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Ergonomics of human-system interaction —

Part 312: Readability of electrophoretic displays

Ergonomie de l'interaction homme-système —

Partie 312: Lisibilité des écrans électrophorétiques

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Foreword

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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

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A list of all parts in the ISO 9241-300 series can be found on the ISO website.

Introduction

Electrophoretic technology has led to the development of reflective e-paper displays (EPD) that have fundamentally different optical characteristics compared to emissive display devices, such as backlit liquid crystal displays (LCD) or organic light emitting diode displays (OLED). EPD are used in reading devices, also known as e-readers. See Annex A for more information on the standardization of electronic displays.

The ISO 9241-300 series provides requirements from the viewpoint of human beings' visual properties and are organized by subjects.

Electrophoretic EPD were selected for the experiments reported in this document because of their widespread use as electronic reading devices.

Ergonomics of human-system interaction —

Part 312: Readability of electrophoretic displays

1 Scope

This document provides an overview of recent research on readability of electrophoretic displays. It also provides information for evaluating readability of electrophoretic displays and defining the context of their use.

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
visual analogue scale
psychometric response measurement scale

3.2
legibility
ability for unambiguous identification of single characters or symbols that may be presented in a non-contextual format

[SOURCE: ISO 9241-302: 2008, 3.3.35]

3.3
readability
characteristics of a text presentation on a display that affect performance when groups of characters are to be easily discriminated, recognized and interpreted

[SOURCE: ISO 9241-302: 2008, 3.3.38]

3.4
electronic paper display
EPD
electronic display that shows information by diffuse reflection and holds the image with low power consumption

3.5
electrophoretic display
electronic paper display (3.4) which forms an image by rearranging charged pigment particles using an applied electric field

4 Literature review on readability and legibility for electronic paper displays

4.1 General

A human action of reading is basically analysed by two subjective attributes, that is, readability[1] and legibility[2].

4.2 Readability for electronic paper displays

In 2006, Alex Henzen, et al. suggested that the EPD[3] would provide a reader with “immersive reading”[4]. Another paper reported that the viewing distance for EPD was similar to that of VDTs at around 500 mm, but greater than normal paper, at about 360 mm[5].

In 2007, An-Hsiang Wang reported on the visual performance for bending/curvature EPD.[6] This study indicated a future fashion of EPD, but require further exploration with progress of radiometric measurements. Wang also reported on the reading comprehension of subjects under several ambient illuminance conditions for electronic displays[7].

In 2009, there was a report on the difference of usability between EPDs and conventional books[8], but it was difficult to generalize, considering the results were based on a group of 20 university students. I-Hsuan Shen, et al. studied the visual performance and visual fatigue from EPD and found that a greater illumination than 700 lx was necessary.[9] Wang studied the effects of ambient illuminance on EPD and concluded the following:

1) under lower illuminance of 50 lx, the conventional LCD with a transmissive mode was the only choice;

2) under higher illuminance of 500 lx, the EPD can perform as well as the conventional LCD[10].

In 2010, Wang studied the visual performance of those subjects who were advancing in age[11].

In 2011, Der-Song Lee, et al. investigated the effects of light source, ambient illuminance, character size, and interline spacing on visual performance and visual fatigue for reader of electronic displays.[12] H.C. Wu studied the preferable viewing distance and character size for EPD and suggested that age factors can be considered for EPD design and VDT guidelines[13].

In 2012, Wang examined the effects of text/background colour combinations under three levels of ambient illuminance on the discriminating performance of young and elderly subjects.[14] This e-paper became a guide for the designers of colour EPD. Monika Pölönen, et al. evaluated eyestrain, visually induced motion sickness, changes in visual functioning, user experience, and the essential optical parameters of reading equipment for near-to-eye displays such as small size displays (of mobile phones) and paper.[15] The results indicated that reading from a hard copy was the most comfortable experience.

Wang, et al. investigated the effects of bending curvature EPD[16], but the sample size was too small to estimate effectively the effects.

Eva Siegenthaler, et al. concluded that the image quality seemed crucial for reading against the expectation of differential effects for reading between EPD and LCD.[17] Siegenthaler, et al. also analysed the reading behaviour between EPD and tablet LCD with an eye-tracking measurement.[18] The participants showed no difference in fixation duration, but there were significant differences in reading speed in the proportion of regressive saccades under special artificial light conditions. C. Connell, et al. studied the reading comprehension of subjects using EPD and tablet LCD.[19] The results indicated that the subjects read printed material faster than EPD and tablet.

In 2013, Po-Chun Chang, et al. investigated the effects of ambient illuminance and light source on the reading performance of 100 participants as well as visual fatigue as they read three types of reading tasks on an EPD and paper text.[20] This paper showed that the reading speed depended on ambient illuminance. Simone Benedetto, et al. studied the effects of display technology on visual fatigue over an average period of 10 days. Their evaluation was to measure the blinks per second of each subject and the visual fatigue scale. The results suggested that reading on tablet LCD triggered higher visual fatigue compared to both EPD and paper[21].

In 2014, M. Miyao started to investigate readability of EPD compared to LCD and printed paper under various ambient illuminance levels[22] to [30]. The advantage of the experiment was to employ more than 100 participants and to analyse the results by elaborate statistical processing.

In 2015, S. Matsunami investigated the readability of EPD for aging under various illuminance levels[31].

4.3 Legibility

By definition, legibility is closely related to typeface design. The typeface design went through changes from type-casting of lead block to outline font of font data on a computer. The outline font is scalable and enables desktop publishing (DTP) with increasing display resolution. In the past, bitmap font existed on a low-resolution display but was not scalable. With the beginning of DTP, the idea of page layout on a computer emerged in the 1980s, although page layout was originally omnipresent in the printing industry and publishing world from the age of movable type. Page layout has clearly become conscious of readability, as proved by the large sales of books in the field of printing and publishing business.

In the field of visual information processing, it is commonly believed that there is a unified concept: shape perception is explained by spatial frequency. Every shape responding to visual stimulus can be described as a composite function with a various sinusoidal wave by Fourier analysis of its contrast function. Elements of the contrast function are contrast sensitivities to various sinusoidal waves[32].

There has been a great deal of research in this fields[33].

5 Overview

This document explains the following 7 evaluations and results related to readability of EPD:

1) readability evaluation for EPD under 14 levels of illumination conditions (Clause 6);

2) proposing a baseline setup for readability using VAS evaluation (Clause 7);

3) verification of the minimum illuminance for readability of an EPD (Clause 8);

4) contribution of character sizes to the readability of mobile devices (Clause 9);

5) difference in readability of the contrast ratio of mobile devices (clause 10);

6) the effects of long-term reading on visual functions and subjective symptoms (Clause 11);

7) evaluation of readability for tablet devices by the severity of cataract cloudiness (Clause 12).

Equipment used in these reports:

— 6-inch ILU-EPD: Kindle®[1)] Paperwhite (2012 model);

— 9,7-inch EPD: Kindle®[1)] DX;

— 9,7-inch backlit LCD: iPad3®[1)] (2012 launched) model: A1416.

Kindle®[1)] is used due to its widespread use as an electronic reading device.

1) Kindle and iPad are trademarks of products supplied by Amazon and Apple, respectively. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

6 Readability evaluation for EPD under 14 levels of illumination conditions

6.1 General

The readability of EPD with and without integrated lighting unit (ILU) was compared to liquid crystal display (LCD) with backlight and printed paper to evaluate the contributions of built-in front- or backlights on the readability under different ambient illuminance levels from 10 lx to 8 000 lx. The comparison was carried out under a wide range of illuminance levels. Readability was evaluated using short English words[22].

6.2 Evaluation condition

6.2.1 Equipment

a) 6-inch ILU-EPD

b) 9,7-inch EPD

c) 9,7-inch backlit LCD

d) conventional paper as a reference (whiteness 69 % copy paper)

6.2.2 Participants

a) Number: 110

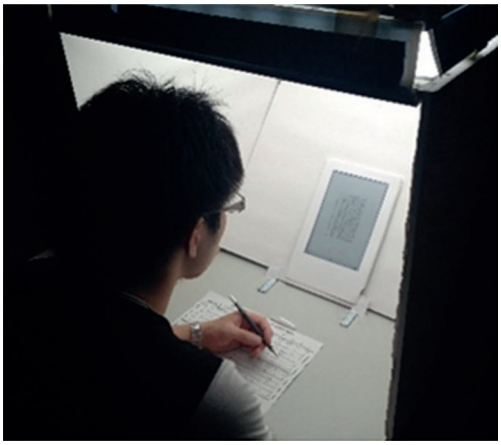
b) Gender: male (56), female (54)

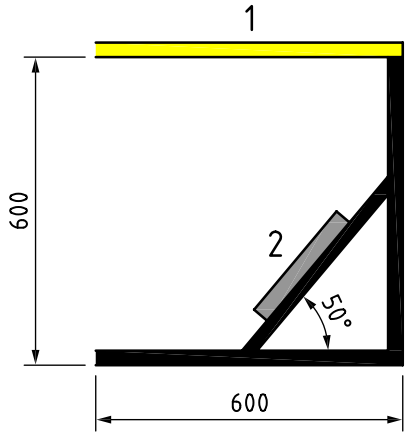
c) Age: from 19 to 86 [mean: 45,7, standard deviation (SD): 17,8]

6.2.3 Illumination condition

Ideally, it would be best to measure the readability under natural surroundings but those are not stable and they vary through time. Artificial stable lighting circumstances were created for 110 participants to make several statistical comparisons. For immersive reading, a small compartment was developed to produce stable illumination conditions. The compartment was set on a desk in a dark room for optical measuring. Its structure is shown schematically in Figure 1. Its light source was D65 by certified fluorescent lights (6 500 K). The illumination level was adjusted incrementally based on sophisticated electronic circuits. Relations between set values and actual measured values of illuminance are shown in Table 1.

Dimensions in millimetres





Key

1 lighting system

2 EPD

Figure 1 — Compartment structure

Table 1 — Illuminance value table

Set value lx	Measured value lx
10	13,47
20	22,73
50	51,60
100	101,4
150	151,4
200	176,3
300	261,7
500	516,7
750	787,7
1 000	1 042
1 500	1 591
2 000	1 983
5 000	4 670
8 500	8 017

6.2.4 Task (Evaluation methods)

1) The participants read aloud short English words in 9-point (3,18 mm in height) Times New Roman font, black-on-white background, shown on a display for 15 s as shown in Figure 2.

BOY	CAT	CAP	DOG	BOOK
BOX	GREEN	OPEN	JAPAN	MILK
APPLE	CITY	SEVEN	CAR	FISH
MAP	PEN	MAN	BAG	DESK
STOP	HOTEL	PIANO	RED	HAND
JAPAN	MILK	APPLE	CAP	DESK
OPEN	RED	DOG	SEVEN	BOY
GREEN	MAP	CAT	HOTEL	MAN
STOP	CAR	BOOK	PIANO	CITY
PEN	HAND	FISH	BOX	BAG

Figure 2 — Example of contents

2) While they were reading, their reading speed was measured as the number of words they could read in 15 s. The viewing distance between the eyes and the device was measured during reading.

3) After reading, the participants evaluated readability for each display by using the visual analogue scale (VAS) shown in Figure 3. They converted the VAS to points between 0 and 100. If they felt that readability was the worst, they marked the left edge of the scale as 0. If they felt that readability was the best, they marked the right edge as 100. It can be considered that VAS = 50 is appropriate for a split decision line (an allowable limit of readability) in this subjective assessment.

Key

1 worst

2 best

Figure 3 — Visual analogue scale (VAS)

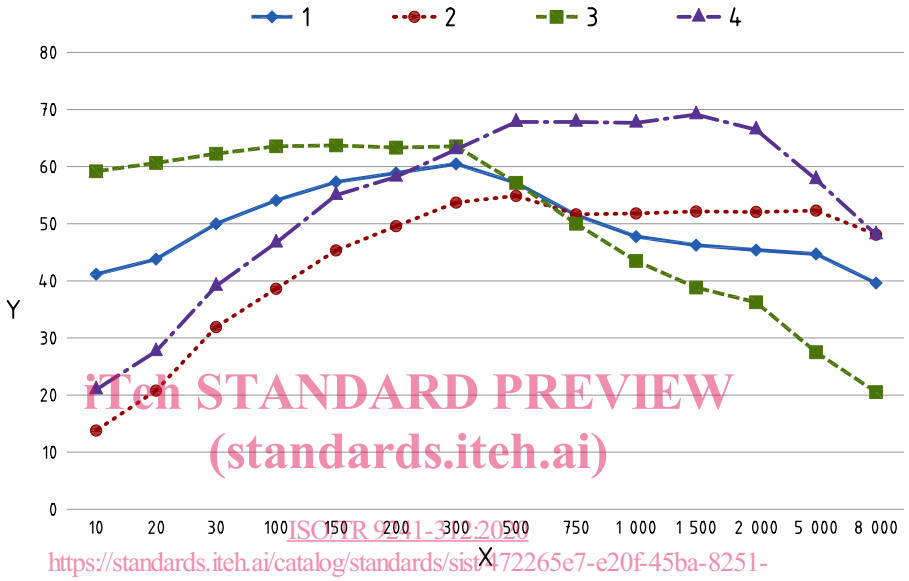
6.3 Experimental results

VAS is a subjective assessment for readability. Figure 5 shows the number of words read aloud by the participants and Figure 6 shows the viewing distance for each display. After reading, the participants evaluated readability for each display by using VAS shown in Figure 4.

6.4 Discussion

1) Participants' evaluation of readability (Figure 4)

ILU-EPD can provide readability under low illuminance conditions in comparison with EPD, backlit LCD, and conventional paper text. Under conditions of illuminance of less than 300 lx, the participants evaluated ILU-EPD significantly higher than EPD. The ILU has a profound effect on readability under low illuminance conditions. However, under conditions of illuminance of more than 750 lx, the participants evaluation of ILU-EPD was worse than EPD. This is an interesting result to investigate in detail in the future.



Key

X	illuminance, lx	1	ILU-EPD
Y	subjective evaluation	2	EPD
		3	LCD
		4	paper

Figure 4 — Participants' evaluation

2) Reading speed (Figure 5)

Differences in reading speed were observed at illuminance levels below 200 lx. Here, the lowest reading speed was with the EPD. The use of an ILU considerably improved reading speed with EPD. Below 200 lx, the order of the 4 devices in terms of reading speed (Figure 5) was almost the same as in terms of subjective readability (Figure 4). At illuminance levels above 300 lx, the reading speeds converged to approximately 30 words in 15 s. These results did not correspond to the subjective evaluation, but indicated the minimum illuminance for comfortable reading can be 300 lx.