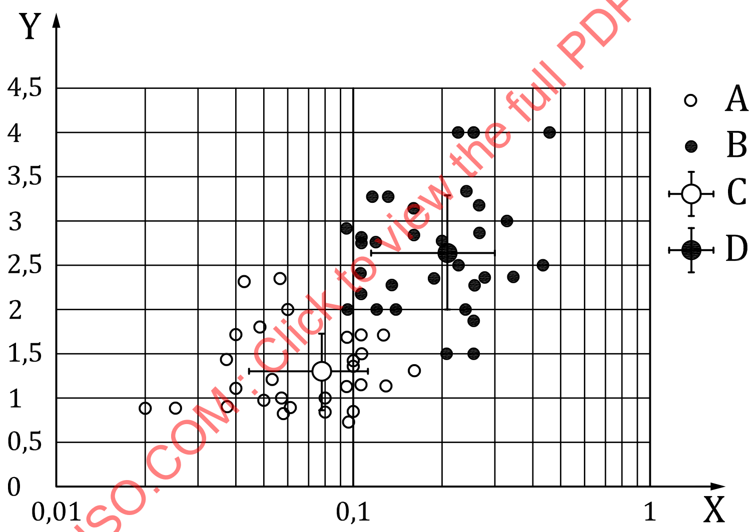


a) Von Frey hair **b) Tactile resolution by JVP dome**

Figure 45 — Methods of measurements of tactile pressure sense

6.4.1.4 Data

Figure 46 shows two-dimensional plotting of the threshold of tactile pressure sense taken as X-axis (in a logarithmic unit of gram-force) and the threshold width of spatial resolution as Y-axis (in a linear unit of mm). Small data points of open and closed circles represent individual data of young and older people, respectively, and a larger open and a larger closed circle represent the averaged values of them. It is clear that the data points of older people are higher than those of young people both for pressure sense (horizontal) and for spatial resolution (vertical). This means that older people are less sensitive for detecting tactile pressure and for resolving spatial information than young people.



Key

X threshold of tactile pressure sense (gf)
Y tactile spatial resolution (mm)
A young people, individuals
B older people, individuals
C young people, mean and standard deviation
D older people, mean and standard deviation

Figure 46 — Tactile sensitivity of pressure sense and tactile spatial resolution

6.4.1.5 Limitations

The data shows the characteristics of normal tactile sense without any impairment such as diabetes that reduces tactile sensitivity in general. As mentioned in the method section (see 6.4.1.3), the data presented here, were measured in a static condition. The data, therefore, should be used basically for designing a static tactile sign, but can be used as a baseline even for a dynamic condition (see 6.4.1.6).

6.4.1.6 Application examples

The threshold value presented here for pressure sense and spatial resolution can be used as a baseline when tactile markings or signals are designed. For young people, the mean pressure sense is 0,078 gf with a standard deviation of 0,034 gf, and mean spatial resolution is 1,3 mm with a standard deviation of 0,43 mm, and any tactile marking should have a stronger pressure or a wider separation than these mean values. For older people the mean values are much larger which are 0,21 gf (sd = 0,094 gf) for the pressure sense and 2,6 mm (sd = 0,66 mm) for spatial resolution respectively. For older people, much stronger pressure sense and wider spatial separation are needed.

It should be noted that the static touch sense (passive touch) for which the present data is based on is generally worse than the dynamic touch sense (i.e. active touch). Many of tactile markings in our everyday life are designed so that people can touch them freely by moving hands or fingers (i.e. active touch) in which a higher sensitivity is expected. Taking into account this passive-to-active sensitivity difference, it can be said that if any tactile marking is designed on the basis of the passive data (6.4.1.4), it gives a guarantee that a better sensation is obtained when it is sensed by the active touch. In other words, any tactile marking that has a less strong pressure or a smaller separation than the present data should be avoided.

6.4.1.7 References

— Data source: Reference [85];

— Cross-references in this document: 6.4.2;

— Other references: none.

6.4.2 Tactile spatial resolution (people with visual disabilities)

6.4.2.1 General

One of the advantages and effectiveness of using tactile markings (i.e. tactile symbols, characters and Braille) is that information can be presented to people with visual impairment. It has been pointed out empirically that the congenitally blind people have better tactile sensitivity than those who can use visual information because they have long experience of using tactile information from birth or an early stage of their life span.

This subclause presents data on tactile spatial resolution of people with visual impairment (totally blind) who have been using Braille and other tactile cues in their daily life. The data show how good their tactile sensitivity is in comparison with those who are not using tactile markings so often.

6.4.2.2 Sampled population

A total of 73 people who were totally blind or almost blind participated in the experiment. Their age ranged from early 20s to late 70s.

6.4.2.3 Methods and conditions of data collection

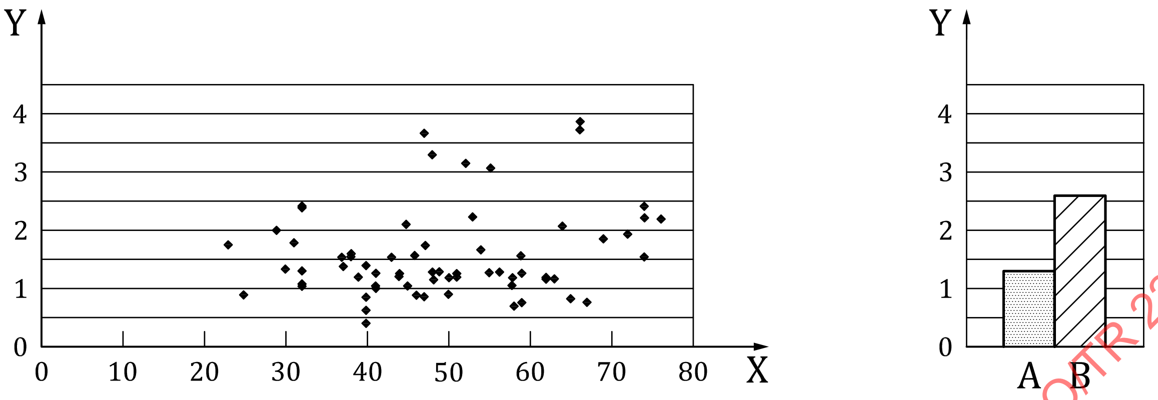
Spatial resolution was measured by the same method using JVP dome as described in 6.4.1.

6.4.2.4 Data

Figure 47 a) shows the threshold width of the JVP dome for individual blind participants as a function of their age. Figure 47 b) shows the average spatial resolution of sighted people (56 young and 44 older people) for comparison, which was measured in another study using the same method.

In Figure 47 a), the spatial resolution of the blind people does not show a clear ageing effect. The resolution is almost constant regardless of age. The mean value for the blind people over 60 years old (1,90 mm) does not reach the mean value for older sighted people (= 2,63 mm), average age 66,6 years, shown in the right column in Figure 47 b). This means that blind people who use Braille or tactile markings keep good spatial resolution which is comparable to that of young people even at a later stage of their life span.

The results indicate that tactile markings for people with visual disabilities do not need to be enlarged even to take account of age, but can remain the same size as those for young people.



a) **Blind people (individuals)**

b) **Sighted people (mean)**

Key

X age (years)

Y spatial resolution (mm)

A young people (mean value)

B older people (mean value)

Figure 47 — Ageing effect on tactile spatial resolution

6.4.2.5 Limitations

The data present the static characteristics of tactile sense at the fingertip. They do not directly apply to moving tactile markings or those for other body parts.

6.4.2.6 Application examples

The fact that blind people who use Braille in their daily life keep good tactile spatial resolution comparable to that of young people has the advantage that tactile markings for older blind people do not always need to be as large as those for older sighted people.

6.4.2.7 References

— Data source: Reference [77];

— Cross-references in this document: 6.4.1;

— Other references: none.

6.4.3 Tactile spatial resolution (body location and ageing effect)

6.4.3.1 General

Tactile spatial resolution varies depending on the body part measured. When a tactile mark is designed, the choice of body part on which the mark applies is critically important. The most sensitive parts to tactile stimuli include the fingers, nose and lips whereas the least sensitive parts include the back, legs and sole of the foot.

6.4.3.2 Sampled population

The data presented here are taken from 30 young people (18–28 years old) and 31 older people (above 65 years old).

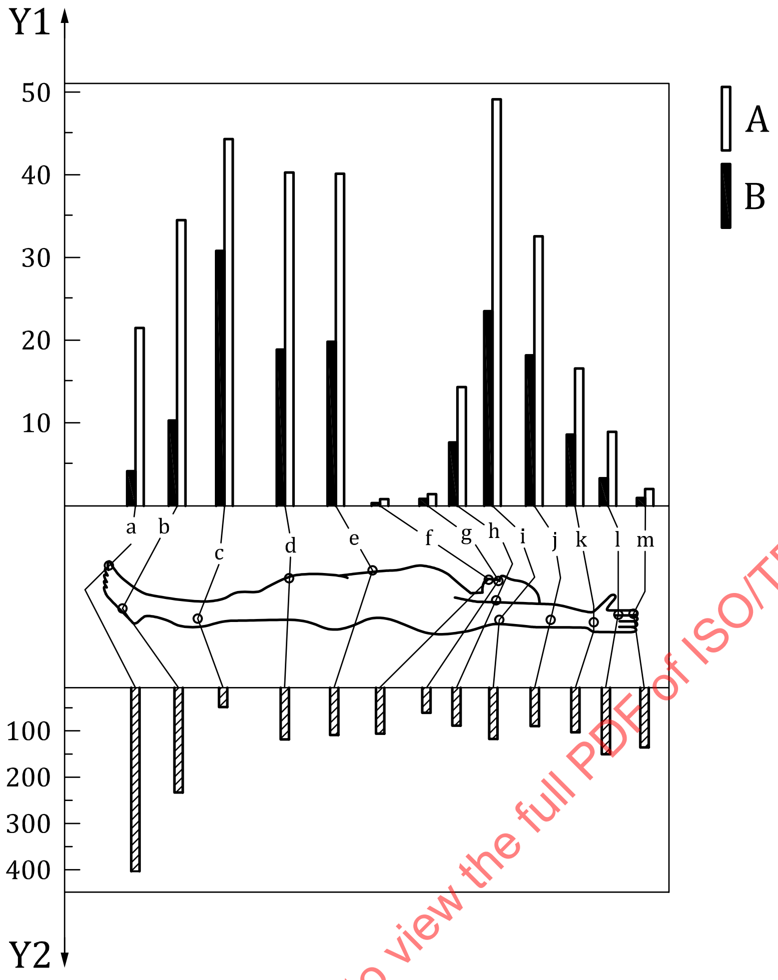
6.4.3.3 Methods and conditions of data collection

Spatial resolution was measured by a two-point stimulus in which two tactile points were presented on the skin with a variable separation of the points. The spatial resolution was defined as the minimum distance of separation at which the two points were still perceived as separated.

The measurement was carried out for 13 different body parts.

6.4.3.4 Data

Figure 48 shows average two-point separations for young and older persons for the 13 body regions. For all the body parts, the spatial resolution was much worse for older people than young people. The vertical bars on the bottom half of Figure 48 show the percentage difference in threshold of older persons relative to that of young persons. The most prominent ageing effects can be seen for the sole and toe. The sensitivity of older persons decreases by 50 % for most parts of the body.



Key

X	body locations	A	percent decline with age	C	18–28 years
Y	mean threshold (mm)	B	over 65 years		
a	toe	f	tongue	j	fore arm
b	sole	g	lip	k	palm
c	calf	h	cheek	l	finger (base)
d	thigh	i	upper arm	m	fingertip
e	belly				

Figure 48 — Ageing effect on tactile spatial resolution at various body locations

6.4.3.5 Limitations

Tactile spatial resolution depends on the stimulus conditions such as the temperature of surface, whether the stimulus is moving or not, or whether it is wet or dry. Another critical condition is the type of touch, i.e. free moving (the active touch where the person is allowed to move his/her fingers or hands voluntarily to obtain tactile information) or fixed touching (the passive touch where the person is not allowed to move his/her fingers or hands, but the stimulus moves). In most conditions, the active touch is more sensitive than the passive touch.

Some people with diabetes have neurosensory pathology and consequently degraded tactile sensitivity. Reading Braille for a long time can be painful for them.

6.4.3.6 Application examples

These threshold values presented here can be used for designing tactile marks and signals applied to various body parts.

6.4.3.7 References

— Data source: Reference [100];

— Cross-references in this document: 6.4.1, 6.4.2;

— Other references: none.

6.4.4 Tactile temporal resolution (sensitivity to vibration, ageing effect)

6.4.4.1 General

Vibration or temporal change of a tactile stimulus is one of the effective ways to convey information by tactile sense. Vibration is used, for example, in alarm clocks or in mobile phones in silent mode. The sense of touch is very sensitive to a vibration at a high frequency up to a few hundred hertz, which is much higher than that for visual sensation.

This temporal tactile sensitivity declines with age and its loss should be taken into consideration when designing tactile signals based on vibration.

The loss of temporal tactile sensitivity is also observed for people with diabetes. A number of clinical reports show the effect of diabetes on tactile (static), vibration and thermal sense for medical examination (see Reference [75], for example).

6.4.4.2 Sampled population

Data were taken from four groups with a different mean age of 10, 21, 50 and 65 years. Each group consisted of 3 male and 3 female participants. They had no peripheral neuropathies confirmed by clinical examination.

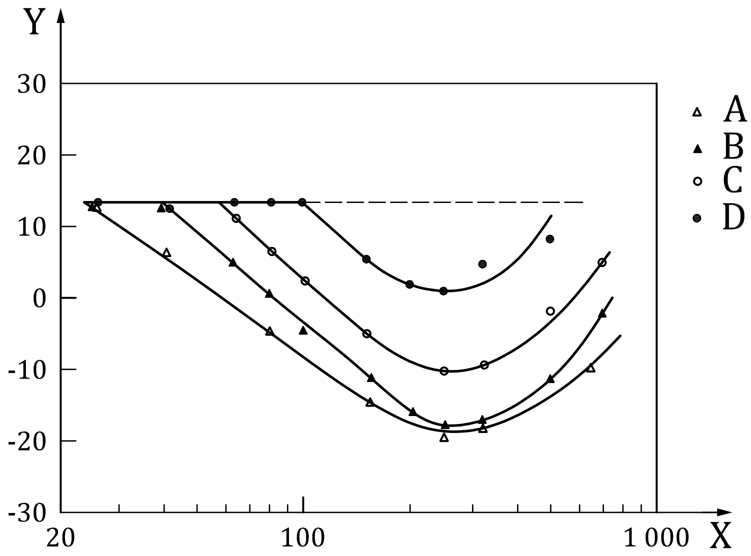
6.4.4.3 Methods and conditions of data collection

A precisely aligned vibrator was used to touch the thenar eminence (the group of muscles on the palm of the human hand at the base of the thumb) and the vibration threshold, i.e. the minimum amplitude of the vibrator that causes feeling of vibration, was measured. The measurements were made for 8 frequencies in the range from 25 Hz to 600 Hz.

6.4.4.4 Data

Figure 49 shows how the minimum amplitude for detecting a vibro-tactile stimulus changes along with frequency for four age groups with mean age of 10, 20, 50 and 65 years. The amplitude is defined as the peak amplitude of vibration stimulus expressed in dB relative to 1,0 μm.

For all age groups, the frequency at which they were most sensitive to the vibration (i.e. the minimum threshold) is observed at around 250 Hz and the threshold gradually increases (i.e. sensitivity decreases) both below and above that frequency. The minimum amplitude for detecting vibration increases with age. However, for most of the age groups the amplitude reaches an upper limit level (shown as dashed line) at shorter frequency region below about 100 Hz.



Key

X frequency (Hz)

Y threshold (dB relative to 1,0 µm peak)

A 10 years old

B 20 years old

C 50 years old

D 60 years old

Figure 49 — Detection threshold for a vibro-tactile stimulus for two young and two older groups as a function of frequency

6.4.4.5 Limitations

The basic data were measured at the threshold level, i.e. the level of just perceptible tactile stimuli. The data can be applied to very weak vibration, but not to strong tactile vibration above threshold.

6.4.4.6 Application examples

General trends in tactile sensitivity to temporal changes can be referred to for designing tactile markings that use vibration and temporal changes.

It is effective to use vibro-tactile stimuli at a high frequency around 250 Hz, which is much higher than the effective flicker frequency for visual stimuli. However, care is needed to allow for the large difference in sensitivity between young and older people at that frequency.

6.4.4.7 References

— Data source: Reference [105];

— Cross-references in this document: none;

— Other references: Reference [75].

6.4.5 Legibility of tactile symbols and characters (effects of ageing and experience in the use of tactile symbols and characters for people with visual disabilities)

6.4.5.1 General

Tactile symbols and characters are often used in markings or signage of products and built environments to increase accessibility for people with visual disabilities, as an alternative way to convey visual information. Tactile markings and signs are also becoming popular for sighted people as a secondary method for presenting information. A common and important problem in designing tactile markings is to know how large the markings should be for attaining good legibility and how ageing or experience in the use of tactile symbols such as Braille affects legibility.

This subclause provides data on legibility of simple tactile symbols and characters for young and older people and people with visual disabilities who are familiar with tactile cues and information such as Braille.

6.4.5.2 Sampled population

The following three groups of people participated in the legibility of tactile character experiments:

— 33 young people aged from 18 years to 42 years (average 22,8 years);

— 33 older people aged from 60 years to 73 years (average 66,6 years);

— 72 young and older people with visual disabilities aged from 23 years to 76 years (average 49,8 years).

All of them had normal sensitivity to tactile pressure and spatial resolution checked by the Von Frei hair and JVP domes. They were Japanese and familiar with the Japanese phonetic signs used in the experiment.

6.4.5.3 Methods and conditions of data collection

Tactile symbols and characters were made as an embossed type of tactile stimulus on a flat plate of thermosetting resin. A single symbol or character was mounted on each plate. There were 4 different sizes for symbols (4 mm, 8 mm, 12 mm and 16 mm) and 5 sizes for characters (4 mm, 8 mm, 12 mm, 18 mm and 24 mm). The participant touched each of the items with his/her forefinger, right or left, and read in the active touch mode (moving the finger) to tell what symbol or character was printed on the plate.

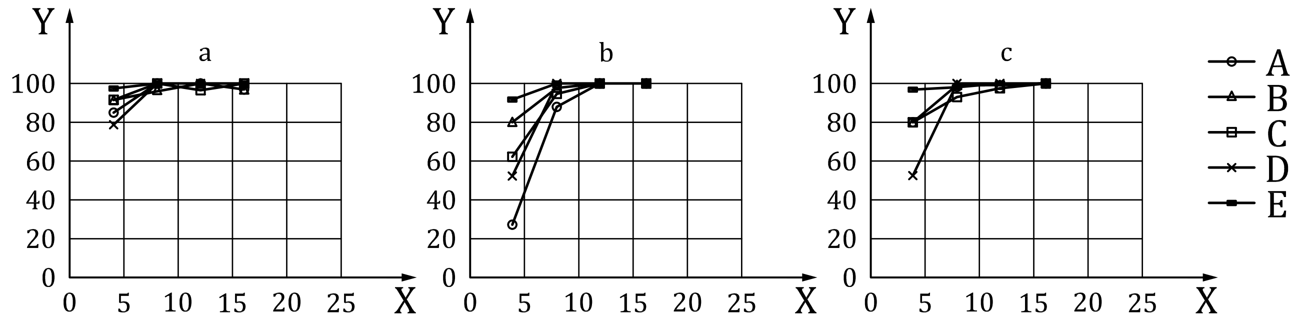
Five symbols (circle, triangle, square, arrow and bar) were used as test symbols and five numerals (2, 4, 5, 6, and 8) were used as test characters. In some sessions, Japanese phonetic signs or Katakanas (レ, ナ,チ,ネ and ヤ) were also used as characters. Experiments on symbols and on characters were done separately. The participants were informed beforehand what symbols and characters would be used in the experiment.

6.4.5.4 Data

Figure 50 and Figure 51 show legibility of tactile symbols and characters (numerals and Katakanas) respectively for young people, older people and people with visual disabilities. The legibility is expressed as a percentage of correct identification of symbols and characters as a function of the size.

Tactile symbols showed higher legibility than characters because the former were simpler than the latter. Older people showed worse sensitivity than young people for both symbols and characters.

On the other hand, people with visual disabilities (some of whom were old) showed no large ageing effect with almost the same level of legibility as that of young people.



Key

X size (mm)

Y percent correct

a young people

b older people

c people with visual disabilities

A symbol “triangle”

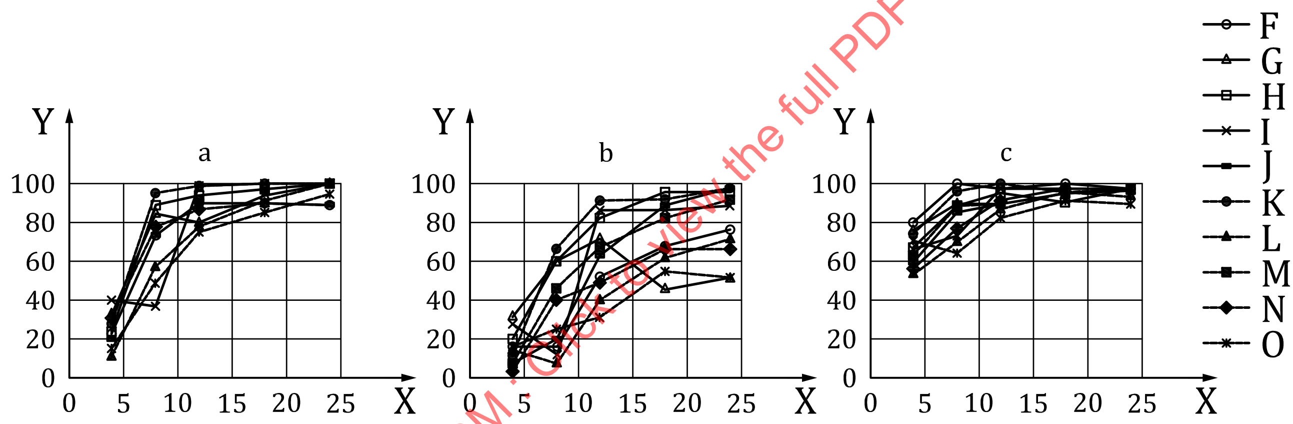
B symbol “square”

C symbol “circle”

D symbol “arrow”

E symbol “bar”

Figure 50 — Legibility data of tactile symbols for young, older people, and people with visual disabilities



Key

X size (mm)

Y percent correct

a young people

b older people

c people with visual disabilities

F character “2”

G character “4”

H character “5”

I character “6”

J character “8”

K character “レ”

L character “ナ”

M character “チ”

N character “ネ”

O character “ヤ”

Figure 51 — Legibility data of tactile characters for young, older people, and people with visual disabilities

6.4.5.5 Limitations

The data were collected using embossed (convex) type of tactile symbols and characters. For concave type tactile stimuli, another measurement is necessary.

6.4.5.6 Application examples

Tactile symbols and characters are used effectively for home appliances (e.g. washing machines), building facilities (e.g. lifts/elevators) and packaging, etc. The data shown here can be used for designing tactile symbols and characters of appropriate size.

6.4.5.7 References

— Data sources: References [56] and [44];

— Cross-references in this document: 6.4.6;

— Other references: none.

6.4.6 Legibility of tactile symbols and characters (international comparison)

6.4.6.1 General

This subclause provides data on legibility of tactile characters measured in different countries using the same tactile samples of simple symbols and numerals to allow international comparison. The legibility of tactile characters can differ among countries because finger sizes vary among people of different ethnicities and this can affect the legibility of tactile symbols and characters.

The international comparison was conducted in 2008–2010 to develop standards on legibility of tactile character. The results are presented in this subclause.

6.4.6.2 Sampled population

Six countries (China, Germany, Japan, Rep. of Korea, Thailand and the USA) participated in the experiments. Each country employed 15–20 people in each young group and older group. All had normal tactile sensitivity as tested by the JVP domes (see 6.4.1).

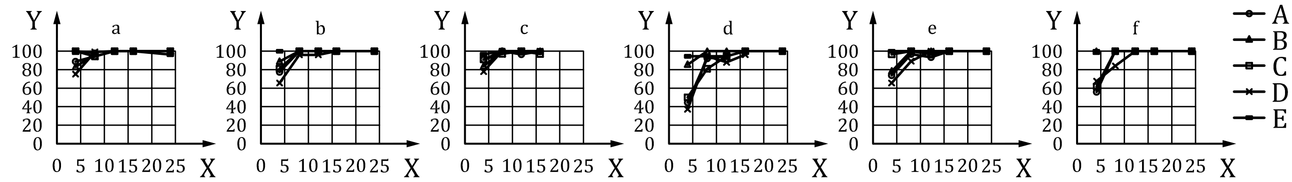
6.4.6.3 Methods and conditions of data collection

Tactile symbols and characters were made as an embossed type of tactile stimulus on a flat plate of thermosetting resin. A single symbol or character was mounted on each plate. Five different sizes (4 mm, 8 mm, 12 mm, 16 mm and 24 mm) were used for both symbols and characters except for characters in Japan where the 16 mm size was replaced with 18 mm. The participant touched each of the stimuli with his/her forefinger, right or left, and read what symbol or character was printed on the plate.

Five symbols (a circle, a triangle, a square, an arrow and a bar) were used as tactile symbols and five numerals (2, 4, 5, 6 and 8) were used as characters. Experiments were done separately on symbols and on characters. The participants were informed beforehand what symbols and characters would be used in the experiments.

6.4.6.4 Data

Figure 52 and Figure 53 show the legibility of tactile symbols for young and for older people in six countries respectively. Though there are some differences, the effect of ageing is observable for those six countries.

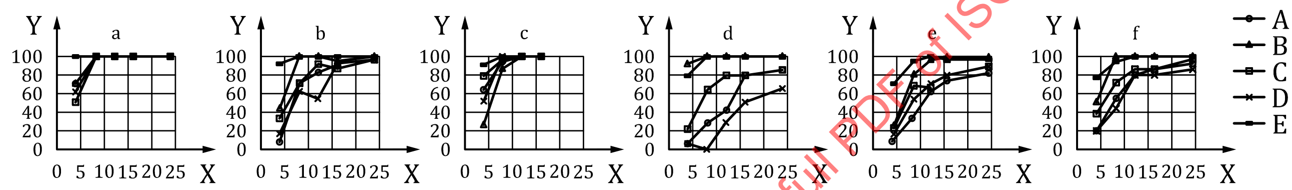


Key

X size (mm)
Y percent correct
A symbol "circle"
B symbol "triangle"
C symbol "square"
D symbol "arrow"
E symbol "bar"

a China
b Germany
c Japan
d Rep. of Korea
e Thailand
f USA

Figure 52 — Legibility of tactile symbols for young people in six countries



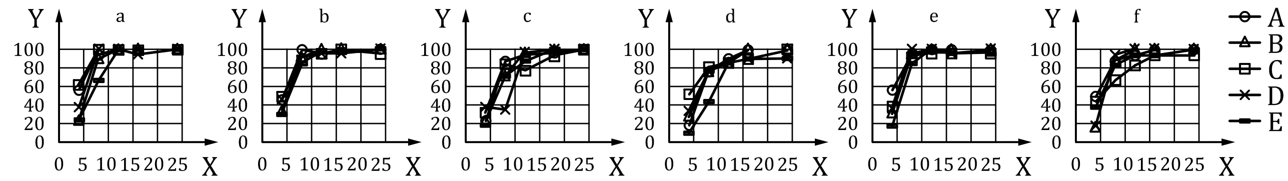
Key

X size (mm)
Y percent correct
A symbol "circle"
B symbol "triangle"
C symbol "square"
D symbol "arrow"
E symbol "bar"

a China
b Germany
c Japan
d Rep. of Korea
e Thailand

Figure 53 — Legibility of tactile symbols for older people in six countries

Similar results were obtained for tactile characters (numerals) as shown in Figure 54 and Figure 55. Again, there was no fundamental difference among the six countries.

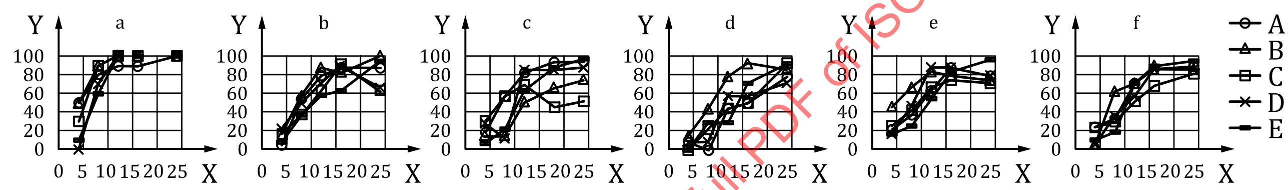


Key

X size (mm)
Y percent correct
A numeral “2”
B numeral “4”
C numeral “5”
D numeral “6”
E numeral “8”

a China
b Germany
c Japan
d Rep. of Korea
e Thailand
f USA

Figure 54 — Legibility of tactile numerals for young people in six countries



Key

X size (mm)
Y percent correct
A numeral “2”
B numeral “4”
C numeral “5”
D numeral “6”
E numeral “8”

a China
b Germany
c Japan
d Rep. of Korea
e Thailand
f USA

Figure 55 — Legibility of tactile numerals for older people in six countries

6.4.6.5 Limitations

The data were collected using an embossed (convex) type of tactile symbols and characters. Another measurement is required for concave type stimuli.

6.4.6.6 Application examples

There is no large difference in legibility of tactile symbols and characters among the countries tested with regard to the appropriate size. One standardized size can be used globally if determined appropriately.

6.4.6.7 References

— Data source: Reference [77];

— Cross-references in this document: 6.4.5;

— Other references: Reference [34].

6.5 Thermal sense

6.5.1 Surface temperature (ageing effect)

6.5.1.1 General

This subclause provides data on thermal sense, i.e. subjective reporting of warm or cold, when people touch an object of a given temperature. Subjective reporting of temperature varies with age, which should be taken into account when designing objects that touch the user's skin.

6.5.1.2 Sampled population

Data were taken from a total of 16 young and 16 older individuals. All were female. The average and standard deviation of young and older females were (24,8 ± 2,5) years and (64,9 ± 3,1) years, respectively.

6.5.1.3 Methods and conditions of data collection

An object in a thermo-neutral condition (an equilibrium condition where no heat comes in or out) between 30 °C and 35 °C (the temperature at which people did not feel the object as warm or cold) was prepared and gradually made warmer or colder by a thermos-stimulator. The stimulator surface consisted of a thin film of heat flux mounted on an aluminium plate with Peltier modules. The participant touched the object with the foot and reported when he/she felt the surface become warm or cold.

The participants wore only a pair of shorts and a brassiere, and the air temperature remained constant at 28 °C.

6.5.1.4 Data

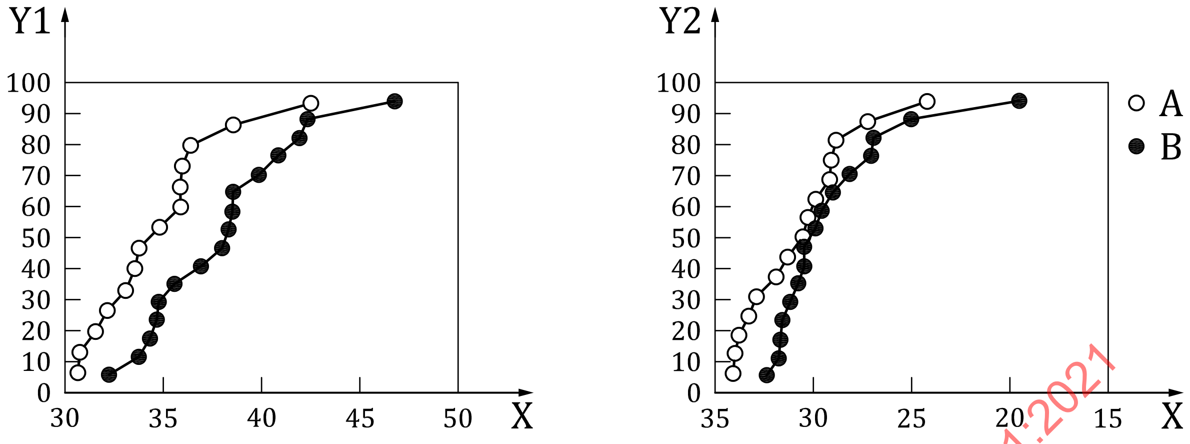
Figure 56 shows the percentage of participants reporting that the surface felt warm or cold at a given temperature. As the surface temperature increased or decreased, the figure shows that the percentage of the sample reporting it felt warm or cold gradually increased or decreased.

However, there are clear differences between the temperatures at which younger and older individuals reported the surface of the object as feeling warm or cold. The differences are as follows.

The surface temperature that young people typically felt as warm was 34 °C or above, whereas the surface temperature that older individuals felt as warm was 38,5 °C or above.

The surface temperature that both young and older individuals typically felt as cold was 30,5 °C or below.

Therefore, the acceptable surface temperature range neither too warm nor too cold for young and older people is between 30,5 °C and 34 °C.



a) warm feeling

b) cold feeling

Key

X surface temperature (°C)
Y1 percentage of feeling warm (%)
Y2 percentage of feeling cold (%)
A young people
B older people

Figure 56 — Percentage of young and older people reporting a surface warm or cold

6.5.1.5 Limitations

The feeling of warm or cold depends on the body part touching the object and other factors affecting thermal sensation. The present data shows basic data obtained for the foot at a fixed room temperature (28 °C). The warm/cool feeling also depends on the material properties touched.

6.5.1.6 Application examples

The data can be applied in the design of home appliances, furniture and facilities of buildings that are touched by hands. It should be kept within a temperature range that is neither too warm nor too cold for younger or older people.

6.5.1.7 References

— Data source: Reference [101];

— Cross-references in this document: 6.5.2;

— Other references: References [40], [26], [27] and [28].

6.5.2 Air temperature (ageing effect)

6.5.2.1 General

Thermal sensation (i.e. a feeling of warmth or coldness) depends on air temperature, but also on age, season, humidity, air velocity and clothing. The ambient air temperature should be set appropriately by referring to the combined effect of the air temperature and other variables.

6.5.2.2 Sampled population

In each experimental condition, i.e. summer or winter, 20 young people and about 20 older people (17–23 people depending on the temperature settings) participated. Average ages were 22,5 years for young and 73,3 years for older people in the summer condition, and 23,5 years and 72,4 years respectively in the winter condition.

6.5.2.3 Methods and conditions of data collection

The data were collected for both summer and winter seasons with the relative humidity at 60 %. The mean radiant temperature was equal to the air temperature, and the air velocity was less than 0,3 m/s. The participants wore long sleeved shirts and long pants of 0,6 clo. Air temperature varied while the other variables were held constant.

For each air temperature, the participant was asked to evaluate the thermal sense, i.e. warm or cool, on a 9-point scale, and also whether the air temperature condition was acceptable or not.

NOTE Clo is a special definition of thermal insulation (1 clo = 0,155 $m^2 \cdot K \cdot W^{-1}$) (see ISO 9920). An overall clo value can be calculated simply by adding together the clo values, taken from a table, of each individual garment worn by the person: 0 clo corresponds to a naked person, 1 clo corresponds to a person wearing a typical business suit.

6.5.2.4 Data

Figure 57 to Figure 59 show thermal sense and unacceptable rate (%) as a function of air temperature. The unacceptable rate is the percentage of people who reported the air temperature condition as not acceptable.

Figure 57 shows the relationship between thermal sensation and air temperature in winter and summer. The effect of seasonal acclimatization indicates that the neutral temperature in summer is higher than that in winter. Thus, the point at which individuals do not feel hot or cold is obtained at 25,5 °C in winter and 27,5 °C in summer, for young individuals. The neutral temperature for older individuals wearing the same light long-sleeved clothing is 26,5 °C in both the summer and winter seasons.

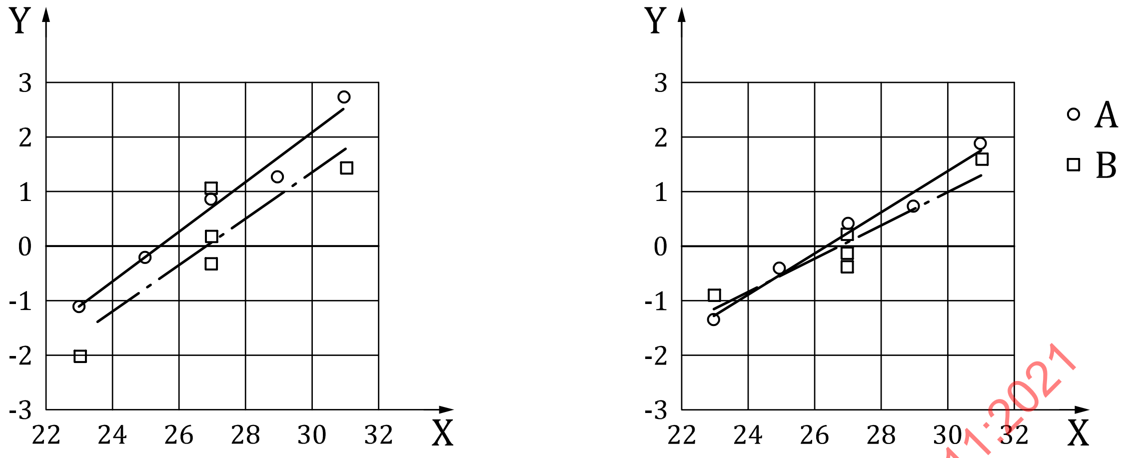
Figure 58 depicts the data showing the relationship between the unacceptable rate (%) and air temperature. The effect of seasonal acclimatization is also shown in the unacceptable rate which is lower in summer than in winter at a temperature higher than the neutral temperature.

The range over which 75 % of young people feel the temperature to be acceptable is between 23 °C and 29,0 °C in winter and between 23,5 °C and 31,5 °C in summer. The equivalent range for older people is between 23,0 °C and 30,5 °C in winter, and the upper limit is 31,5 °C in summer while the lower threshold is not clearly demonstrated in the data.

NOTE These acceptable temperature ranges change if we assume the clo value changes from 0,6. For example, if the clothing insulation increases up to 1,2 clo in winter, the acceptable temperature range for young people drops to a range between 20 °C and 25,5 °C based on a conversion between air temperature and clo value. When the clothing insulation reduces to 0,4 clo in summer, the lower threshold of the acceptable temperature is 26 °C for younger people.

These two data sets are combined into Figure 59 where the relationship between unacceptable rate and thermal sensation is shown. Again, the effects of seasonal acclimatization result in the unacceptable rate which is lower in summer than in winter at the cooler than thermos-neutral sensation.

Air temperature has a slightly larger effect on young people than older people in judgment of thermal sensation (Figure 57). Older people are less likely to feel hot and cold in the higher and lower temperatures, respectively. This decreasing response in thermal sense can be caused by their lower thermoregulatory response ability.



a) Young people **b) Older people**

Key

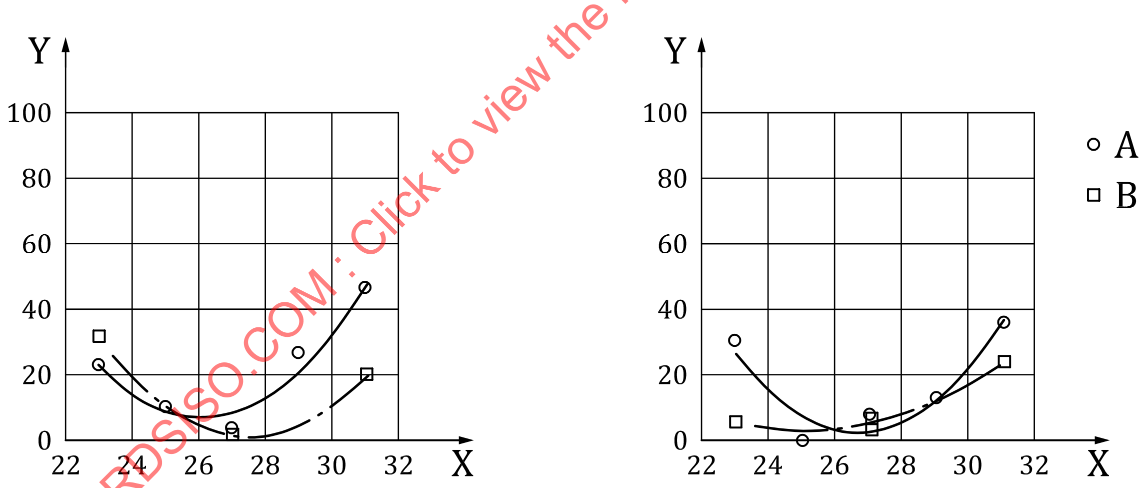
X air temperature (°C)

Y thermal sensation

A winter

B summer

Figure 57 — Mean thermal sensation as a function of air temperature



a) Young people **b) Older people**

Key

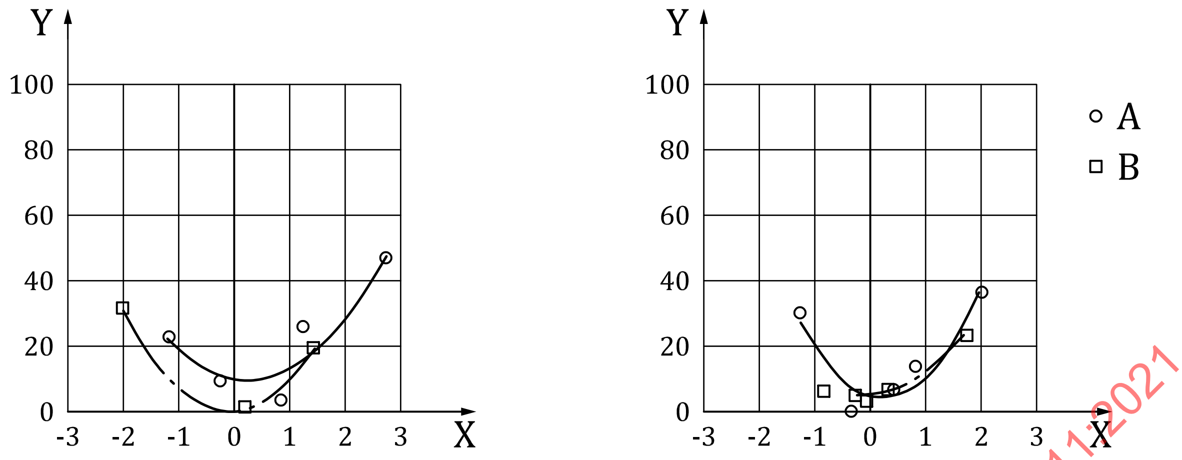
X air temperature (°C)

Y unacceptable rate (%)

A winter

B summer

Figure 58 — Unacceptable rate as a function of air temperature



a) Young people **b) Older people**

Key

X thermal sensation

Y unacceptable rate (%)

A winter

B summer

Figure 59 — Unacceptable rate as a function of mean thermal sensation

6.5.2.5 Limitations

Thermal sense and the unacceptable rate might also reflect differences in gender, ethnicity, national–geographic location, etc. However, the relevant data for those differences are not currently available.

6.5.2.6 Application examples

Though unacceptable rate is not identical to PPD in ISO 7730, the data are equivalent to PPD and can be used for controlling the temperature of air conditioners, in homes or work places. When age-related differences or seasonal changes, local or global, are taken into account, the data can be referred to.

6.5.2.7 References

— Data source: Reference [45];

— Cross-references in this document: 6.5.3;

— Other references: Reference [15].

6.5.3 Thermal comfort (physical disabilities)

6.5.3.1 Thermal comfort responses of people with physical disabilities

The data in this subclause show how a range of people with various physical disabilities rate their thermal comfort in three conditions: "slightly cool to cool", "neutral" (comfortable) and "slightly warm to warm". These are compared with the predictions resulting from the application of ISO 7730 which is based on sample populations that did not explicitly include people with disabilities.

Overall, the actual mean sensation ratings by the groups with disabilities, when compared with the predicted mean sensation, show that the closest agreement occurs in the neutral (comfortable) condition. However, the data show a high level of variability between groups and within groups, and higher levels of rated dissatisfaction in the groups with disabilities than would be predicted.

6.5.3.2 Sampled population

119 people with a physical disability, recruited from a town with a population of 60 000 people in the UK. They were assigned to one of 10 sub-groups, depending on the self-classification of the origin of their disability. The sub-groups varied in size from 4 to 32 and are shown in Figure 60, Figure 61 and Figure 62.

6.5.3.3 Methods and conditions of data collection

This was a laboratory study in which the participants sat in a thermal chamber for 2 h on three separate occasions at least 1 week apart. The thermal chamber was set up as a living room and they were able to watch films on video during the session. Each person wore a standard set of clothing for each visit consisting of shoes, socks, underwear, light trousers, long sleeved shirt and sweat shirt (1,0 clo). They experienced a different set of thermal conditions on each occasion, corresponding to what would be predicted to be "slightly cool to cool", "neutral" (comfortable) and "slightly warm to warm" in ISO 7730. These were based on air temperatures of 18,5 °C, 23,0 °C and 29,0 °C, respectively, with radiant temperatures equal to air temperature in each case, and 50 % relative humidity and still air.

During each session, participants rated their thermal sensations on an ISO 7730 rating scale of +3, hot; +2, warm; +1, slightly warm; 0, neutral; −1, slightly cool; −2, cool; −3, cold. This is the basis for the predicted mean vote (PMV) in ISO 7730 and enables the calculation of the actual mean sensation vote. The participants also rated their thermal comfort in the environment which enables the calculation of the percentage dissatisfied which can be compared with the percentage dissatisfied predicted by ISO 7730 for the three thermal conditions used in this study.

6.5.3.4 Data

6.5.3.4.1 General

The data presented in Table 12 are based on the final set of ratings made at the end of the two-hour session, at which point people were no longer adapting to the environment and their responses had stabilised.

Table 12 — Thermal sensation and dissatisfaction rates for each disability group

Physical disability	Number of people	Males	Females	Room temperature (°C)	Predicted mean sensation	Actual mean sensation	Plus one standard deviation	Minus one standard deviation
Cerebral palsy	12	4	8	18,5	−1,5	−0,3	1,9	−2,4
				23	0	1,3	2,2	0,3
				29	1,5	2,6	> 3	1,9
Spinal injury including tetra- and quadriplegic	9	5	4	18,5	−1,5	−1,5	−0,1	<-3
				23	0	0,3	0,9	-0,4
				29	1,5	2	>3	0,4
Spinal degenerative	8	1	7	18,5	−1,5	−2,5	−1,8	<3
				23	0	0,3	0,6	0
				29	1,5	2	2,6	1,4
Spina bifida	10	5	5	18,5	−1,5	−0,6	−1,9	0,7
				23	0	1	2,2	−0,2
				29	1,5	2,1	>3	1
Hemiplegia including stroke	4	1	3	18,5	−1,5	−2,6	−2,1	<−3
				23	0	−0,4	0	−0,8
				29	1,5	1,3	3	−0,5

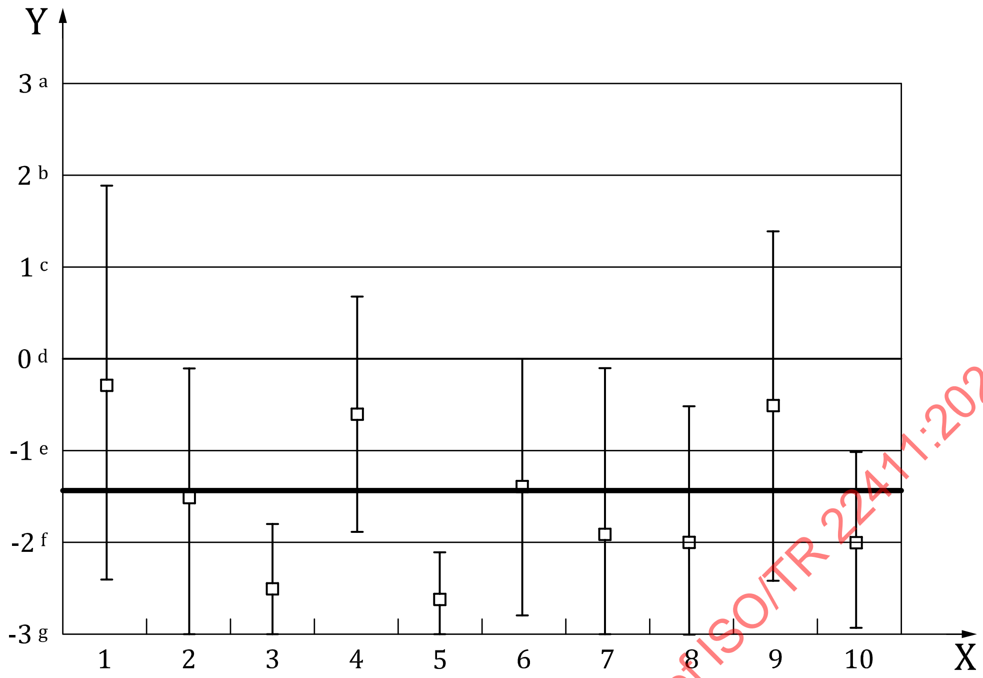
Table 12 *(continued)*

Physical disability	Number of people	Males	Females	Room temperature (°C)	Predicted mean sensation	Actual mean sensation	Plus one standard deviation	Minus one standard deviation
Polio	11	6	5	18,5	−1,5	−1,4	0	−2,8
				23	0	0,1	1,4	−1,2
				29	1,5	2,2	>3	0,5
Osteoarthritis	17	6	11	18,5	−1,5	−1,9	−0,1	<−3
				23	0	−0,2	1,6	−1,9
				29	1,5	2,5	>3	1,7
Rheumatoid arthritis	10	2	8	18,5	−1,5	−2	−0,5	<−3
				23	0	−1,1	−0,7	−1,4
				29	1,5	2	>3	0,7
Head injury	6	4	2	18,5	−1,5	−0,5	1,4	−2,4
				23	0	0,3	1,9	−1,4
				29	1,5	2,2	2,2	2,2
Multiple sclerosis	32	15	17	18,5	−1,5	−2	−1	−2,9
				23	0	0,1	0,7	−0,4
				29	1,5	2,2	2,8	1,7

6.5.3.4.2 Thermal sensation ratings

6.5.3.4.2.1 Thermal sensation ratings for slightly cool to cool – PMV = −1,5

Figure 60 shows mean and standard deviations of final sensation ratings of people with physical disabilities compared with those predicted by ISO 7730. The predicted mean vote (PMV) of a large group of people exposed to those conditions is PMV = −1,5 (slightly cool to cool). The predicted percentage of dissatisfied (PPD) is 50 %.



Key

X physical disability category
Y thermal sensation rating
a hot
b warm
c slightly warm
d neutral
e slightly cool
f cool
g cold

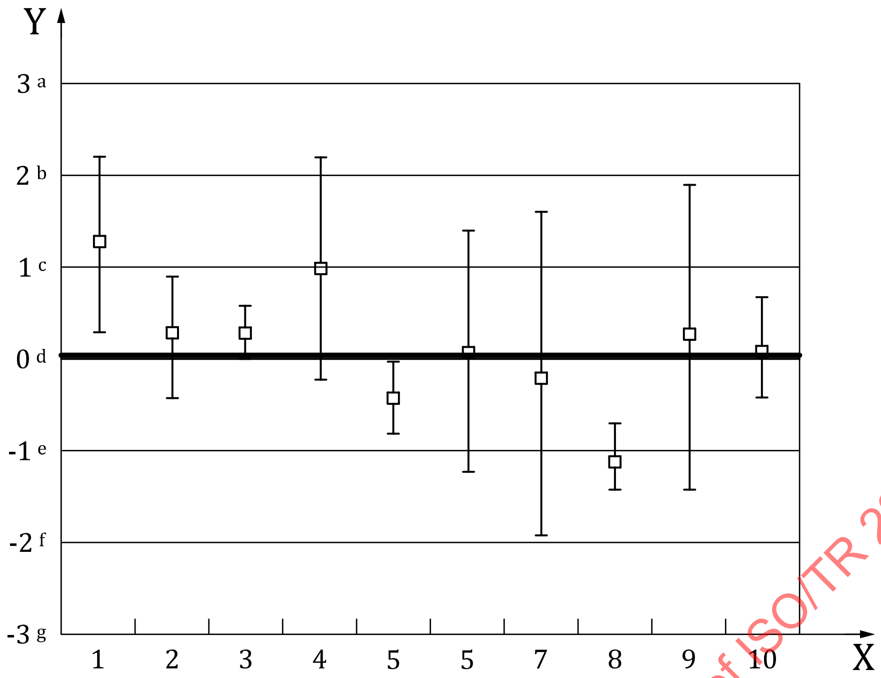
1 cerebral palsy (*n* = 12)
2 spinal injury (*n* = 9)
3 spinal degenerative (*n* = 8)
4 spina bifida (*n* = 10)
5 hemiplegia (including stroke) (*n* = 4)
6 polio (*n* = 11)
7 osteoarthritis (*n* = 17)
8 rheumatoid arthritis (*n* = 10)
9 head injury (*n* = 6)
10 multiple sclerosis (*n* = 32)

Figure 60 — Mean and standard deviations of final sensation ratings of people with physical disabilities for slightly cool to cool (PMV = −1,5) at room temperature 18,5 °C

On average, all groups found the conditions cooler than neutral. Some groups found it colder than predicted but some found it more towards neutral than predicted. All groups, except people with cerebral palsy, indicated much greater dissatisfaction than predicted.

6.5.3.4.2.2 Thermal sensation ratings for neutral (comfortable) – PMV = 0,0

Figure 61 shows mean final sensation ratings of people with physical disabilities compared with those predicted by ISO 7730 as neutral (comfortable). The predicted mean vote (PMV) of a large group of people exposed to those conditions is PMV = 0,0 [neutral (comfortable)].



Key

X physical disability category

Y thermal sensation rating

a hot

b warm

c slightly warm

d neutral

e slightly cool

f cool

g cold

1 cerebral palsy (*n* = 12)

2 spinal injury (*n* = 9)

3 spinal degenerative (*n* = 8)

4 spina bifida (*n* = 10)

5 hemiplegia (including stroke) (*n* = 4)

6 polio (*n* = 11)

7 osteoarthritis (*n* = 17)

8 rheumatoid arthritis (*n* = 10)

9 head injury (*n* = 6)

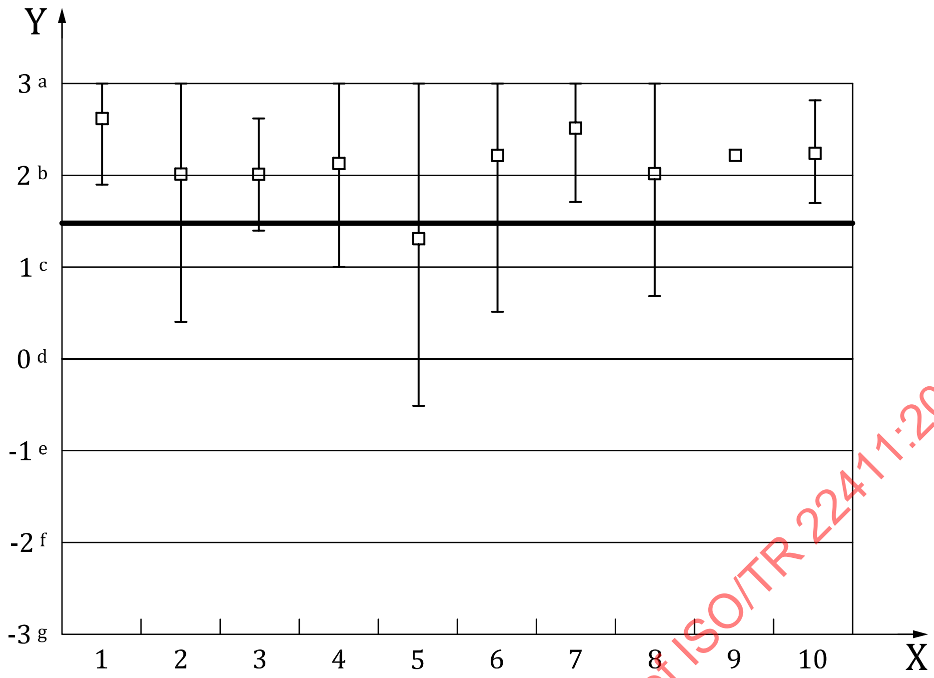
10 multiple sclerosis (*n* = 32)

Figure 61 — Mean and standard deviations of final sensation ratings of people with physical disabilities for neutral (PMV = 0) at room temperature 23 °C

On average, most groups found the conditions close to neutral (comfortable) as predicted by ISO 7730. People with cerebral palsy and spina bifida found it slightly warm and people with rheumatoid arthritis found it slightly cool. All groups, except people with cerebral palsy and spina bifida, indicated much greater dissatisfaction than predicted. Out of 10 people with rheumatoid arthritis, 8 were dissatisfied in what would be predicted as a comfortable environment by ISO 7730.

6.5.3.4.2.3 Thermal sensation ratings for slightly warm to warm – PMV = +1,5

Figure 62 shows mean final sensation and dissatisfaction ratings of people with physical disabilities compared with those predicted by ISO 7730 as slightly warm to warm. The predicted mean vote (PMV) for sensation of a large group of people exposed to those conditions is PMV = +1,5 (slightly warm to warm).



Key

X	physical disability category	1	cerebral palsy (*n* = 12)
Y	thermal sensation rating	2	spinal injury (*n* = 9)
a	hot	3	spinal degenerative (*n* = 8)
b	warm	4	spina bifida (*n* = 10)
c	slightly warm	5	hemiplegia (including stroke) (*n* = 4)
d	neutral	6	polio (*n* = 11)
e	slightly cool	7	osteoarthritis (*n* = 17)
f	cool	8	rheumatoid arthritis (*n* = 10)
g	cold	9	head injury (*n* = 6)
		10	multiple sclerosis (*n* = 32)

Figure 62 — Mean and standard deviations of final sensation ratings of people with physical disabilities for slightly warm to warm (PMV = +1,5) at room temperature 29 °C

On average, all groups found the conditions warmer than predicted, except people with hemiplegia.

6.5.3.4.3 Dissatisfaction ratings

The percentage of people dissatisfied with each of the three thermal conditions in each disability group was calculated. This enables a comparison to be made with the percentage dissatisfied that is predicted for each thermal condition for the general population by ISO 7730. For the cool to slightly cool condition the predicted percentage of people dissatisfied is 50 %. For the neutral condition the predicted percentage of people dissatisfied is 5 %. For the warm to slightly warm condition the predicted percentage of people dissatisfied is 50 %.

Table 13 — Percentage of people dissatisfied in each group in each condition

Physical disability category	Thermal comfort condition	Predicted percentage dissatisfied	Percentage dissatisfied
Cerebral palsy (*n* = 12)	Cool to slightly cool	50	50
	Neutral	5	8
	Warm to slightly warm	50	58
Spinal injury (*n* = 9)	Cool to slightly cool	50	78
	Neutral	5	44
	Warm to slightly warm	50	67
Spinal degenerative (*n* = 8)	Cool to slightly cool	50	100
	Neutral	5	25
	Warm to slightly warm	50	63
Spina bifida (*n* = 10)	Cool to slightly cool	50	60
	Neutral	5	10
	Warm to slightly warm	50	30
Hemiplegia (including stroke) (*n* = 4)	Cool to slightly cool	50	100
	Neutral	5	50
	Warm to slightly warm	50	25
Polio (*n* = 11)	Cool to slightly cool	50	73
	Neutral	5	45
	Warm to slightly warm	50	64
Osteoarthritis (*n* = 17)	Cool to slightly cool	50	88
	Neutral	5	65
	Warm to slightly warm	50	76
Rheumatoid arthritis (*n* = 10)	Cool to slightly cool	50	90
	Neutral	5	80
	Warm to slightly warm	50	79
Head injury (*n* = 6)	Cool to slightly cool	50	67
	Neutral	5	33
	Warm to slightly warm	50	17
Multiple sclerosis (*n* = 32)	Cool to slightly cool	50	84
	Neutral	5	47
	Warm to slightly warm	50	78

The results presented in Table 13 show that the percentage of people dissatisfied was higher in all the disability groups than would be predicted for the general population. Overall, all three thermal conditions had higher percentages of people dissatisfied than would be predicted. However, some of the groups, spina bifida, hemiplegia and head injury seem to prefer the warmer condition of warm to slightly warm to the other conditions. A comparison of the percentage dissatisfied for each condition within each group suggests that the percentage dissatisfied in most groups is higher for the cool to slightly cool conditions than for the warm to slightly warm condition. In the cool to slightly cool condition, only the group with cerebral palsy indicated similar levels of dissatisfaction to those predicted for the general population. In the neutral (comfortable) condition only the people with cerebral palsy and spina bifida indicated similar levels of dissatisfaction to those predicted.

6.5.3.4.4 Variability in data

The variability in the data between groups of people with different disabilities, and within some of those groups is high. This indicates that, while the design target set in ISO 7730 for the thermal environment that produces comfortable conditions is appropriate as a setting to satisfy a large number of people including people with disabilities, the variability in the thermal comfort responses of individuals indicates the need to provide a means of supporting diversity in requirements.

6.5.3.5 Limitations

This is a laboratory-based study which simulated normal living conditions. The data reported for some of the groups with specific sources of disability is based on small sample sizes. The age and fitness level of the participants in the sample reported here is not known, so they can be confounding factors.

6.5.3.6 Application examples

If selecting one temperature for the typical settings in a built environment, the recommendations in ISO 7730 should be used. However, there is a need to provide the capacity to adjust the thermal environment to meet individual needs. It is also important to consider the operation of the system as a whole, including the capacity of individuals to adapt their personal circumstances, for example by changes in clothing. This can involve the provision of personal support and care.

6.5.3.7 References

— Data sources: References [16] and [82];

— Cross-references in this document: none;

— Other references: References [106] and [107].

7 Physical characteristics and capabilities

7.1 Overview of physical characteristics and capabilities

In principle, all physical characteristics and capabilities change and decrease with age. Stature, for example, declines with age after peaking at approximately 25–35 years. Decreasing mobility and strength with age, in particular, causes problems in daily life. However, the decrease in strength with age can show significant variation between individuals or specific population groups due to lifestyle, habitual activity, occupational activity or exercise.

There are also some people who have physical disabilities and have different functional capabilities. Design of products, services, and environments should take into account the characteristics and abilities of those people who have special requirements in using them.

In addition to these age-related differences and the differences originating from various types of physical disabilities, there exist non-negligible ethnicity differences in physical characteristics and capabilities compared to other sensory or cognitive capabilities which should be taken into account in the design of products, services and environments.

Table 14 presents a list of physical variables of human physical characteristics and capabilities, the extent of the ageing effect and references providing data for the ageing effect. In the table, the effect of ageing is classified into two categories: “minimal”, which means slight effect of ageing, and “yes”, which means apparent or strong effect of ageing.

References relevant to study general characteristics of aging effect for physical characteristics and capabilities are given in Table 14. Data were basically taken from those references. The data book collected in the Netherlands (one of countries with the tallest people in the world's population) contains a large volume of data for a wide range of physical items. Therefore, it is often cited in this subclause. However, care should be taken when applying those data for national or regional differences originated from body size, etc., if the data source is only available for the physical item.

Table 14 — List of physical variables and effects of age

Physical variables	Particular effect of age	Main references
Body dimension		
Stature	Minimal	[14] and [5]
Fist height	Minimal	[94]
Sitting height	Minimal	
Eye height, seated	Minimal	
Shoulder height, seated	Minimal	
Frontal grip reach, seated	Minimal	
Upper arm length	Minimal	[97]
Elbow–grip length	Minimal	
Elbow–fingertip length	Minimal	
Shoulder breadth	Minimal	
Breadth across elbow	Minimal	[94]
Buttock–popliteal length	Minimal	
Buttock–knee length	Minimal	
Popliteal height	Minimal	
Abdominal depth	Minimal	
Thigh clearance, seated	Minimal	
Hand length	Minimal	
Hand breadth without thumb	Minimal	
Thumb breadth	Minimal	
Forefinger tip breadth	Minimal	
Grip diameter	Minimal	
Foot length	Minimal	
Foot breadth	Minimal	
Exertion of force		
Gripping force	Yes	[97]
Pulling force	Yes	[74]
Torque	Yes	[6]
Shoulder strength	Yes	[48] [78]
Elbow strength	Yes	
Wrist strength	Yes	
Minimal slight effect of ageing Yes apparent or strong effect of ageing		

Table 14 *(continued)*

Physical variables	Particular effect of age	Main references
Ranges of movement of joints		
Wrist–pronation	Yes	[97]
Wrist–supination	Yes	
Wrist–flexion	Yes	
Wrist–extension	Yes	
Wrist–deviation (radial and ulnar)	Minimal	
Forefinger flexion	Minimal	
Head–flexion	Minimal	
Head–extension	Minimal	
Head–rotation	Minimal	
Head–lateral bending	Minimal	
Reaching envelopes		
Comfortable reaching vertical–standing	Yes	[97]
Maximum reaching vertical–standing	Yes	
Comfortable reaching horizontal–sitting	Yes	
Maximum reaching horizontal–sitting	Yes	
Step length, step height and walking velocity		
Step length	Yes	[97]
Walking normal	Yes	
Walking hurried	Yes	
Step height–comfortable ascent	Yes	
Step height–comfortable descent	Yes	
Step height–maximum ascent	Yes	
Step height–maximum descent	Yes	
Minimal slight effect of ageing Yes apparent or strong effect of ageing		

7.2 Physical characteristics related to body size

7.2.1 Basic body size (design range from small to large size)

7.2.1.1 General

Human body size is represented by sets of anthropometric data values for mass (weight) and a range of static linear dimensions of people measured when standing, sitting, and with arms relaxed or outstretched. Significant variability in human size exists across age and gender and in different regions of the world (see ISO/IEC Guide 71:2014).

The design targets most commonly used are the 5th percentile female values, and the 95th percentile male values. The 2nd and 98th percentiles, or even the 1st and 99th percentiles, can be used in order to be inclusive of a larger portion of the population.

7.2.1.2 Sampled population

The approach developed and used involved analysing the many anthropometric databases that were available from around the world, and organizing the information into a presentation of an expanded design range useful for designers.

The data sources used for the analysis are:

— Korean Agency for Technology and Standards (KATS), 2004;

— Daanen & Robinette, 2001;

— HQL Laboratory (Japan), 2007;

— Thai Industrial Standards Institute (TISI), 2001;

— Fubini et al., 1993;

— Harrison & Robinette, 2002.

7.2.1.3 Methods and conditions of data collection

The method that was used maximized the inclusion of sizes and shapes of adults. To create a design range for the most commonly used dimensions, the procedures below were followed.

— Compare the smallest 5th percentile values from the published literature from all the sources across the world.

— Select the smallest 5th percentile value, male or female, for the small design value.

— Compare the largest 95th percentile values from the published literature from all the sources across the world.

— Select the largest 95th percentile value, male or female, for the large design value.

— Calculate the design range as, the large value minus the small value. The design range is useful for knowing the upper and lower limits that need accommodated by the design of products or workspaces where adjustability or other types of accommodation are possible.

NOTE The values used for the design range in Table 15 are based on designing products to be designed for a global population. The same approach, based on specific national values, can be used for the design of products and workspaces designed for an intended user population from a specific country or region.

7.2.1.4 Data

Table 15 shows the smallest (the 5th percentile) and the largest (the 95th percentile) values for each of the body dimensions listed in the first column, which have been selected out of the data sets collected from various countries.

Table 15 — Expanded recommended design range for body dimensions

Dimensions in centimetres

	Small	Source	Large	Source	Design range
Abdominal depth, sitting	16,9	Korea	35,8	Netherlands	18,9
Buttock-knee length	49,7	Japan	70,3	Netherlands	20,6
Buttock-popliteal length (seat depth)	41,0	Korea	56,5	Netherlands	15,5
Elbow grip length	27,0	Thailand	39,3	Netherlands	12,3
Elbow height	88,9	Japan	123,9	Netherlands	35,0
Elbow height, sitting	18,6	Italy	30,0	Netherlands	11,4
Elbow-elbow breadth	32,2	Japan	57,1	Italy	24,9
Eye height	136,3	Thailand	184,2	Netherlands	47,9
Eye height, sitting	66,8	Thailand	89,2	Netherlands	22,4
Foot breadth	8,1	Thailand	11,6	Netherlands	3,5

Table 15 *(continued)*

	Small	Source	Large	Source	Design range
Foot length	21,0	Thailand	29,6	Netherlands	8,6
Forearm-fingertip length	38,2	Japan	53,0	Netherlands	14,8
Grip reach (forward reach)	58,8	Japan	82,3	Netherlands	23,5
Hand breadth	6,3	Thailand	11,0	Italy	4,7
Hand length	16,1	Korea	22,1	Netherlands	6,0
Head breadth	13,4	Italy	17,3	Japan	3,9
Head circumference	51,3	Thailand	60,6	Netherlands	9,3
Head length	15,8	Thailand	21,2	United States	5,4
Hip breadth, sitting	30,1	Thailand	50,1	United States	20,0
Knee height	41,8	Japan	61,7	Netherlands	19,9
Lower leg length (popliteal height)	33,3	Korea	53,8	Netherlands	20,5
Shoulder (bideltoid) breadth	35,4	Thailand	55,0	United States	19,6
Shoulder elbow length	27,0	Italy	41,5	Netherlands	14,5
Shoulder height	118,2	Japan	162,5	Netherlands	44,3
Shoulder height, sitting	50,1	Italy	68,8	Netherlands	18,7
Sitting height	77,5	Italy	101,2	Netherlands	23,7
Stature	147,3	Thailand	195,9	Netherlands	48,6
Thigh clearance	11,0	Italy	17,9	Korea	6,9
Weight (kg)	40,0	Thailand	117,0	Netherlands	77,0

The design range from the size data for universal design guidance includes 29 commonly used values based on the 5th to the 95th percentiles. ISO 7250-3:2015, Table 1, design range is very similar to those 29 values but it lists 56 values in total along with the 1st and the 99th percentiles.

7.2.1.5 Limitations

While many designs require that multiple body dimensions are taken into account, use of single percentile values as a design guide is generally not the preferred approach. The result is that many design guidelines and ISO standards are framed in terms of percentile values for a list of dimensions.

7.2.1.6 Application examples

An information sheet about the application of body size values on determining design requirements offers for example; procedures to calculate small, medium and large, or for determining a range of adjustability (see Reference [117]).

Requirements for additional space can be associated with the presence of accompanying persons, assistance dogs, assistive products, assistive technology and equipment. Examples of associated equipment can include protective clothing, orthotics and personal mobility aids.

7.2.1.7 References

— Data source: Reference [63];

— Cross-references in this document: 7.2.2;

— Other references: Reference [14]

7.2.2 Grip diameter (ageing effect)

7.2.2.1 General

Dimensions of hands, fingers and thumbs are factors that affect the operation of products and controls that have knobs, grips, push-buttons, etc. The diameter of the circle made by the thumb and forefinger is one of the basic data for designing products.

This subclause provides data on the maximum diameter of the circle made by the thumb and forefinger.

7.2.2.2 Sampled population

People in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of about 750 Dutch people (about 360 men and 390 women) in the Netherlands in 1995 and 1996. The age distribution is shown in Table 16 together with the data measured.

7.2.2.3 Methods and conditions of data collection

As shown in Figure 63 the tips of the thumb and the forefinger were held together to make a circle. The circle was slid down along a cone while the tips of the thumb and the forefinger remained together still making a circle. The maximum diameter at the holding location was measured.

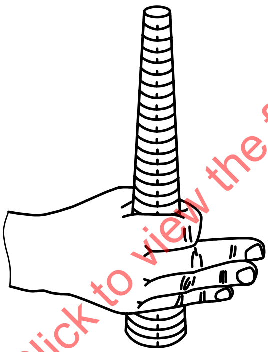


Figure 63 — Method of measurements of a grip diameter with a cone

7.2.2.4 Data

Mean grip diameters and their standard deviations are shown in Table 16 and Figure 64 for men and women in different age groups. In the figure, the standard deviation is shown for each of the age and sex groups.

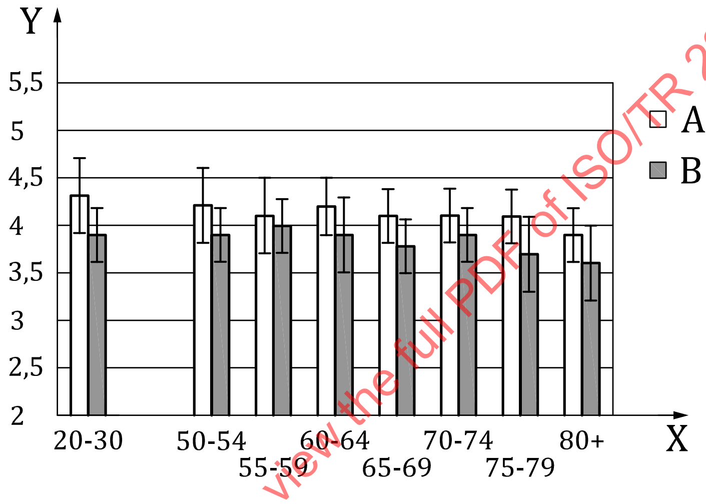
The mean grip diameter is in the range from 3,9 cm to 4,3 cm for men, and 3,6 cm to 4,0 cm for women. There is a consistent difference between men and women, and also a slight difference between age groups, i.e. the older the people the smaller the grip diameter.

Table 16 — Mean grip diameters and standard deviations of men and women for different age groups

Age groups (years)	Men			Women		
	Number of participants, *n*	Mean cm	Standard deviation, *s* cm	Number of participants, *n*	Mean cm	Standard deviation, *s* cm
20–30	55	4,3	0,4	68	3,9	0,3
31–49	—	—	—	—	—	—
50–54	35	4,2	0,4	35	3,9	0,3

Table 16 *(continued)*

Age groups (years)	Men			Women		
	Number of participants, *n*	Mean cm	Standard deviation, *s* cm	Number of participants, *n*	Mean cm	Standard deviation, *s* cm
55–59	46	4,1	0,4	50	4,0	0,3
60–64	44	4,2	0,3	53	3,9	0,4
65–69	50	4,1	0,3	51	3,8	0,3
70–74	59	4,1	0,4	62	3,9	0,3
75–79	36	4,1	0,3	38	3,7	0,4
80+	33	3,9	0,3	35	3,6	0,4



Key

X age groups (years)
Y grip diameter (cm)
A men
B women

Figure 64 — Mean grip diameters and standard deviations of men and women for different age groups

7.2.2.5 Limitations

The grip diameters given here represent the maximum grip when no force is required.

7.2.2.6 Application examples

The data are relevant for designing handrails, banisters, grips, knobs and umbrella that need gripping by hands. When force has to be exerted, the grip diameter should be reduced by 0,6 mm to 0,7 mm[97].

7.2.2.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.2.1;

— Other references: Reference [5].

7.3 Movement – fine hand use abilities

7.3.1 Hand steadiness (ageing effect)

7.3.1.1 General

Manipulation of tools and controls depends among other motoric functions on hand steadiness which declines with age. This subclause provides the age-related change of hand steadiness.

7.3.1.2 Sampled population

People in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.3.1.3 Methods and conditions of data collection

Hand steadiness is measured using a plate with 9 holes with different diameters of 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 9 mm, 11 mm, 15 mm and 20 mm. The participant has to pass through the holes with a fine stick (a stylus pen) of 2,0 mm diameter using one hand. Hand and arm do not rest on the table. Hand steadiness is represented by the minimum hole diameter the participant can pass the stick through without touching the edge.

The data is based on participants who have no physical impairments.

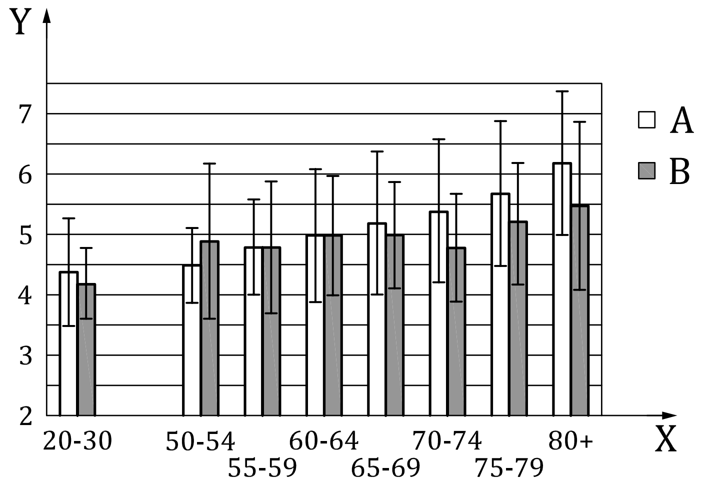
7.3.1.4 Data

Table 17 and Figure 65 show the mean hand steadiness scores and their standard deviations measured for the different sex and age groups from 20 to over 80 years. In Figure 65, standard deviations are also shown. The hand steadiness score (the Y-axis) means the minimum hole diameter through which the participant can pass the stick as described in 7.3.1.3.

The hand steadiness score increases with age meaning that fine motor skills deteriorate with increasing age. This ageing effect is more clearly observed for men than for women. Women over 65 years are better in hand steadiness than men of the same age.

Table 17 — Mean hand steadiness scores and standard deviations measured as a minimum diameter of a hole one can pass through a thin stick for men and women of different age groups

Age groups years	Men			Women		
	Number of participants, *n*	Mean mm	Standard deviation, *s* mm	Number of participants, *n*	Mean mm	Standard deviation, *s* mm
20–30	55	4,4	0,9	69	4,2	0,6
31–49	—	—	—	—	—	—
50–54	33	4,5	0,6	35	4,9	1,3
55–59	46	4,8	0,8	49	4,8	1,1
60–64	44	5,0	1,1	53	5,0	1,0
65–69	50	5,2	1,2	49	5,0	0,9
70–74	59	5,4	1,2	60	4,8	0,9
75–79	35	5,7	1,2	41	5,2	1,0
80+	33	6,2	1,2	34	5,5	1,4



Key

X age groups (years)

Y hand steadiness score (the minimum diameter of a hole in mm through which one can pass through a thin stick of 2,0 mm diameter without touching the edge of the hole)

A men

B women

Figure 65 — Mean hand steadiness scores and standard deviations expressed as a minimum hole diameter through which one can pass through a thin stick (2,0 mm diameter) by hand without touching the edge of the hole

7.3.1.5 Limitations

With any support for hand and arm available, the steadiness is increased, i.e. the diameter is smaller.

The data is based on participants who have no physical impairment. Effects of physical impairments such as Parkinson's disease or a disease that causes tremor of the hands should be taken into account when designing products requiring fine motor skills for their operation but currently no appropriate data is available.

7.3.1.6 Application examples

The data can be applied to the design of tools, controls and objects that require fine motor skills of the hands such as precise pointing, fine spatial orientation, threading a needle, etc.

7.3.1.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.3.2;

— Other references: none.

7.3.2 Eye-hand coordination (dexterity, ageing effect)

7.3.2.1 General

Movement that requires eye-hand coordination is involved in many activities of daily living, for example, pouring water from a jug into a cup, operation of touch displays or simply pushing buttons. Most of these actions require fine control of hands and fingers, i.e. dexterity.

This subclause provides data that show how the eye-hand coordination declines with age.

7.3.2.2 Sampled population

People in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.3.2.3 Methods and conditions of data collection

As shown in Figure 66, a pegboard task was used to measure eye-hand coordination. The participants were asked to insert all of 25 (5 × 5) pegs into the 5 by 5 array of holes as fast as possible, one peg at a time and using one hand only. The order of inserting the pegs was from left to right and from top to bottom. The time for the participants to insert all the 25 pegs into the holes was measured. The maximum time allowed for the test was 5 min.

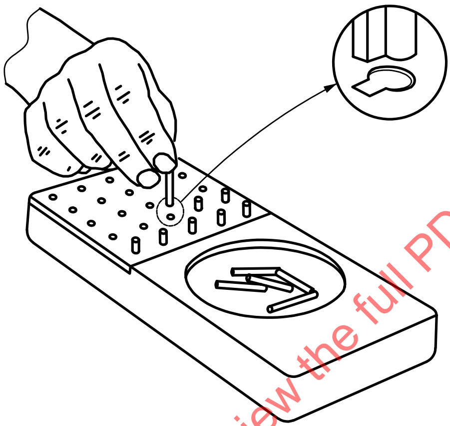


Figure 66 — A pegboard for measuring eye-hand coordination

7.3.2.4 Data

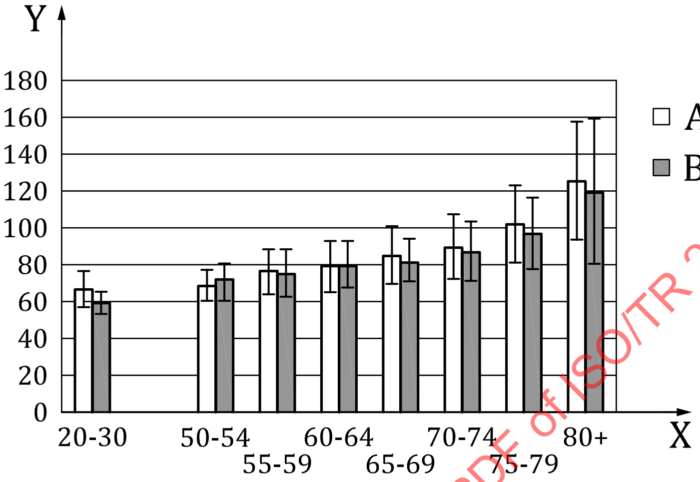
Table 18 and Figure 67 show mean time averaged over participants for different age and sex groups which are required for inserting 25 pegs as fast as possible into the holes on a peg board. In Figure 67, the standard deviation of each participant group is also shown. The time needed to perform the pegboard operation increases with age which means ability for fine hand manipulation decreases with age.

Table 18 — Mean pegboard operation times and standard deviations for men and women of different age groups

Age groups years	Men			Women		
	Number of participants, *n*	Mean s	Standard deviation, *s* s	Number of participants, *n*	Mean s	Standard deviation, *s* s
20–30	55	66,2	9,7	69	59,2	5,7
31–49	—	—	—	—	—	—
50–54	33	68,4	8,3	35	70,4	10,0
55–59	46	76,6	12,5	49	75,2	12,5
60–64	45	78,8	14,0	53	80,1	12,6
65–69	50	85,5	15,8	49	82,0	11,7
70–74	58	89,3	17,9	59	87,5	16,4
75–79	34	102,1	21,3	38	97,3	19,7

Table 18 *(continued)*

Age groups years	Men			Women		
	Number of participants, *n*	Mean s	Standard deviation, *s* s	Number of participants, *n*	Mean s	Standard deviation, *s* s
80+	32	125,8	32,2	34	119,9	38,8



Key

X age groups (years)

Y pegboard task completion time (s)

A men

B women

Figure 67 — Mean pegboard task completion times and standard deviations for men and women of different age groups

7.3.2.5 Limitations

Eye-hand coordination is affected by many factors such as illumination, temperature, tremor of fingers and hands when nervous, or wearing mittens or gloves. These effects are not included in the data should therefore be taken into account additionally when applying them.

7.3.2.6 Application examples

Eye–hand coordination data can be applied in designing products that need accurate positioning of pointing devices like computer cursors, fine tuning and sliding knobs, rotating controls, and opening and closing packages.

7.3.2.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.3.1;

— Other references: none.

7.4 Movement – functions of upper body structure

7.4.1 Reach range (effects of ageing and stature)

7.4.1.1 General

Reach envelope or reach range in upper limbs has a great effect on manipulating products placed not close to the user's body. The envelope depends on the range of motion in upper limbs, which decreases with age.

This subclause provides age related changes of reach range when standing and sitting.

7.4.1.2 Sampled population

People in different age groups from 20 to over 75 years participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

For vertical measurements in standing, participants were classified into three age groups of 20–30, 50–74, and over 75 years. Each age group was then divided into two groups in stature, the taller and the shorter. In total, data for six groups were obtained.

For horizontal measurements in sitting position, the same participants were classified into two age groups, 20–30 years and over 50 years, and only the group over 50 years was then divided into the taller and the shorter group in stature. In total, data for three groups were collected.

7.4.1.3 Methods and conditions of data collection

In the measurements of vertical reach range, the data were taken by asking participants to mark with their right arm the distances and angles within comfortable reach, and the maximum reach on the vertical plane on the right side. The comfortable reach is a reach without bending the body forwards, and the maximum reach is a reach while keeping both legs stretched and bending the trunk.

In the measurements of horizontal reach range, the data were taken by asking participants to mark with their right arm the distances and angles within a comfortable reach, and the maximum reach on the horizontal plane at elbow height. The comfortable reach is a reach without bending the body forwards and the maximum reach is a reach while bending the trunk.

7.4.1.4 Data

Table 19 provides mean reach range data of the comfortable and the maximum vertical reach when standing for six participant groups of different ages and statures. The data are presented at 6 angles from the horizontal line to the vertical line in 15° steps with the origin point at the participants' feet. The symbol *n* is the number of participants who reached the related radius among total number of each group.

Figure 68 a) and b) shows graphical representations of mean reach range of the comfortable and the maximum reach respectively for 6 typical groups divided into three different age groups (20–30, 50–74, over 75 years) and two different stature groups (shorter, taller), respectively.

Table 19 — Reach range of the vertical reach when standing for different age and stature groups

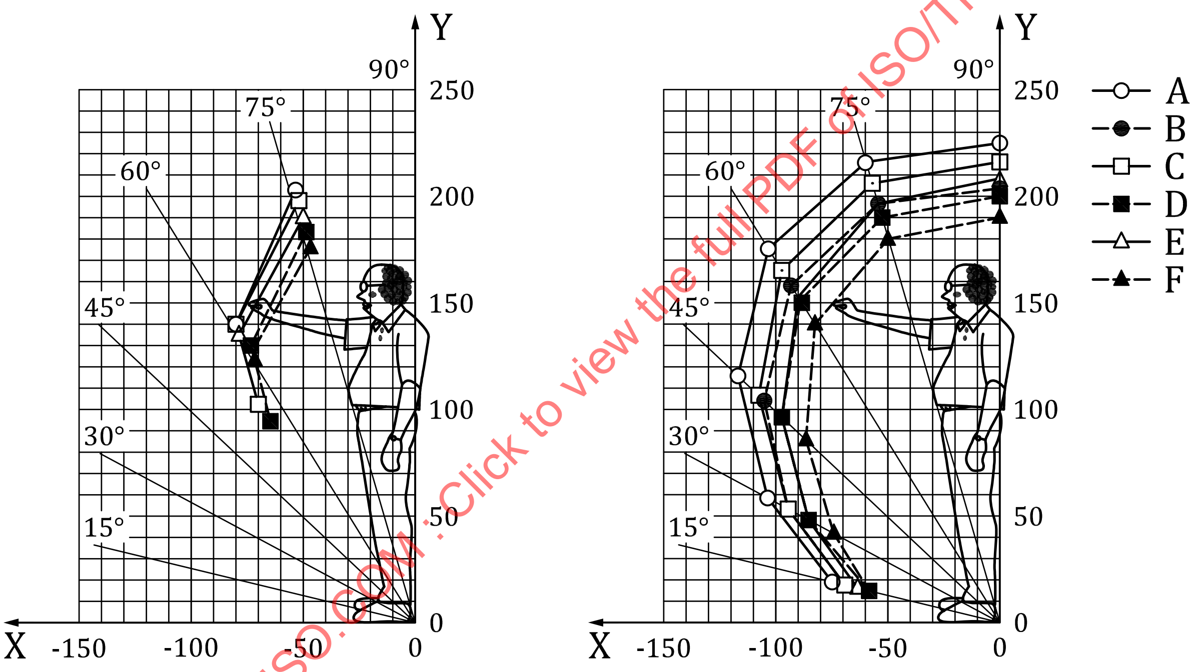
Age groups years	Stature cm	Radius °	Comfortable Number of participants *n*	Comfortable Mean radius cm	Maximum Number of participants *n*	Maximum Mean radius cm
20–30	≥175	90	—	—	54	225

Table 19 *(continued)*

Age groups years	Stature cm	Radius °	Comfortable Number of participants *n*	 Mean radius cm	Maximum Number of participants *n*	 Mean radius cm
		75	29	209	62	225
		60	46	161	62	204
		45	—	—	62	165
		30	—	—	50	120
		15	—	—	24	77
Total number of participants			62			
20–30	<175	90	—	—	49	204
		75	34	191	60	204
		60	49	147	60	184
		45	—	—	60	149
		30	—	—	53	110
		15	—	—	27	73
Total number of participants			60			
50–74	≥170	90			140	216
		75	135	205	207	214
		60	188	160	209	149
		55	20	125		
		45	—	—	202	152
		30	—	—	143	109
		15	—	—	43	72
Total number of participants			209			
50–74	<170	90	—	—	182	199
		75	179	189	259	198
		60	231	149	258	176
		55	30	115		
		45	—	—	250	138
		30	—	—	172	99
		15	—	—	85	63
Total number of participants			259			
75+	≥165	90			32	210
		75	41	197	63	205
		60	50	157	63	178
		45	—	—	55	138
		30	—	—	29	98
		15	—	—	13	66
Total number of participants			64			

Table 19 *(continued)*

Age groups years	Stature cm	Radius °	Comfortable		Maximum	
			Number of participants *n*	Mean radius cm	Number of participants *n*	Mean radius cm
75+	<165	90	—	—	27	191
		75	50	183	71	189
		60	64	145	72	165
		45	—	—	60	123
		30	—	—	35	86
		15	—	—	11	59
Total number of participants			74			



a) Comfortable reach range   b) Maximum reach range

Key

X horizontal distance (cm)
Y vertical distance (cm)
A 20–30 years, ≥175 cm
B 20–30 years, <175 cm
C 50–74 years, ≥170 cm
D 50–74 years, <170 cm
E 75+ years, ≥165 cm
F 75+ years, <165 cm

NOTE The person in the graph illustrates the method of reaching but not the respective stature.

Figure 68 — Reach ranges of the vertical reach when standing for six groups of different ages and statures

Table 20 provides the range data of the comfortable reach and the maximum horizontal reach while sitting, for three different groups in age and stature. The symbol *n* is the number of people who reached the related radius among the total number of participants of each group.

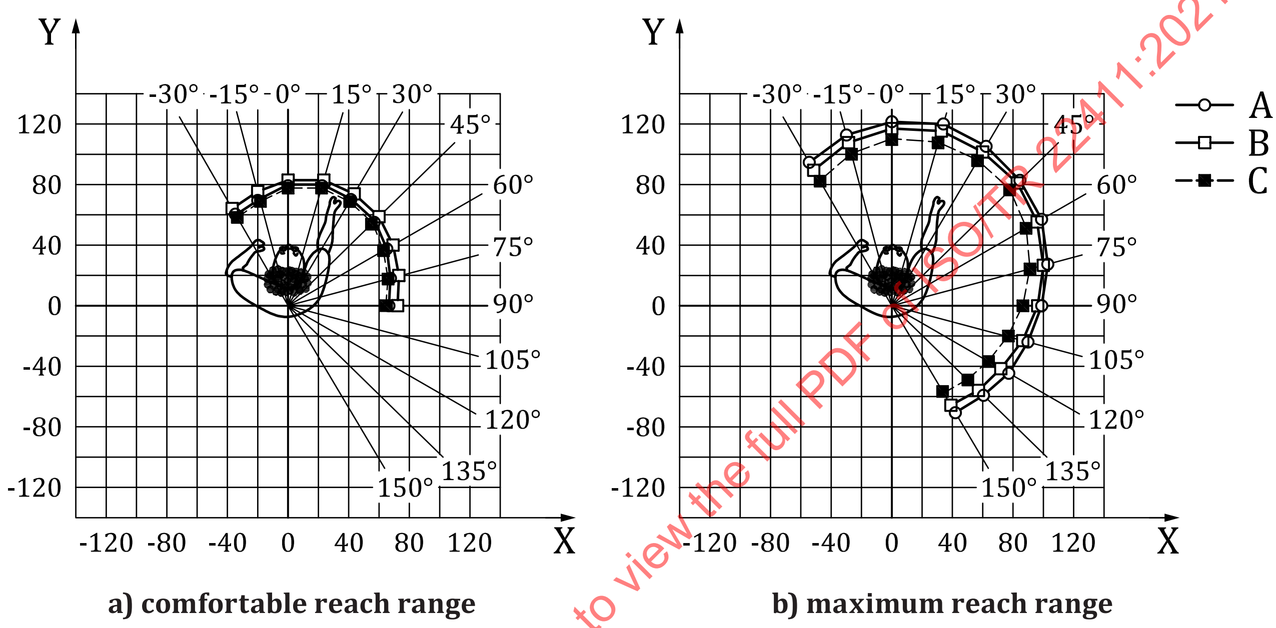
Figure 69 a) and b) shows graphical representation of the data of the comfortable and the maximum reach, respectively, for the three groups of different age and different stature.

Table 20 — Reach ranges of the horizontal reach when sitting for different age and stature groups

Age groups years	Stature cm	Radius °	Comfortable		Maximum	
			Number of participants, *n*	Mean radius cm	Number of participants, *n*	Mean radius cm
20–30	—	−30	63	69	91	108
		−15	99	75	117	116
		0	116	79	117	120
		15	117	81	117	121
		30	117	81	117	120
		45	114	79	117	117
		60	102	76	117	112
		75	87	72	117	105
		90	67	68	117	98
		105	—	—	114	92
		120	—	—	114	88
		135	—	—	111	83
		150	—	—	48	82
Total number of participants			117			
50+	≥170	−30	169	73	190	103
		−15	233	79	251	112
		0	247	84	251	117
		15	250	86	251	119
		30	249	86	251	118
		45	245	84	251	115
		60	236	80	250	109
		75	207	76	250	102
		90	180	72	247	95
		105	—	—	239	89
		120	—	—	229	83
		135	—	—	212	79
		150	—	—	77	76
Total number of participants			361			
50+	<170	−30	246	70	259	95
		−15	330	72	358	103
		0	355	82	360	109
		15	359	84	361	110
		30	360	83	361	110
		45	359	81	361	107
		60	341	76	359	101
		75	314	70	358	93
		90	264	66	354	85
		105	—	—	340	79
		120	—	—	327	73

Table 20 *(continued)*

Age groups years	Stature cm	Radius °	Comfortable		Maximum	
			Number of participants, *n*	Mean radius cm	Number of participants, *n*	Mean radius cm
		135	—	—	289	69
		150	—	—	72	68
Total number of participants			361			



Key

X right-left axis (cm)

Y forward-backward axis (cm)

A 20–30 years

B 50+ years, ≥170 cm

C 50+ years, <170 cm

Figure 69 — Reach ranges of the horizontal reach when sitting for three groups of different ages and statures

7.4.1.5 Limitations

The maximum reach ranges while standing are data taken while keeping both legs stretched and bending the trunk. The comfortable range is for the case without bending the trunk. Care should be taken since different postures can produce different reach ranges.

Anthropometric parameters such as body size and arm length affect the reach range as well. Geographic regional differences should be taken into consideration when applying these data. Smaller reach ranges are more critical for design purposes.

7.4.1.6 Application examples

When using these data for practical situations such as designing equipment and dwelling spaces, it is necessary to consider also the physical characteristics of the persons who use the equipment or spaces as well as the situations those are used.

The data on comfortable reach range can be used for situations in which individuals have to reach frequently for products and/or parts in dwelling spaces. The optimum location for those objects or components can be appropriately determined using data.

The data on maximum reach range also can be used for situations in which individuals have to reach for light-weight products or for situations in which products have to be reached for only occasionally.

In both cases, it is important to ensure that the design items, equipment or spaces are within the smallest reach envelopes among the user population.

7.4.1.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.4.2, 7.4.3;

— Other references: none.

7.4.2 Reach range (graspability, female 5th percentile of body size)

7.4.2.1 General

The extent of reach range of hands changes not only with body size but also with the type of body action or operation of products.

This subclause provides the reach range in terms of graspability which means the range a person can grasp an object by hand but not simply reaching it. The data is shown for only women with the 5th percentile of body size which is typically used as the minimum case for the reach range.

7.4.2.2 Sampled population

Female participants with body size in the 5th percentile were tested.

7.4.2.3 Methods and conditions of data collection

The data were taken for one handed use (either the right or the left hand) asking the participants to grasp an object with three fingers on a work surface 750 mm high.

The data are summarized in DIN-Fachbericht 124 which are based on data derived from DIN 15996 but slightly adapted due to investigations on human body dimensions published in DIN 33402-2 and ISO 14378.

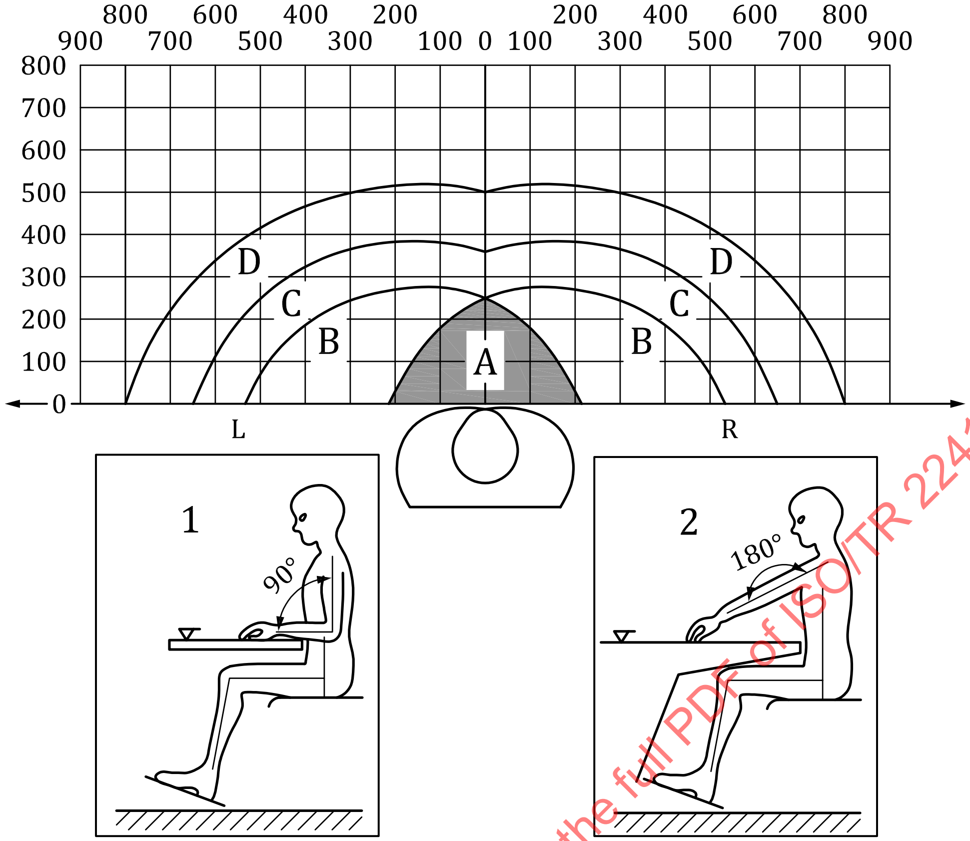
7.4.2.4 Data

Figure 70 shows reach range for grasping measured for women of 5th percentile of body size at a work surface height of 750 mm together with two postures of bent arm and stretched arm.

The data are for one-handed use (right and left hand were treated equally) and, though data are available both for sitting and standing in a working space, they are generally assumed for use in the sitting position.

The optimum grasping area is reachable in an upright posture with bent arm, elbow joint 90°, while the functional grasping area is reachable in an upright posture with stretched arm, elbow joint 180° (see Figure 70). Accessing the extended grasping area requires bending of the upper body.

Dimensions in millimetres



Key

A optimum grasping area for both hands (envelope curves)
B optimum grasping area (envelope curves)
C functional grasping area (envelope curves)
D extended grasping area (envelope curves)
L left hand
R right hand
1 upright seating posture with bent arm, e.g. elbow joint 90°
2 upright seating posture with stretched arm, e.g. elbow joint 180°

Figure 70 — Reach range for grasping

7.4.2.5 Limitations

The data show only results for females of 5th percentile of body size. This group is regarded as the most critical in terms of setting the limits on the distance at which items that need to be grasped can be located.

7.4.2.6 Application examples

Though the data is available both for sitting and standing in working space, they are generally assumed for use in the sitting position.

7.4.2.7 References

— Data source: Reference [3];

— Cross-references in this document: 7.4.1, 7.4.3;

— Other references: References [4], [5] and [7].

7.4.3 Reach range in three dimensions of height, forward distance (depth), and left-right width for older people and people with disabilities (rheumatism and Parkinson's disease)

7.4.3.1 General

The reaching and grasping range of a person is important when retrieving an object from a storage area, a shelf or a table while standing or sitting.

This subclause provides reach ranges for height, forward distance (depth), and left-right at which it is easy to reach and to pick up an object. These data can be used, for example, for designing furniture or living spaces.

As the range is affected by physical disabilities, the data are shown not only for older people, but also for people with conditions such as rheumatism and Parkinson's disease.

7.4.3.2 Sampled population

Japanese older people, people with rheumatism and people with Parkinson's disease participated. The number of the participants in each group and their profiles of physical characteristics are shown in Table 21. The numbers of participants with physical disabilities were rather limited.

Table 21 — Profile of physical characteristics of participants

Number and physical characteristics	Older people	People with Rheumatism	People with Parkinson's disease
Number of participants	28	6	6
Age (years)	67,3 (4,2)	64,8 (7,9)	68,8 (3,0)
Stature (cm)	165,3 (7,7)	148,8 (9,4)	156,1 (16,5)
Eye height (cm)	147,6 (7,1)	133,9 (8,1)	139,1 (16,1)
Shoulder height (cm)	134,7 (6,7)	121,3 (7,4)	126,7 (14,1)
Hip height (cm)	88,1 (5,2)	83,1 (3,3)	85,2 (4,7)
Eye height in sitting (cm)	113,9 (6,9)	97,6 (7,3)	101,2 (8,8)
Shoulder height (cm)	106,9 (6,0)	89,2 (7,6)	93,1 (8,4)
NOTE Figures in parenthesis are standard deviations.			

7.4.3.3 Methods and conditions of data collection

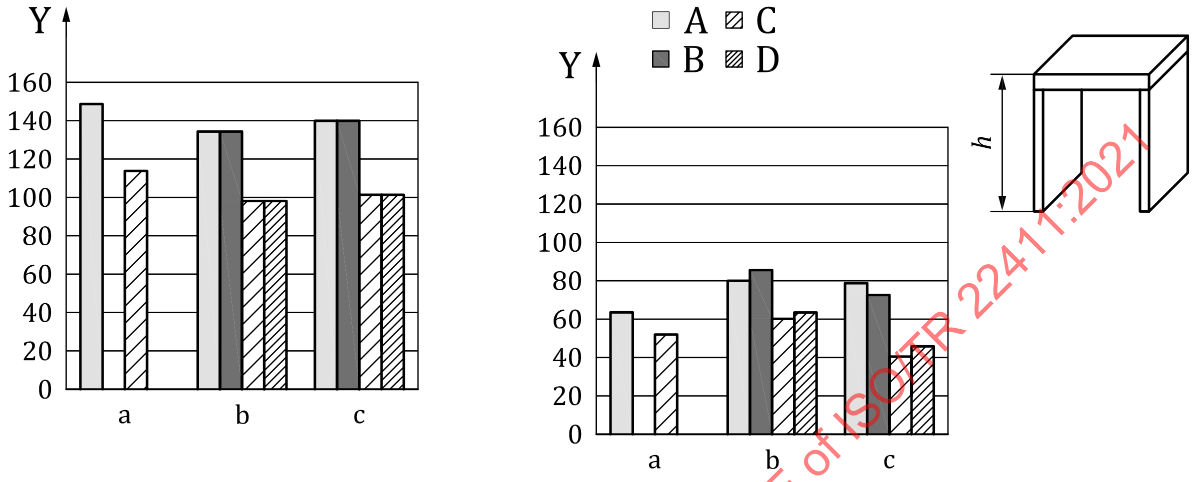
The reach range was measured as the range for the participant to easily reach for and grasp an object by one hand and with both hands while standing and sitting. The participants stretched their hand(s) as though to grasp an object and the maximum range at which the participants felt comfortable was measured. The measurements were carried out for three directions, height, forward distance (horizontal reach in front) and left-right width (horizontal range of left to right). A 3D measurement system was used to measure all the movements of the participants. The measurements were carried out for upper and lower limits of the height, for three height level (eye, shoulder and hip) for the forward distance and left-right width measurements.

A mechanical guide was used to show the direction of movement for participants with rheumatism or with Parkinson's disease.

7.4.3.4 Data

Figures 71 to 73 show the data for reach range in height, forward distance and left-right width direction, respectively, for older people and people with physical disabilities.

Comparing the data for physical disabilities with those for older people, the ranges for three directions are significantly limited to from two thirds to a half for people with rheumatism, but not so much for people with Parkinson's disease. The biggest differences for people with Parkinson's disease are seen for the left-right width direction which means they have a difficulty moving their hands left to right. This effect also reflects the reduced range for the forward distance direction for the one-hand side condition (to move and stretch the hand to the side of the body).



a) Upper limit

b) Lower limit

Key

Y reach range, height (cm)

A standing, one hand

B standing, both hands

C sitting, one hand

D sitting, both hands

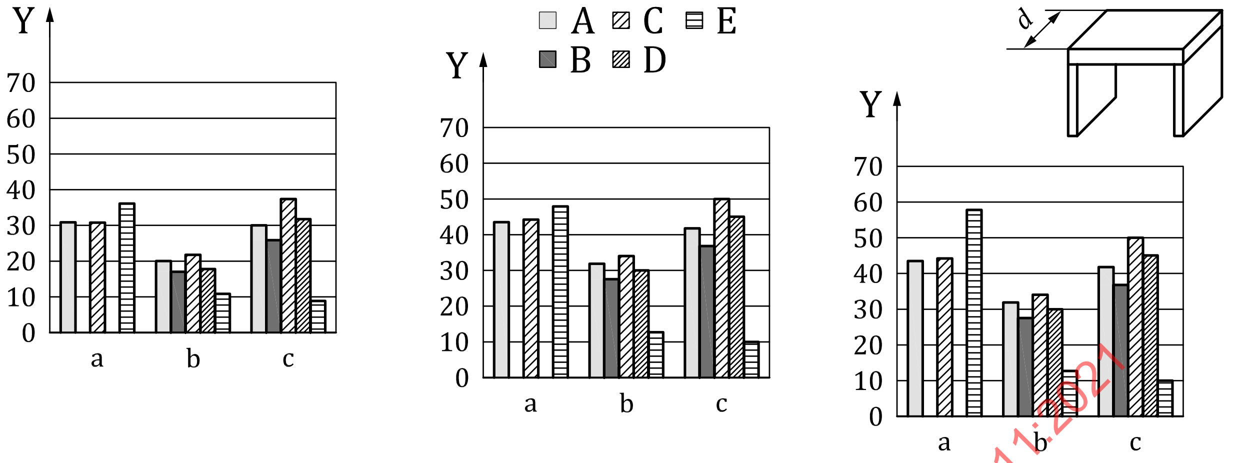
a older people

b people with rheumatism

c people with Parkinson's disease

h height

Figure 71 — Reach range for height for older people, people with rheumatism, and people with Parkinson's disease



a) **Eye-height level** b) **Shoulder-height level** c) **Hip-height level for standing or 70 cm for sitting**

Key

Y reach range, forward distance (cm)

A standing, one hand

B standing, both hands

C sitting, one hand

D sitting, both hands

E sitting, one hand side

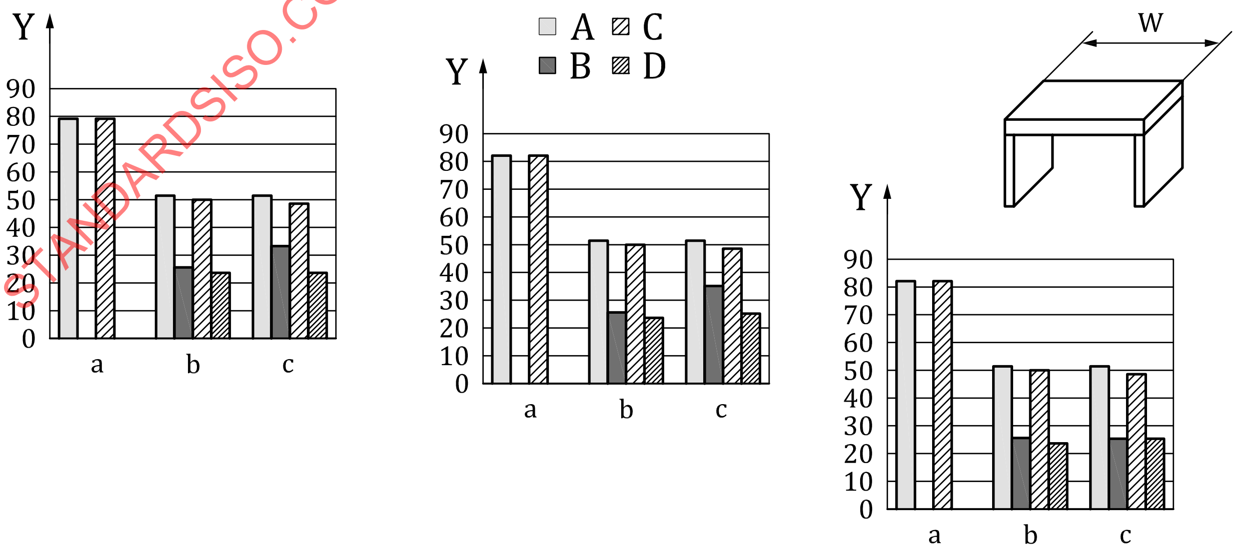
a older people

b people with rheumatism

c people with Parkinson's disease

d forward distance

Figure 72 — Reach range for forward distance for older people, people with rheumatism, and people with Parkinson's disease



a) **Eye-height level** b) **Shoulder-height level** c) **Hip-height level**

Key

Y reach range, left-right width (cm)

A standing, one hand

B standing, both hands

C sitting, one hand

D sitting, both hands

a older people

b people with rheumatism

c people with Parkinson's disease

w left-right width

Figure 73 — Reach range for left-right width for older people, people with rheumatism, and people with Parkinson’s disease

7.4.3.5 Limitations

The number of participants with disabilities was limited in this assessment and the individual differences affected the extent of disabilities. The present data only provide a reference data source for people with Parkinson's disease. More data is needed to obtain a general feature for people with disabilities.

7.4.3.6 Application examples

The data can be applied to designing living spaces and home appliances and furniture. A kitchen system is one example. The data can also be applied to tables for displaying objects at exhibitions, for example, where visitors with rheumatism or Parkinson’s disease can have difficulty in picking up an object displayed on the table due to their limited range of reach.

7.4.3.7 References

— Data source: Reference [114];

— Cross-references in this document: 7.4.1, 7.4.2;

— Other references: none.

7.4.4 Rotation: pronation and supination (ageing effect)

7.4.4.1 General

Movement of a wrist is important when people handle and manipulate products and controls. This movement is also important when people use fingers as the finger movements are always associated with movement of a wrist.

This subclause provides data on maximum angle of wrist rotation inward and outward, i.e. pronation and supination.

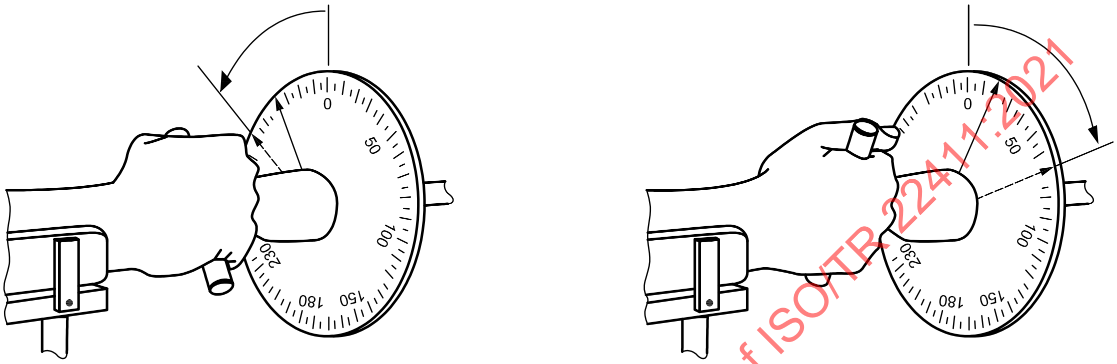
7.4.4.2 Sampled population

People in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.4.4.3 Methods and conditions of data collection

Pronation and supination were measured with a device with a T-shaped handle as shown in Figure 74. The hand and the fully supported lower arm were in line, and the participant turned his/her wrist inward or outward from the thumb-up position of the fist without moving the lower arm and the hand remains in the fist.

The data of pronation and supination were measured as maximum values. The data in Table 22 and Table 23 represent the 5th percentile of those maximum values, which is meaningful for designing.



a) Pronation **b) Supination**

Figure 74 — A device for measuring pronation and supination

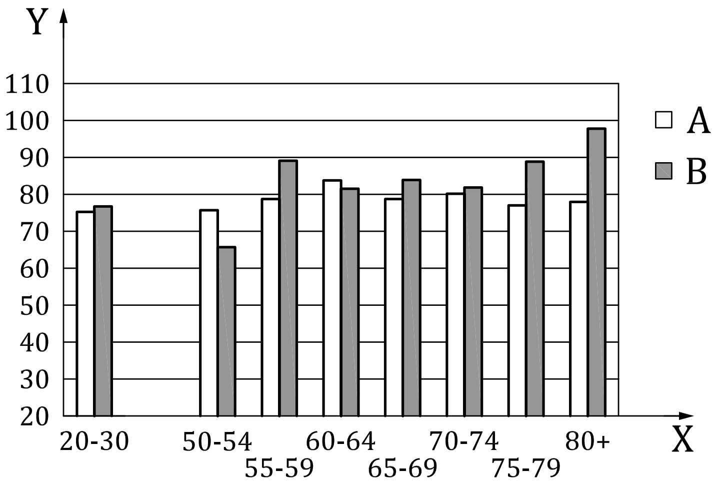
7.4.4.4 Data

The data of Table 22 and Figure 75 show the maximum inward rotation of a wrist (pronation). Table 23 and Figure 76 show the maximum outward rotation of a wrist (supination). The data show only the 5th percentile data (denoted as P_5).

The data show that the women's wrist is more flexible than the men's one, but almost no ageing or slightly enhanced ageing effect of flexibility was observed for inward rotation (pronation) while ageing effect of reduced range is observed for outward rotation (supination).

Table 22 — Maximum inward rotation of the wrist (pronation) for men and women of different age groups

Age groups years	Men		Women	
	Number of participants *n*	5th percentile, P_5 °	Number of participants *n*	5th percentile, P_5 °
20–30	55	75	68	77
31–49	—	—	—	—
50–54	35	76	35	66
55–59	46	79	50	89
60–64	44	84	53	82
65–69	50	79	51	84
70–74	59	80	62	82
75–79	36	77	38	89
80+	33	78	35	98
NOTE Only P_5 data are available.				



Key

X age groups (years)

Y maximum rotation angle inward (P_5 data in degrees)

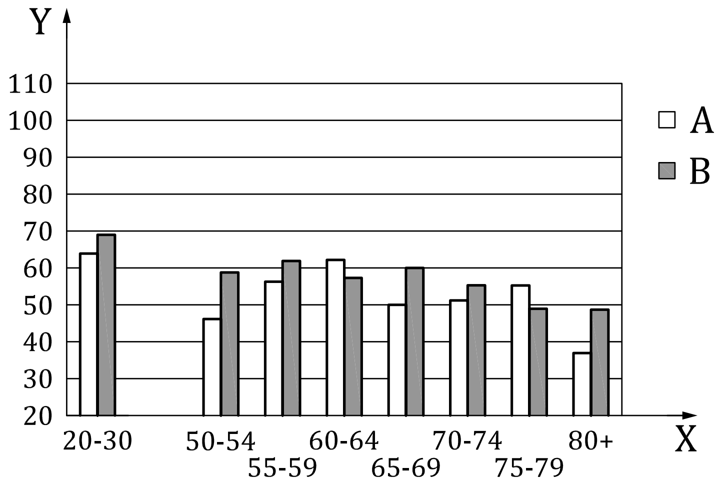
A men

B women

Figure 75 — Maximum inward rotation of the wrist (pronation) for different age groups (P_5 data)

Table 23 — Maximum outward rotation of the wrist (supination) for different age groups

Age groups years	Men		Women	
	Number of participants *n*	5th percentile, P_5 °	Number of participants *n*	5th percentile, P_5 °
20–30	55	64	68	69
31–49	—	—	—	—
50–54	35	46	35	59
55–59	46	56	50	62
60–64	44	62	53	57
65–69	50	50	51	60
70–74	59	51	62	55
75–79	36	55	38	49
80+	33	37	35	49
NOTE Only P_5 data are available.				



Key

X age groups (years)

Y maximum rotation angle outward (P_5 data in degree)

A men

B women

Figure 76 — Maximum outward rotation of the wrist (supination) for different age groups (P_5 data)

7.4.4.5 Limitations

The data of pronation and supination shown here were measured as maximum values. The data in Table 22 and Table 23 represent the 5th percentile of those maximum values, which are meaningful as the minimum values in designing products.

7.4.4.6 Application examples

The data can be applied to the position of hand-held objects or controlling parts (especially for rotational manipulation) such as a cap on a bottle, a key or a screwdriver, etc.

7.4.4.7 References

— Data source: Reference [97];

— Cross-references in this document: none;

— Other references: none.

7.5 Movement – Functions of lower body structure

7.5.1 Step height (ageing effect)

7.5.1.1 General

The height of a step or stairs is one of the important design issues in buildings and transportations. Some national regulations already prescribe the dimensions of steps for accessibility and safety reasons. However, it is not clear whether those dimensions are suitable for older people, in particular, for older women.

This subclause provides data on a step height for ascending and descending a single step comfortably or with maximum acceptable effort.

7.5.1.2 Sampled population

People in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.5.1.3 Methods and conditions of data collection

A step height was measured by the following four criteria:

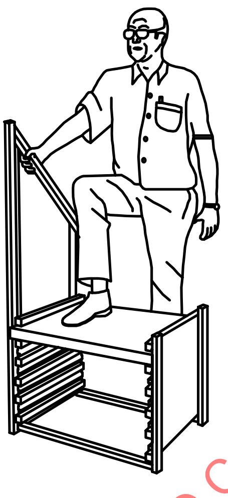
— comfortable height of a step to ascend;

— comfortable height of a step to descend;

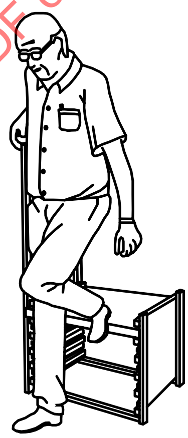
— maximum acceptable height of a step to ascend;

— maximum acceptable height of a step to descend.

The measuring equipment consisted of a frame as shown in Figure 77 in which a plank was inserted at different heights. The frame had one sloping handrail. The participant was asked to step on or step down on a single plank set at a given height and to evaluate the height which comfortable or maximum acceptable for ascending and descending stairs.



a) Ascending



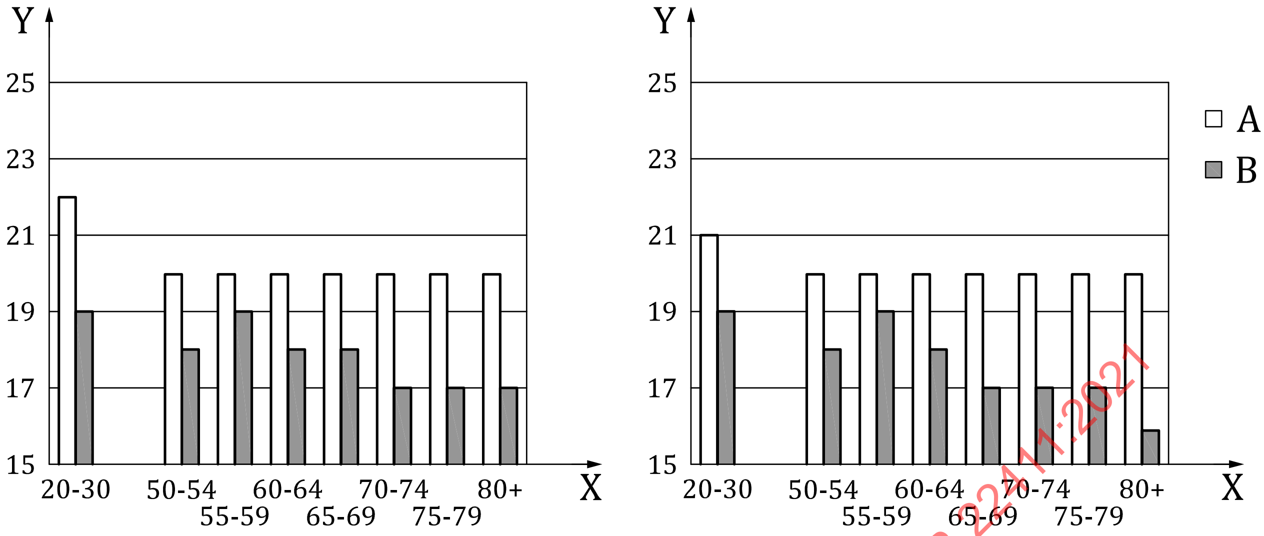
b) Descending

Figure 77 — An experimental method for measuring a step height ascending and descending

7.5.1.4 Data

Figure 78 and Figure 79 show the data of step height evaluated as comfortable and the maximum acceptable height respectively. They both include the data for ascending and descending.

The step height for men is much larger than that for women for both the comfortable and maximum acceptable conditions. The ageing effect was also observed but not demonstrated clearly for men in case of the comfortable step height condition.



a) **Comfortable step height, ascending**

b) **Comfortable step height, descending**

Key

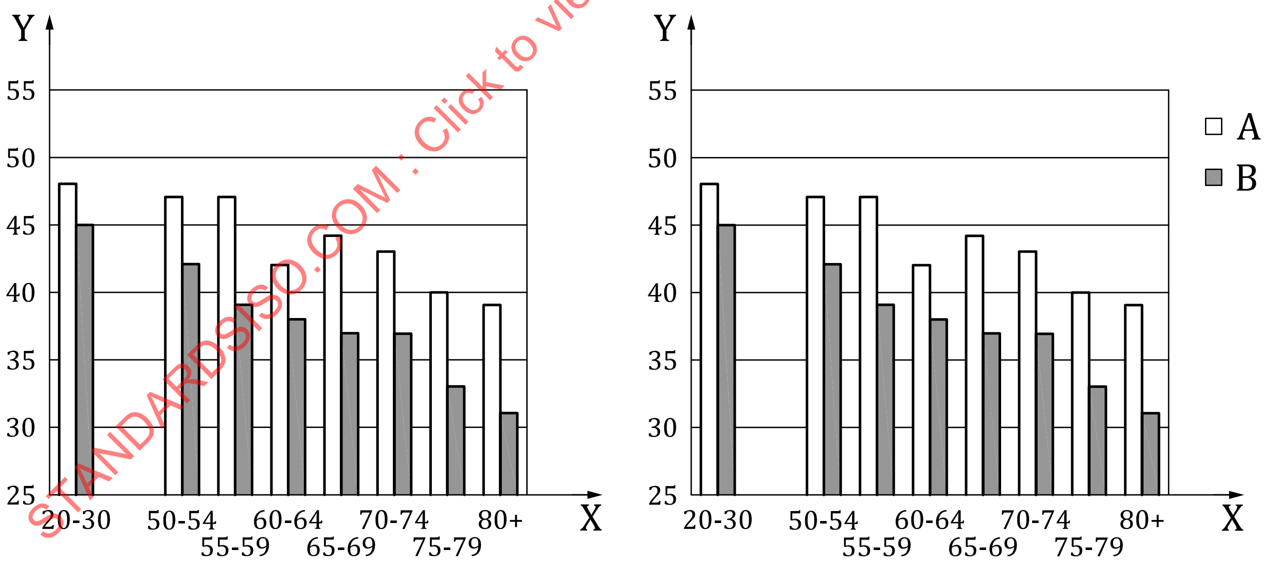
X age groups (years)

Y step height (cm)

A men

B women

Figure 78 — Comfortable step height of men and women of different age groups



a) **Maximum step height, ascending**

b) **Maximum step height, descending**

Key

X age groups (years)

Y step height (cm)

A men

B women

Figure 79 — Maximum acceptable step height for men and women of different age groups

7.5.1.5 Limitations

The data were obtained for a single step but not for several consecutive steps (stairs). The data can be influenced by many of other factors such as leg length of individual participants, ability to keep body balance and slope of the step or stairs.

Care should be taken whether handles or grips are available in the right place. The present data is for the case where a handrail is available.

7.5.1.6 Application examples

The data can be used for designing a single step in buildings or in transportation (buses, trains, aircraft, etc.).

7.5.1.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.5.2;

— Other references: none.

7.5.2 Step height: Subjective evaluation of physical load (ageing effect, international comparison)

7.5.2.1 General

A comfortable or maximum step height depends on body dimensions. Therefore, it is important to compare step heights among different countries with different body sizes.

This subclause provides data on the subjective evaluation of a step height taken from four countries, Germany, Rep. of Korea, Japan and the USA, for international comparison using the same method and conditions.

7.5.2.2 Sampled population

Each country recruited 15 to 20 participants in the experiment for each category, young/male, young/female, older/male and older/female.

7.5.2.3 Methods and conditions of data collection

Each of the four countries used the same experimental method and condition for the evaluation of step height. The participants were asked to ascend a single step with a given height and to evaluate perceived physical effort of the action of ascending by using a 10-point scale from 0 to 9, where 0 means "no effort" and 9 means "maximum effort". The same procedure applied for the descending. No handrail was available (see Figure 80).

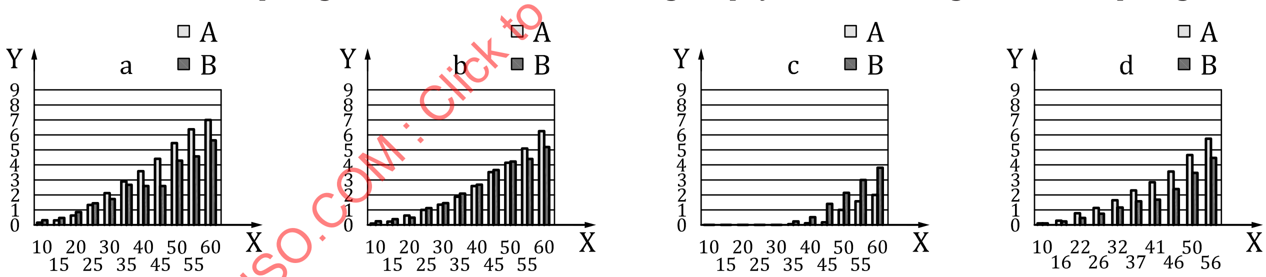
a) **Ascending** b) **Descending**

Figure 80 — Experimental method for perceived physical effort in ascending and descending a single step

7.5.2.4 Data

Figure 81 and Figure 82 show two sets of data on subjective evaluation of perceived physical effort as a function of step height for ascending (Figure 81) and descending (Figure 82). Each set contains data from the 4 countries, averaged for young and older participants.

The data provide a general feature of the load of ascending and descending a step with variable step height. There is no critical step height that causes sudden change in physical load along with the step height.



Key

X step height (cm)

Y evaluation score of physical load

A young people

B older people

a Germany

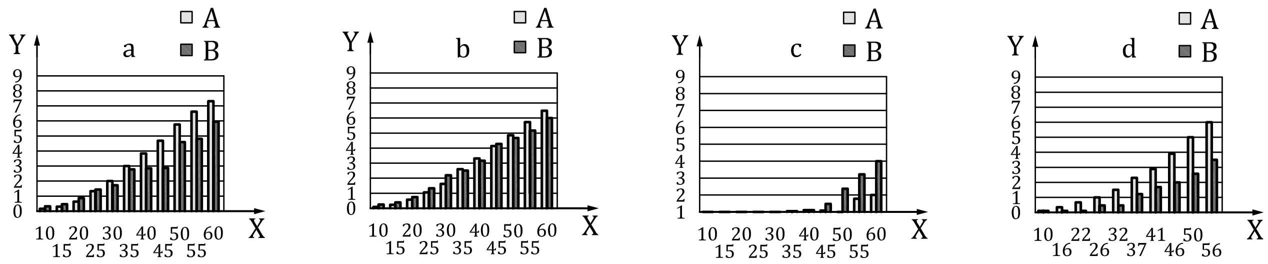
b Japan

c Rep. of Korea

d USA

NOTE Sampling of step height in the USA is slightly different from other countries.

Figure 81 — Subjective evaluation for ascending a single step respectively measured in four countries for young and older people



Key

X step height (cm)

Y evaluation score of physical load

A young people

B older people

a Germany

b Japan

c Rep. of Korea

d USA

NOTE Sampling of step height in the USA is slightly different from other countries.

Figure 82 — Subjective evaluation for descending a single step respectively measured in four countries for young and older people

The data for the 4 countries show that physical effort gradually increases as a function of step height. The trend of the data for Germany, Japan and the USA are similar but the Korean data are slightly different from them. In the Republic of Korea, the perceived effort is greater for older people than for young people with no great difference between ascending and descending.

7.5.2.5 Limitations

The data were measured for a single step but not for stairs which consist of several steps. No handrail was available. If a handrail or any other support is used, the required physical effort is considerably reduced. The number of countries was limited to four: two in Asia, one in Europe and one in North America, but the data seem to reflect common features.

7.5.2.6 Application examples

The data can be used for designing a single step and stairs in buildings or in transportation (buses, trains aircrafts, etc.).

7.5.2.7 References

— Data source: Reference [72];

— Cross-references in this document: 7.5.1;

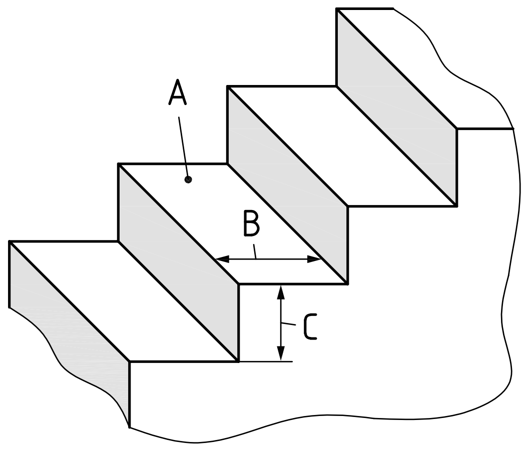
— Other references: none.

7.5.3 Tread depth of stairs (ageing effect)

7.5.3.1 General

The depth of tread of stairs, as shown in Figure 83, is one of the important factors influencing ease of going up and down stairs. The stairs in public spaces, buildings, trains and buses, as well as in private homes, should have appropriate dimensions of tread depth to ensure safety and comfort walking on stairs.

This subclause provides data concerning subjective evaluation of tread on ease of walking as a function of its depth for young and older people.



Key

A tread

B tread depth

C rise height

Figure 83 — Stairs and their dimensions

7.5.3.2 Sampled population

Participants were 20 young people and 30 older people. The average age, stature and weight of the young participants were 24,0 years, 1,740 m, and 68,0 kg, respectively, and those of older participants were 70,3 years, stature 1,572 m, and 57,2 kg.

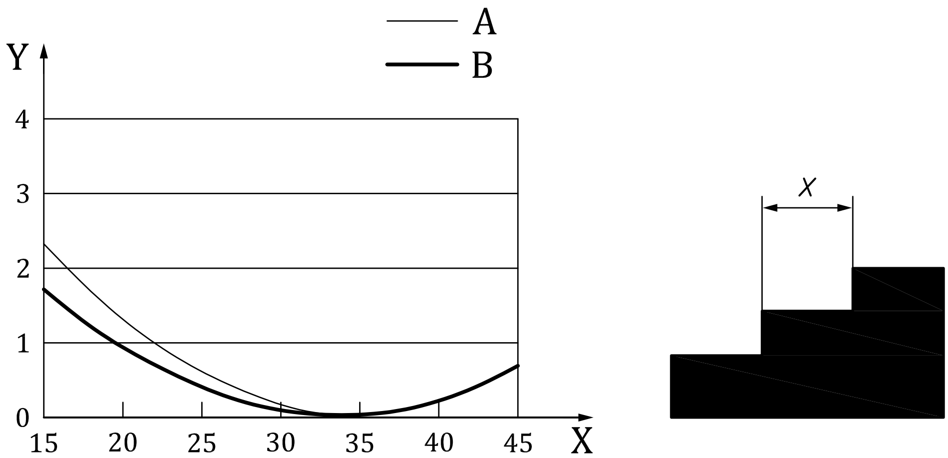
7.5.3.3 Methods and conditions of data collection

Using a 7-steps stairway with variable rise height, and variable tread depth, each participant was asked to ascend and descend the stairway at his/her comfortable pace while being allowed to use a handrail. After ascending and descending the stairway, the participants evaluated the combined feeling of muscular effort and difficulty of walking by using a 5-point scale from 0 (no effort and difficulty) to 4 (very strong feeling of effort and difficulty).

7.5.3.4 Data

As shown in Figure 84, the relationship between tread dimension and subjective evaluation on the muscular effort and difficulty of walking can be formulated by a quadratic polynomial (probability and significance level, $p < 0{,}001$). The load and difficulty are lowest at around 35 cm of tread for both younger and older people. There is a slight increase of the difficulty but no difference in age is seen. Below the minimum point, i.e. shorter than 35 cm, the muscular effort and walking difficulty gradually increase again as a function of the reduction in tread depth. The effect of reduction in tread depth is relatively higher for younger people than for older people. The reason that treads shorter than 35 cm are more difficult for younger people than for the older ones is not clear but foot length might be one of the affecting factors for this.

NOTE The important point emerging from this study is a tread depth about 35 cm to be used in the design of stairs at which both younger and older people feel easiest walking and experience the least muscle load.



Key

X tread depth (cm)

Y subjective evaluation of muscular effort and walking difficulty (0: no effort and difficulty and 4: very strong feeling of effort and difficulty)

A young people

B older people

Figure 84 — Relationship between tread depth and subjective evaluation on stair-walking effort and difficulty

7.5.3.5 Limitations

The data are valid only when no handrail is available.

7.5.3.6 Application examples

By using Figure 84, the subjective evaluation of the muscular effort and the difficulty of walking can be determined when the tread dimension is given, which is useful data for designing steps and stairs

The data can be used for designing stairs in buildings or in transportation (buses, trains, aircrafts, etc.) with regard to subjective evaluation of muscular effort and difficulty for walking stairs.

7.5.3.7 References

— Data source: Reference [115];

— Cross-references in this document: 7.5.1, 7.5.2;

— Other references: none.

7.5.4 Walking speed (ageing effect)

7.5.4.1 General

Walking is one of the most fundamental movements in daily life. Ageing also affects walking speed. For example, older people need more time to pass automatic doors or to use pedestrian crossings for examples. It is very unpleasant for older people to be forced to walk at a pace other than their normal pace.

This subclause provides data for normal and hurried walking pace in the Netherlands and for normal pace in Japan.

7.5.4.2 Sampled population

A total number of about 750 people (about 360 men and 390 women) in different age groups from 20 to over 80 years participated in the measurements conducted in the Netherlands in 1995 and 1996.

For the Japanese data, 790 men and 839 women (total 1 629) took part in the measurements. They were aged between 0 to 79 years and have been divided into groups in 5 years steps. The age range of 0–4 actually starts from 1,5 years (see NOTE in Figure 86).

7.5.4.3 Methods and conditions of data collection

In the Netherlands data, the participants were asked to walk 10 m at a normal and a hurried pace. The normal pace means the speed that the participant usually adopts when walking outside. The hurried pace is the speed the participant adopts when catching a bus or a train, for example, but without running. The measurements were carried out in a flat indoor room.

The measurements in Japan were carried out for a walking distance of 50 m at a normal pace.

7.5.4.4 Data

Table 24 and Table 25 present the data of walking speed for Dutch people at two walking paces, normal and hurried, respectively. Figure 85 shows these data with standard deviations. The walking speed decreases with age, and men walk faster than women at both speeds.

Table 24 — Walking speed at a normal pace for Dutch people in different age groups

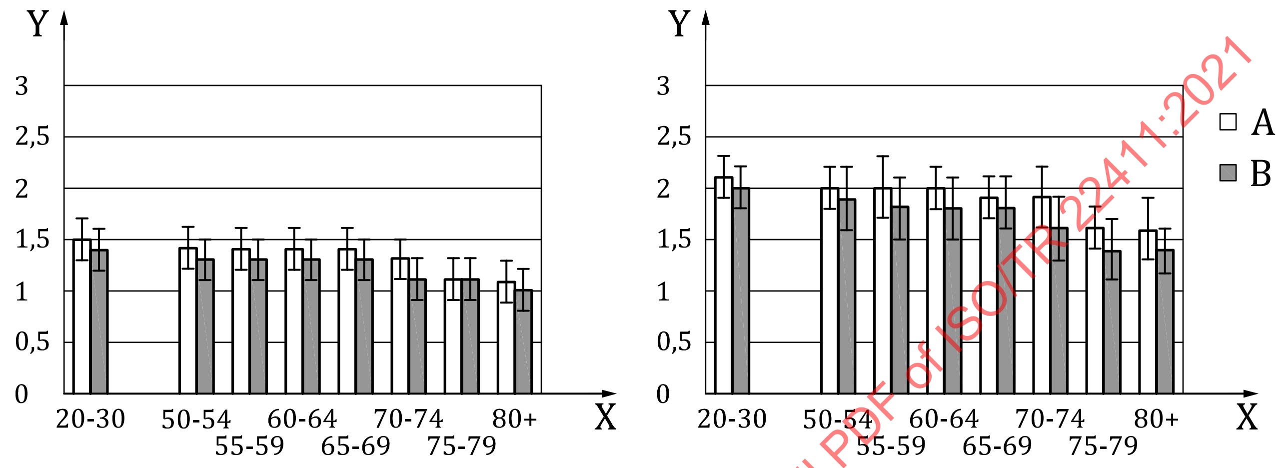
Age groups years	Men			Women		
	Number of participants *n*	Mean m/s	Standard deviation *s*	Number of participants *n*	Mean m/s	Standard deviation *s*
20–30	55	1,5	0,2	68	1,4	0,2
31–49	—	—	—	—	—	—
50–54	35	1,4	0,2	35	1,3	0,2
55–59	46	1,4	0,2	50	1,3	0,2
60–64	44	1,4	0,2	53	1,3	0,2
65–69	50	1,4	0,2	51	1,3	0,2
70–74	59	1,3	0,2	62	1,1	0,2
75–79	36	1,1	0,2	38	1,1	0,2
80+	33	1,1	0,2	34	1,0	0,2

Table 25 — Walking speed in a hurried pace of Dutch people for different age groups

Age groups years	Men			Women		
	Number of participants *n*	Mean m/s	Standard deviation *s*	Number of participants *n*	Mean m/s	Standard deviation *s*
20–30	55	2,1	0,2	68	2,0	0,2
31–49	—	—	—	—	—	—
50–54	35	2,0	0,2	35	1,9	0,3
55–59	46	2,0	0,3	50	1,8	0,2
60–64	44	2,0	0,2	53	1,8	0,3
65–69	50	1,9	0,2	50	1,8	0,3
70–74	59	1,9	0,3	62	1,6	0,3
75–79	35	1,6	0,2	38	1,4	0,3

Table 25 *(continued)*

Age groups years	Men Number of participants *n*	Men Mean m/s	Men Standard deviation *s*	Women Number of participants *n*	Women Mean m/s	Women Standard deviation *s*
80+	33	1,6	0,3	34	1,4	0,2



a) **Normal pace**

b) **Hurried pace**

Key

X age groups (years)

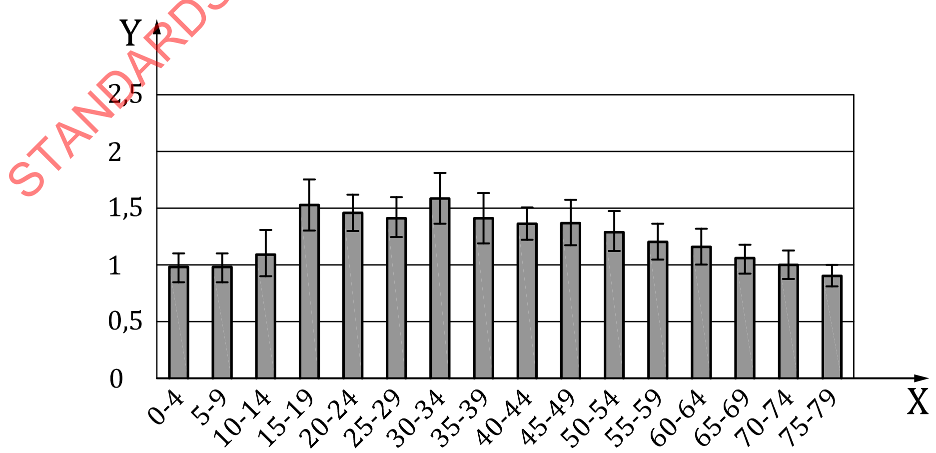
Y walking speed (m/s)

A men

B women

Figure 85 — Walking speed at a normal and a hurried walking pace of Dutch people in different age groups

Figure 86 presents the average data of the Japanese male and female participants for the range of age from 0 (1,5 years) to 79 years in 5 years steps. A peek speed is observed at around 30–34 years of age.



X age groups (years)

Y walking speed (metres/sec)

NOTE The age range of 0–4 means 1,5 to 4 years.

Figure 86 — Walking speed at a normal walking pace of Japanese people in different ages

7.5.4.5 Limitations

Walking speed is affected by the body size factor such as stride length, etc. The speed can also be affected by walking distance used for the measurements as well as sloped ways or the outdoor/indoor difference.

7.5.4.6 Application examples

The data can be used for pedestrian crossing signal timing, which should take account of older pedestrians' walking speed for safety and comfort for green or red signals. The data can also apply to the speed of escalators or moving walkways.

7.5.4.7 References

— Data source: References [97] and [47];

— Cross-references in this document: none;

— Other references: none.

7.5.5 Slope of ramps and wheelchair operation (physical disabilities)

7.5.5.1 General

The gradient of a ramp is an important factor to enable a wheelchair user or a user with crutches to move independently and easily. Handling of a wheelchair becomes difficult as the gradient of a ramp increases.

This subclause provides data on the relationship between ramp gradient and ease of wheelchair operation.

7.5.5.2 Sampled population

Wheelchair users operating by themselves without help and without additional power.

7.5.5.3 Methods and conditions of data collection

There is no information in the data source.

7.5.5.4 Data

Figure 87 shows the relationship between ramp gradient and ease of operation of a wheelchair without any power assist or other help. It gives examples of cases how the ramp gradient affects the wheelchair handling by the user. It is relatively easy for wheelchair users to ascend and descend by themselves when the gradient is less than 3,4° (1/17).

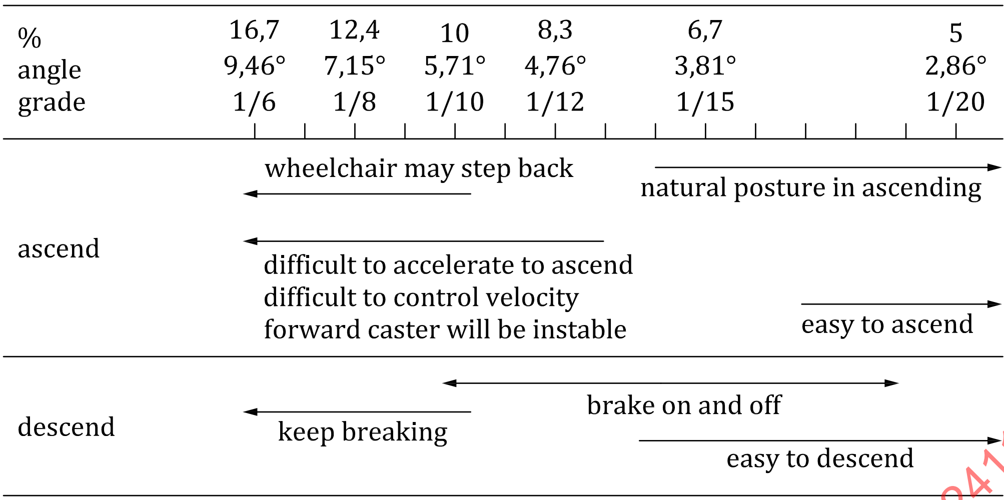


Figure 87 — Relationships between a slope of ramp and ease of operation of a wheelchair

NOTE Similar data in the same data source is also presented for crutches used for walking. According to these data, there is no effect of gradient when less than 1/14; easy to descend is at less than 1/13,5, easy to ascend is at less than 1/12, step size is controllable at less than 1/8, need adjusting crutches at over 1/12, and walking by small steps is at over 1/9. For a person with crutches, the slope for easy ascending and descending is less than 4,1° (1/14).

7.5.5.5 Limitations

The data in Figure 87 cannot be applied to wheelchair operation by children or elderly people. The data give some indications for users of walking frames or persons pushing a wheelchair.

7.5.5.6 Application examples

This data provides information to determine the appropriate gradient of a ramp for independent wheelchair users.

7.5.5.7 References

— Data source: Reference [49];

— Cross-references in this document: none;

— Other references: none.

7.6 Muscle strength and muscle endurance

7.6.1 Grip force of the hand (ageing effect)

7.6.1.1 General

Muscle strength is one of the important human functions when people handle and manipulate products. This subclause provides basic data on the maximum muscle strength while clenching the hand into a fist.

7.6.1.2 Sampled population

A hundred women and 100 men between 50 and 70 years of age and 25 women and 25 men between 20 and 30 years of age took part in this biomechanical study that was carried out in Germany in 2006 and 2007. All the participants were healthy and had no physical impairment.

7.6.1.3 Methods and conditions of data collection

The right hand grips the larger rubber ball of the vigorimeter from below and squeezes it as hard as possible, while the hand is clenched into a fist (see Figure 88).

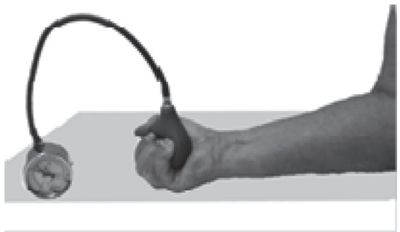


Figure 88 — Method for measuring grip force of the hand

7.6.1.4 Data

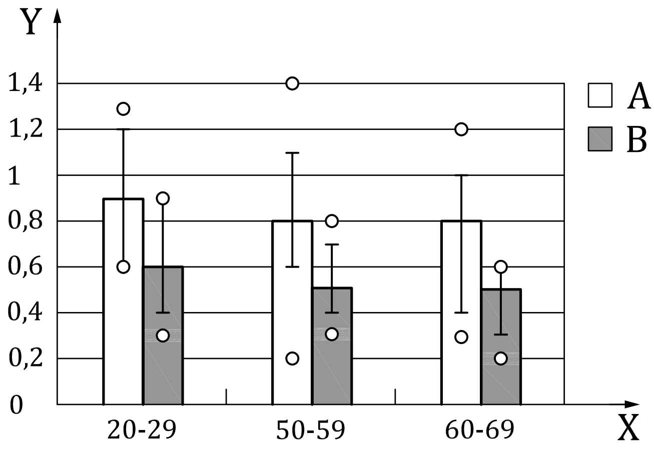
Table 26 and Figure 89 show the data for the grip pressure of the hand in a unit of bar (1 bar = 100 KPa or 100 KN/m^2) for men and women in three different age groups. The P_5, P_{50} and P_{95} in the table mean the 5th, 50th and 95th percentile, respectively. The values used for the variation refer to the lowest and highest values for the individuals within the group.

The data that are of most interest are the values for the 5th percentiles, since they represent the least force that can be exerted to be taken into account in order to include the largest number of people able to use a product, system or service. This also applies to the data in 7.6.2 to 7.6.4. In Table 26, the value is 0,6 bar for men aged 20–29 years.

The measure is an indicator for the muscular strength of the hand, which decreases while adulthood.

Table 26 — Grip force of the hand (unit: bar)

	Age groups years	P_5	P_{50}	P_{95}	Variation
Men	20–29	0,6	0,9	1,2	0,6–1,3
	50–59	0,6	0,8	1,1	0,2–1,4
	60–69	0,4	0,8	1,0	0,3–1,2
Women	20–29	0,4	0,6	0,9	0,3–0,9
	50–59	0,4	0,5	0,7	0,3–0,8
	60–69	0,3	0,5	0,6	0,2–0,6
NOTE P_5, P_{50}, and P_{95} are the 5th, 50th and 95th percentile, respectively.					



Key

X age groups (years)

Y grip force of the hand (bar)

A men

B women

NOTE Vertical arrow bars refer the 5th and the 95th percentile data. Open circles indicate the upper and the lower limit of the data.

Figure 89 — Grip force of the hand at the 50th percentile for three age groups

7.6.1.5 Limitations

The strength of the hand depends on the types of grip which are summarized in 7.6.5. Exertion of gripping force depends on size, length and texture of a surface.

7.6.1.6 Application examples

When designing the cap of a jar, a bottle and other packaging that needs gripping, clenching or rotating, the maximum grip force of the hand should be taken into account.

7.6.1.7 References

— Data source: Reference [58];

— Cross-references in this document: 7.6.5;

— Other references: none.

7.6.2 Pressing force of the thumb

7.6.2.1 General

This subclause provides data on the maximum pressing force of the thumb.

7.6.2.2 Sampled population

A hundred women and 100 men between 50 and 70 years of age and 25 women and 25 men between 20 and 30 years of age took part in this biomechanical study that was carried out in Germany in 2006 and 2007.

7.6.2.3 Methods and conditions of data collection

A middle rubber ball of the vigorimeter is held between index finger and middle finger of the right hand with the palm of the hand is facing upwards (see Figure 90). The rubber tube hangs down between both fingers. The ball is compressed by the thumb as strongly as possible. The index finger should not touch the rubber ball while measurement is proceeding.

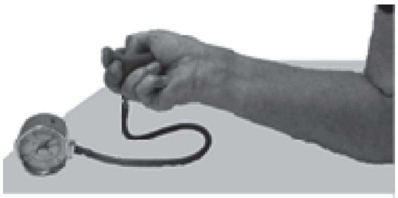


Figure 90 — Method for measuring pressing force of the thumb

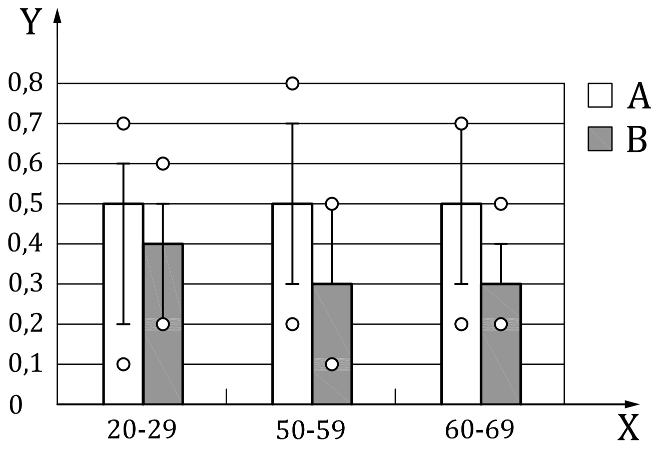
7.6.2.4 Data

Table 27 and Figure 91 show the pressing force of the thumb in bar (1 bar = 100 KPa or 100 KN/m^2) for men and women in three different age groups. The P_5, P_{50}, and P_{95} in the table mean the 5th, 50th, and 95th percentile, respectively. The values used for the variation refer to the lowest and highest values for the individuals within the group.

The measure is an indicator for the muscular strength of the thumb, which does not change so much in adulthood.

Table 27 — Pressing force of the thumb in bar

	Age groups years	P_5	P_{50}	P_{95}	Variation
Men	20–29	0,2	0,5	0,6	0,1–0,7
	50–59	0,3	0,5	0,7	0,2–0,8
	60–69	0,3	0,5	0,7	0,2–0,7
Women	20–29	0,2	0,4	0,5	0,2–0,6
	50–59	0,3	0,3	0,5	0,1–0,5
	60–69	0,3	0,3	0,4	0,2–0,5
NOTE P_5, P_{50}, and P_{95} are the 5th, 50th and 95th percentile, respectively.					



Key

X age groups (years)

Y pressing force (bar)

A men

B women

NOTE Vertical arrow bars refer to the 5th and the 95th percentile data. Open circles indicate the upper and the lower limit of the data.

Figure 91 — Pressing force of the thumb at the 50th percentile for three age groups

7.6.2.5 Limitations

Pressing force of the thumb depends on types of grip which are summarized in 7.6.5. It is noted that exertion of the pressing force depends on the size, length, texture and environment of a button.

7.6.2.6 Application examples

When designing buttons for emergency call systems, the maximum pressing force of the thumb should be taken into account.

7.6.2.7 References

— Data source: Reference [58];

— Cross-references in this document: 7.6.3;

— Other references: none.

7.6.3 Compressive force of the index finger

7.6.3.1 General

This subclause provides data on the maximum compressive force of the index finger.

7.6.3.2 Sampled population

A hundred women and 100 men between 50 and 70 years of age and 25 women and 25 men between 20 and 30 years of age took part in this biomechanical study that was carried out in the Germany in 2006 and 2007.

7.6.3.3 Methods and conditions of data collection

A smaller rubber ball of the vigorimeter is held between the right hand's thumb and middle finger, so that the rubber hose is hanging down between both fingers (see Figure 92). The ball is pressed from above with the index finger as strongly as possible.

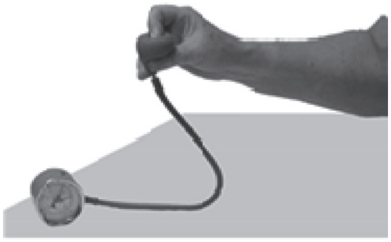


Figure 92 — Method for measuring compressive force of the index finger

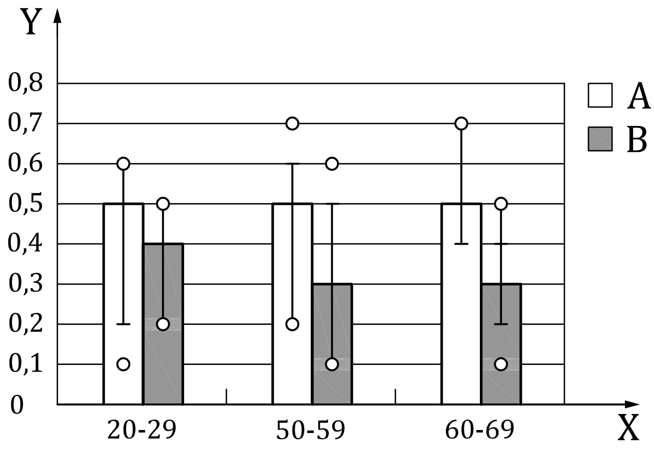
7.6.3.4 Data

Table 28 and Figure 93 show the compressive force of the index finger in bar (1 bar = 100 KPa or 100 KN/m^2) for men and women in different age groups. The P_5, P_{50} and P_{95} mean the 5th, 50th and 95th percentile, respectively. The values used for the variation refer to the lowest and highest values for the individuals within the group.

The measure is an indicator for the muscular strength of the index finger, which does not change so much in adulthood.

Table 28 — Compressive force of the index finger (unit: bar)

	Age groups years	P_5	P_{50}	P_{95}	Variation
Men	20–29	0,2	0,4	0,6	0,1–0,6
	50–59	0,2	0,5	0,6	0,2–0,7
	60–69	0,4	0,5	0,7	0,1–0,7
Women	20–29	0,2	0,3	0,5	0,2–0,5
	50–59	0,1	0,4	0,5	0,1–0,6
	60–69	0,2	0,4	0,5	0,1–0,5
NOTE P_5, P_{50}, and P_{95} are the 5th, 50th and 95th percentile, respectively.					



Key

X age groups (years)

Y pressing force (bar)

A men

B women

NOTE Vertical arrow bars refer to the 5th and the 95th percentile data. Open circles indicate the upper and the lower limit of the data.

Figure 93 — Compressive force of the index finger at the 50th percentile for three age groups

7.6.3.5 Limitations

Pressing force of the index finger depends on the types of grip which are summarized in 7.6.5. It is noted that exertion of the pressing force also depends on the size, length, texture and environment of the button.

7.6.3.6 Application examples

When designing buttons for emergency call systems, the maximum pressing force of the index finger should be taken into account.

7.6.3.7 References

— Data source: Reference [58];

— Cross-references in this document: 7.6.2, 7.6.10;

— Other references: none.

7.6.4 Operating torque in four different conditions

7.6.4.1 General

Operating torque is one of the important physical activities concerned with handling and manipulation of products, especially for manipulating doors and handles, opening jars, etc. As the exerted torque depends on the various physical and human factors of products and operators, it is necessary and useful to know the amount of torque that can be exerted.

This subclause provides basic data on maximum operating torque for the right hand when turning a screw cap anticlockwise. Two diameters (Ø 85 mm and Ø 31 mm) were each tested in horizontal and vertical orientations.

7.6.4.2 Sampled population

A hundred women and 100 men between 50 and 70 years of age and 25 women and 25 men between 20 and 30 years of age took part in this biomechanical study that was carried out in the Germany in 2006 and 2007.

7.6.4.3 Methods and conditions of data collection

The four conditions used in the measurements of operating torque which are shown in Figure 94 a) to d). Details of each condition are as follows:

a) Horizontally situated screw cap of a large size (Ø 85 mm)

The fingers and the thumb of the right hand take hold of the horizontally situated screw cap of the operating torque meter that is fixed on a horizontal surface, and try to move it anticlockwise. The resulting operating torque is measured. “Horizontally situated” means that the plane of revolution is horizontal [see Figure 94 a)].

b) Vertically situated screw cap of a large size (Ø 85 mm)

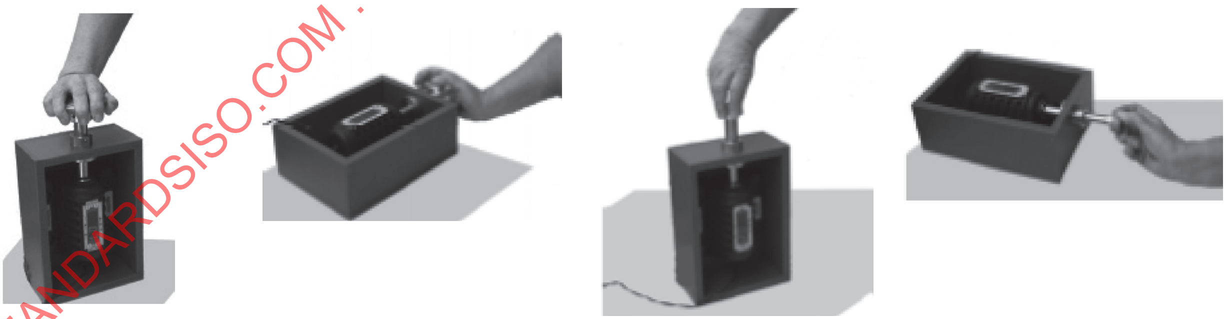
The fingers and the thumb of the right hand take hold of the vertically situated screw cap of the operating torque meter that is fixed on a vertical surface, and try to move it anticlockwise. The resulting operating torque is measured [see Figure 94 b)].

c) Horizontally situated screw cap of a small size (Ø 31 mm)

The index finger, the middle finger and the thumb of the right hand take hold of the horizontally situated screw cap of the operating torque meter that is fixed on a horizontal surface, and try to move it anticlockwise. The resulting operating torque is measured [see Figure 94 c)].

d) Vertically situated screw cap of a small size (Ø 31 mm)

The index finger, the middle finger and the thumb of the right hand take hold on the vertically situated screw cap of the operating torque meter, fixed on a vertical surface, and try to move it anticlockwise. The resulting operating torque is measured [see Figure 94 d)].



a) Large, horizontal **b) Large, vertical** **c) Small, horizontal** **d) Small, vertical**

Figure 94 — Methods for measuring operating torque for different screw sizes and positions

7.6.4.4 Data

Tables 29 to 32 and Figure 95 a) and b) show the operating torque in Nm for each of the four different measuring conditions described in 7.6.4.3. Data are presented for men and women in three different age groups. The P_5, P_{50} and P_{95} in the table mean the 5th, 50th and 95th percentile, respectively. The variation refers to data distribution from the lowest to the highest value.

The measure is an indicator for the muscular strength of the hand, which changes gender-specifically in adulthood. It slightly decreases for women with age, but slightly increases for men.

Table 29 — Operating torque data, in Nm, for screw caps of different sizes and in different positions – horizontally situated large screw cap of a large size (Ø 85 mm)

	Age groups years	P_5	P_{50}	P_{95}	Variation
Men	20–29	4,0	7,7	11,2	3,2–11,9
	50–59	4,4	9,2	14,8	3,0–15,3
	60–69	4,1	9,1	13,3	3,3–14,7
Women	20–29	3,8	6,0	8,3	2,1–8,5
	50–59	3,3	6,2	10,1	2,8–10,9
	60–69	2,3	4,9	8,4	1,9–9,0
NOTE P_5, P_{50}, and P_{95} are the 5^{th}, 50^{th} and 95^{th} percentile, respectively.					

Table 30 — Operating torque data, in Nm, for screw caps of different sizes and in different positions – vertically situated large screw cap of a large size (Ø 85 mm)

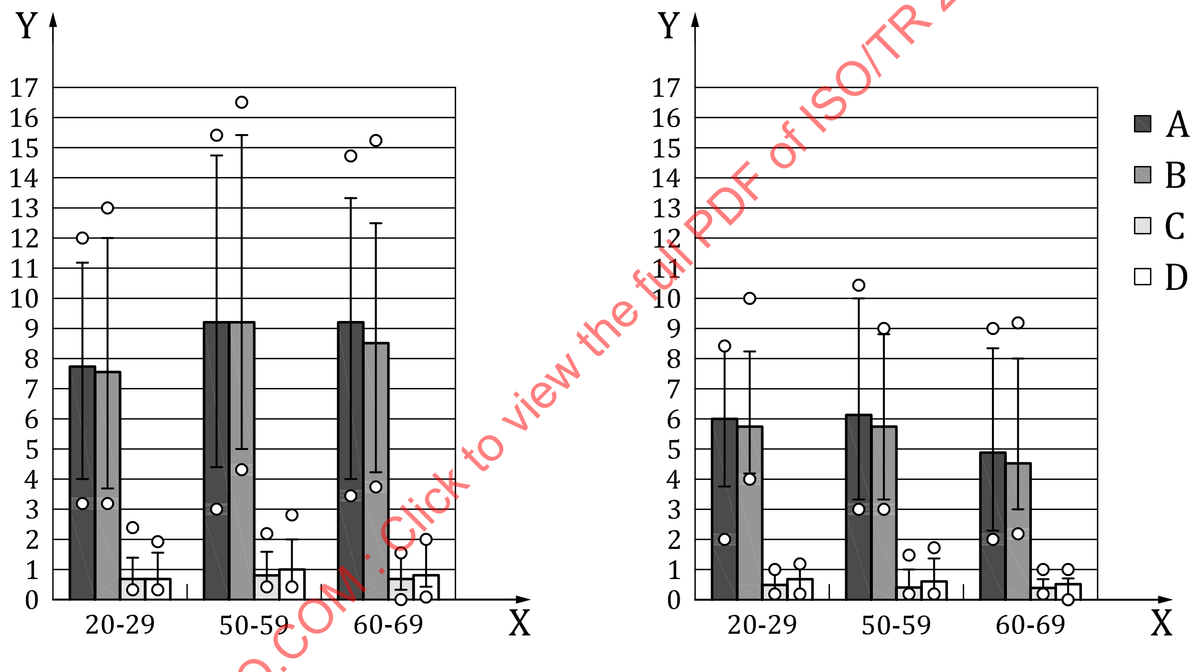
	Age groups years	P_5	P_{50}	P_{95}	Variation
Men	20–29	3,7	7,6	12,1	3,2–13,2
	50–59	4,9	9,2	15,4	4,3–16,4
	60–69	4,2	8,5	12,5	3,7–15,2
Women	20–29	4,1	5,8	8,3	3,8–9,9
	50–59	3,3	5,8	8,9	2,9–9,2
	60–69	3,0	4,6	8,1	2,2–9,3
NOTE P_5, P_{50}, and P_{95} are the 5^{th}, 50^{th} and 95^{th} percentile, respectively.					

Table 31 — Operating torque data, in Nm, for screw caps of different sizes and in different positions – horizontally situated small screw cap of a small size (Ø 31 mm)

	Age groups years	P_5	P_{50}	P_{95}	Variation
Men	20–29	0,4	0,7	1,4	0,3–2,4
	50–59	0,4	0,8	1,6	0,3–2,2
	60–69	0,3	0,7	1,5	0,0–1,6
Women	20–29	0,3	0,5	0,9	0,2–1,0
	50–59	0,2	0,4	1,1	0,2–1,5
	60–69	0,2	0,4	0,7	0,2–0,9
NOTE P_5, P_{50}, and P_{95} are the 5^{th}, 50^{th} and 95^{th} percentile, respectively.					

Table 32 — Operating torque data, in Nm, for screw caps of different sizes and in different positions – vertically situated small screw cap of a small size (Ø 31 mm)

	Age groups years	P_5	P_{50}	P_{95}	Variation
Men	20–29	0,4	0,7	1,6	0,2–1,8
	50–59	0,5	1,0	2,1	0,4–2,7
	60–69	0,4	0,8	1,9	0,2–2,0
Women	20–29	0,2	0,7	1,1	0,2–1,2
	50–59	0,3	0,6	1,4	0,2–1,7
	60–69	0,2	0,5	0,8	0,0–1,0
NOTE P_5, P_{50}, and P_{95} are the 5th, 50th and 95th percentile, respectively.					



Key

X age groups (years)

Y operating torque (Nm)

A horizontally situated large screw cap of a large size (Ø 85 mm)

B vertically situated large screw cap of a large size (Ø 85 mm)

C horizontally situated small screw cap of a small size (Ø 31 mm)

D vertically situated small screw cap of a small size (Ø 31 mm)

NOTE Vertical arrow bars refer to the 5th and the 95th percentile data. Open circles indicate the upper and the lower limit of the data.

Figure 95 — Operating torque for screw caps of different sizes and in different positions

7.6.4.5 Limitations

Operating torque depends of the types of grip which are summarized in 7.6.5. It is noted that exertion of operating torque also depends on the diameter, size and texture of a cap surface.

7.6.4.6 Application examples

When designing a cap for bottles, screw plugs or doors handles and opening jars, the maximum operating torque data for different sizes and positions should be applied.

7.6.4.7 References

— Data source: Reference [58];

— Cross-references in this document: 7.6.11, 7.6.12, 7.6.13;

— Other references: none.

7.6.5 Grip strength (ageing effect)

7.6.5.1 General

Easy and firm handling and manipulation of products by fingers, hands or arms are necessary when people use them. The amount of force required for manipulating the products is one of the critical quantities in designing products. Gripping is one of the methods for handling and manipulation when people hold or handle products such as jars, scissors, pliers, etc. With this data designers are also able to know whether a product can withstand maximum forces.

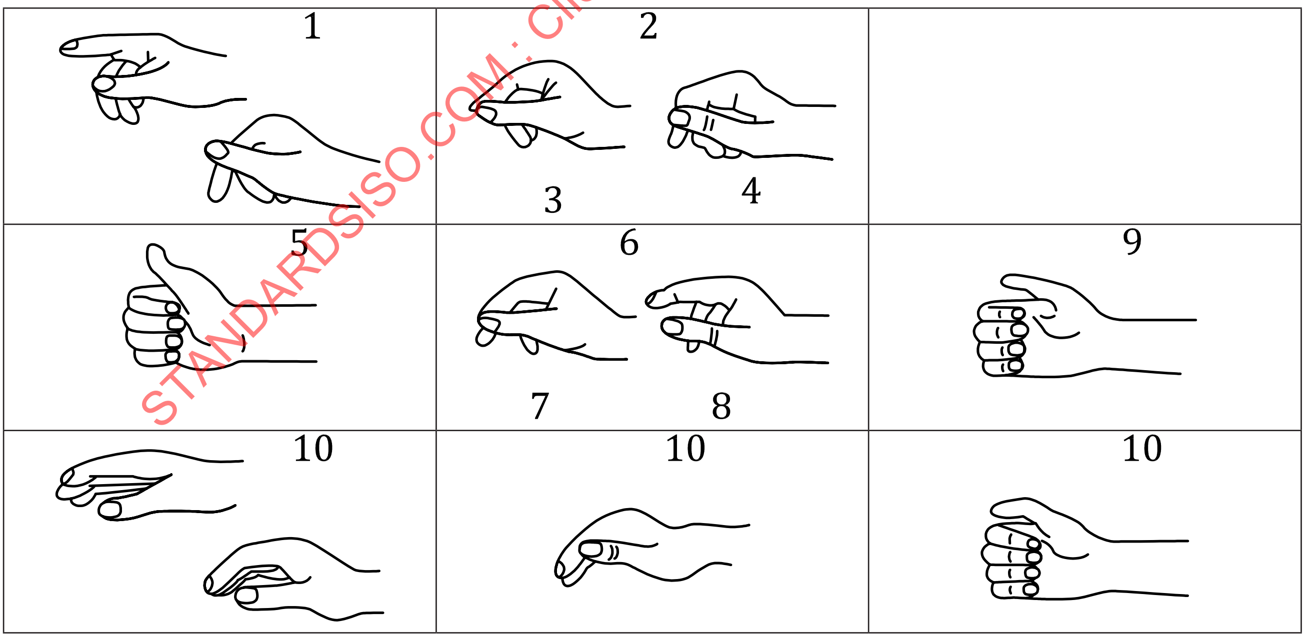
Figure 96 illustrates the different types of grip of the operator's hand and the control.

— Contact grip is one where a unidirectional force is applied by a finger, the thumb or a hand to the control.

— Pinch grip is one where a control is held by fingers and/or the thumb without clenching a fist.

— Clench grip uses all fingers wrapped around a control (see ISO 9355-3).

The size suitable for a control depends on the type of grip used.



contact actuation   pinch actuation   clench actuation

Key

1 finger
2 two fingers
3 thumb opposed
4 thumb at right angle
5 thumb
6 three fingers
7 evenly spaced
8 thumb opposed
9 finger
10 hand

Figure 96 — Types of grips (from ISO 9355-3)

This subclause provides data on grip strength as a function of age which were measured in Japan and the Netherlands.

7.6.5.2 Sampled population

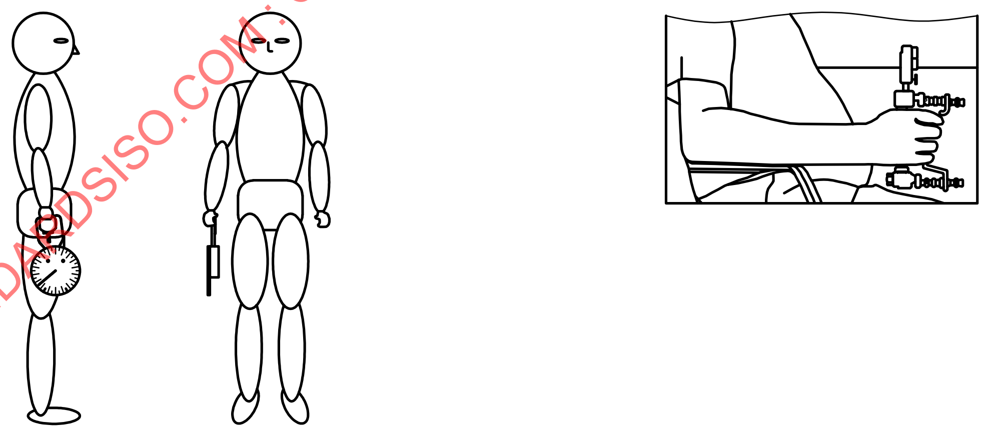
Japanese data were based on measurements of people aged from 6 years (the starting age of elementary school in Japan) to 79 years with a total of about 30 000 participants. The measurements are regularly performed every year and the 2016 data of 32 700 participants are presented here.

For the data of the Netherlands, people in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.6.5.3 Methods and conditions of data collection

The measurements in Japan were conducted using the Smedley hand dynamometer in a standing posture. Figure 97 a) shows the method. The grip strength was measured as the maximum effort contraction for both right and left hand and the stronger grip strength of the two was taken as the data.

The data of the Netherlands were taken with the Jamar dynamometer. The participant sits upright in the measuring chair with the lower arm supported. Maximum exerted strength during 3 s was measured [see Figure 97 b)].



a) **Method used in Japan**

b) **Method used in the Netherlands**

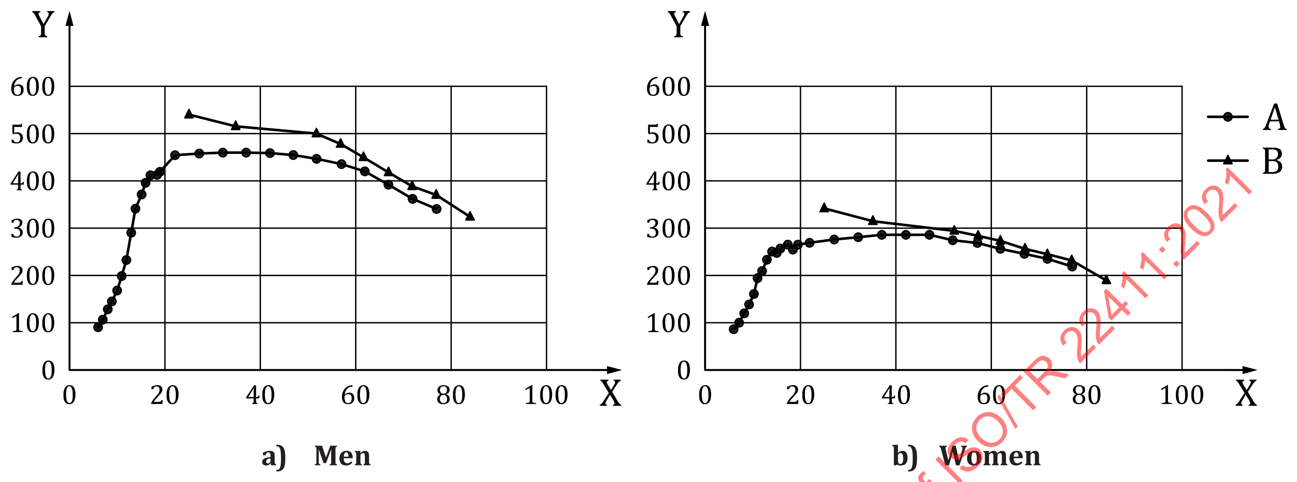
Figure 97 — Methods used to measure the grip strength in Japan and in the Netherlands

7.6.5.4 Data

Figure 98 shows the data on maximal grip strength of men and women as a function of age for two data sources in Japan and in the Netherlands plotted together. Both sets of data show a similar ageing effect.

The grip strength increases from childhood up to around the age of 20 years, keeps almost constant on peak level over the next 20 years and then gradually decreases with age.

The average strength of women is about two-thirds that of men, and the average of older people is about two-thirds that of the peak achieved by young people.



Key

X age (years)

Y grip strength (N)

A Japan

B Netherlands

Figure 98 — The grip strength of men and women as a function of age in two data sources in Japan and the Netherlands

7.6.5.5 Limitations

Grip strength depends on the types of grip which are summarized in Figure 96. It is noted that exertion of gripping force also depends on the size and length of a grip and texture of the surface.

The presented data are mean values of maximum exerted strength but they are not comfort gripping forces.

7.6.5.6 Application examples

When designing caps for jars, bottles and other packaging that need gripping, rotating and squeezing, the maximum gripping force of a hand should be taken into account.

Maximum force is not always accepted in designing products as it is the extreme case. It is preferable to exert comfortable force when using most of products, in particular where they are used often. Furthermore, if the force has to be exerted for a longer time without interruption, less force is preferred for users in operating the products.

It is generally considered that a third to half of the maximum exerted force can be applied when it has to be exerted many times or comfortably exerted, and about 15 % of the maximum force can be applied for continuous exertion[110].

7.6.5.7 References

— Data sources: References [22], [73] and [97];

— Cross-references in this document: 7.6.1;

— Other references: Reference [110].

7.6.6 Lifting strength (gender effect)

7.6.6.1 General

Lifting is one of the most frequent actions required for carrying or moving objects in our daily life. Designing products in terms of their weight or the force required for easy and comfortable lifting is one of the important criteria for safe and comfort handling of objects. Effects of age and sex exist in the exertion of lifting.

This subclause provides data on maximum lifting strength measured in Germany showing gender-related differences.

The general relationship between maximum force and comfortable one is described in 7.6.5.6 as that a third to half of the maximum exerted force can be applied for the force that has to be exerted many times or comfortably exerted, and about 15 % of the maximum force can be applied for the continuous exertion[110].

7.6.6.2 Sampled population

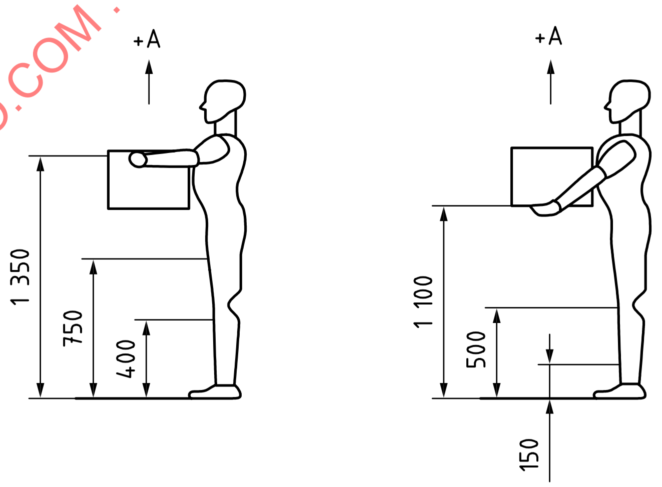
Data were collected from 1 967 males between 16 and 62 years of age and 1 113 females between 18 and 59 years of age. All participants were healthy and had no physical impairment.

7.6.6.3 Methods and conditions of data collection

Lifting strengths were obtained for 6 heights from 150 mm to 1 350 mm.

The data were collected for two types of two-handed lifting: gripped by the sides and lifted from the bottom, as illustrated in Figure 99. Three heights were employed for each grip type: 400 mm, 750 mm and 1 350 mm for side-gripping, and 150 mm, 500 mm and 1 110 mm for bottom-gripping. The participant lifted different weights by side-gripping and by bottom-lifting. Bending knees was allowed and the position of the feet was at the participant's discretion.

Dimensions in millimetres



Key

+A vertical force direction

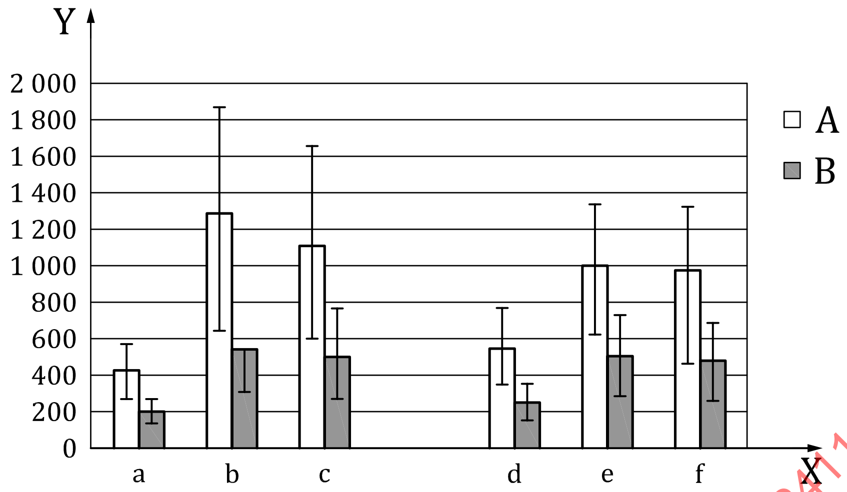
Figure 99 — Methods of measurements for the two-handed lifting strength with a box (width 500 mm)

7.6.6.4 Data

Table 33 and Figure 100 show the data for 6 conditions of different types of gripping (side and bottom) and different heights. The data are given for five levels of percentiles for both men and women. In Figure 100, the 50th percentile data are shown together with the 5th and 95th percentile as error bars. In most cases, the exerted force of women is much lower (less than half) than that of men.

Table 33 — Two-handed force exerted to lift a crate (width 500 mm)

Force direction	Point of force application mm	Force percentiles	Gender-related force N Women	 Men
A (vertical)	1 350 Side-gripping	5	123	268
		10	134	305
		15	144	323
		50	186	417
		95	268	570
	1 110 Bottom-gripping	5	153	353
		10	176	393
		15	190	419
		50	248	541
		95	353	784
	750 Side-gripping	5	294	642
		10	345	739
		15	375	821
		50	528	1 274
		95	985	1 868
	500 Bottom-gripping	5	284	617
		10	339	718
		15	363	774
		50	507	990
		95	724	1 329
	400 Side-gripping	5	281	603
		10	326	687
		15	349	762
		50	490	1 108
		95	770	1 651
	150 Bottom-gripping	5	256	587
		10	301	678
		15	338	736
		50	470	971
		95	689	1 324



Key

X type of gripping and height
Y lifting strength (N)
A men
B women
a side-gripping, height = 1 350 mm
b side-gripping, height = 750 mm
c side-gripping, height = 400 mm
d bottom-gripping, height = 1 110 mm
e bottom-gripping, height = 500 mm
f bottom-gripping, height = 150 mm

NOTE Vertical arrow bars refer to the 5th and the 95th percentile range.

Figure 100 — Maximum lifting strength of men and women in different gripping types and heights at the 50th percentile

7.6.6.5 Limitations

The data are for the maximum force but not for the comfortable or continuous one. These measurements reveal the gender effect but do not take account of ageing.

7.6.6.6 Application examples

The data can be used when designing household appliances which need to be carried or lifted by users. Comfortable lifting force is obtained between about a third and half of the maximum force given in Table 33 (see 7.6.5.6).

7.6.6.7 References

— Data source: Reference [6];

— Cross-references in this document: 7.6.7;

— Other references: Reference [95].

7.6.7 Lifting strength (effects of age and gender)

7.6.7.1 General

Lifting strength is affected not only by gender but also by age.

This subclause provides data of ageing effect on maximum lifting strength measured for Japanese children, young people and older people both male and female.

7.6.7.2 Sampled population

Table 34 shows the distribution of participants by age and sex. The number of participants depends on each of the measurement conditions taking account of the differences in stature. Detailed sampling was taken for children to see a larger age-related change in childhood.

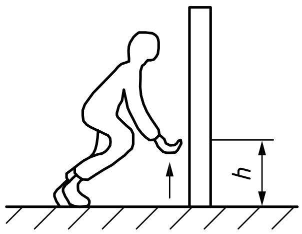
Table 34 — Participants of the lifting strength measurements

	3 years old		4 years old		5 years old		Young people		Older people	
Sex	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Age (years)	3	3	4	4	5	5	19,5	20,5	79,5	77,8
Number of participants	16	30	34	25	28	24	19	4	4	28
Stature (average, cm)	—	—	—	—	—	—	171,6	160,5	—	—
Weight (average, kg)	—	—	—	—	—	—	60,8	50,1	—	—

7.6.7.3 Methods and conditions of data collection

Lifting strength was measured by a force measurement system designed for this measurement with a flexible ring. The ring was connected to a handle made by a pipe and the force applied to the handle can be measured through the distortion of the ring. As Figure 101 shows, the handle was set to a specific height and the participant was asked to lift the pipe handle upwards with both hands. The position of feet was decided by the participant.

The height was set in steps of 20 cm in the range of 20 cm to 80 cm for child participants, 40 cm to 160 cm for young participants, and 60 cm to 100 cm for older participants.



Key

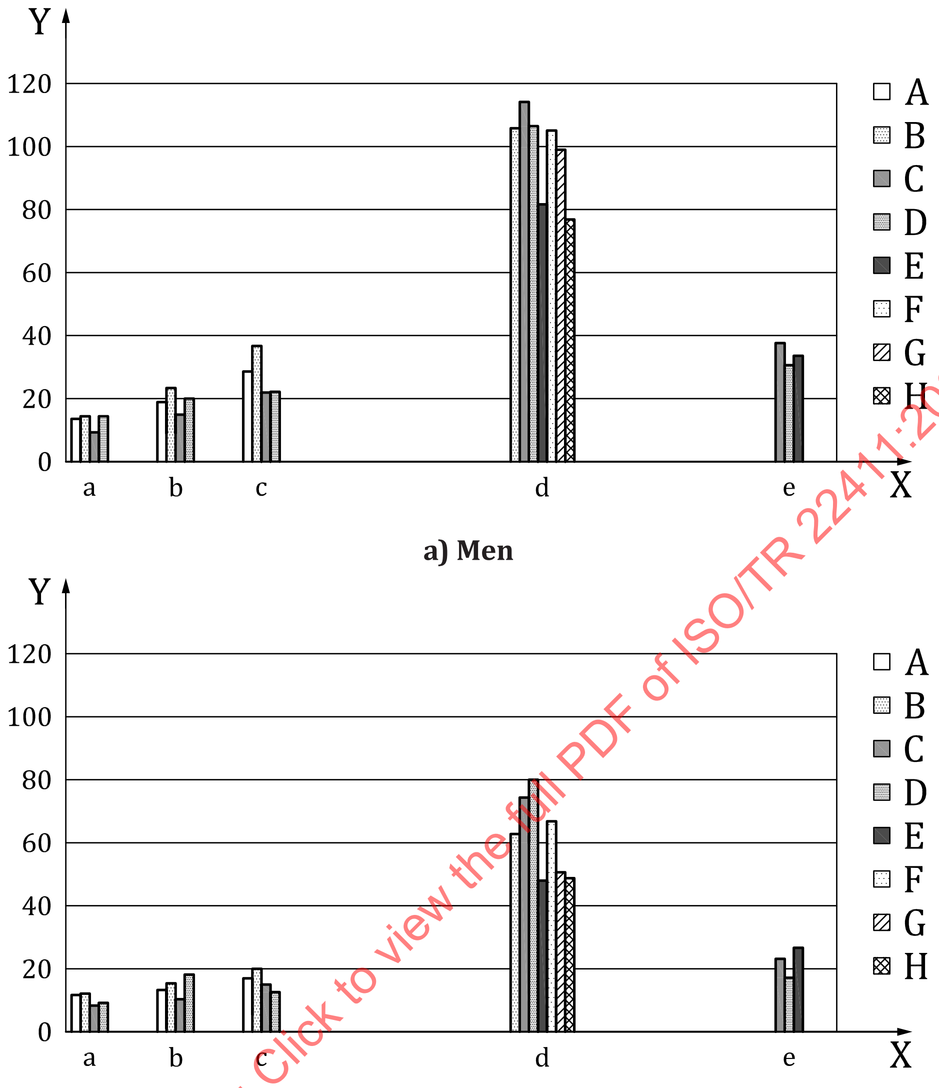
h height of the handle to be lifted

Figure 101 — Method of measurements of two-handed lifting strength

7.6.7.4 Data

Figure 102 shows lifting strength data of Japanese people in 5 age groups at various heights of the handle.

A similar ageing effect occurs for men and women. In general, the force is maximum at youth and much reduced with age. During childhood, the force is significantly increased with age for both male and female.



a) Men

b) Women

Key

X age groups
Y lifting strength (kgf)
a 3 years old
b 4 years old
c 5 years old
d young people
e older people
A height = 20 cm
B height = 40 cm
C height = 60 cm
D height = 80 cm
E height = 100 cm
F height = 120 cm
G height = 140 cm
H height = 160 cm

Figure 102 — Lifting strength of Japanese men and women in childhood, youth and older age

7.6.7.5 Limitations

The data are only for maximum force not for comfortable use of force.

7.6.7.6 Application examples

The data can be used when designing household appliances which need to be carried or lifted by users. Comfortable lifting force is obtained between about a third and half of the maximum force (see 7.6.5.6).

7.6.7.7 References

— Data source: Reference [54];

— Cross-references in this document: 7.6.6;

— Other references: Reference [95].

7.6.8 Pushing force with two hands (ageing effect)

7.6.8.1 General

Pushing is one of the basic physical actions when a person opens or closes doors, for example. As there is an ageing effect also in the pushing force, it is important to understand how the ageing affects pushing force when opening a heavy door such as an emergency exit.

This subclause provides data on pushing force with two hands for different age groups.

7.6.8.2 Sampled population

People in different age groups from 20 to over 80 years were participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.6.8.3 Methods and conditions of data collection

Figure 103 illustrates a measuring device and scene used for measurements. The participant stood in front of the measuring device and adopted a free posture to exert maximum pushing force. The time for exerting force was limited to 3 s.

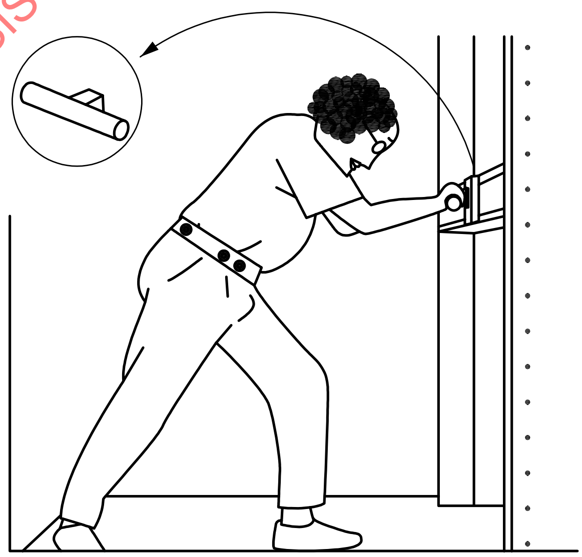


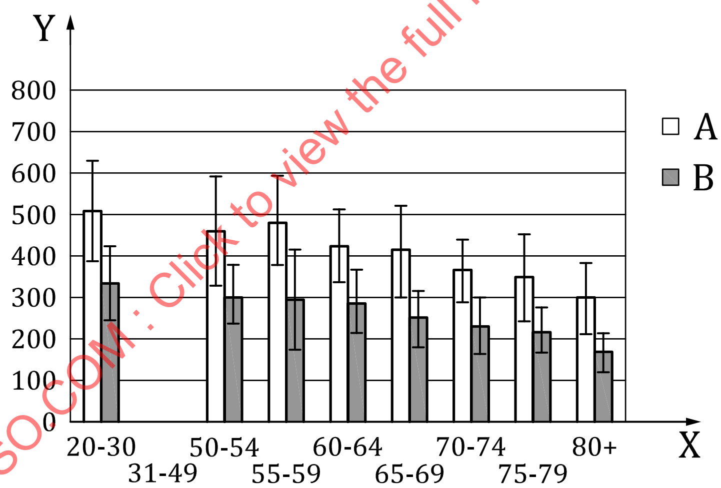
Figure 103 — Method of measurements for pushing force with two hands

7.6.8.4 Data

Data on maximum pushing force with two hands are shown in Table 35 for men and women in different age groups. Figure 104 also shows this together with standard deviations. Women exert less force than men for all age groups, and an ageing effect was observed clearly for both men and women.

Table 35 — Pushing force with two hands for men and women in different age groups

Age groups years	Men			Women		
	Number of participants, *n*	**Mean** N	**Standard deviation, *s*** N	**Number of participants, *n***	**Mean** N	**Standard deviation, *s*** N
20–30	54	508	123	68	333	90
31–49	—	—	—	—	—	—
50–54	35	459	131	35	307	70
55–59	46	485	107	49	294	122
60–64	44	424	88	53	288	76
65–69	50	409	111	51	250	66
70–74	59	361	74	62	230	71
75–79	36	349	103	37	219	57
80+	33	295	87	34	165	44



Key

X age groups (years)

Y pushing force (N)

A men

B women

Figure 104 — Pushing force with two hands for different age groups

7.6.8.5 Limitations

The data show the maximum pushing forces with two hands but not the comfortable one. Comfortable pushing force or maximum pushing force with one hand is lower than the presented data.

7.6.8.6 Application examples

The data can be useful when designing products or equipment that need pushing such as doors, shopping carts and cart bags with casters.

7.6.8.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.6.9;

— Other reference: Reference [95].

7.6.9 Pulling force with one hand (ageing effect)

7.6.9.1 General

Pulling is one of the basic physical actions when a person opens or closes doors, for example. As there is an ageing effect also in the pulling force, it is important to know how much force a person of a given age can exert.

This subclause provides data on pulling force with one hand.

7.6.9.2 Sampled population

People in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of about 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.6.9.3 Methods and conditions of data collection

Figure 105 illustrates a measuring device and scene used for the measurement. The participant stood in front of the measuring device and adopted a free posture to exert his/her maximum pulling force. The time for exerting force was limited to 3 s.

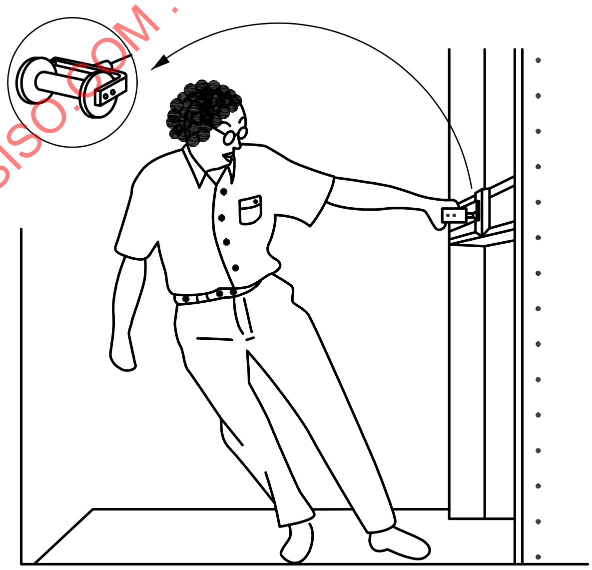


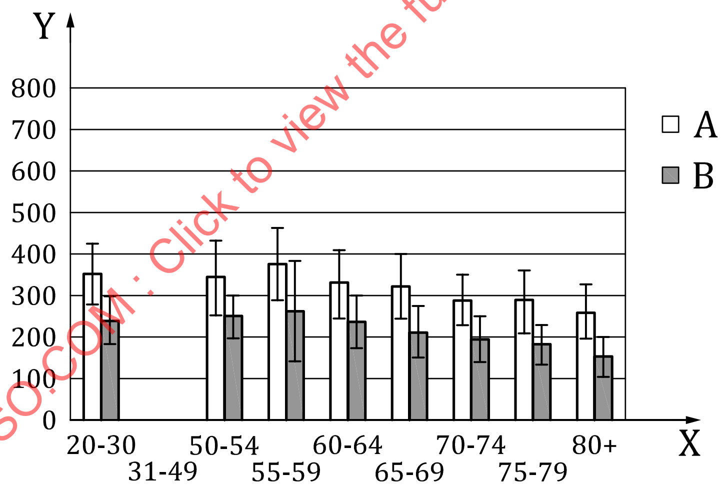
Figure 105 — Method of measurements of pulling force with one hand

7.6.9.4 Data

Data on maximum pulling force with one hand are shown in Table 36 for men and women in different age groups. Figure 106 also shows this together with standard deviations. Women can exert less force than men for all age groups as in the case of pushing force. An ageing effect was also observed for both men and women.

Table 36 — Pulling force with one hand for men and women in different age groups

Age groups years	Men			Women		
	Number of participants, *n*	**Mean** N	**Standard deviation, *s*** N	**Number of participants, *n***	**Mean** N	**Standard deviation, *s*** N
20–30	55	349	73	68	240	56
31–49	—	—	—	—	—	—
50–54	35	342	88	35	247	52
55–59	46	374	86	50	262	120
60–64	44	330	80	53	238	64
65–69	50	321	75	51	212	60
70–74	59	288	60	62	194	55
75–79	36	287	71	37	184	46
80+	33	258	66	35	155	40



Key

X age groups (years)

Y pulling force (N)

A men

B women

Figure 106 — Pulling force with one hand for men and women in different age groups

7.6.9.5 Limitations

The data show maximum pulling force with one hand. Comfortable pulling force with one hand is lower than the presented data (see 7.6.5.6).

7.6.9.6 Application examples

The data can be used when designing products or equipment e.g. household appliances that need to be pulled or when loads or products have to be moved by one hand such as a drawer.

7.6.9.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.6.8;

— Other references: Reference [95].

7.6.10 Pushing force with a finger (ageing effect)

7.6.10.1 General

Pushing with a finger is one of the frequent actions used to operate home appliances or other products that need fine handling. It is useful to know how much pushing force can be exerted by a finger and how the pushing force is affected by ageing. For example, this information can be used in designing a push button of power on/off in electric appliances or a control panel in elevators.

This subclause provides data on pushing force by the forefinger measured for Japanese people.

7.6.10.2 Sampled population

Data were collected from 332 Japanese participants (196 men and 136 women) aged from 20 to over 80 years. Distribution of the participants in age is presented in Table 37.

7.6.10.3 Methods and conditions of data collection

The forefinger of the right hand was used in measuring finger force for pushing a button that was placed on a horizontal and a vertical panel. Figure 107 illustrates the measurement scene. The horizontal and vertical panel with the push-button were placed at the elbow height and at 30 cm in front of the participant. The participants pushed the button while standing. The maximum pushing force was measured.

a) Push-button on a horizontal panel **b) Push-button on a vertical panel**

Figure 107 — Methods for measuring pushing force with the forefinger

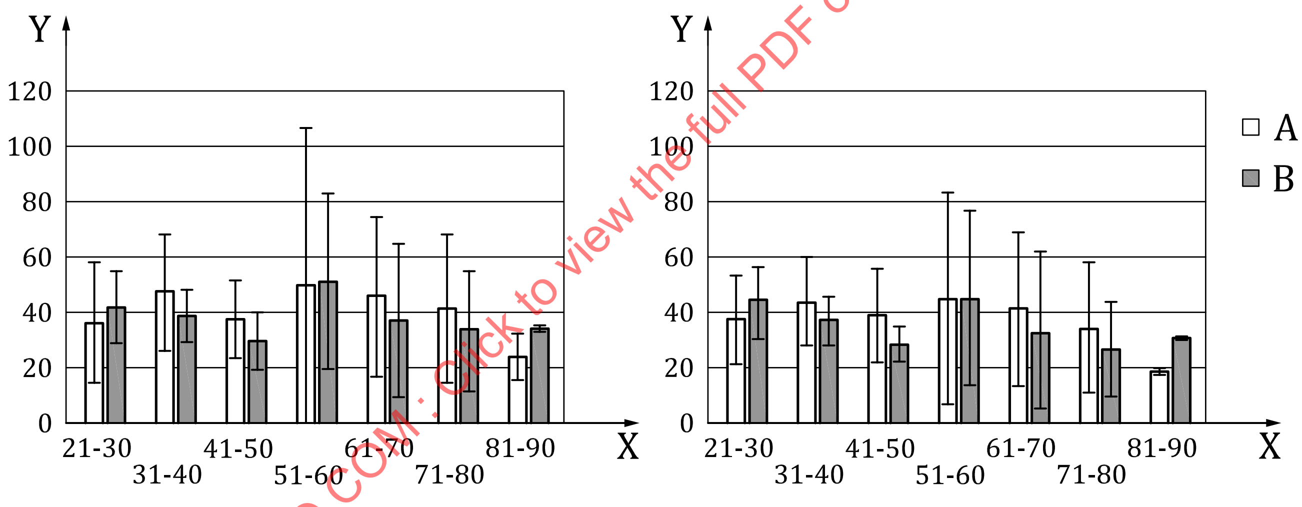
7.6.10.4 Data

Table 37 and Figure 108 show data on maximum pushing forces with the forefinger for men and women in different age groups. Two data for the horizontal and the vertical push-button show no large differences. Slightly less force is required for vertical push-buttons.

An ageing effect is observed. Pushing force decreases particularly for older age groups.

Table 37 — Maximum pushing force with the forefinger for men and women in different age groups

Age groups	Horizontal push button						Vertical push button					
	Men			Women			Men			Women		
years	Number of participants, *n*	Mean N	Standard deviation, *s* N	Number of participants, *n*	Mean N	Standard deviation, *s* N	Number of participants, *n*	Mean N	Standard deviation, *s* N	Number of participants, *n*	Mean N	Standard deviation, *s* N
21–30	5	36,0	21,35	9	41,8	12,84	5	37,2	15,92	9	44,0	11,96
31–40	20	47,2	20,44	5	38,6	8,99	20	43,2	15,57	5	37,1	8,92
41–50	15	37,3	13,81	7	29,4	10,29	15	38,8	16,87	7	28,6	5,9
51–60	13	49,5	56,37	11	50,6	31,95	12	44,8	38,19	10	45,2	31,6
61–70	87	45,5	28,59	70	37,0	27,07	85	41,0	27,81	71	33,2	28,12
71–80	54	40,7	26,83	32	33,3	21,83	56	34,2	23,28	32	26,6	17,24
81–90	2	24,0	8,33	2	33,3	0,98	2	19,1	1,47	2	30,8	0,49



a) Horizontal push-button

b) Vertical push-button

Key

X age groups (years)

Y pushing force (N)

A men

B women

Figure 108 — Pushing force with the forefinger for men and women in different age groups

7.6.10.5 Limitations

The data was measured at the elbow height and can be affected by other heights. The data for different heights of measurements are available at the NITE database (7.6.10.7). The data is based on the maximum exerted force but not for comfortable or normally exerted force which is lower than the maximum force. Pushing force with other finger or pushing with a few fingers is different. The present data shows only the force exerted with the forefinger of the right hand which is most commonly used in manipulating house appliances. The data for other fingers are also available at the NITE database (7.6.10.7).

7.6.10.6 Application examples

The present data can be used for designing controls or tools that need pushing with fingers. Small push-buttons or push-buttons for operating an elevator are the most common examples. The information can also be used in designing a push button used to power electric appliances on and off.

7.6.10.7 References

— Data source: Reference [78];

— Cross-references in this document: 7.6.2, 7.6.3;

— Other references: none.

7.6.11 Static torque with two hands (ageing effect)

7.6.11.1 General

Torque force is required when people open and close packages like jars and bottles with lids or any other products that needs rotation for handling. It is useful to know how much torque a person can exert with their hands for the design of packages or appliances. It also gives designers an indication of capacity required for products to withstand the torque in use.

This subclause provides static torque by two hands of men and women for different age groups.

7.6.11.2 Sampled population

People in different age groups from 20 to over 80 years participated in the measurements. The data were collected from a total of 750 people (about 360 men and 390 women) in the Netherlands in 1995 and 1996.

7.6.11.3 Methods and conditions of data collection

Figure 109 illustrates a measuring device for torque with two hands which simulates opening a jam jar–like bottle. The participant stood in front of the measuring device and adopted a free posture whether holding the jar or leaving it on a table. The diameter of the lid and the jar was 6,6 cm and 7,5 cm, respectively. The participant was asked to exert maximum torque force for 3 s.

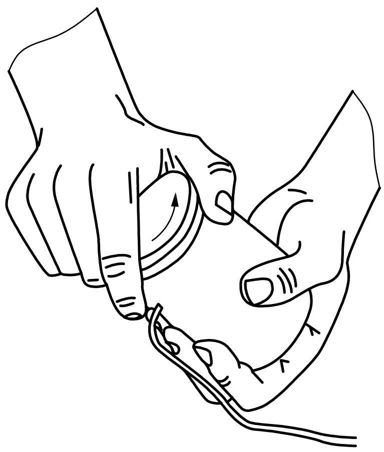


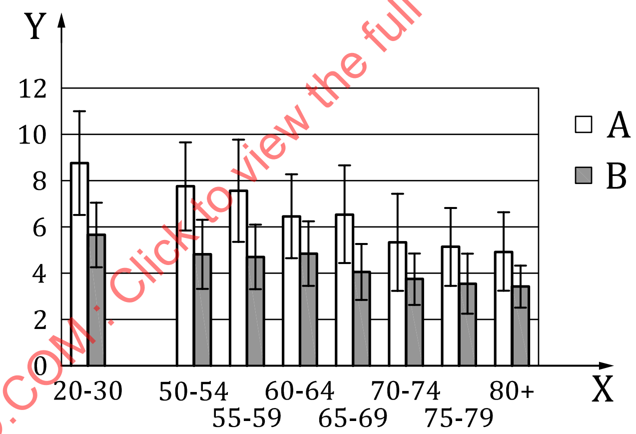
Figure 109 — Method of measurement of static torque with two hands

7.6.11.4 Data

Data on maximum torque with two hands are shown in Table 38 and Figure 110 for men and women in different age groups. Figure 110 also shows standard deviations. Women can exert less torque force than men at all age groups, and an ageing effect was observed for both men and women. The exerted torque constantly decreases with age.

Table 38 — Maximum static torques with two hands for different age groups

Age groups years	Men			Women		
	Number of participants, *n*	Mean Nm	Standard deviation, *s*	Number of participants, *n*	Mean Nm	Standard deviation, *s*
20–30	55	8,7	2,2	68	5,6	1,4
31–49	—	—	—	—	—	—
50–54	35	7,7	1,9	35	4,8	1,5
55–59	46	7,5	2,2	50	4,7	1,4
60–64	44	6,4	1,8	53	4,8	1,4
65–69	50	6,5	2,1	51	4,0	1,2
70–74	59	5,3	2,1	62	3,7	1,1
75–79	35	5,1	1,7	38	3,5	1,3
80+	33	4,9	1,7	35	3,4	0,9



Key

X age groups (years)

Y torque force (N)

A men

B women

Figure 110 — Maximum static torque with two hands for different age groups

7.6.11.5 Limitations

The data show the maximum static torque with two hands. Comfortable torque is lower than the presented data. The torque data cannot simply be applied to other lid diameters.

7.6.11.6 Application examples

The data can be applied to products that require torque with two-handed manipulation, e.g. one part has to be turned relative to the other. Gender difference and age differences should be taken into account in the application. For a torque for comfortable operation, about a third to half of the maximum torque can be applied. For continuous operation, about 15 % of the maximum force is generally adopted (see 7.6.5.6).

7.6.11.7 References

— Data source: Reference [97];

— Cross-references in this document: 7.6.12, 7.6.13;

— Other references: none.

7.6.12 Torque and force for opening packages (effects of ageing and disabilities)

7.6.12.1 General

Torque and force are required particularly for opening and closing packages and it is important to know how much torque and force a person can exert to open packages used on a daily basis. The required torque and force for people of different ages as well as for people with various types of physical disabilities should be identified.

This subclause presents practical data on the torque and force exerted by people of different ages and with different types of physical disabilities to open various types of jars. It also presents data on the force exerted by these same individuals in opening the tab of a washing powder package. The packaging employed in this study represents that used for typical everyday products in the home.

7.6.12.2 Sampled population

Two sets of participants participated in the measurements: men and women in different age groups, and participants grouped by various physical disabilities. Total numbers of men and women in the set grouped by age were 54 (31 and 23 for ages 61–70 and over 71 years, respectively) and 140 (31, 30, 28, 23, 28 for ages 20–40, 41–50, 51–60, 61–70 and over 71 years, respectively) respectively, and 88 people participated comprised the set in the group with physical disabilities.

The following six types of disabilities and the number of people were represented in the sample:

— rheumatic diseases (A): 30;

— multiple sclerosis (MS): 11;

— Parkinson's disease (PS): 9;

— cerebral palsy (CP): 7;

— one-handed function (hemiplegia) (OHH): 20;

— one-handed function (amputation) (OHA):11.

7.6.12.3 Methods and conditions of data collection

A total of 8 different types of packages were used to measure the torque or force, as relevant, needed to open the packages, as follows:

— one-litre bottle (1LB);

— small jar with a smooth lid of diameter 73 mm (SLS = small lid, smooth);

— small jar with a knurled lid of diameter 73 mm (SLK = small lid, knurled);

— small jar with a deep lid of diameter 73 mm (SMD = small lid, deep);

— large jar with a smooth lid of diameter 85 mm (LLS = large lid, smooth);

— large jar with a knurled lid of diameter 85 mm (LLK = large lid, knurled);

— large jar with a deep lid of diameter 85 mm (LLD = large lid, deep).

— washing powder packet (WPP).

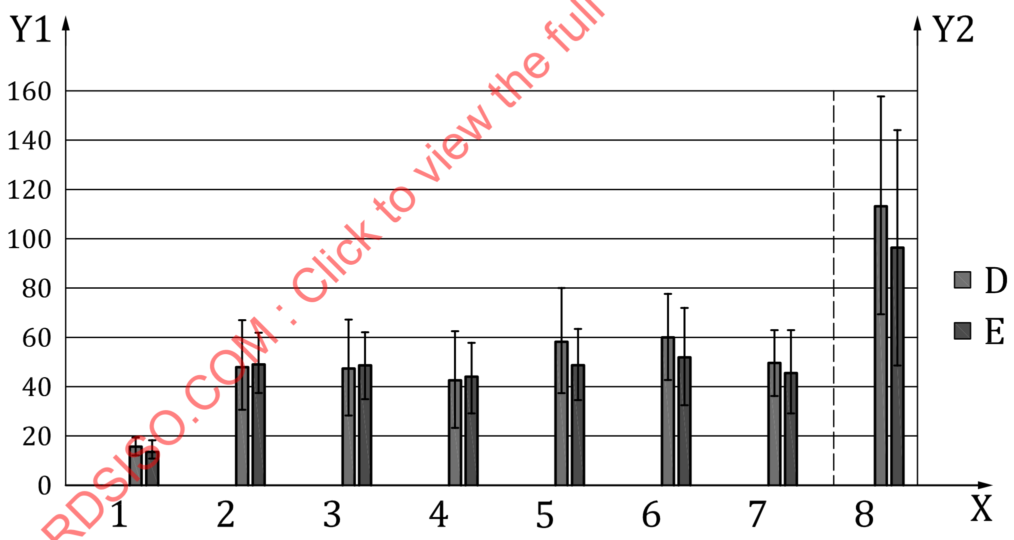
The participants were asked to open each of these packages with both maximum and comfortable effort, and the torque and force required for that action were measured by a measuring device attached to the package. In this subclause, only the maximum effort data are presented.

7.6.12.4 Data

Figure 111 and Figure 112 show the data for maximum torque or force, as relevant, for the 8 types of packaging for men and women, respectively, grouped by age. Torque was measured for the bottle and jars and force was measured for the washing package. The unit for the latter is kgf and is shown on the Y2-axis.

The effect of age is clearly observed in the data for women. The measures show a peak at around the age of 41–50 years and decreases at younger and older ages. This ageing effect applies for all the types of packages. There is very little difference in the age data for men. The 60–70 years olds exert somewhat greater torque and force than do those 71 and over.

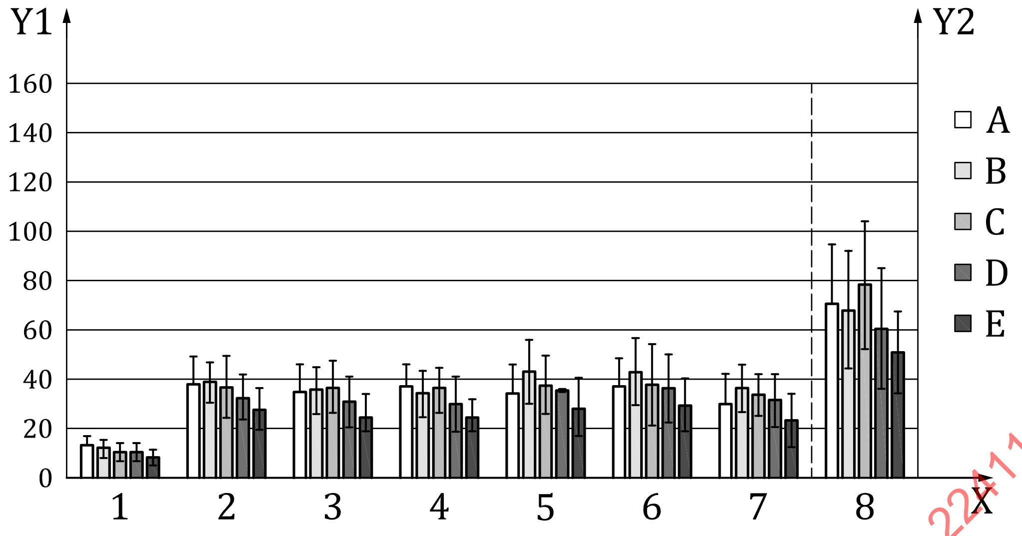
The level of torque largely depends on the types of packages for both men and women. Among the six lids of different size and surface, the large lid with a knurled surface (LLK) resulted in the greatest maximum torque.



Key

X type of package and lid
Y1 torque (kgf·m × 10^{-2})
Y2 force (kgf × 10^{-1})
1 one-litre bottle (1LB)
2 small lid, smooth (SLS)
3 small lid, knurled (SLK)
4 small lid, deep (SLD)
5 large lid, smooth (LLS)
6 large lid, knurled (LLK)
7 large lid, deep (LLD)
8 washing powder packet (WPP)
D 61–70 years
E 71+ years

Figure 111 — Static torque and force maximally exerted for opening packages of men in different age groups



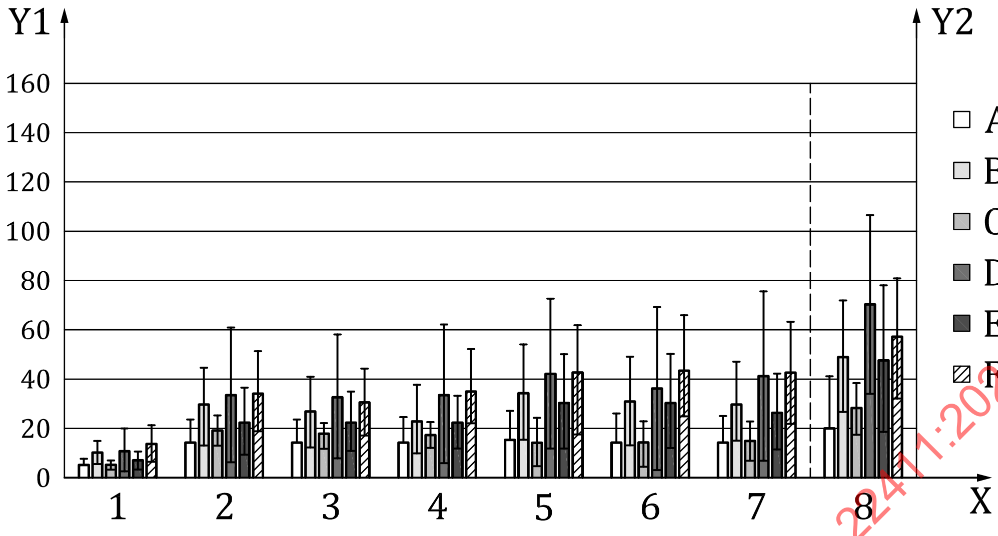
Key

X	type of package and lid	1	one-litre bottle (1LB)
Y1	torque (kgf·m × 10^{-2})	2	small lid, smooth (SLS)
Y2	force (kgf × 10^{-1})	3	small lid, knurled (SLK)
A	20–40 years	4	small lid, deep (SLD)
B	41–50 years	5	large lid, smooth (LLS)
C	51–60 years	6	large lid, knurled (LLK)
D	61–70 years	7	large lid, deep (LLD)
E	71+ years	8	washing powder packet (WPP)

Figure 112 — Static torque and force maximally exerted for opening packages of women in different age groups

Figure 113 shows the similar data but for people with physical disabilities. Six bars, representing maximum torque (or force) data for the six types of disabilities, are shown for each package type. Among the participants with disabilities, people with rheumatic diseases (A) and Parkinson's disease (PS) exerted less maximum torque than people with other physical disabilities such as multiple sclerosis (MS) or cerebral palsy (CS).

The exerted torque and force averaged over all the types of disabilities presented here are much less than for people with no physical disabilities. Yet, the general trend for different types of packages is nearly the same, indicating that the large lid with knurled surface (LLK) resulted in the greatest maximum torque relative to the other packaging types.



Key

X	type of package and lid	1	one-litre bottle (1LB)
Y1	torque (kgf·m × 10^{-2})	2	small lid, smooth (SLS)
Y2	force (kgf × 10^{-1})	3	small lid, knurled (SLK)
A	rheumatic diseases = A	4	small lid, deep (SLD)
B	multiple sclerosis = MS	5	large lid, smooth (LLS)
C	Parkinson's disease = PS	6	large lid, knurled (LLK)
D	cerebral palsy = CP	7	large lid, deep (LLD)
E	one-handed function (hemiplegia) = OHH	8	washing powder packet (WPP)
F	one-handed function (amputation) = OHA		

Figure 113 — Static torques and force maximally exerted for opening packages for different of types of disabilities

7.6.12.5 Limitations

The number of subjects for each age group and each disability is limited. The male participant sample was limited to people older than 50 years, so the ageing effect across the life span cannot be clearly demonstrated for men. The pattern of results may or may not mirror the results for women.

The sample size for groups of people with disabilities is too small to make clear distinctions based on disabilities type. However, the data do show that, in general, people with disabilities exert significantly lower amounts of torque/force than those without disabilities. This should, therefore, be considered during the design of packaging.

7.6.12.6 Application examples

The data can be directly applied to the design of packages for ease of opening. In particular, the data are useful for designing packaging that is more accessible for people with physical disabilities.

7.6.12.7 References

— Data sources: References [50] and [51];

— Cross-references in this document: 7.6.11, 7.6.13;

— Other references: none.

7.6.13 Jar opening (perceived effort, older women)

7.6.13.1 General

Jar opening is one of the most difficult activities with respect to packaging. This is particularly true for older women who also have a physical disability affecting their hands. Testing the practical jar-opening performance of these women who represent the worst-case scenario can provide us with insights that can be utilized to increase accessibility of jars and other similar packages.

This subclause provides data on jar opening performance of older women aged over 80 years who have disabilities involving hand function.

7.6.13.2 Sampled population

Data were obtained from 18 women with a mean age 85,4 years (sd = 5,4 years). They had hand use limitations which were verified using a six-measure hand function assessment method[112].

7.6.13.3 Methods and conditions of data collection

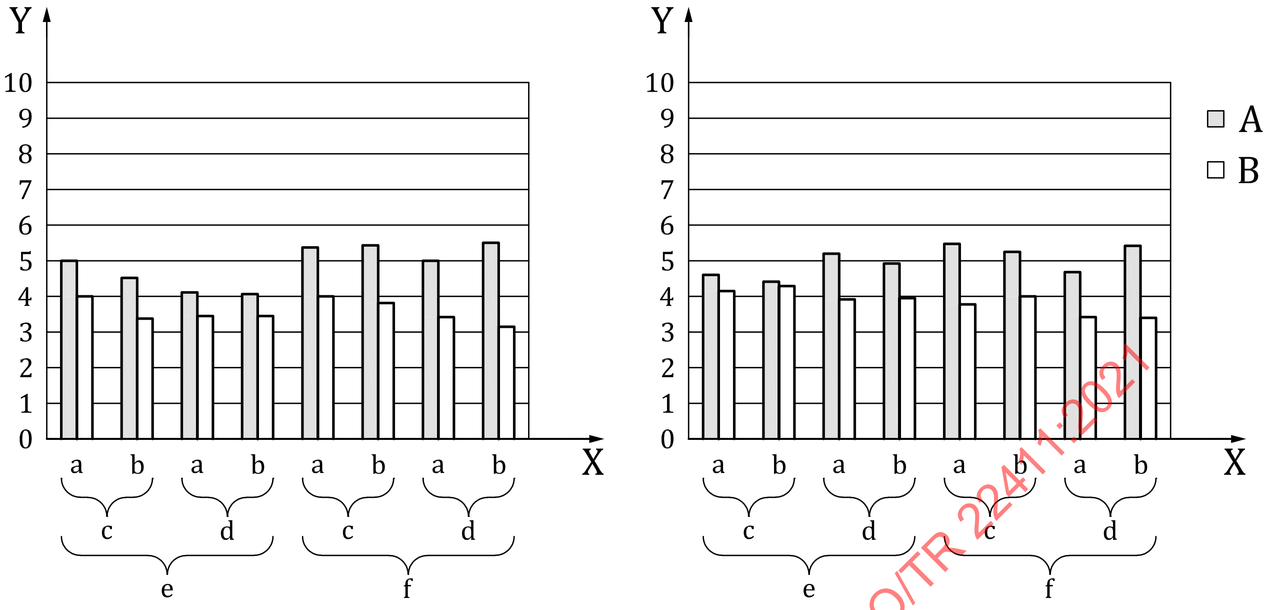
The jar opening performance was measured as a perceived effort rating (PER), using the 0 to 10 point Borg CR10 scale[52], where 10 means “strong almost maximal effort”. For the purpose of the experiment, the torque needed to open the jar was set for each participant at 70 % of their mean maximum voluntary torque (MTV), so as to minimize fatigue and discomfort for each participant over the repeated trials of the experiment. The MVT was measured a few times before testing for each participant.

The packaging variables were lid diameter (28 mm and 42 mm), lid height (9 mm and 17 mm), top shape (circular and hexagonal), side shape (flat and convex) and texture (smooth and serrated) which resulted in a total of 32 jars to be tested, based on all combinations of the variables.

7.6.13.4 Data

The mean data for PER are shown in Figure 114 a) and b) for the lid diameters of 28 mm and 42 mm, respectively. The individual bars in Figure 114 a) and b) represent the PER data for each of the 16 combinations of lid height, texture, top shape and side shape for each lid diameter.

Lid height is the most important factor (the taller the better). The least perceived effort was observed in the condition of the tall (17 mm) height, rough surface texture, hexagonal top and convex side shape jar lid (the rightmost bar in each figure).



a) **Lid diameter, 28 mm**

b) **Lid diameter, 42 mm**

Key

X type of lid and jar
Y perceived effort rating (0–10)
A lid height, 9 mm
B lid height, 17 mm
a smooth
b rough
c circular
d hexagon
e flat
f convex

Figure 114 — Perceived effort rating for jar opening obtained from 18 older women with functional hand limitations

7.6.13.5 Limitations

The data presented here are for the worst case (i.e. for older women with hand problems). Different results would be likely to be obtained for other people who are different in age, gender or functional capability.

7.6.13.6 Application examples

Designers of packages like jars should refer the data and implications presented in this subclause to maximize the ease of opening of their packaging.

7.6.13.7 References

— Data source: Reference [112];

— Cross-references in this document: 7.6.11, 7.6.12;

— Other references: References [113] and [52].

7.6.14 Upper extremity muscle strength (ageing effect)

7.6.14.1 General

Muscle strength of the upper limbs has a great impact on activities of daily life and on quality of life. This subclause provides data on muscle strength for joint torque of a wrist, an elbow and a shoulder of Japanese men and women as a function of age.

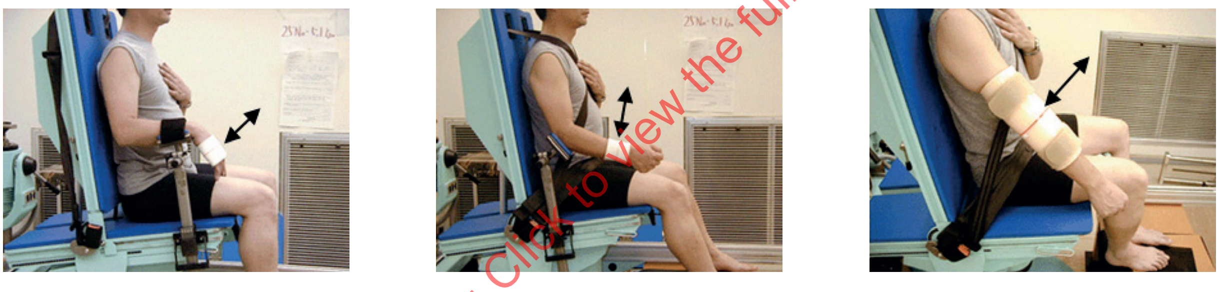
7.6.14.2 Sampled population

The data were collected from about 400 Japanese men and 400 women ranging in age from 20 to 80 years for each measurement of wrist, elbow and shoulder torque.

7.6.14.3 Methods and conditions of data collection

The muscle strength data were defined as the gravity-compensated extremity joint torque (EJT) values. The EJT values were measured by isometric "make" tests in the sagittal plane with a hand-held dynamometer (HHD). Figure 115 a), b) and c) shows pictures of a measuring scene for each of the wrist, elbow and shoulder muscle strength. The measurements were done with the right hand while the left hand was held on the chest.

NOTE The "make" test is a muscular strength testing method for measuring the force exerted by individuals against an unmoving object such as a wall. Isometric means that the muscle length is kept constant without joint movement during the testing.



a) **Wrist strength** b) **Elbow strength** c) **Shoulder strength**

Figure 115 — Method of measurements for muscle strength of the upper extremity

7.6.14.4 Data

Tables 39 and 40 together with Figure 116, Tables 41 and 42 together with Figure 117, and Tables 43 and 44 together with Figure 118 show the data on joint torques for flexion and extension for the wrist, the elbow and the shoulder, respectively. Joint torque of any kind measured and shown here has a slight peak at the young to middle age (30 to 50 years) and decreases with age above that. Large differences in torques are also found between men and women for all the joint torques.

Table 39 — Torque data for wrist flexion for Japanese men and women for different age groups

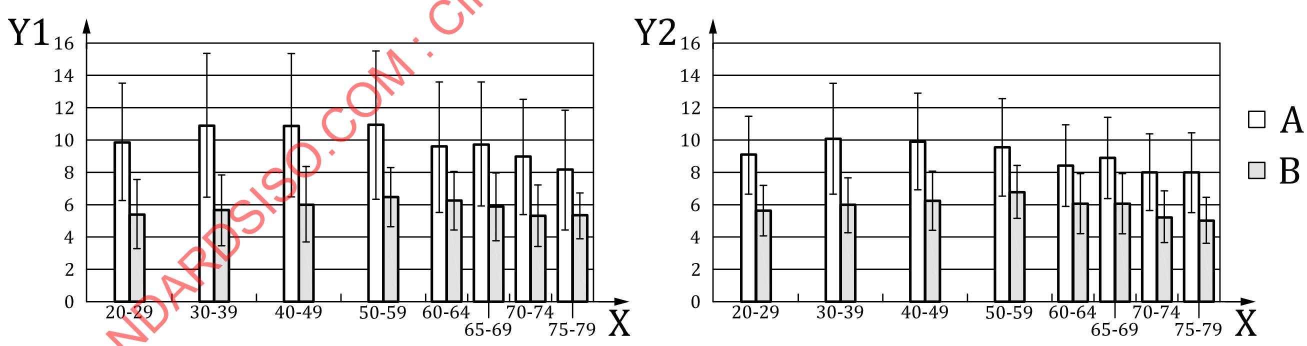
Age groups years	Men			Women		
	Number of participants, *n*	Mean Nm	Standard deviation, *s* Nm	Number of participants, *n*	Mean Nm	Standard deviation, *s* Nm
20–29	36	9,9	3,6	33	5,4	2,1
30–39	43	10,9	4,4	33	5,6	2,2
40–49	39	10,9	4,4	30	6,0	2,4

Table 39 *(continued)*

Age groups years	Men Number of participants, *n*	Men Mean Nm	Men Standard deviation, *s* Nm	Women Number of participants, *n*	Women Mean Nm	Women Standard deviation, *s* Nm
50–59	39	10,9	4,6	39	6,5	1,9
60–64	68	9,5	4,0	66	6,2	1,8
65–69	103	9,7	3,8	93	5,8	2,2
70–74	84	8,9	3,5	68	5,2	1,8
75–79	23	8,0	3,7	17	5,3	1,4

Table 40 — Torque data for wrist extension for Japanese men and women for different age groups

Age groups years	Men Number of participants, *n*	Men Mean Nm	Men Standard deviation, *s* Nm	Women Number of participants, *n*	Women Mean Nm	Women Standard deviation, *s* Nm
20–29	36	9,1	2,4	30	5,6	1,5
30–39	43	10,1	3,4	33	6,0	1,7
40–49	40	9,9	3,0	30	6,2	1,8
50–59	40	9,5	3,0	40	6,8	1,6
60–64	70	8,4	2,5	67	6,1	1,9
65–69	101	8,9	2,5	89	6,1	1,9
70–74	87	8,0	2,4	69	5,3	1,6
75–79	19	8,0	2,5	16	5,0	1,4



a) Wrist flexion

b) Wrist extension

Key

X age groups (years)
Y1 wrist flexion torque (Nm)
Y2 wrist extension torque (Nm)
A men
B women

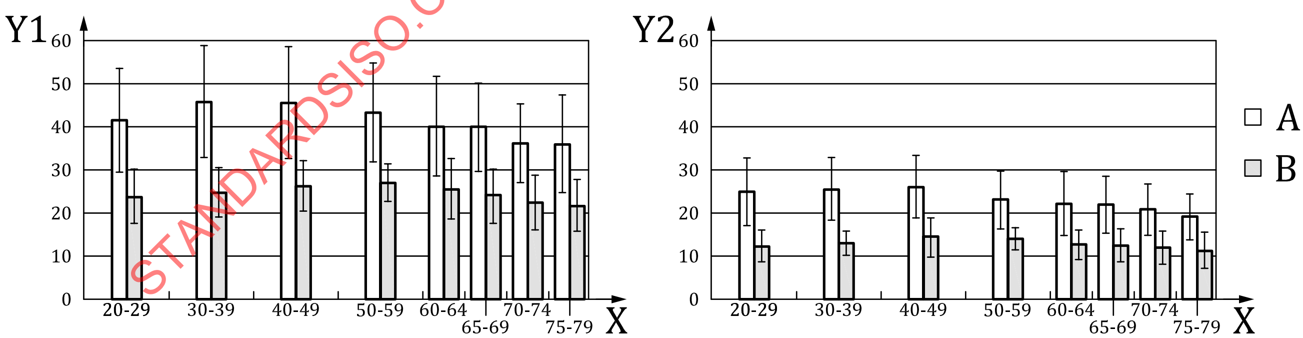
Figure 116 — Torque data for wrist flexion and extension for Japanese men and women as a function of age

Table 41 — Torque data for elbow flexion for Japanese men and women for different age groups

Age groups years	Men			Women		
	Number of participants, *n*	Mean Nm	Standard deviation, *s* Nm	Number of participants, *n*	Mean Nm	Standard deviation, *s* Nm
20–29	37	41,4	11,9	35	23,7	6,2
30–39	45	45,7	12,9	33	24,8	5,8
40–49	44	45,6	13,0	29	26,2	5,8
50–59	39	43,3	11,4	40	26,9	4,3
60–64	72	40,0	11,6	75	25,6	7,0
65–69	109	39,9	10,2	95	24,2	6,4
70–74	86	36,1	9,1	78	22,4	6,3
75–79	25	35,9	11,3	20	21,7	6,0

Table 42 — Torque data for elbow extension for Japanese men and women for different age groups

Age groups years	Men			Women		
	Number of participants, *n*	Mean Nm	Standard deviation, *s* Nm	Number of participants, *n*	Mean Nm	Standard deviation, *s* Nm
20–29	34	24,6	7,9	33	12,0	3,7
30–39	35	25,3	7,2	32	12,7	2,9
40–49	33	25,8	7,2	28	14,2	4,5
50–59	33	22,9	6,9	39	13,8	2,5
60–64	62	22,5	7,4	66	13,0	3,4
65–69	96	22,2	6,6	94	12,8	3,9
70–74	74	21,1	5,9	68	12,4	3,8
75–79	21	19,4	5,3	19	11,6	4,2



a) **Elbow flexion** b) **Elbow extension**

Key

X age groups (years)

Y1 elbow flexion torque (Nm)

Y2 elbow extension torque (Nm)

A men

B women

Figure 117 — Torque data for elbow flexion and extension for Japanese men and women as a function of age

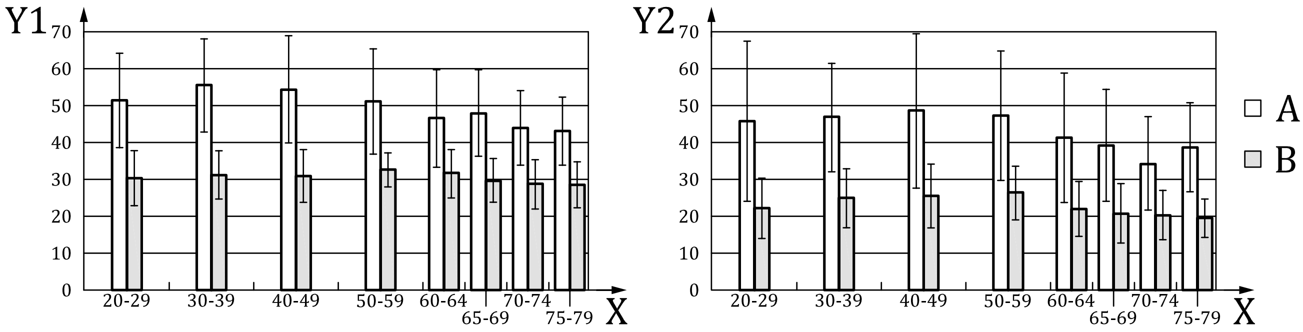
Table 43 — Torque data for shoulder flexion for Japanese men and women for different age groups

Age groups years	**Men**			**Women**		
	Number of participants, *n*	**Mean** Nm	**Standard deviation, *s*** Nm	**Number of participants, *n***	**Mean** Nm	**Standard deviation, *s*** Nm
20–29	34	51,4	12,8	34	30,2	7,4
30–39	35	55,4	12,6	31	31,2	6,5
40–49	33	54,2	14,5	29	31,0	7,1
50–59	31	51,0	14,2	40	32,6	4,6
60–64	64	46,7	13,2	66	31,8	6,9
65–69	89	48,0	11,7	82	29,8	6,1
70–74	72	44,0	10,1	62	28,8	6,6
75–79	19	43,1	9,1	15	28,6	6,2

Table 44 — Torque data for shoulder extension for Japanese men and women for different age groups

Age groups years	**Men**			**Women**		
	Number of participants, *n*	**Mean** Nm	**Standard deviation, *s*** Nm	**Number of participants, *n***	**Mean** Nm	**Standard deviation, *s*** Nm
20–29	—	45,5	21,5	34	22,0	8,1
30–39	—	46,5	14,5	32	24,7	8,1
40–49	—	48,5	21,0	29	25,4	8,5
50–59	—	47,0	17,5	40	26,2	7,2
60–64	—	41,0	17,5	70	21,7	7,4
65–69	—	39,0	15,0	93	20,7	8,0
70–74	—	34,0	12,5	65	20,1	6,7
75–79	—	38,5	12,0	16	19,3	5,2

NOTE Data of shoulder extension for men were visually inspected from the original figure, and the number of participants were unknown.



a) Shoulder flexion

b) Shoulder extension

Key

X age (years)

Y1 shoulder flexion torque (forward elevation) (Nm)

Y2 shoulder extension torque (Nm)

A men

B women

Figure 118 — Torque data for shoulder flexion and extension for Japanese men and women as a function of age

7.6.14.5 Limitations

The data show the maximum torque for the muscle strength of the wrist, elbow and shoulder but not provide data for comfortable or continuous torque.

7.6.14.6 Application examples

The data can be used as basic data for designing and evaluating objects that involve movements of hands and arms.

7.6.14.7 References

— Data source: Reference [78];

— Cross-references in this document: none;

— Other references: none.

8 Cognitive characteristics and capabilities

8.1 Overview of cognitive characteristics and capabilities

Cognitive characteristics and capabilities are those concerned with central information processing in brain, such as directing attention to information, processing information, storing and recalling information, which relate to human intellectual functions such as understanding, learning, language and literacy. Cognitive performances decline with ageing in general. There are also various types of disabilities in cognitive characteristics and capabilities caused by medical disorders or impairments in brain functions. However, no clear dependency is observed for either gender or ethnicity.

Table 45 summarizes cognitive characteristics and capabilities with regard to effects of ageing and disabilities. Due to the high degree of variability in the data in this cognitive science field, only data related to consistently observed effects are cited in this clause. More relevant information and data can be found in scientific studies for each cognitive function, for example in References [83] and [98].

Table 45 — List of major sensory functions and effects of ageing and disabilities

Cognitive functions	Effects of ageing/disabilities
Attention	
Selective attention	Affected (difficult to control)
Sharing attention	Affected (difficult to control)
Sustaining attention	Reduced
Information processing	
Processing speed	Affected (slower)
Processing capacity	Affected (reduced)
Memory	
Sensory memory	Affected
Working memory (short-term memory)	Affected (mostly)
Long-term memory	Affected
Episodic memory	Affected
Intellect	
Understanding	Ability reduced
Learning	Ability reduced
Language and literacy	Minimal or not affected for age; Affected for people with various cognitive disabilities

8.2 Attention

8.2.1 Selective attention (selective listening, effect of age)

8.2.1.1 General

In a dichotic selective listening task [i.e. different messages presented simultaneously to each ear, with the subject instructed to repeat the message presented to the designated ear (right or left)], performance errors increased as a function of age. Around the age of 60, the ability to correctly report either of two messages declines markedly. Hence, in noisy listening conditions, older subjects can be more adversely affected by distractors than younger ones.

8.2.1.2 Sampled population

Twenty-five female participants each in age group 17–24, 25–32, 33–40, 41–48, 49–56, 57–64, and 65–72 were screened for normal health and hearing. Within each age group, the most common educational level was high school graduate.

8.2.1.3 Methods and conditions of data collection

Twenty-four messages, consisting of letters or digits (0–9), were presented simultaneously at the rate of two items per second, one message to each ear. Each message segment consisted of 16 letter/digit pairs. One of the messages was preceded by a tone, which indicated that the subject should report items that were subsequently presented to that ear.

The independent variable was the subject’s age. The dependent variable was the number of errors.

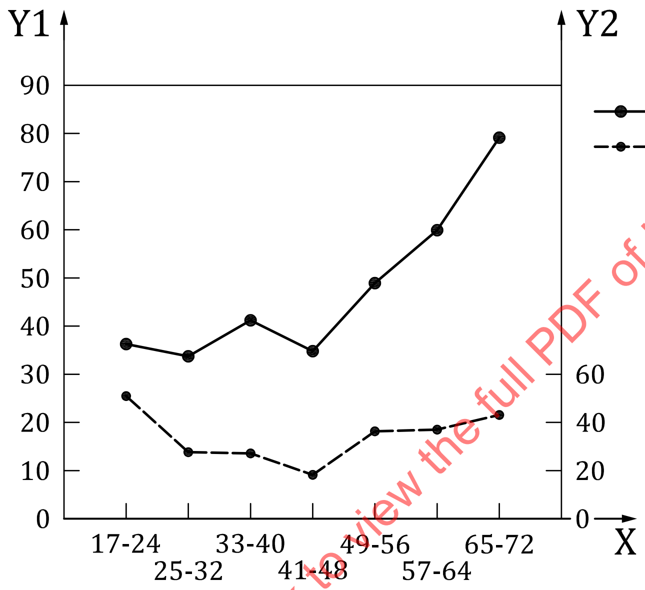
The participant's task was, after hearing the tone, to report all digits or letters heard in the relevant ear immediately upon hearing them.

8.2.1.4 Data

The ability to selectively attend to messages declined with age (probability and significance level, $p < 0{,}001$), particularly in the 60s (probability and significance level, $p < 0{,}05$). Significance was determined by a multivariate analysis and Newman-Keuls analysis. Figure 119 shows the mean total error and standard deviation as a function of age.

Other studies employing related tests of selective attention generally have shown that selective attention ability begins to decline in the 60s.

In this study, other tests were administered to the same participants. The oldest group deviated from the others on portable rod-and-frame, group embedded figures and complex reaction time tests, but less so on a simple choice reaction time test (Figure 120 and Figure 121).



Key

X age groups (years)

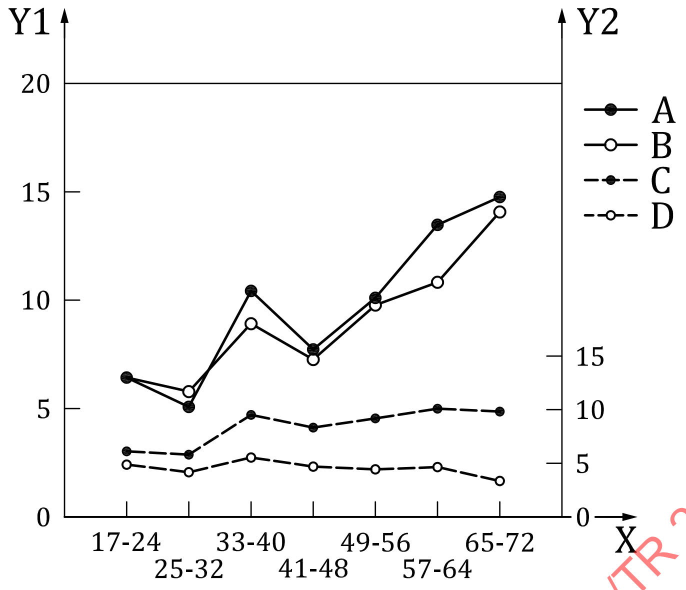
Y1 total errors

Y2 standard deviation

A mean

B standard deviation

Figure 119 — Information-processing performance as a function of age — Selective attention test



Key

X age groups (years)

Y1 degrees of deviation (portable rod-and-frame test)/misses (group embedded figures test)

Y2 standard deviation

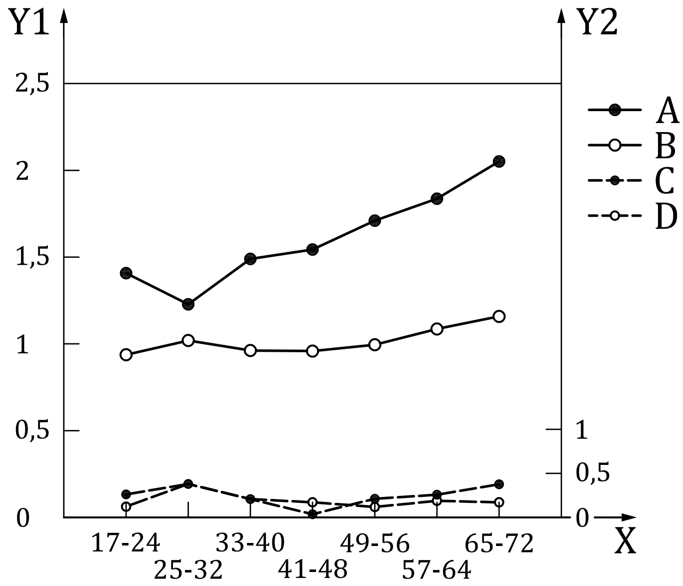
A mean (portable rod-and-frame test)

B mean (group embedded figures test)

C standard deviation (portable rod-and-frame test)

D standard deviation (group embedded figures test)

Figure 120 — Information-processing performance as a function of age — Portable rod-and-frame test and group embedded figures test



Key

X age groups (years)
Y1 reaction times, s
Y2 standard deviation, s
A mean (complex reaction)
B mean (simple choice reaction)
C standard deviation (complex reaction)
D standard deviation (simple choice reaction)

Figure 121 — Information-processing performance as a function of age — Complex reaction time and simple choice reaction time

8.2.1.5 Limitations

The limitations of the study include that only females were tested, and the age range did not extend beyond the age of 72. Nevertheless, there is no reason to assume that the observed trend would not be replicated with male participants. Similarly, there is no reason to assume that the observed performance trend would not continue if groups with participants older than 72 were tested. Although the study involved an auditory task specifically, there is evidence from a variety of sources that the same effect occurs for other sensory-related tasks (particularly vision tasks).

8.2.1.6 Application examples

Applying these results involves ensuring that products, systems and services designed for older adults avoid presenting extraneous information that distracts the user from the task they are attempting to perform. If a person is trying to understand and follow a conversation, for example, other sources of extraneous auditory information (e.g. background conversation from a television set) should be turned off. Similarly, a website allowing people to place an order for a product online should not present non-task-related animation (i.e. extraneous information) that would distract the user while they are completing the data entry task involved in placing their order.

Persons with some cognitive disabilities can also have the same distractive effect from unrelated or background noises, perhaps in a more pronounced form. Therefore, care should be taken in designing products and applications for those individuals.

8.2.1.7 References

— Data source: Reference [99];

— Cross-references in this document: none;

— Other references: References [57], [93] and [109].

8.2.2 Dual task performance (task complexity, ageing effect)

8.2.2.1 General

Performance is generally better when individuals perform a single task rather than when they are required to divide their attention among multiple tasks. Additionally, performance is generally better for simple tasks than for difficult or complex tasks under dual-task conditions. With respect to ageing effects, the extent of the performance decline for older adults under dual task conditions depends on the nature of the particular tasks being performed. While performance for tasks that involve visual attention or reaction time tend to decline more markedly for older adults than younger adults as difficulty increases, task performance for tasks that involve meaningful, connected speech decline at approximately the same rate for younger and older adults.

This subclause presents data for dual-task conditions which involved recall of spoken text (i.e. sentences) and recognition of pictures as having been previously viewed or not previously viewed on a computer screen.

8.2.2.2 Sampled population

Subjects were 25 young adults, aged 18 to 27 (mean age = 20,3 years), and 25 older adults, aged 60 to 78 (mean age = 68,0 years). All had good hearing acuity.

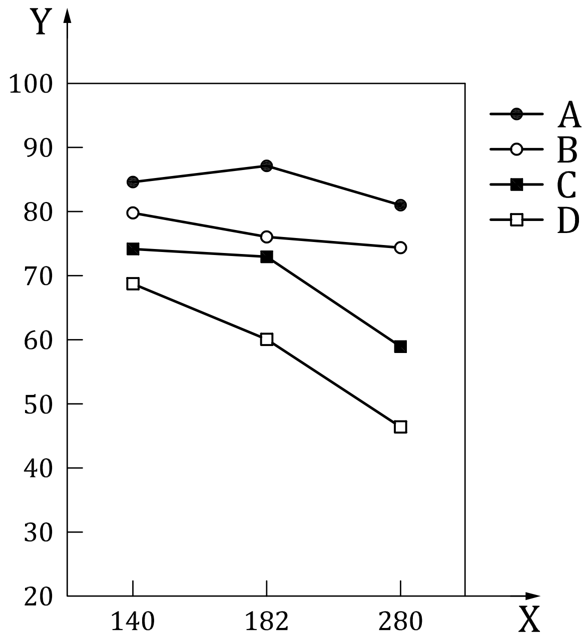
8.2.2.3 Methods and conditions of data collection

In the dual task condition, the participant was asked to recall all of the words in sentences verbally presented at one of three different speech rates [140 words per minute (wpm), 182 wpm, and 280 wpm], while simultaneously responding to pictures presented on computer screen, in terms of whether they had been previously viewed (i.e. old pictures) or not previously viewed (i.e. new pictures). The 3 different speech rates of the sentences were designed to vary the difficulty of the sentence recall task. In the single task condition, participants performed only the sentence recall task.

8.2.2.4 Data

Figure 122 shows that the sentence recall of both older and younger adults decreased under dual task conditions, relative to single task conditions, and the pattern of the decrease is similar for older and younger adults. Figure 122 presents the experimental results showing a clear decline in the percentage of correctly recalled words by older people (but not younger people) as the speech rate increased. The decline in the performance of older people with increasing speech rates is thought to reflect a cognitive slowing of information processing, such that they need more time to process information presented at fast rates.

It should be noted that additional similar studies by Tun, McCoy, and Wingfield[102] in which hearing acuity, was also included as a grouping variable, indicated that poor hearing acuity decreased accuracy in a primary word recall task, even though the words were presented at an intensity level that was verified as audible by all participants. In addition, the effect was greatest for older adults with poor hearing relative to the other groups. The authors explain the result in terms of the greater mental effort required for older adults with hearing impairments to perceptually identify the words, resulting in less capacity available for the performing the task(s).



Key

X speech rate (words per minute)
Y percentage of words correctly recalled
A young: single-task
B young: dual-task
C elderly: single-task
D elderly: dual-task

Figure 122 — Percentage of words correctly recalled from sentences as a function of age, task difficulty (i.e. words per minute) and single vs. dual task conditions

8.2.2.5 Limitations

This pattern of results is typical of studies in which the task involves meaningful connected speech, However, in studies in which the task performance measured involves reaction time or visual (as opposed to auditory) attention, older adults show a greater decline than younger adults under dual task conditions as difficulty increases. Thus, designers should consider the nature of the tasks to be performed when applying the results.

8.2.2.6 Application examples

Designers should not ask users to perform two tasks simultaneously unless they are simple ones. This is especially true for older adults. The higher the level of difficulty of the task of interest, the more important it is for tasks to be performed one at a time. Designers should also consider the particular task involved when determining whether two tasks can be performed simultaneously. Performance for tasks involving meaningful speech can be less affected for older adults under dual task conditions than tasks that require other types of performance (visual information processing or fast reaction times). However, designers should keep in mind that older adults with hearing impairments can be especially burdened by speech-related tasks under dual-task conditions, even if attempts are made to ensure audibility of the speech, due to the mental effort required to identify the words.

8.2.2.7 References

— Data sources: References [104] and [102];

— Cross-references in this document: 6.3.1, 8.2.3;

— Other references: References [55], [96], [103] and [68].

8.2.3 Memory under dual task conditions (effects of dual tasks and ageing)

8.2.3.1 General

The tasks of memorizing information require attention and processing capacity. Therefore, performance of tasks involving memory can be adversely affected when other tasks, not directly related to the memory task, need to be performed at the same time. Doing this requires additional attention and processing capacity.

This subclause presents data from younger and older people, showing how memory task performance is affected by the simultaneous performance of other non-related tasks.

8.2.3.2 Sampled population

A total of 56 young (34 male and 22 female) people and 56 older people (35 male and 21 female) participated in the experiment. Young people ranged in age from 15 to 35 years with mean values of 21,1 years and 21,7 years for males and for females, respectively. Older people ranged in age from 60 to 85 with mean values of 67,4 years and 66,0 years for males and for females, respectively.

8.2.3.3 Methods and conditions of data collection

Figure 123 shows the experimental procedure. The participant was asked to memorize 5 one-digit numbers sequentially presented on a screen for 1 s each in every 3 s and to recall all 5 numbers verbally. During the 3 s interval, the participant was asked to do a task (distraction) inputting a one-digit number by mouse-clicking on a separate device. The task differs in each trial according to the following:

— the same one-digit number as displayed on the screen to memorize;

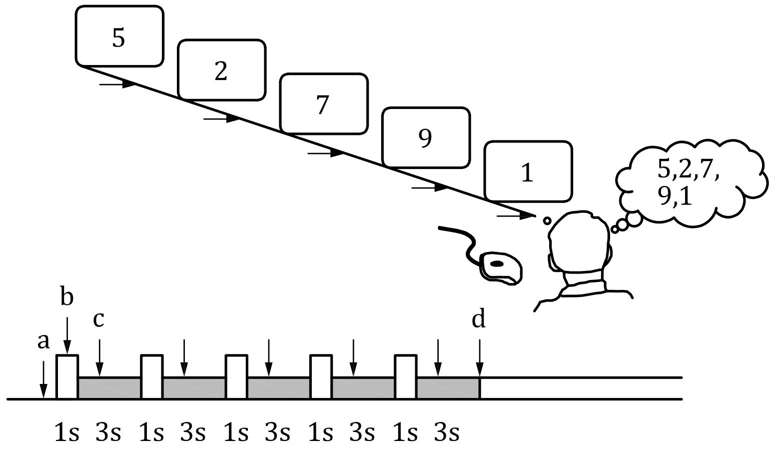
— the one-digit number subtracted the given number from 9, i.e. “2” in case of “7”;

— any one-digit number read out from a 5-digit number printed on a separate card;

— any one-digit number taken from the date (day and month) of the experiment.

Before and after these task-associated trials, a control trial with no task was carried out at the beginning and the end of trials.

The dependent measure is the accuracy of memory recall of the 5 digits presented sequentially for the 4 conditions with different input tasks.



Key

a start signal (0,3 s prior)

b one-digit number presentation on a screen

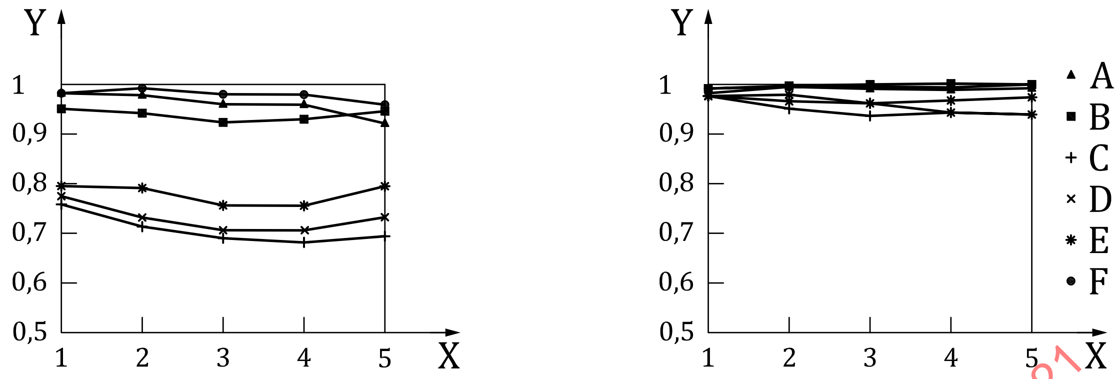
c input task using a mouse

d memory recall of all 5 one-digit numbers presented sequentially

Figure 123 — Experimental procedure for memory with input tasks

8.2.3.4 Data

Figure 124 shows how the digit recall accuracy was affected by the distractive tasks. The accuracy is the percentage of correct recall for each of the 1^{st} to 5^{th} presentations of repeated trials. For older adults, performance was negatively affected by the subtraction, card reading and date input typing tasks. In contrast, any typing task condition had little or no effect on the digit recall performance of the younger adults.



a) Older people **b) young people**

Key

X order of digit presentation (1 is the the first, 5 is the the last)
Y percentage of correct memory recall
A no task (as a control at the beginning)
B input of the same one-digit number as presented
C input a digit subtracted from 9
D input of a digit in a printed card
E input of a digit taken from a date
F no task (as a control at the end)

Figure 124 — Percentage of correct recalling of five numbers consecutively presented with distractive tasks in between

8.2.3.5 Limitations

The present results are task-specific. For different tasks, the recall accuracy is affected differently. However, difficult distractive tasks can affect performance for a memory task, and the effect is more pronounced in older people than in young people.

8.2.3.6 Application examples

It is not appropriate for older people to have imposed on them different non-related tasks during while performing a primary task involving memorization. When watching several screens or displays and the information from a previous screen or display is needed to understand the current screen or display, it should be avoided to interrupt a person, especially an older person, who is engaged in the task by introducing new information or asking him/her to do something else.

8.2.3.7 References

— Data source: Reference [77];

— Cross-references in this document: 8.2.2;

— Other references: none.

8.3 Information processing

8.3.1 Processing speed and capacity

8.3.1.1 General

Age differences in cognitive task performance, to a large degree, are caused by a decline in working memory capacity and expressed through a reduced information processing speed.

Generally, performance of learned mental tasks and skills take longer than they would for younger people. Similarly, older people can acquire new knowledge and master new skills, but doing so requires more time than it does for younger people.

This subclause presents data demonstrating how processing speed decreases with age.

8.3.1.2 Sampled population

Adults ranging in age from 20 to 90, grouped in 10-year increments (20–29, 30–39, etc.) comprised the sample. The number of subjects in each group ranged from 40–54, except for the eldest group (i.e. 80–89), which contained only 23 individuals.

8.3.1.3 Methods and conditions of data collection

Subjects were asked to complete a variety of pencil-and-paper tasks and memory tests over the course of a 3-day period. Three of those tasks were designed to assess changes in processing speed.

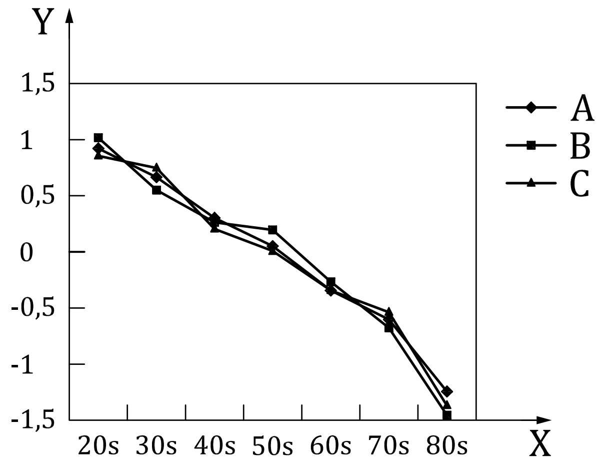
In the digit-symbol task, subjects were presented with 9 geometric figures, each assigned a digit (1–9). They were then presented with a series of random digits (1–9) and asked to copy the symbol associated with each digit as fast as possible onto a scoring sheet. The dependent measure was the number of digits symbols correctly copied in 90 s.

In the letter comparison task, subjects were presented with pairs of letter strings, three, six, or nine characters in length, and asked to judge whether the strings in the pair were the same or different. The dependent measure was the total number of correct decisions made in three, 30 s trials (one trial for pairs of each string length).

Similarly, in the pattern comparison task, subjects were presented with pairs of geometric figures, and asked to judge if they were the same or different. The pairs were figures with 3, 6 or 9 line-segments. The dependent measure was the number of correct decisions made in each of three, 30 s trials (one trial for each line segment condition).

8.3.1.4 Data

Participant data for each of the three dependent measures were normalized by transformation into Z-scores. Figure 125 shows that processing speed decreased in a linear fashion with age, for all three tasks. As age increased, the number of items that were completed in 90 s in the digit-symbol task decreased, as did the number of correct pattern and letter comparisons that were made in a 30 s period. This cognitive slowing is presumed to occur at all stages of information processing. It also increases both the time taken to perceive incoming information and the time required to process it and make decisions as to what response(s) to make.



Key

X age by decade

Y Z-score

A digit symbol

B pattern comparison

C letter comparison

Figure 125 — Processing speed as a function of age

8.3.1.5 Limitations

Although the data show a general decrease in processing speed (i.e. an increase in task performance time) with age, the absolute amount of the decrease cannot be determined because it depends on a variety of other factors, including the subject's skill level, and the nature of the particular task involved.

8.3.1.6 Application examples

Because the changes in processing speed are large as age increases, even for the simple tasks involved in this study, product and application developers are best served by not imposing time limits on user tasks, in order to ensure that users of any age have sufficient time to complete those tasks successfully. If an application requires such limits, developers should set the limits high enough so that all users can complete the tasks in the allotted time frames. For a given product or application, testing should be conducted with users representing a broad age range, to verify that the set limits are appropriate.

Likewise, learning and instructional material designers can take into account the changes in processing speed that occur with age, and ensure that appropriate amounts of time are provided during training and testing for older users who can require more time to complete learning tasks.

8.3.1.7 References

— Data sources: References [81] and [61];

— Cross-references in this document: none;

— Other references: Reference [53].

8.4 Memory

8.4.1 Effects of ageing and cognitive disabilities on memory

8.4.1.1 General

Ageing is accompanied by a reduction in processing capacity. All forms of memory generally decrease as a function of age for nearly everyone. This memory decline accelerates after the age of about 75. Working memory seems to be most strongly affected by the process of ageing. The decline of working memory is believed to affect performance in many tasks such as recalling information, information processing, language fluency and understanding grammatical complexity as well as under multi-task performance conditions.

However, memory for vocabulary does not show evidence of a decline with age. It increases with age until at least age 80.

Certain cognitive impairments and medical conditions have similar effects (to ageing) on memory. In addition, people with cognitive impairments often have difficulties remembering the exact sequencing of multi-step procedures or lose their orientation in a long sequence of steps. They rely more heavily on external memory aids and have problems holding a large amount of information in working memory. It should also be noted that the vocabulary memory increasing with age for adults without cognitive impairments does not necessarily apply to people with cognitive impairments, especially learning disabilities. These people can have significant difficulties with the language acquisition and vocabulary retention.

8.4.1.2 Sampled population

Adults ranging in age from 20 to 90, grouped in 10-year increments (20–29, 30–39, etc.) composed the sample. The number of subjects in each group ranged from 40–54, except for the eldest group (i.e. 80–89), which contained only 23 individuals.

8.4.1.3 Methods and conditions of data collection

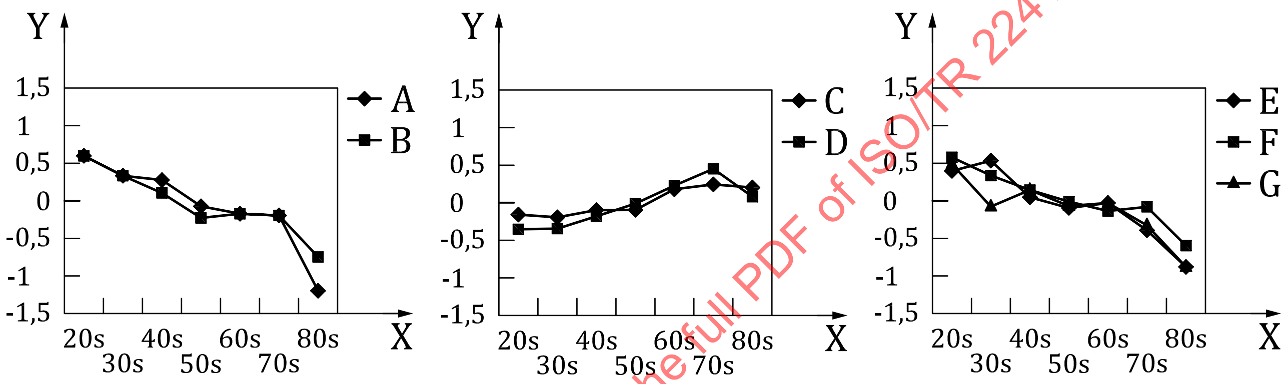
Subjects completed several pencil-and-paper tasks and memory tests over a 3-day period. Memory for vocabulary was measured through the WAIS-R vocabulary test, and the vocabulary section of the Shipley Institute of Living Scale[116]. Two tasks measuring recall memory were also completed. In the free recall task, two lists of 25 words (each containing 5 words each from 5 semantic categories) were generated. The words on each list were then presented individuals for 5 s each. After the list was presented, the subjects were then asked to recall as many words as possible, in any order. The dependent measure was the total number of words recalled for each list. In the cued recall task, participants received two lists of 22 word pairs; one word of each pair was the “cue” presented in small letters, and had an association with the target word, which was presented simultaneously in capital letters. Each of the 22 pairs for a given list was presented for 5 s. After that, each “cue” word was presented alone, and the subject had 8 s to write down the target word associated with it. The dependent measure was the number of target words recalled for each list.

Three tasks/tests were designed to measure working memory specifically. The backward digit span subscale of the WAIS-R[108] was administered, and subjects completed a reading span task and a computation span task. The latter two tasks were adapted from Reference [90]. In the reading span task, subjects read a series of sentences aloud, and answered a simple question about each sentence. At the same time, they were instructed to remember the last word in the sentence just presented, and hold this in their memory, along with the last words from previously presented sentences. The number of words to be held in memory (set size) was varied from 1 to 7 (i.e. from the last word from only one previously presented sentence to the last word from 7 previously presented sentences.). Three trials were conducted at each set size. A trial was terminated after three consecutive errors. The reading span score was the total number of trials in which both recall of the “last word” and answers to the questions were correct up until the point at which the task was terminated.

Similarly, in the computation span task, subjects saw a simple mathematical equation on a screen (e.g. 7 + 6 = ?), and were given three possible answers, from which they were to select the correct answer. At the same time, they were asked to hold in their memory the final digit in the equation. After viewing/solving a series of equations, they were asked to recall the series of final digits. The set size, number of trials, and scoring were the same as for the reading span task.

8.4.1.4 Data

All data were normalized by transformation into Z-scores. The results of the testing are shown in Figure 126. Panel a) shows that performance on both free recall and cued recall tasks decreased steadily with age, with an acceleration in the decline after age 70. Interestingly, panel b) shows that memory for vocabulary shows small but steady increases with age, and no significant decline in the older age groups. Finally, the three tasks assessing working memory showed steady declines with age, and an acceleration in the level of decline in the older age groups.



a) Memory **b) Vocabulary** **c) Working memory**

Key

X age by decade
Y Z-score
A free recall
B cued recall
C WAIS-R vocabulary
D shipley vocabulary
E computation span
F reading span
G backward digit span

Figure 126 — Memory changes as a function of age

8.4.1.5 Limitations

The data provide a general picture of how several different types of memory change with increasing age, and do not provide specific numbers for design. However, for tasks that place demands on working memory, the results are generalizable.

8.4.1.6 Application examples

Because vocabulary memory is just as good, if not better, as people age, the same vocabulary can be used for older and younger adults in applications and products. However, as noted previously, if an application or product is expected to be used by people with cognitive disabilities, whose vocabulary and vocabulary memory can be limited in various ways, the use of simple vocabularies is recommended (e.g. “big” instead of “gigantic”, “home” instead of “residence).

However, with respect to working memory tasks, it possible for younger adults to be able to maintain 5 to 9 items of information in working memory at one time, but 3 to 5 only for older adults, for later recall. Thus, applications that require people to maintain bits of information in working memory (for later recall and use) should limit the number of items that need to be maintained in working memory, so all users can effectively use the application. For example, a voice menu delivered as part of a banking application over the telephone gives people the choice to "make a deposit", "make a withdrawal", "get their account balance" or "other". Although the bank can offer many additional services, it limits the ones offered by any given menu to less than 5, so that all users can remember all the options presented and effectively make their selection.

Additionally, it is preferable to limit the load on working memory, where possible, by using visual presentations of menus, so that users do not have to remember the information items at all (i.e. the options persist on the display until the user makes a selection).

8.4.1.7 References

— Data sources: References [81] and [61];

— Cross-references in this document: 8.5.1;

— Other references: Reference [53].

8.5 Language and literacy

8.5.1 Language use (ageing effects)

8.5.1.1 General

As noted in 8.4.1.4, older adults gain steadily in vocabulary and vocabulary memory throughout their lives. Thus, it also makes sense that their language use would improve over time and with experience. Two studies have shown that this does occur in some tasks, and dramatically so. This subclause reports the results of four studies employing crossword puzzles that demonstrate these effects.

8.5.1.2 Sampled population

Seven groups of participants, grouped by age (20s, 30s, 40s, 70s), who regularly worked crossword puzzles were recruited for each of the studies. Between 195 and 218 adults participated in each of the studies.

8.5.1.3 Methods and conditions of data collection

Participants were asked to spend 15 min attempting to solve a crossword puzzle taken from the New York Times. The dependent measure was the number of words correctly completed in 15 min.

8.5.1.4 Data

The results of all 4 studies showed surprising similar results. The number of words completed in 15 min increased steadily across the age groups. For the youngest group in their 20s, the number of words completed ranged from approximately 16 to 21. Participants in their 40s completed between approximately 34 and 45 words. Finally, people in their 60s completed 42–56 words in 15 min, which was also approximately the same range as for those in their 70s.

8.5.1.5 Limitations

This study can be considered to involve a best-case scenario in which the participants in all groups had experience with crossword puzzles, and the task was specifically about solving crossword puzzles. This sort of improvement can be generalizable across other, similar language-related tasks for which people have experience. Howwever, it is possible that it would not apply to other types of tasks.

8.5.1.6 Application examples

The data suggest that people can improve across the life span in at least some language-related skills that they have routine experience applying. There is no need to make special age-related design accommodations for these types of tasks.

8.5.1.7 References

— Data sources: References [60] and [89];

— Cross-references in this document: 8.4.1;

— Other references: none.

Annex A
(informative)

Additional textual descriptions of figures

This annex is intended to provide textual descriptions of information which is presented in the figures of the main body of the document in a pure visual way and not verbally explained there. It is intended support persons who have problems to retrieve or understand the visual information from graph, bar and chart diagrams, scatter charts or other types of visual presentations and illustrations. It is the goal to provide all readers of this document the same quality of data information, even if they cannot see the figures or have problems estimating values from them. Therefore, this annex is much more than a collection of simple figure captions.

In many cases, where a textual description of graphs or scatter charts would be very long, simple tables of the data are provided which save space and are easy to use even by screen reader (electronic version of the document). Data provided for this purpose are taken from the original but the number of significant figures is rounded down to the level sufficient to provide an image of the graphs. In case the original data are not available, data are taken from the figures by visual inspection and tabulated.

This annex provides additional, but not full, textual information for each figure in the main document. It cannot be understood without reading the text in the corresponding clause. For example, this annex first shows the text associated with a figure, and below its additional description. Hyperlinks to the main document support easy reading without searching.

Descriptive texts as provided in this annex should not be mistaken with so called "alternative texts" which are hidden, very short texts in electric documents such as pdf providing blind persons or persons with low vision with information about the function or content of figures or icons, e.g. when using a screen reader.

This approach of descriptive texts is not intended to become a standard form for other documents of different types. Still, this annex can be a reminder of the necessity to provide all relevant visually presented information also in text form to address the needs of all readers.

NOTE A data point in a two-dimensional diagram is expressed as (a, b) in this annex where a and b mean the X-axis (horizontal) coordinate and the Y-axis (vertical) coordinate, respectively.

Figure 1: Two approaches to address accessibility in standards described in ISO/IEC Guide 71:2014

Visualization of the text above and below the figure about the structure of ISO/IEC Guide 71:2014.

Figure 2: Spectral sensitivity curves of the human eye for seven age groups from 11 to 78 years

A diagram with X-axis for wavelength (nm) from 350 to 750 nm and Y-axis for the relative sensitivity logarithmic from 0,001 to 1. The diagram provides seven lines, each presenting an age decade. The parabolic lines start at a wavelength of about 420 nm with a maximum at a wavelength of about 550 nm, ending at a wavelength of 700 nm.

Curves start at a sensitivity of 0,006 for people in their 70s and 0,05 for people in their 10s, the other curves have equally spaced starting points in the order of age. The maximum relative sensitivity for all curves is about 1. All curves end with a sensitivity between 0,005 and 0,008 at 700 nm. The curves cross at peak wavelength of about 550 nm to have a reverse order in longer wavelength region than 550 nm but the differences are negligible. The curves for people in their 10s and in their 70s are denoted as A and B, respectively, for clarification.

Figure 3: An application of spectral sensitivity for calculating contrast of a coloured sign

Sign presenting the word "ISO". The diagram below shows two lines of radiance distribution in a range from 375 to 725 nm wavelength (X-axis) and spectral radiance of 0,000 0 to 0,002 0 watt/m^2 (Y-axis).

Parabolic line labelled “a” shows the radiance distribution of a blue letter starting at (375 nm, 0,000 0 watt/m^2) with a maximum at (450 nm, 0,008 5 watt/m^2), ending to nearly zero at 575 nm. A line labelled “b” shows the radiance of a dark yellow background starting at (480 nm, 0,000 0 watt/m^2) with a steep maximum at (630 nm, 0,000 75 watt/m^2) and a smaller steep peak at (710 nm, 0,000 6 watt/m^2), ending to nearly zero at 725 nm.

Two illustrations to visualize the results for calculation of contrast for an observer in his/her 20s and in his/her 70s. Each illustration consists of three bars presenting the luminance of a dark yellow background, of a blue letter and of a dark yellow background. The values are given in the key of this figure.

Figure 4: Measurements of colour similarity and definition of colour category (in case of red fundamental colour)

Figure 4 a) is a visualization of the experimental procedure described in the text above the figure. The colour red is selected from the 13 fundamental colours and the colour dark yellow is selected from the 286 test colours for the similarity test as an example.

Figure 4 b) shows an example of results (the contour map) of the procedure for the red fundamental colour in the Munsell value 5 plane classified into four categories of different similarity (see key of the figure).

Figure 5: Spans of fundamental colours for young people at photopic level (50 % similarity level)

Colour category data for young people, older people, people with defective colour vision and people with low vision are presented in Figures 5 to 8, respectively. Each figure consists of data at four different lightness levels in the Munsell colour space of values 9, 7, 5 and 3 presented from top to the bottom of each figure (see keys of the figures). The size and shape of the spans differ for types of colour vision, i.e. young people, older people, people with defective colour vision or people low vision, and also for fundamental colours.

There are a total of 13 fundamental colours in each figure, and a span of a fundamental colour is shown for each fundamental colour in four cross-sections along with Munsell value axis (lightness axis) as the span forms a three-dimensional space like a small rugby ball distributed in the colour space.

Figure 6: Spans of fundamental colours for older people at photopic level (50 % similarity level)

See above description of Figure 5.

Figure 7: Spans of fundamental colours for people with defective colour vision at photopic level (50 % similarity level)

See above description of Figure 5 a) protanope and b) deuteranope.

Figure 8: Spans of fundamental colours for people with low vision at photopic level (50 % similarity level)

See above description of Figure 5.

Figure 9: Example of colour combination for older people under photopic condition

Visualization of the text above the figure. The figure shows one colour circle at the value 5 plane with spans of five fundamental colours (yellow-red, green-yellow, blue-green, purple-blue and red-purple) used for colouring five lines of a traffic network which is shown at the right side to the colour circle.

Figure 10: Span of fundamental colour “red (reference 5R5/12)” for young people at photopic vision (moderately bright level) measured in six countries (50 % similarity level)

The figure shows a matrix of colour circles with contour map for the Munsell values 9, 7, 5 and 3 (horizontal or in rows) and the countries 1: Japan, 2: USA, 3: Germany, 4: Republic of Korea, 5: Thailand and 6: China (vertical or in columns) for young people.

Figure 11: Span of fundamental colour “red (reference 5R5/12)” for older people at photopic vision (moderately bright level) measured in six countries (50 % similarity level)

See above description of Figure 10, but for older people.

Figure 12: Contrast sensitivity function plotted on the spatial frequency vs. contrast plane

An illustration of a diagram with vertical axis ranging from high contrast (bottom) to low contrast (top) and with horizontal axis ranging from low (left) to high (right) spatial frequency. Six circles are placed in a matrix of two rows and three columns in the spatial frequency vs. contrast domain. The solid circles present visible and the dashed circles (left upper and right upper location) present invisible parts. The grating detection borderline starts at approximately 80 % of contrast at low spatial frequency and closes the visible parts ending at approximately 65 % of contrast at high spatial frequency. Its maximum is at approximately 15 % of contrast at the middle range of spatial frequency.

Figure 13: Contrast sensitivity function of human visual system for young people, older people and people with low vision

A diagram with X-axis for spatial frequency logarithmic from 0,01 cycles per degree (cpd) to 100 cpd and Y-axis for contrast at threshold logarithmic from 100 % (bottom) to 0,1 % (top).

The diagram shows three curves for young, older and low vision people.

Nearly parabolic graph a is for young people starting at (0,07 cpd, 12 %) with a maximum at about (3 cpd, 0,5 %) ending at (30 cpd, 100 %).

Nearly parabolic graph b for older people starting at (0,08 cpd, 12 %) with a maximum at (2 cpd, 1 %) ending at (20 cpd, 100 %).

Nearly parabolic graph c for people with low vision starting at about (0,01 cpd, 100 %) with a maximum at (0,6 cpd, 6 %) ending at (3 cpd, 100 %).

The visible range at 10 % contrast is from 0,08 cpd to 20 cpd, from 0,09 cpd to 10 cpd, and from 0,1 cpd to 1,0 cpd for younger people, older people, and people with low vision respectively.

Figure 14: Character on a grey background with variable contrast

Visualization of the text above showing a character "A" with four different contrasts.

Figure 15: Legibility of simple characters of seven different font sizes with positive polarity as a function of contrast

Two diagrams, a) for young people and b) for older people, with X-axis for contrast (%) logarithmic from 0,1 % to 100 % and Y-axis for legibility evaluation score from 0 to 5 with 7 curves for each diagram showing the data in the following two data tables. The Y-axis data are given for 7 different font sizes from A, 160 pt to G, 8 pt.

In Table A.1, the data of the two diagrams are shown combined.

Table A.1 — Legibility of simple characters of seven different font sizes with positive polarity as a function of contrast

X (%)	Y: A, 160 pt young	Y: B, 80 pt young	Y: C, 40 pt young	Y: D, 28 pt young	Y: E, 18 pt young	Y: F, 12 pt young	Y: G, 8 pt young	Y: A, 160 pt older	Y: B, 80 pt older	Y: C, 40 pt older	Y: D, 28 pt older	Y: E, 18 pt older	Y: F, 12 pt older	Y: G, 8 pt older
0,35	0,0	0,0	—	—	—	—	—	0,0	—	—	—	—	—	—
0,76	0,2	0,1	0,0	0,0	—	—	—	0,1	0,0	0,0	—	—	—	—

Table A.1 *(continued)*

X (%)	Y: A, 160 pt young	Y: B, 80 pt young	Y: C, 40 pt young	Y: D, 28 pt young	Y: E, 18 pt young	Y: F, 12 pt young	Y: G, 8 pt young	Y: A, 160 pt older	Y: B, 80 pt older	Y: C, 40 pt older	Y: D, 28 pt older	Y: E, 18 pt older	Y: F, 12 pt older	Y: G, 8 pt older
1,5	0,7	0,3	0,1	0,1	0,0	0,0	—	0,5	0,2	0,0	0,0	—	—	—
2,9	1,2	1,0	0,6	0,6	0,3	0,0	—	1,3	0,9	0,3	0,1	0,0	—	—
5,0	1,6	1,5	1,1	1,1	0,8	0,3	0,0	2,1	1,6	0,8	0,3	0,1	—	—
8,2	2,0	2,0	1,6	1,6	1,3	0,8	0,1	2,6	2,1	1,3	0,8	0,3	0,0	—
12	2,3	2,4	2,1	2,1	1,6	0,9	0,2	2,8	2,4	1,7	1,3	0,6	0,0	—
17	2,6	2,7	2,3	2,3	2,0	1,4	0,5	3,2	2,7	2,2	1,7	1,0	0,1	0,0
24	3,0	3,2	2,9	2,9	2,4	1,9	0,8	3,5	3,3	2,5	2,1	1,4	0,3	0,1
34	3,5	3,5	3,3	3,3	2,9	2,4	1,2	3,9	3,5	2,9	2,6	1,8	0,5	0,1
49	4,0	4,0	3,8	3,8	3,4	2,8	1,6	4,2	4,0	3,5	3,1	2,3	0,9	0,3
70	4,6	4,6	4,3	4,3	4,0	3,3	2,1	4,7	4,5	4,0	3,5	3,0	1,3	0,5
100	5,0	4,9	4,7	4,7	4,4	3,8	2,8	4,8	4,8	4,4	3,8	3,3	2,0	1,1

Figure 16: Map of legibility level as a function of font size (in pt) and contrast for simple characters for young and older people.

Two diagrams, a) for young people and b) for older people, with X-axis for font size (pt) logarithmic from 1 point to 1 000 points and Y-axis for contrast (%) logarithmic from 0,1 % to 100 % with data points as shown in Table A.2. The data are for 6 different legibility levels labelled level 0 to level 5. The size vs contrast plane is separated to 6 zones by those data and coloured differently with a grey scale in the diagram. White dot at font size 18 pt with 40 % contrast is in both diagrams.

In Table A.2, the data of the two diagrams are shown combined.

Table A.2 — Legibility level as a function of font size and contrast for simple characters for young and older people

X (pt)	Y: level 0 (%) young	Y: level 1 (%) young	Y: level 2 (%) young	Y: level 3 (%) young	Y: level 4 (%) young	Y: level 5 (%) young	Y: level 0 (%) older	Y: level 1 (%) older	Y: level 2 (%) older	Y: level 3 (%) older	Y: level 4 (%) older	Y: level 5 (%) older
8	11	52	—	—	—	—	26	94	—	—	—	—
12	6,9	28	63,8	—	—	—	15	54	98,1	—	—	—
18	2,8	12	25,3	55	—	—	6,1	17	39,3	70	—	—
28	2,2	6,2	16,6	37	72	—	2,6	9,4	22,0	46	—	—
40	1,2	4,5	11,3	27	57	—	2,2	6,2	14,5	36	69	—
80	0,63	2,8	8,5	21	49	99	1,2	3,1	7,6	20	50	100
160	0,59	2,2	8,4	24	48	90	0,59	2,2	8,4	24	48	90

Figure 17: Visual acuity as a function of viewing distance for seven age groups

A diagram with X-axis for viewing distance (m) logarithmic from 0,1 m to 10 m and Y-axis for visual acuity logarithmic from 0,1 to 10 with curves drawn using the data in Table A.3. The data are for 7 age groups from A, 10–19 years to G, 70–79 years.

Table A.3 — Visual acuity as a function of viewing distance for seven age groups

X (m)	Y: A, 10–19 years	Y: B, 20–29 years	Y: C, 30–39 years	Y: D, 40–49 years	Y: E, 50–59 years	Y: F, 60–69 years	Y G, 70–79 years
0,3	1,1	1,2	0,9	0,4	0,3	0,2	0,3
0,5	1,3	1,3	1,1	0,6	0,4	0,4	0,3
1	1,4	1,4	1,2	1,0	0,8	0,7	0,6
2	1,5	1,5	1,3	1,2	1,2	1,0	0,7
5	1,4	1,5	1,3	1,4	1,3	1,1	0,8

Figure 18: Visual acuity as a function of luminance for seven age groups

A diagram with X-axis for luminance (cd/m^2) logarithmic from 0,1 cd/m^2 to 10 000 cd/m^2 and Y-axis for visual acuity logarithmic from 0,1 to 10 with curves drawn based on the data in Table A.4. The data are for 7 age groups data from A, 10–19 years to G, 70–79 years.

Table A.4 — Visual acuity as a function of luminance for seven age groups

X (cd/m^2)	Y: A, 10–19 years	Y: B, 20–29 years	Y: C, 30–39 years	Y: D, 40–49 years	Y: E, 50–59 years	Y: F, 60–69 years	Y G, 70–79 years
0,05	0,3	0,3	0,3	0,2	0,3	0,2	0,2
0,1	0,4	0,4	0,4	0,3	0,3	0,3	0,3
0,3	0,6	0,6	0,5	0,5	0,5	0,4	0,3
1	0,8	0,8	0,7	0,7	0,6	0,6	0,4
3	0,9	1,0	0,8	0,8	0,8	0,7	0,6
10	1,1	1,2	1,0	1,0	0,9	0,9	0,7
30	1,4	1,4	1,3	1,1	1,1	1,0	0,7
100	1,5	1,5	1,4	1,4	1,2	1,1	0,9
1 000	1,7	1,7	1,5	1,4	1,4	1,3	0,9

Figure 19: Minimum font size for legibility of single characters for young and older people

Two bar diagrams, a) for young people and b) for older people, with X-axis for viewing conditions from condition 1 to condition 8 and Y-axis for font size (pt) showing the data in Table A.5. The data are for three different character conditions from A, simple characters to C, complex characters.

In Table A.5, the data of the two diagrams are shown combined.

Table A.5 — Minimum font size for legibility of single characters for young and older people

X	Y: A, simple characters (Japanese Kana, Numerals) (pt) young	Y: B, complex characters 1 (Chinese with 5–10 strokes) (pt) young	Y: C, complex characters 2 (Chinese with 11–15 strokes) (pt) young	Y: A, simple characters (Japanese Kana, Numerals) (pt) older	Y: B, complex characters 1 (Chinese with 5–10 strokes) (pt) older	Y: C, complex characters 2 (Chinese with 11–15 strokes) (pt) older
1: 0,5 m, 100 cd/m^2, serif font	3,4	4,3	4,8	11,4	12,3	13,1

