Enhancing Accessibility through Typography in Thai Government Mobile Applications: Identifying Issues and Recommending Inclusive Guidelines for Typefaces, Type Sizes, and Color Contrast

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Abstract

Background Typography plays a critical role in enhancing the user experience in mobile application design, particularly for individuals with low visual acuity. However, inclusive typographic principles have yet to receive enough attention in Thai government standards. This study aims to identify and review issues with the use of Thai typefaces in government mobile applications and inspires future research to develop effective typographic design.

Methods The study examined the typography used in five Thai government mobile applications for public services related to healthcare, taxes, and utilities. Two primary categories of Thai typefaces were identified, and 30 Thai volunteers with varying levels of near visual acuity were recruited to investigate the effects of age on near visual acuity. The participants underwent two tasks: one while wearing blur simulation goggles and one without. They read selected words and texts on mobile applications at viewing distances of 40 cm, 35 cm, 30 cm, and 25 cm. The results were recorded in the experimental log sheet, and the data were analyzed.

Results Typeface, type size, and contrast ratio significantly impacted the legibility and readability of text, especially for individuals with low visual acuity (as demonstrated by low visual acuity simulation), while some applications had high contrast ratios and larger type sizes, longer texts in small typefaces, and low contrast ratios hindered legibility. The use of Roman-like Thai typefaces also had a negative impact on reading proficiency, particularly for longer texts.

Conclusions Inclusive typography principles are crucial for enhancing the user experience in mobile application design and ensuring accessibility for all users, specifically individuals with low visual acuity. The study highlights the need for more detailed guidelines for Thai typography in government standards to address typographical concerns. By incorporating appropriate typefaces, ensuring uniformity in type sizes, and utilizing color contrast, designers can create products that are accessible to a broader range of users. The study provides valuable insights into the importance of incorporating inclusive typography principles in mobile application design and encourages further research to enhance the effective typographic design.

Keywords Accessible Typography, Font Size, Color Contrast, Mobile Application, Recommendation for Guidelines Development

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1. Introduction

The significance of typography in ensuring legibility and readability must be considered, given that perfect eyesight is not a universal attribute, regardless of whether individuals wear glasses or not. Therefore, reading efficiency must be a core consideration for typographers when selecting letterforms or typefaces. The choice of font can significantly influence the ease of reading (Noel, 2015; Slattery & Rayners, 2009), underscoring the need for substantial investments in developing typography in all languages.

The paramount consideration in design is the end-user, and the success of a product is measured by its ability to fulfill the user's needs and elicit a positive reaction (Frascara, 2015). Inclusive typography, which is a critical aspect of communication design, should be given due attention. It enables individuals with low visual acuity to continue reading, even when their visual acuity is low (Ompteda, 2009). By incorporating inclusive typographic principles, designers can create products that are accessible to a broader range of users. Such a design approach would be in line with the principles of universal design, which aims to create products and environments that cater to a diverse range of users.

In mobile application design, typefaces hold a significant position as they play a critical role in ensuring the readability of textual content on devices. The selection of appropriate typefaces is crucial to guarantee that users can easily comprehend textual information presented on their devices. Additionally, maintaining uniformity in the type sizes throughout the application is essential for smooth navigation, as it enables users to move effortlessly through the application. Another critical aspect to consider in mobile application design is color contrast. The use of contrasting colors aids in making essential components, such as buttons, headings, and text, more noticeable on the screen, thereby enhancing accessibility. When color contrast is appropriately used, it ensures that users can rapidly and effortlessly locate the required information, making the application more user-friendly.

The World Wide Web Consortium (W3C) provides guidelines for enhancing accessibility. As per the WCAG 2.1 Understanding Docs, the minimum contrast (AA) required for text (including images of text) is a contrast ratio of at least 4.5:1 for regular-size text and at least 3:1 for large-scale text (at least 18 points/24 pixels or bold and at least 14 points/18.5 pixels), unless the text is purely decorative (World Wide Web Consortium: W3C, 2016a; 2022a; 2023a). For enhanced contrast (AAA), text (including images of text) must have a contrast ratio of at least 7:1 for regular-sized text and at least 4.5:1 for large-scale text (at least 18 points/24 pixels or bold and at least 14 points/18.5 pixels), unless the text is purely decorative (World Wide Web Consortium: W3C, 2016b; 2022b; 2023b). These guidelines ensure that digital content is accessible to all users, regardless of their visual acuity. Many countries have developed guidelines for government websites and mobile applications that adhere to the Web Content Accessibility Guidelines (WCAG). For instance, the Digital Service Standard established by the Commonwealth of Australia (Digital Transformation Agency, 2023), the Guidance on Public Sector Website and Mobile Application Accessibility Monitoring issued by the UK Government Digital Service (2023), the Guidelines for Indian Government

Websites developed by the National Informatics Centre (NIC, 2018), the NZ Government Web Standards released by the New Zealand Government (2019), the Standard on Optimizing Websites and Applications for Mobile Devices established by the Government of Canada (Treasury Board of Canada, 2013), and the Accessibility Standards for GOV.WALES provided by the Welsh Government (2023) all make use of the WCAG criteria.

The Electronic Government Agency (Public Organization) (EGA) (n.d.; 2012) in Thailand has taken steps to introduce the Government Website Standards and Government Mobile Application Standards (EGA, 2015) to promote better design practices. However, these standards do not provide detailed guidelines for addressing typographical concerns specific to the Thai language, such as legibility and visibility. The significance of fostering online learning communities and promoting strong social integration has been highlighted in Strategy 6, Stratagem 6.5 of the Information and Communication Technology Policy Framework 2011–2020. To comply with this framework, the EGA has established the Government Mobile Application Standard Version 1.0. This standard ensures that mobile application development adheres to technical standards and requirements such as personal data protection and security protocols (EGA, 2015). Despite this, it is worth noting that the Thai Government Mobile Application Standard does not provide recommendations for suitable Thai typefaces and sizes to be used in mobile applications.

This study focused on enhancing the user-friendliness of Thai government mobile applications by identifying and reviewing issues with Thai typefaces, including their classifications, sizes, and color contrast. The aim was to raise awareness of these problems and inspire future research to develop better mobile applications for the Thai government that incorporate positive typographic design. The study analyzed the effectiveness of typefaces on small sizes and color contrasts in Thai government mobile applications by examining five different examples, highlighting both their advantages and disadvantages. Ultimately, the goal was to enhance updating Government Mobile Application Standards that prioritize positive typographic design for the benefit of Thai citizens.

The legibility of Thai letters depends on eight key characteristics of type anatomy associated with each letter, including a line, a first loop, a tail, a second loop, a foot, a beak, a limb, and a core. These features can vary in position and aspect, with different options for vertical, horizontal, diagonal, and double-storey lines, as well as loops positioned on top, at the bottom, or within the letter. The foot, beak, limb, and core have stable aspects and positions, and are found in specific characters.

Punsongserm et al. (2018a) described how Roman-like Thai typefaces modify Roman letterforms into Thai letterforms, using a Romanized approach. However, some key features have been omitted or diminished in the glyphs of Roman-like Thai typefaces that are patterned on and adapted from the original Roman typeface.

While conventional Thai text fonts are typically used for body texts, many typographers and font users nowadays prefer Roman-like Thai fonts instead of conventional Thai text fonts for various media and documents. Therefore, the current study focused on two primary categories of Thai typefaces: Thai conventional text fonts and Roman-like Thai fonts.

2. Method

2. 1. Materials: Selected Mobile Applications

The present study examined the government mobile applications available on Android for public services in healthcare, taxes, and utilities in Thailand. A carefully selection process was employed to choose a range of widespread applications from the offices of the Thai government that are easily accessible to the public and offer valuable resources to Thai citizens. The five applications we chose were ทางรัฐ (Thang Rath), สมุดสุขภาพ (Smud Sukhaphap), RD Smart Tax, PEA Smart Plus, and PWA Plus Life (Table 1). As of 9 April 2024, the downloads for each app on Google Play were as follows: 500K+ for Thang Rath, 5K+ for Smud Sukhaphap, 500K+ for RD Smart Tax, 5M+ for PEA Smart Plus, and 1M+ for PWA Plus Life. The study analyzed 78 words and texts, each containing specific details, as outlined in Appendices 1–5.

An analysis was conducted to acquire comprehensive insights into the typography employed in these mobile applications. This analysis led to the identification of two primary categories of Thai typefaces: Thai conventional text fonts and Roman-like Thai fonts. The results of this analysis are visually depicted in Figure 1, and a comprehensive overview of the typefaces utilized in each of the selected Thai government mobile applications can be found in Table 1. According to Table 1 and Figure 1, Droid Sans Thai (Regular) was the conventional text typeface used in both the ทางรัฐ (Thang Rath) and PWA Plus Life mobile applications for titles, subtitles, headings, and body text. However, the PWA Plus Life also utilized Mitr (Regular), which is a Roman-like Thai typeface for the Words/Texts (W/T) 01, 02, 03, 08, 14, 15, and 16 (Appendix 5). In contrast, other selected mobile applications such as สมุดสุขภาพ (Smud Sukhaphap) and PEA Smart Plus used only the Roman-like Thai typeface Prompt (Regular), while RD Smart Tax used Athiti (Regular).

Table 1 Selected Thai government mobile applications and their used typefaces

No.	Application Name	Category	Application Name			
			Conventional Text Typeface		Roman–Like Thai Typeface	
			Title, Subtitle, Heading	*Body*	*Title, Subtitle, Heading*	*Body*
1	ทางรัฐ (Thang Rath) Version 2.5.0	Government Services	Droid Sans Thai	Droid Sans Thai	–	–
2	สมุดสุขภาพ (Smud Sukhaphap) Version 2.0.0	Health Care	–	–	Prompt	Prompt
3	RD Smart Tax Version 3.3.0	Revenue	–	–	Athiti	Athiti
4	PEA Smart Plus Version 3.2.11	Public Utility: Electricity Authority	–	–	Prompt	Prompt
5	PWA Plus Life Version 3.5.2	Public Utility: Water Supply	Droid Sans Thai	Droid Sans Thai	Mitr	Mitr

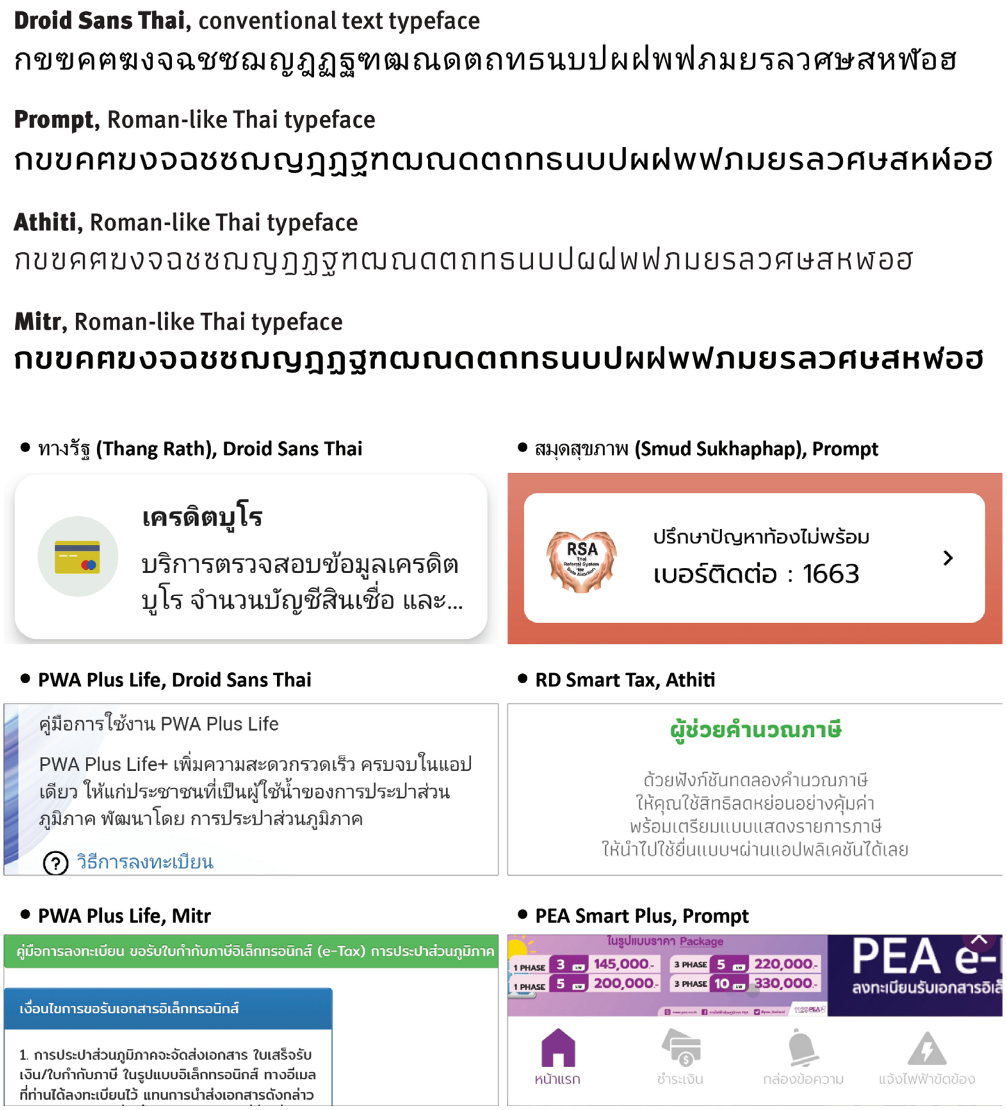


Figure 1 Alphabet set of the typefaces and examples of partial typefaces used in selected Thai government mobile applications

2. 2. Experiment

1) Participants

We recruited a sample of 30 Thai volunteers with varied near visual acuity, comprising 13 males and 17 females aged between 20 and 45 years (early adults and middle adults) (average = 30.10 years), to investigate the effects of age on near visual acuity. The sample's average near visual acuity was logMAR 0.043, close to normal visual acuity. To ensure the accuracy of our findings, we only recruited volunteers with normal visual acuity. This allowed us to compare the data collected under normal conditions with the data collected when the same volunteers wore blur simulation goggles, which are explained in the next section, Apparatus. We collected data on each participant's age, gender, educational background, occupation, and visual acuity, which are presented in Table 2.

Table 2 Participants' age, gender, educational background, occupation, and visual acuity

Participant No.	Age	Gender	Highest Educational Qualification Obtained	Occupation	Near Visual Acuity (LogMAR)
1	23	Female	High School, Grade 12	Undergraduate Student (Industrial Crafts Design)	0.00
2	26	Male	Bachelor's Degree (Industrial Technology)	Book Center Staff	0.00
3	21	Female	High School, Grade 12	Undergraduate Student (Interdisciplinary Studies of Social Science)	0.20
4	22	Female	High School, Grade 12	Undergraduate Student (Interdisciplinary Studies of Social Science)	0.00
5	20	Female	High School, Grade 12	Undergraduate Student (Law)	0.00
6	21	Female	Bachelor's Degree (Interdisciplinary Studies of Social Science)	Administrative Staff	0.00
7	20	Male	High School, Grade 12	Undergraduate Student/Computer Science	0.30
8	25	Male	Bachelor's Degree (Computer Science)	Musician	0.00
9	26	Male	Bachelor's Degree (Industrial Design)	Design Entrepreneur	0.10
10	26	Male	Bachelor's Degree (Industrial Crafts Design)	Convenience Store Staff	0.00
11	20	Male	High School, Grade 12	Undergraduate Student (Law)	0.00
12	23	Female	Bachelor's Degree (Product Design)	Barista/ Freelance Designer	0.00
13	20	Male	High School, Grade 12	Undergraduate Student (Interdisciplinary Studies of Social Science)	0.00
14	20	Male	High School, Grade 12	Undergraduate Student (Law)	0.00
15	24	Male	Bachelor's Degree (Industrial Crafts Design)	Furniture Designer	0.00
16	39	Female	Bachelor's Degree (Business Administration)	Salesman	0.20
17	39	Female	Bachelor's Degree (Interdisciplinary Studies of Social Science)	Library Staff	0.00
18	34	Female	High School, Grade 12	Housewife	0.00
19	34	Female	Master's Degree (Architecture)	Freelance Designer	0.00
20	38	Female	Bachelor's Degree (Political science)	Pharmacy Manager	0.00
21	34	Female	Bachelor's Degree (Business Administration)	Drug Store Staff	0.00
22	31	Female	High Vocational Certificate (Business Administration)	Drug Store Staff	0.00
23	41	Female	High Vocational Certificate (Business Administration)	Self-Employed	0.10
24	33	Male	Bachelor's Degree (Business Administration)	Bank Teller	0.20
25	37	Male	Bachelor's Degree (Business Computer)	Correctional Officer	0.00
26	32	Female	Bachelor's Degree (Public Administration)	University Staff	0.10
27	44	Female	Bachelor's Degree (Law)	University Staff	0..00
28	42	Male	Bachelor's Degree (Communication Arts)	Librarian	0.00
29	43	Male	High School, Grade 9	Self-Employed	0.00
30	45	Female	High School, Grade 12	Self-Employed	0.10
	30.10		**Average of Age and Visual Acuity**		**0.043**

2) Apparatus

In this study, we experimented with various apparatus, including a smartphone, chinrest, and smartphone stand. Specifically, we utilized the Infinix Hot 12 Play smartphone model, which features a 6.82-inch screen diagonal with a display resolution of 720 x 1612 pixels. The smartphone's maximum rated brightness was set to 480 nits, while the screen width and height were 2.78 inches and 6.23 inches, respectively.

We captured screenshots of specific pages from the mobile application user interface (UI) and imported them into Adobe Illustrator 2021. These screenshots were then resized to approximately 200.35 x 448.56 pixels, ensuring that their dimensions conformed to the physical screen size of 2.78 x 6.23 inches. To measure the physical type sizes used on Thai government mobile applications, we followed the Bo Baimai height measurement in millimeters, as established in previous research (Punsongserm et al., 2017a, 2017b, 2018b, 2018c; Punsongserm, 2019, 2020; Punsongserm & Suvakunta, 2022a).

Moreover, we utilized the CCA version 3.2.1 developed by TPGi (2023) to measure the color contrast of the chosen Thai government mobile applications. This application conforms to the feature compliance indicators for WCAG 2.1 (World Wide Web Consortium: W3C, 2018), which is crucial for improving accessibility to all users. Using this tool, our analysis involved measuring the color contrast between foregrounds (texts) and backgrounds on selected Thai government mobile applications. Finally, we have presented the measured type sizes, colors, and color contrasts used in each selected mobile application in Appendices 1–5.

It is widely understood that the perceived size of objects is influenced by their distance from the viewer. According to Boccardo (2021), traditional optometric exams typically use a near-point of 40 cm. Various studies have explored the viewing distances of young adults when reading from a smartphone. Long et al. (2017) found that the mean viewing distance over a 60-minute period was 29.2 ± 7.3 cm, with the distance being significantly shorter during the first, second, and fifth 10-minute periods compared to the final 10-minute period. Similarly, Yoshimura et al. (2017) found that the viewing distance for smartphones varied between 13.3 and 32.9 cm while sitting and between 9.9 and 21.3 cm while lying down. Panke et al. (2019) discovered that the viewing distance for digital active tasks was shorter (29.3 ± 4.7 cm) than for passive tasks (32.3 ± 6.0 cm). They also found that the distance for digital passive tasks was shorter (32.3 ± 6.0 cm) than for hardcopy passive tasks (34.4 ± 5.9 cm). Finally, Boccardo (2021) conducted a study on viewing distance in presbyopic and non-presbyopic age groups. The study revealed that the average viewing distance while sitting was 36.1 ± 7.2 cm, and while standing, it was 37.4 ± 6.8 cm. It should be noted that average viewing distances vary depending on gender and age.

A chinrest was installed on a standard table with a height of 73 cm to ensure consistent positioning. A 23 x 70 cm white cardboard was affixed to the table, and a smartphone stand was placed on top of it. The distance between the inner edge of the forehead barrier of the chinrest and the smartphone was measured using a laser distance meter (ATuMan LS-P). The smartphone was set up vertically at an angle of approximately 90 degrees to the table, and four different distances were assigned, namely approximately 40, 35, 30, and 25 cm (flexible according to user behavior's viewing distance mentioned above). The length for each distance was marked with a marker pen on the white cardboard at the base of the smartphone stand. In addition, to prevent the participants from seeing the messages on the mobile application first for each mobile application, each page, and each viewing distance, we utilized a black matt card (2.8 x 6.5 inches) covered on the smartphone screen for overlaying. The light condition in the room was measured using a light meter (TENMARS TM-209M MULTI-LED) placed at the center of the marked chart, between the farthest mobile standing mark (40 cm) and the chinrest. The illuminance was found to be 260 lux.

The conditions of low visual acuity have been simulated by various researchers using different methods. For example, Arai et al. (2010), Legge et al. (1985), and Nakano et al. (2010) used a wide view ground glass filter, while Hakamada et al. (2011), Panasonic Corporation (2021), and Waleetorncheepsawat et al. (2013) employed pseudo-cataract experience goggles. Additionally, Yamamoto and Yamamoto (2000) utilized computer software to simulate blur and test the performance of Japanese fonts. Punsongserm et al. (2017a, 2017b) used this method to examine the legibility and visibility of various Thai typefaces.

In a series of studies, Punsongserm et al. (2018b, 2018c) and Punsongserm (2020) investigated the effectiveness of homologous Thai letterforms under low visual acuity conditions. To simulate these conditions, their first study used a blur glass filter that simulated isolated blur characters, similar to blurry vision (Punsongserm et al., 2018b). In the current study, we used a blur simulation method with cataract simulation goggles, similar to Nakano et al. (2006) and Punsongserm (2020), for several reasons:

- The method allowed control and maintenance of a low visual acuity level in young people with strong visual acuity, which significantly benefited the study.
- The method avoided the issue of fatigue in older adults with vision health problems and strong visual deficiency. Therefore, the study did not include older adults as participants.
- The simulation allowed us to view the same object and blur words, making discussions easier.
- The technique was smooth and cost-effective.

To simulate low visual acuity in elderly individuals, the experiment employed cataract simulation goggles (Panasonic Corporation, 2021), also referred to as cataract-experiencing goggles (Obama et al., 2005; Rattanakasamsuk, 2013; Wongsompipatana et al., 2011; Waleetorncheepsawat et al., 2012). The goggles were designed to mimic a Snellen acuity 6/15 (Phuangsuwan & Ikeda, 2017), equivalent to LogMAR 0.4, corresponding to mild vision impairment (World Health Organization, 2019).

3) Procedure

The experimental process began by assessing the quality of near vision in each participant using Smart Optometry (Smart Optometry, n.d.), a mobile application for measuring eye function. The distance between the mobile phone and the participant's eyes for measurement viewing was approximately 400 mm. The results obtained from early adults (between 20 and 26 years old) with eye quality ranging from LogMAR 0.0 to 0.3 and middle adults (between 31 and 45 years old) showed their visual quality value in the LogMAR 0.0 to 0.2 range, as presented in Table 2.

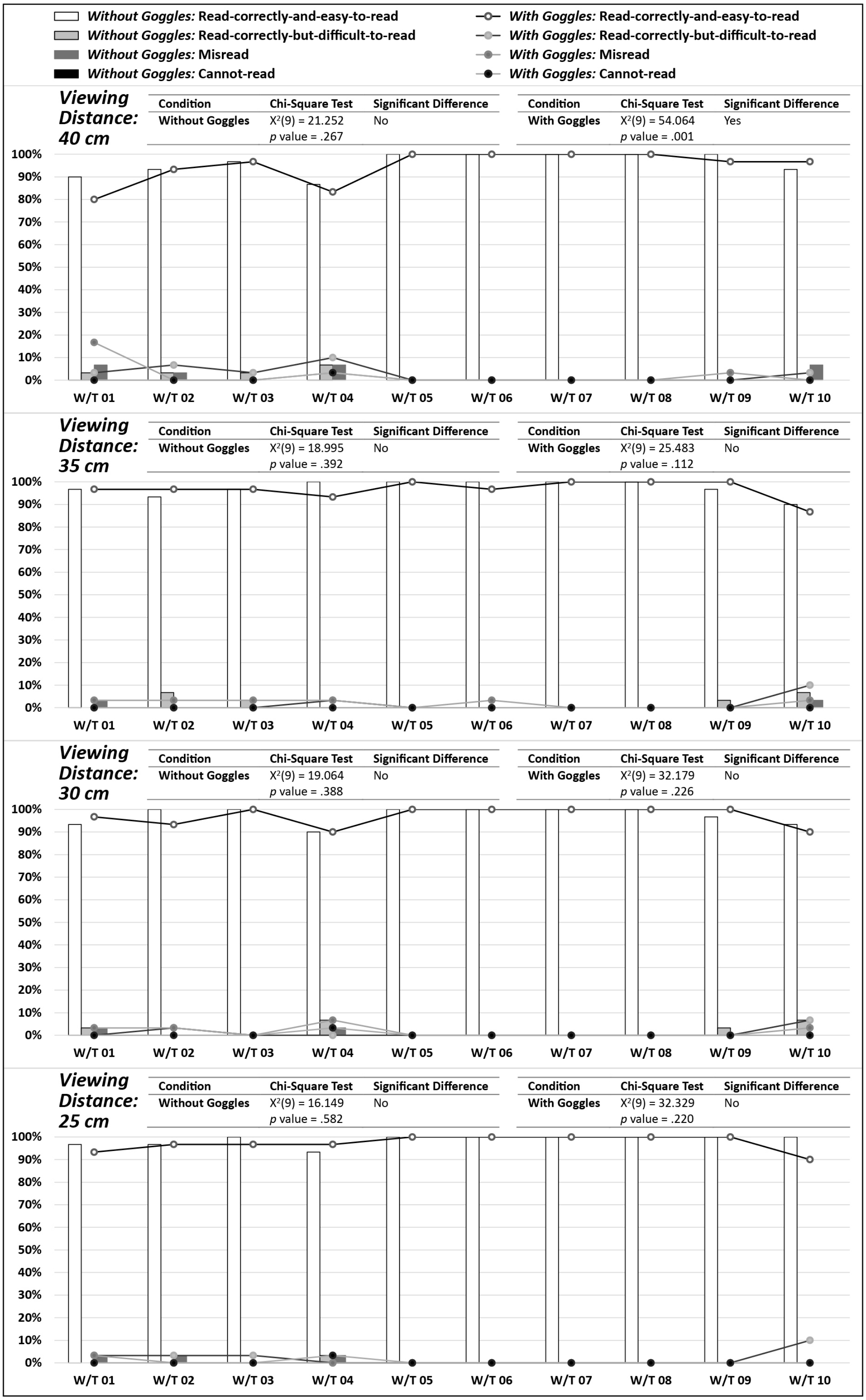
The experiment was divided into two tasks. In the first task, participants wore blur simulation goggles, while in the second task, they did not wear any goggles. Participants were seated on comfortable chairs and wore blur simulation goggles during the first task. They maintained fixation on a vertical smartphone screen with binocular vision while their heads were positioned on the chin and forehead rests. The default viewing distance was 40 cm.

Once the participants were ready, we randomly selected a page of mobile applications and uncovered the black matte card on the smartphone screen. We then pointed to each chosen word and text on the smartphone screen and asked participants to read them aloud. The results were recorded in the experimental log sheet, where reading outcomes were defined into four categories: Read-correctly-and-easy-to-read, Read-correctly-but-difficult-to-read, Misread, and Cannot-read. After thoroughly reading the words and texts on the first page of the mobile application, we randomized the following pages and repeated the same procedure. Once the data collection and the initial viewing distance of 40 cm were completed, we subsequently changed the viewing distance to 35 cm, 30 cm, and 25 cm, respectively. We repeated the same procedure for every viewing distance. Each participant read a total of 312 words and texts across four different viewing distances, with 78 words and texts being read for each distance. Data collection in the second task was conducted using the same method as in the first task. However, participants did not wear the blur simulation goggles.

3. Results

1) ทางรัฐ (Thang Rath) Application

The typeface used in the ทางรัฐ (Thang Rath) application employs a conventional Thai typeface with type sizes ranging from 1.286 to 1.983 mm and contrast ratios between 2.2:1 and 15.1:1. The study found that Words/Texts 01 (W/T 01) had a higher misreading rate (16.70%) compared to other Words/Texts at a viewing distance of 40 cm when blur simulation goggles were worn (see Figure 2). Furthermore, the result of W/T 04 under similar visual conditions showed a slight "Read-correctly-but-difficult-to-read" (10%). Although the W/T 01 and W/T 04 had type sizes of 1.926 and 1.477 mm, respectively, the contrast ratios of 4.4:1 and 2.2:1 (Appendix 1) indicated low contrast conditions (not meeting WCAG 2.1 standards), which hindered the legibility of the text. However, there were no errors in those short words that had smaller type sizes and low contrast ratios, such as W/T 07 and W/T 08. Additionally, the Chi-Square test results in Figure 2 indicate a significant difference at 0.05 only for the viewing distance of 40 cm when the goggles were worn, with no significant differences found in the other results.

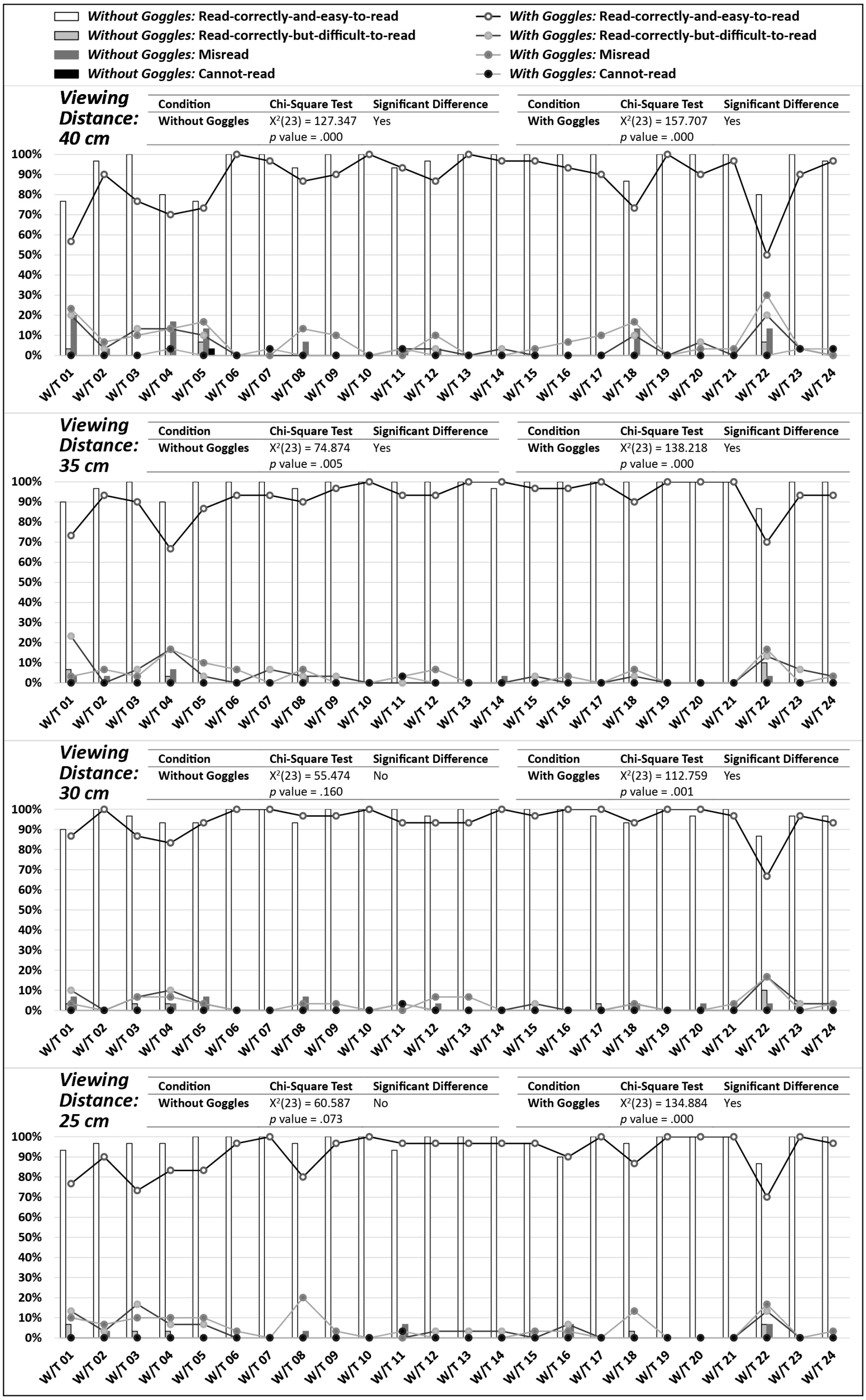


*W/T = Words/Texts

Figure 2 Comparative reading performance rates of ทางรัฐ (Thang Rath) application varied by viewing distances, with and without blur simulation goggles

2) สมุดสุขภาพ (Smud Sukhaphap) Application
The typeface displayed in this application is a Roman-like Thai typeface. The range of type sizes used in the study was 1.025–1.991 mm, with contrast ratios ranging from 2.6:1 to 21:1. The results showed that when wearing the goggles, participants exhibited a significantly high rate of “Read-correctly-but-difficult-to-read” and “Misread.” This was evident in the performance of W/T 1 (type size = 1.862, contrast ratio = 11:1), W/T 22 (type size = 1.861, contrast ratio = 14.9:1), W/T 03 (type size = 1.990, contrast ratio = 20.1:1), W/T 04 (type size = 1.860, contrast ratio = 14.5:1), W/T 05 (type size = 1.859, contrast ratio = 3.7:1), and W/T 18 (type size = 1.414, contrast ratio = 21:1) (see Figure 3 and Appendix 2). Further analysis using the Chi-Square test revealed significant differences at the 0.05 level between the viewing distances of 40 cm and 35 cm, both with and without wearing the goggles (see Figure 3). However, significant differences were observed at viewing distances of 30 cm and 25 cm only when participants wore the goggles, whereas no such differences were observed when the goggles were not worn.

The results indicated that participants experienced a significantly high rate of reading errors and difficulties when using goggles, particularly in the case of W/T 01, where 20% of responses were “Read-correctly-but-difficult-to-read” and 23.30% were “Misread” at a viewing distance of 40 cm. Similarly, W/T 22 demonstrated a 20% “Read-correctly-but-difficult-to-read” and a 30% “Misread” at the same viewing distance. At a viewing distance of 40 cm, W/T 04, W/T 05, W/T 03, and W/T 18 exhibited a “Read-correctly-but-difficult-to-read” rate of 13.30% and a “Misread” rate between 10% and 16.70%. The readability errors and difficulties were primarily observed in W/T 01, W/T 03, and W/T 04 at different viewing distances. W/T 22 had a range of 13–16.70% for both the “Read-correctly-but-difficult-to-read” and “Misread” categories, while W/T 04 had a range of 6.70–16.70% for the same categories. The findings for W/T 01 showed that 23.30% of “Read-correctly-but-difficult-to-read” was at a viewing distance of 35 cm, 10% at a viewing distance of 30 cm, and 13.30% at a viewing distance of 25 cm. Moreover, W/T 03 exhibited 16.70% of “Read-correctly-but-difficult-to-read” and 10% of “Misread” at a viewing distance of 25 cm, while W/T 08 demonstrated a relatively high “Misread” rate of 20%, as shown in Figure 3.



*W/T = Words/Texts

Figure 3 Comparative reading performance rates of สมุดสุขภาพ (Smud Sukhaphap) application varied by viewing distances, with and without blur simulation goggles

The experiment findings conducted without the use of blur simulation goggles revealed that W/T 01 exhibited a 20% "Misread" rate, whereas W/T 04, W/T 05, W/T 18, and W/T 22 had "Misread" rates of 16.70%, 13.30%, 13.30%, and 13.30%, respectively (refer to Figure 3). For other viewing distances, the results indicated a relatively low percentage of "Read-correctly-but-difficult-to-read" and "Misread," ranging from 3.30% to 10%.

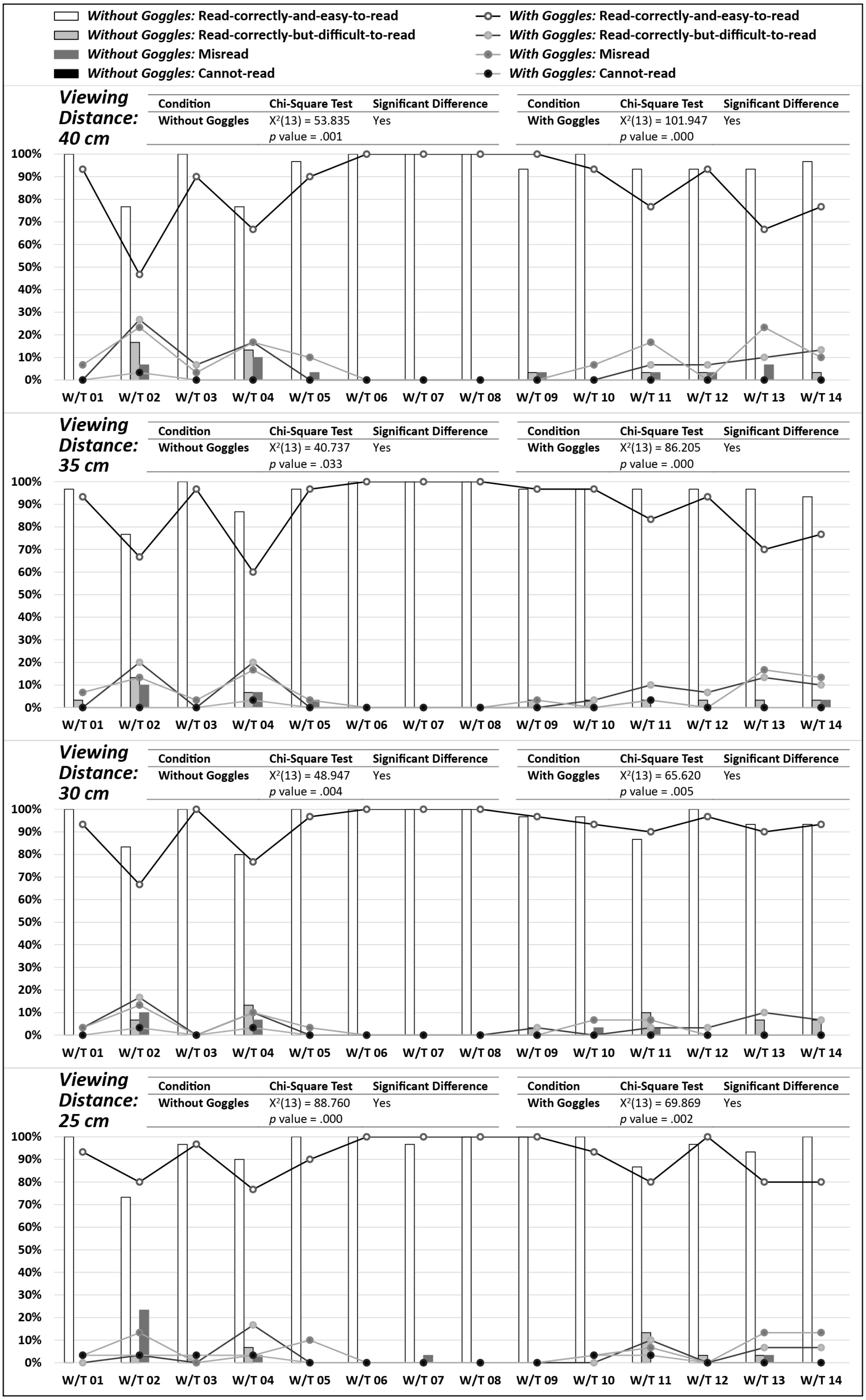
The findings of the สมุดสุขภาพ (Smud Sukhaphap) application revealed that the utilization of Roman-like Thai typeface adversely impacts the accuracy and ease of reading, particularly in the case of longer texts, as observed in the results of W/T 01 and W/T 22. This is despite the display of larger type sizes (1.86 mm) and high contrast ratios (11:1, 14.9:1), as illustrated in Appendix 2. Moreover, the use of a Roman-like Thai typeface in shorter texts also affects reading proficiency, as indicated by the results of W/T 18. This is especially noticeable when the text is viewed from a distance of 40 cm and has a small type size (1.414 mm) and a high contrast ratio (21:1). Hence, it can be inferred that the implementation of Roman-like Thai typeface in small type sizes does not enhance effective reading.

3) RD Smart Tax Application

The typeface displayed in this application is a Roman-like Thai typeface. The typeface had a range of type sizes from 1.348 to 1.798 mm, with contrast ratios ranging from 2.8:1 to 21:1. The findings revealed that the use of goggles resulted in a high rate of "Read-correctly-but-difficult-to-read" and "Misread," specifically for type sizes of 1.605 mm with a contrast ratio of 4.7:1 (W/T 02), 1.348 mm with a contrast ratio of 5.7:1 (W/T 04), 1.413 mm with a contrast ratio of 2.8:1 (W/T 13), 1.604 mm with a contrast ratio of 10.7:1 (W/T 14), and 1.606 mm with a contrast ratio of 6.8:1 (W/T 11) (refer to Figure 4 and Appendix 3). Furthermore, the Chi-Square test results presented in Figure 4 indicate significant differences at the 0.05 level. All the results of the viewing distances show significant differences when wearing the goggles compared to when not wearing them.

The findings revealed that at a viewing distance of 40 cm, W/T 02, which presented longer texts and had a lower contrast ratio, demonstrated significantly higher rates of difficulty and inaccuracy in reading. Specifically, the typeface showed 26.70% of "Read-correctly-but-difficult-to-read" and 23.30% of "Misread," while at a viewing distance of 35 cm, the typeface showed 20% of "Read-correctly-but-difficult-to-read" and 13.30% of "Misread." At a viewing distance of 30 cm, the typeface exhibited 16.70% of "Read-correctly-but-difficult-to-read" and 13.30% of "Misread."

In contrast, the findings without goggles showed lower rates of difficulty and inaccuracy in reading for W/T 02, with "Read-correctly-but-difficult-to-read" and "Misread" rates ranging from 6.70% to 16.70% at viewing distances of 40, 35, and 30 cm. However, at a viewing distance of 25 cm, the "Misread" rate of W/T 02 increased to 23.30%. Additionally, W/T 04, which displayed the smallest type sizes in the application and had a lower contrast ratio, showed 16.70% of "Read-correctly-but-difficult-to-read" and 16.70% of "Misread" at a viewing distance of 40 cm and 20% of "Read-correctly-but-difficult-to-read" and 16.70% of "Misread" at a viewing distance of 35 cm.



W/T = Words/Texts

Figure 4 Comparative reading performance rates of RD Smart Tax application varied by viewing distances, with and without blur simulation goggles

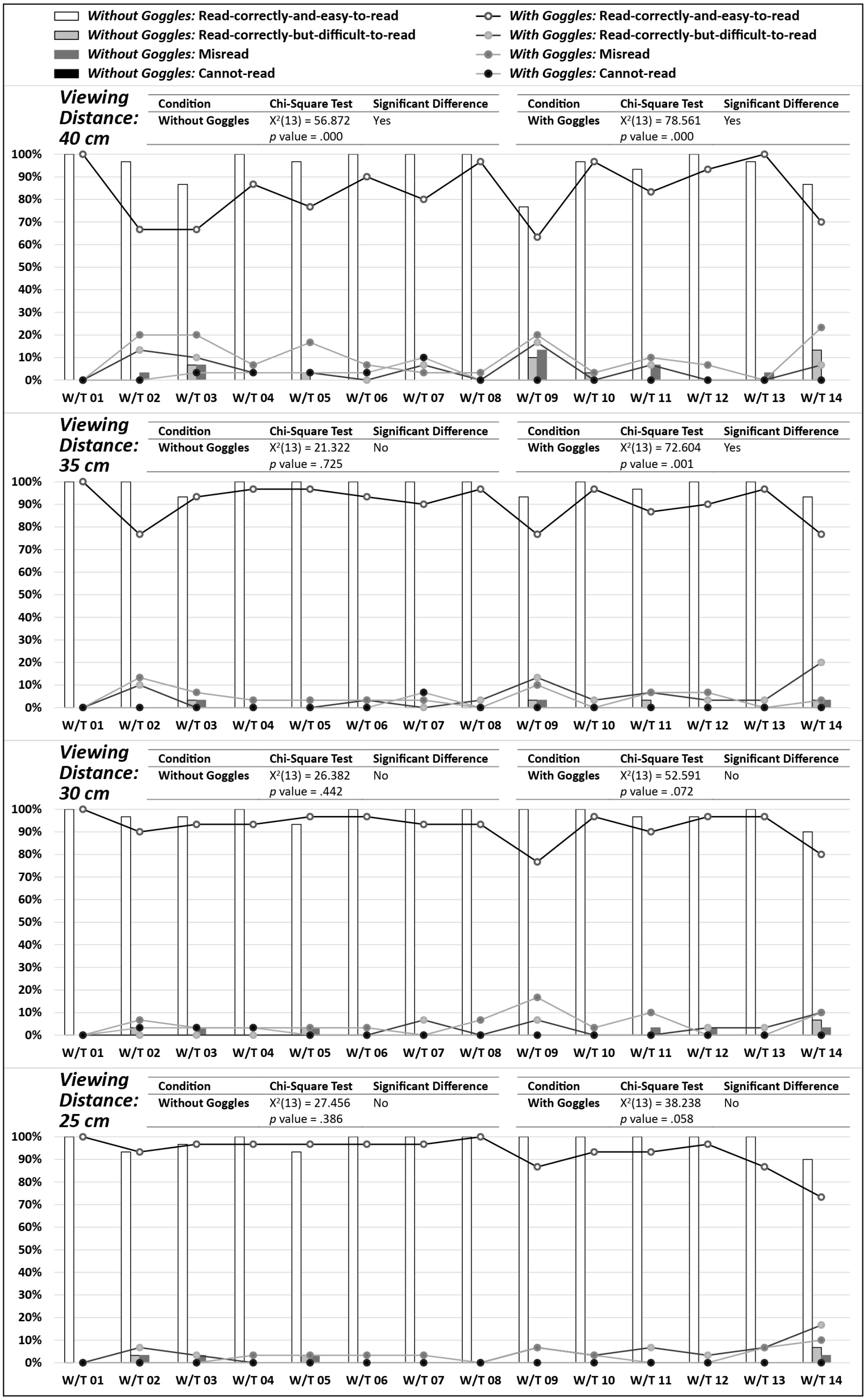
Moreover, W/T 13, which presented text in a type size of 1.413 mm with a very low contrast ratio of 2.8:1, resulted in 10% of "Read-correctly-but-difficult-to-read" and 23.30% of "Misread" at a viewing distance of 40 cm. However, other typefaces with similar type size and contrast ratio properties, such as W/T 12, W/T 03, and W/T 09, had few reading problems. These typefaces presented shorter texts and were consistent with the results of previous studies. Using a Roman-like Thai typeface does not significantly affect the reading of single words or shorter texts, but it may hinder reading longer texts in small sizes.

4) PEA Smart Plus
This application employed a Roman-like Thai typeface, with type sizes ranging from 1.033 mm to 1.866 mm and contrast ratios ranging from 1.9:1 to 14.9:1. Upon wearing goggles, the results indicated a high rate of "Read-correctly-but-difficult-to-read" and "Misread," particularly in texts W/T 02 (type size = 1.291, contrast ratio = 4.5:1), W/T 03 (type size = 1.225, contrast ratio = 4.5:1), W/T 09 (type size = 1.221, contrast ratio = 4.466:1), and W/T 14 (type size = 1.411, contrast ratio = 4.476:1) (refer to Figure 5 and Appendix 4). Further, the Chi-Square test results in Figure 5 indicate significant differences at a significant level of 0.05 in the results of the 40 cm viewing distance, both with and without wearing the goggles. Additionally, significant differences were observed in the results of the 35-cm viewing distance when the goggles were worn. However, the other findings showed no differences.

The results of W/T 07, a well-known short word, indicated that using small font size (1.033 mm) and a very low contrast ratio (1.9:1) had a slightly negative impact on reading performance, particularly when viewed from a distance of 40 cm, with percentages of 6.70%, 3.30%, and 10% for "Read-correctly-but-difficult-to-read," "Misread," and "Cannot-read," respectively. However, reading from other viewing distances did not result in any significant reading problems (see Figure 5).

Further, the study compared the results of W/T 02, W/T 03, and W/T 09, which had similar font sizes and contrast ratios. The percentage of "Misread" at a viewing distance of 40 cm was nearly identical for all three conditions. However, the percentage of "Read-correctly-but-difficult-to-read" varied across the conditions, with percentages of 13.30%, 10%, and 16.70% for W/T 02, W/T 03, and W/T 09, respectively. The reading problems significantly decreased when reading was done from different viewing distances (0–16.70%).

In contrast, the longer text W/T 14, with a font size of 1.411 and a contrast ratio of 4.476:1, showed a higher percentage of "Misread" (23.30%) when viewed at a distance of 40 cm. Additionally, it was found that 20% of participants reported that the text was "Read-correctly-but-difficult-to-read" when viewed from a distance of 35 cm. Even for W/T 07 with goggles, reading from different viewing distances still led to reading problems, such as 10% of "Read-correctly-but-difficult-to-read" and 10% of "Misread" at a viewing distance of 30 cm and 16.7% of "Read-correctly-but-difficult-to-read" and 10% of "Misread" at a viewing distance of 25 cm.



*W/T = Words/Texts

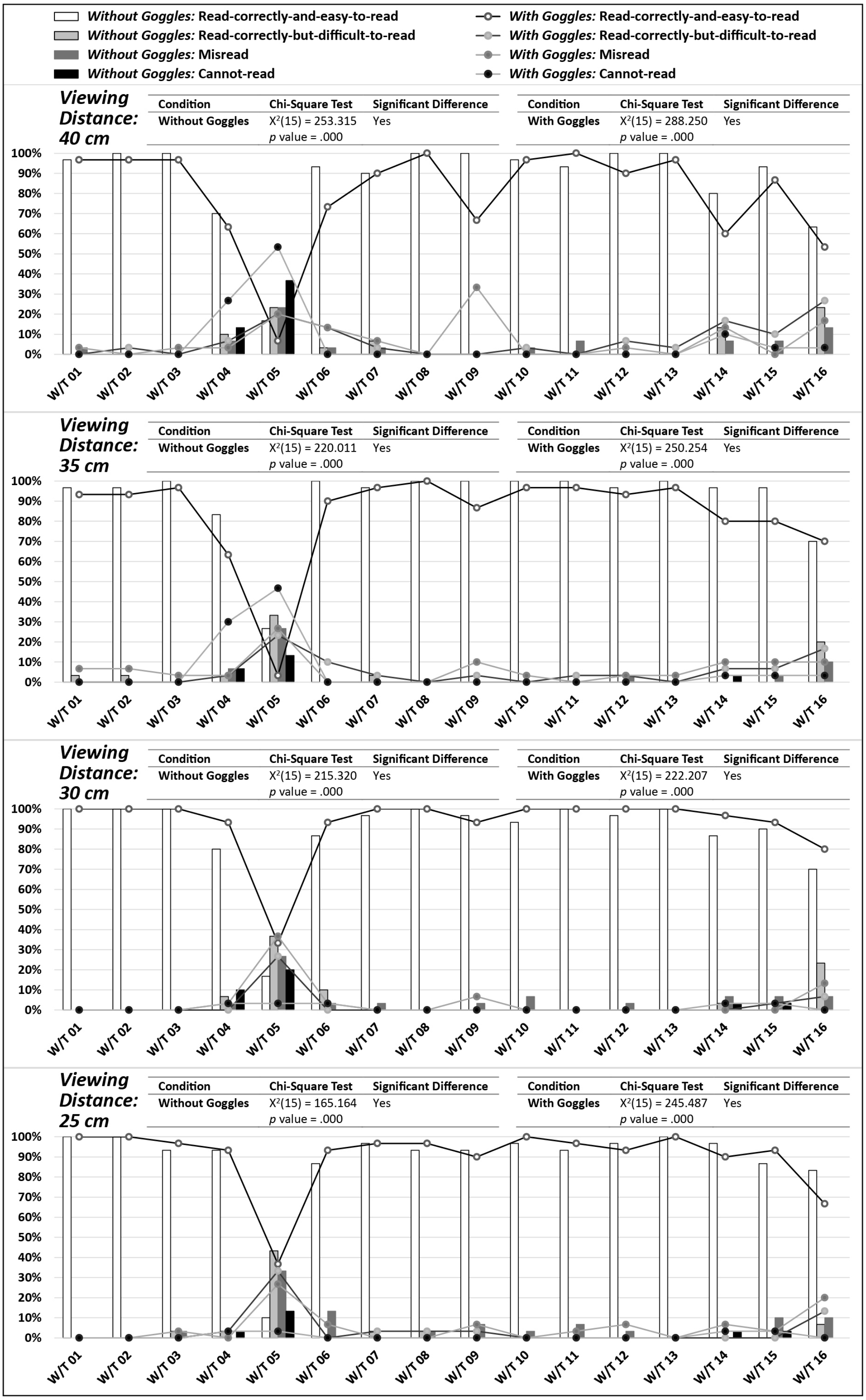
Figure 5 Comparative reading performance rates of the PEA Smart Plus application varied by viewing distances, with and without blur simulation goggles

Finally, the results of the conditions without goggles showed a significant impact on reading performance at a viewing distance of 40 cm for W/T 03 (6.70% of "Read-correctly-but-difficult-to-read" and 6.70% of "Misread"), W/T 09 (10% of "Read-correctly-but-difficult-to-read" and 13.30% of "Misread"), and W/T 14 (13.30% of "Read-correctly-but-difficult-to-read"), as depicted in Figure 5. However, reading from other viewing distances did not result in any significant reading problems (refer to Figure 5).

5) PWA Plus Life

This application employed both Roman-like Thai typefaces and a conventional Thai typeface. It featured a range of type sizes, spanning from 0.642 to 1.992 mm, and contrast ratios that varied from 2.6:1 to 21:1. The results obtained while wearing the goggles revealed a high incidence of "Read-correctly-but-difficult-to-read" and "Misread," particularly in type sizes W/T 05 (type size = 0.642, contrast ratio = 21:1), W/T 04 (type size = 0.642, contrast ratio = 21:1), W/T 09 (type size = 1.670, contrast ratio = 14.4:1), W/T 16 (type size = 1.027, contrast ratio = 12.1:1), W/T 14 (type size = 0.897, contrast ratio = 4.7:1), and W/T 15 (type size = 1.030, contrast ratio = 5.1:1), as depicted in Figure 6 and Appendix 5. Moreover, the Chi-Square test results in Figure 6 indicate significant differences at a significance level of 0.05 in all the viewing distances, both with and without wearing the goggles.

The results of the study revealed that despite being displayed in a conventional Thai typeface with a longer text and the highest contrast ratio of 21:1 (maximum), the text of W/T 05 failed to meet readers' needs at all viewing distances, whether with or without goggles. This was primarily due to the diminutive size of the typeface used, which measured 0.642 mm. The participants experienced reading difficulties at a viewing distance of 40 cm with goggles. These difficulties included 20% of "Read-correctly-but-difficult-to-read," 20% of "Misread," and 53.30% of "Cannot-read." Without goggles, the corresponding figures were 23.30% of "Read-correctly-but-difficult-to-read," 23.30% of "Misread," and 36.70% of "Cannot-read." Similarly, at a viewing distance of 35 cm with goggles, participants experienced 23.30% of "Read-correctly-but-difficult-to-read," 26.70% of "Misread," and 46.70% of "Cannot-read." Without goggles, the corresponding figures were 33.30% of "Read-correctly-but-difficult-to-read," 26.70% of "Misread," and 13.30% of "Cannot-read." Likewise, at a viewing distance of 30 cm with goggles, participants experienced 36.70% of "Read-correctly-but-difficult-to-read," 26.70% of "Misread," and 20% of "Cannot-read." Without goggles, the corresponding figures were 26.70% of "Read-correctly-but-difficult-to-read," 36.70% of "Misread," and 3.30% of "Cannot-read." Finally, at a viewing distance of 25 cm with goggles, participants experienced 43.30% of "Read-correctly-but-difficult-to-read," 33.30% of "Misread," and 13.30% of "Cannot-read." Without goggles, the corresponding figures were 33.30% of "Read-correctly-but-difficult-to-read," 26.70% of "Misread," and 3.30% of "Cannot-read." Furthermore, the study found that the W/T 04 property, which was a short text presented in a conventional Thai typeface and had a contrast ratio similar to that of W/T 05, had a significant impact on reading difficulties, especially the problem of "Cannot-read," at viewing distances of 40 cm and 35 cm with goggles. The corresponding figures were 26.70% and 30%, respectively (see Figure 6).



*W/T = Words/Texts

Figure 6 Comparative reading performance rates of PWA Plus Life application varied by viewing distances, with and without blur simulation goggles

Notwithstanding the utilization of a conventional Thai typeface with a font size of 1.670 mm and a contrast ratio of 14.4:1 for the W/T 09 test (as described in Appendix 5), the outcomes of the said test with goggles revealed that 33.30% and 10% of the text were "Misread" at viewing distances of 40 cm and 35 cm, respectively (refer to Figure 6). Nevertheless, the remaining viewing distances did not exhibit any noteworthy reading difficulties.

The text in W/T 16 was presented in a Roman-like Thai typeface with longer text and a font size of 1.027 mm, as indicated in Appendix 5. This presentation resulted in significant reading errors, as revealed through experiments conducted with and without goggles, as illustrated in Figure 6. Specifically, with goggles, the reading difficulties amounted to 26.70% of "Read-correctly-but-difficult-to-read," 16.70% of "Misread" at a viewing distance of 40 cm; 16.67% of "Read-correctly-but-difficult-to-read," 10% of "Misread" at a viewing distance of 35 cm; 23.30% of "Read-correctly-but-difficult-to-read," 6.70% of "Misread" at a viewing distance of 30 cm; and 6.70% of "Read-correctly-but-difficult-to-read," 10% of "Misread" at a viewing distance of 25 cm. On the other hand, without goggles, the reading difficulties were 23.30% of "Read-correctly-but-difficult-to-read," 13.30% of "Misread" at a viewing distance of 40 cm; 20% of "Read-correctly-but-difficult-to-read," 10% of "Misread" at a viewing distance of 35 cm; 6.70% of "Read-correctly-but-difficult-to-read," 13.30% of "Misread" at a viewing distance of 30 cm; and 13.30% of "Read-correctly-but-difficult-to-read," 20% of "Misread" at a viewing distance of 25 cm.

4. Discussion

1) Typeface

The study results revealed that Roman-like Thai typefaces have an impact on reading accuracy and ease, particularly when it comes to longer texts. The สมุดสุขภาพ (Smud Sukhaphap) and RD Smart Tax applications employed Roman-like Thai typefaces, and both exhibited a high rate of reading errors and difficulties, specifically for longer texts. On the other hand, the ทางรัฐ (Thang Rath) application used a conventional Thai typeface, resulting in no errors for short words that had smaller font sizes and low contrast ratios.

The typeface's impact on reading proficiency was also observed in shorter texts, such as the PEA Smart Plus and PWA Plus Life applications. In these cases, the use of a Roman-like Thai typeface led to a significantly higher rate of reading errors and difficulties. In contrast, the conventional Thai typeface used in the PWA Plus Life application resulted in significant reading difficulties, especially for longer texts with small type sizes and high contrast ratios.

According to Kamollimsakul et al. (2014a), a study on Thai fonts revealed that using a conventional Thai text font, known as a conservative font, results in faster reading and greater efficiency on web pages compared to a modern font, a Roman-like Thai font. It is noteworthy that both young and old adults showed a preference for conservative fonts over modern ones.

Mitchell (2014) observed that Thai typefaces that resemble Roman fonts have fewer features, which may improve visibility when used in small sizes. However, this may also affect legibility and precision because key features of Thai letterforms may be omitted. (Punsongserm et al., 2018a). The advantage of using Roman-like Thai fonts is their increased Bo Baimai height compared to conventional Thai fonts. This means that Roman-like Thai fonts can have more significant consonants than conventional Thai fonts at the same point size (Usakunwathana, 2015). However, the omission of loops and some features in the Roman-like Thai typeface leads to cramped letter spaces, which can be affected by the lack of loop representatives and jutting parts (Punsongserm & Suvakunta, 2022a).

A recent study by Punsongserm and Suvakunta (2022b) found that there may be better approaches than using Roman-like Thai typefaces on drug labels and documentation. The study revealed that Roman-like Thai typefaces, especially PSL Kittithada, which is highly used, were often misread over conventional text typefaces during a word accuracy identification task. The user manuals for Antigen Test Kits (ATK) that used Roman-like Thai typefaces also received low user satisfaction ratings in a user preference test. Additionally, a previous study by the same authors (Punsongserm & Suvakunta, 2022a) found that using Roman-like Thai typefaces negatively impacted participants' reading time. However, the study also revealed that DB Ozone (a Roman-like Thai typeface) outperformed other Roman-like Thai typefaces in the word accuracy identification task and performed better than some in the reading time test. The previous study suggested that DB Ozone's loop representatives (short horizontal lines) resulted in better letter spacing than loopless typefaces (Figure 7).

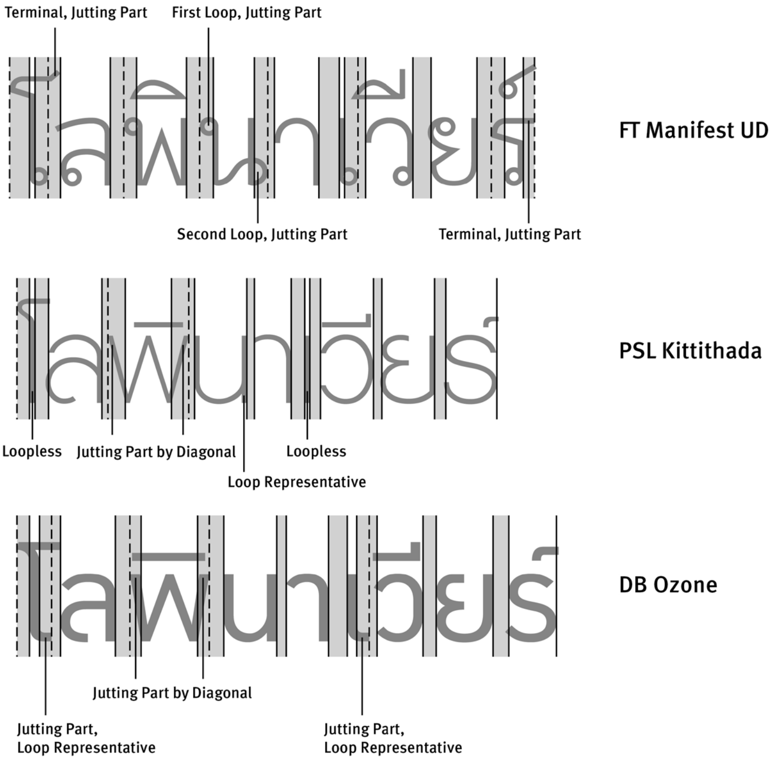


Figure 7 Comparing letterform characteristics and horizontal spacing of FT Manifest UD, PSL Kittithada, and DB Ozone in the same word (Source: Punsongserm & Suvakunta, 2022a)

Therefore, when choosing Thai typefaces for use in small sizes on mobile applications, it is crucial to consider distinct key letter features that enhance legibility. Most of these key letter features can be found in conventional Thai text typefaces. Additionally, providing examples of good typefaces can be helpful. In some cases, Roman-like Thai typefaces may be acceptable, but only if they include jutting parts and loop representatives and proper letter spacing when displayed in small type sizes. However, it is essential to note that these should only be used with large types or for headlines and subheads, as they may not be suitable for texts, particularly longer small texts.

2) Type Size

The study identified that type size is a critical factor affecting the readability of text, particularly for longer texts. The results showed that even if the contrast ratio is high, the smaller type sizes resulted in a high rate of reading errors and difficulties, such as "Cannot-read," "Misread," and "Read-correctly-but-difficult-to-read." Moreover, the results indicated that the reading difficulties associated with smaller type sizes were more pronounced when using blur simulation goggles.

The study also revealed that type size significantly affects the readability of Thai text. The findings indicated that longer texts in smaller font sizes resulted in higher reading difficulties. For instance, the PWA Plus Life application's results demonstrated that the text of W/T 05 failed to facilitate readers' needs at all viewing distances. This was due to the diminutive size of the typeface used, which measured 0.642 mm, even when displayed in a conventional Thai typeface with the highest contrast ratio (21:1). The study suggests that using larger font sizes can enhance the readability of Thai text in mobile applications.

According to a study by Kamollimsakul et al. (2014a), both younger and older adults tend to prefer the conservative font type (conventional Thai text font) over the modern font type (Roman-like Thai font) when browsing web pages. However, font size preferences vary depending on age groups. Younger adults tend to favor 14- and 16-point sizes over 12-point sizes, while older adults prefer 16- to 12- and 14-point sizes. The study recommends using the conservative font type for both age groups. However, it suggests choosing the appropriate font size based on font type. For the conservative font type, 12-point or larger font sizes are recommended for younger adults. In comparison, 14 points or larger are recommended for older adults. For the modern font type, 14 points or larger font sizes are suitable for younger adults. In comparison, 16 points or larger are acceptable for older adults. It is worth noting that the study involved a viewing distance of approximately 57 cm between the participants' eyes (42 people) and the monitor. However, due to the fonts' names not being provided in the study and their Bo Baimai height being unknown, it is impossible to determine the visual angles for each point size of the conservative and modern fonts tested in the experiment. However, assuming we have two well-known Thai fonts, Cordia New and Tahoma, we measured their Bo Baimai height at point sizes 12, 14, and 16. For Cordia New, the Bo Baimai height at these point sizes were 1.693 mm, 1.97 mm, and 2.252 mm, respectively. On the other hand, for Tahoma, the Bo Baimai heights at these point sizes were 2.311 mm, 2.696 mm, and 3.081 mm, respectively. If we view these fonts from 57 cm away, the physical sizes of Cordia New at each point size would convert to visual angles of 0.1702°, 0.1980°, and 0.2264°, respectively. In contrast, the physical sizes of Tahoma for each point size would convert to visual angles of 0.2323°, 0.2710°, and 0.3097°, respectively. Punsongserm and Suvakunta (2022b) have proposed that a minimum visual angle of 0.200° should be provided for optimal legibility. It is important to note that Tahoma's point sizes 12, 14, and 16 exceed most readers' minimum legibility threshold of 0.200°. However, point size 12 of Cordia New falls below the minimum legibility threshold. Nonetheless, point size 14 is almost at a visual angle of 0.200°, and point size 16 is larger than a visual angle of 0.200°.

Based on the results of studies conducted on various mobile applications, it is evident that the appropriate type size is crucial for ensuring easy readability and minimizing reading difficulties. Santayayon et al. (2011) recommended a minimum Thai-type size of 2 mm for a viewing distance of 50 cm, which corresponds to a visual angle of 0.2292°. However, as the viewing distance decreases, the recommended minimum type size should increase in order to maintain legibility. Punsongserm and Suvakunta (2022b) suggested that a range of type sizes between 1.3 and 2 mm in Bo Baimai height may be optimal for easy readability among readers from diverse backgrounds.

It is essential to consider the category of typefaces, thickness stroke, and letter spacing, among other factors, in addition to type size, when designing materials for mobile applications. Furthermore, the optimal font size may vary depending on the intended audience, the device being used, and the distance from which it is being viewed. For example, recent studies suggest that the mean viewing distance for smartphone usage is approximately 29.2 cm, resulting in a corresponding visual angle of 0.2551° (Long et al., 2017).

3) Contrast Ratio

The present study found that contrast ratios play a significant role in determining the readability of text on mobile applications. The results revealed that low contrast ratios lead to inadequate legibility and hinder effective reading of Thai text. Even if the type size is large, low contrast ratios can lead to a high rate of reading errors and difficulties.

The WCAG 2.1 guidelines recommend a minimum contrast ratio of 4.5:1 to ensure that the text is legible for individuals with normal vision. The results of the ทางรัฐ (Thang Rath) application revealed that although the type sizes of W/T 01 and W/T 04 were relatively larger, the contrast ratios were indicative of low contrast conditions, which hindered the legibility of the text. The study suggests that high contrast ratios can significantly enhance the readability of Thai text in mobile applications. However, a study by Ojanpää and Näsänen (2003) investigated the impact of luminance and color contrast on searching for information on display devices. The research revealed that visual search times, the number of eye fixations, and mean fixation durations increased significantly when the luminance contrast decreased, even when color contrast was present. Therefore, achieving high color contrast does not necessarily ensure quick visual perception if the luminance contrast between foreground and background is insufficient. The study suggested that user interfaces require an apparent luminance (brightness) difference between foreground and background to ensure good visibility of alphanumeric information.

To improve mobile application standards or guidelines, further research is necessary to validate assumptions and provide more precise recommendations. However, based on the findings of the studies, it is recommended to use conventional Thai typefaces rather than Roman-like Thai typefaces. The results suggest that using Roman-like Thai typefaces adversely affects the accuracy and ease of reading, particularly in the case of longer texts. Even with larger font sizes and high contrast ratios, the readability and legibility of the text were hindered. Therefore, implementing conventional Thai typefaces is recommended to enhance effective reading. Also, it is recommended that a minimum type size of 1.3 mm in Bo Baimai height be used for reading body text. The font size should be increased for headlines, subheads, and text typed with Roman-like Thai typefaces. Additionally, it is important to maintain appropriate contrast ratios to ensure legibility. In addition, it is recommended that the contrast ratios for Thai mobile applications be higher than the recommendations of the WCAG guidelines. The study found that the contrast ratios of certain words/texts in the tested applications indicated low contrast conditions, which hindered the legibility of the text. Therefore, it is essential to ensure that the contrast ratios for Thai mobile applications are higher than the recommended guidelines in order to enhance reading effectiveness and accessibility for all users. Designers and developers should also consider the typeface, type size, and contrast ratio when designing applications. This is significant to ensure that users can easily read and comprehend the text accurately.

5. Conclusions

The results showed that the typeface, type size, and contrast ratio significantly impact the legibility and readability of text, particularly for individuals with low visual acuity. The study found that although certain applications had high contrast ratios and larger type sizes, legibility was hindered by longer texts in small typefaces and low contrast ratios. The use of Roman-like Thai typefaces also had a negative impact on reading proficiency, especially when it comes to longer texts. The study highlights the importance of incorporating inclusive typography principles into mobile application design to ensure accessibility for all users. It also emphasizes the need for more detailed guidelines for Thai typography in government standards.

The previous study (Punsongserm & Suvakunta, 2022b) recommended that a minimum type size of 1.3–2 mm Bo Baimai height and a visual angle of 0.200° or more would be the most suitable for optimal legibility. However, it should be taken into account that viewers may have different viewing distances based on their visual ability, familiarity, and preferences. Table 3 includes the conversions of physical type sizes to visual angles in selected Thai government mobile applications.

Table 3 The conversions of physical type sizes to visual angles in the selected Thai government mobile applications

Application Name	Word/ Text Code	Number of Character/ Word	Type Size (mm)	Visual Angle (Degree) at Viewing Distance (cm)				Contrast Ratio
				40	*35*	*30*	*25*	
ทางรัฐ (Thang Rath)	W/T 04	15/4	1.477	0.2116	0.2418	0.2821	0.3385	2.2:1
	W/T 10	53/10	1.983	0.2840	0.3246	0.3787	0.4545	15.1:1
สมุดสุขภาพ (Smud Sukhaphap)	W/T 01	137/32	1.862	0.2667	0.3048	0.3556	0.4267	11:1
	W/T 22	171/34	1.861	0.2666	0.3046	0.3554	0.4265	14.9:1
RD Smart Tax	W/T 02	208/50	1.605	0.2299	0.2627	0.3065	0.3678	4.7:1
	W/T 04	118/27	1.348	0.1931	0.2207	0.2574	0.3089	5.7:1
	W/T 13	60/13	1.413	0.2240	0.2313	0.2699	0.3238	2.8:1
PEA Smart Plus	W/T 09	77/16	1.221	0.1749	0.1999	0.2332	0.2798	4.466:1
	W/T 14	151/30	1..411	0.2021	0.2310	0.2695	0.3234	4.476:1
PWA Plus Life	W/T 04	18/4	0.642	0.0920	0.1051	0.1226	0.1471	21:1
	W/T 05	311/65	0.642	0.0920	0.1051	0.1226	0.1471	21:1
	W/T 16	212/44	1.027	0.1471	0.1681	0.1961	0.2354	12.1:1

The results of the analysis conducted on the findings derived from the 25–40 cm viewing distances are presented in Figure 8. The study of the ทางรัฐ (Thang Rath) mobile application revealed that the use of conventional text typeface had minimal negative impact on reading. However, it was observed that the contrast ratio of specific texts and backgrounds did not conform to the WCAG standard, as depicted in Figure 8 and Appendix 1. Insignificant effects were noted in W/T 04 and W/T 10 (Figure 8). While W/T 04 had a character size of 1.477 mm with a number of characters/words = 15/4, it exhibited a very low contrast ratio of 2.2:1. On the other hand, W/T 10 had a character size of 1.983 mm with a number of characters/words = 53/10, but it had a higher contrast ratio of 15.1:1. Nevertheless, both W/T 04 and W/T 10 had visual angles that exceeded the 0.200° threshold at a viewing distance of 40 mm, as shown in Table 3.

On the other hand, based on the findings of the PWA Plus Life Mobile Application, it was observed that the conventional text typeface (Droid Sans Thai typeface) listed in Table 3, with small character sizes (0.642 mm) and tiny visual angle (0.0920° at a viewing distance of 40 cm), had a significant adverse effect on reading, despite having a maximum contrast ratio of 21:1. The reading difficulties were most pronounced in W/T 05, which had a longer text of 311 characters (65 words), whereas W/T 04, which had the same conditions but fewer characters and words (18/4), showed fewer problems, as shown in Figure 8 and Table 3. Moreover, the negative impact on reading was also evident in the results of W/T 16, which used a Roman-like Thai typeface (Mitr typeface) (Figure 8) with a character size of 1.027 and a contrast ratio of 12.1:1, containing a total of 212 characters/44 words (Table 3).

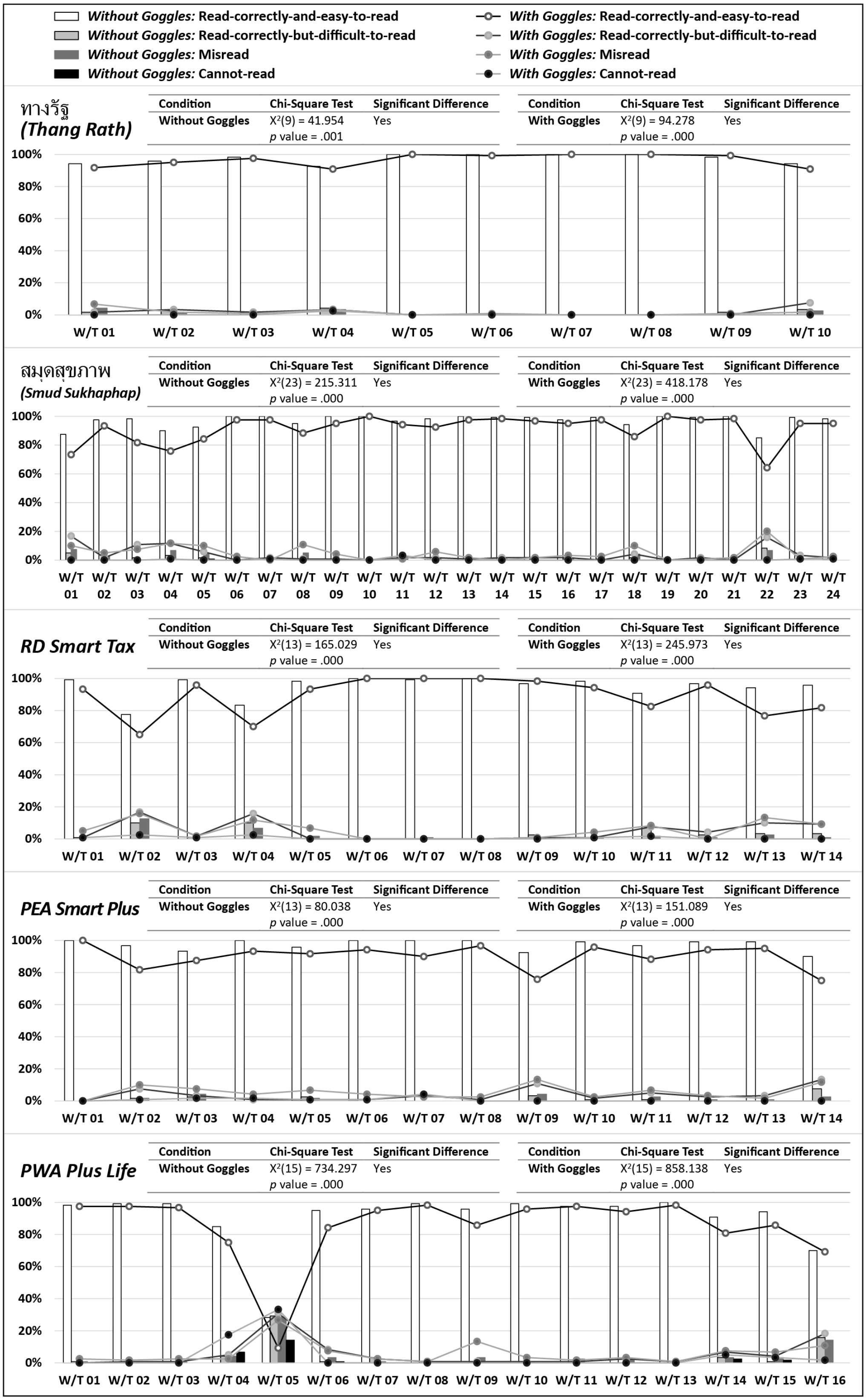


Figure 8 Comparative reading performance rates of all mobile applications, with and without blur simulation goggles

The present study has identified a mobile application that uses a Roman-like Thai typeface with character sizes ranging from 1.348-1.605 mm as having adverse effects on reading. The mobile application in question, RD Smart Tax, is particularly problematic. The typeface used in RD Smart Tax (Athiti) has slim letterforms with low contrast ratios, making reading challenging. These adverse effects were observed during reading tasks in both simulated and non-simulated conditions (Figure 8). The study further found that reading tasks for W/T 02 (which contained 208 characters/50 words with a character size of 1.605 mm and a contrast ratio of 4.7:1) and W/T 04 (which contained 118 characters/27 words with a character size of 1.348 mm and a contrast ratio of 5.7:1) were negatively affected by the typeface. Similarly, the low-contrast typeface used in W/T 13 (which contained 60 characters/13 words with a character size of 1.413 mm and a contrast ratio of 2.8:1) had a negative impact on reading tasks with blur simulation goggles but only had a minor negative effect on tasks without blur simulation goggles.

The utilization of a Roman-like Thai typeface, known as “Prompt typeface,” in the PEA Smart Plus and สมุดสุขภาพ (Smud Sukhaphap) applications was found to have a detrimental impact on reading ability when wearing blur simulation goggles, as evidenced in Figure 8. For example, W/T 14’s (PEA Smart Plus) research results contained an extended text of 151 characters/30 words, with a character size of 1.411 mm and a contrast ratio of 4.476:1 (as demonstrated in Table 3). Similarly, W/T 09 (77 characters/16 words with a character size of 1.221 mm and a contrast ratio of 4.476:1) showed comparable negative effects. Furthermore, despite possessing a larger character size of 1.861 mm and a higher contrast ratio of 14.9:1, the research findings of W/T 22 in สมุดสุขภาพ (Smud Sukhaphap), which contained a longer text of 171 characters/34 words (Table 3), resulted in even more reading difficulties. Similarly, W/T 01’s research results, which contained 137 characters/32 words with a character size of 1.862 mm and a contrast ratio of 11:1, also demonstrated significant errors in reading (Figure 8).

In conclusion, when establishing updated guidelines for Thai Government mobile applications, it is essential to pay close attention to the typefaces used, especially for Thai typography. Considerations must be taken into account when selecting appropriate typefaces for small sizes on mobile applications. These include:

- Considering the key letter features that distinguish Thai typefaces from one another when selecting a typeface for small sizes
- Conventional Thai text typefaces usually have these key letter features, which makes them an excellent option to consider first.
- Providing examples of suitable typefaces in the guidelines can be beneficial in facilitating the decision-making process.

Regarding Roman-like Thai typefaces, the following guidelines should be kept in mind:

- They may be acceptable for small sizes if they have jutting parts, loop representatives, and proper letter spacing.
- They should only be used for headlines and subheads or with large type sizes and may not be suitable for longer small texts.

However, the current study's findings have suggested that the use of Roman-like Thai typefaces may not significantly enhance the legibility of on-screen text reading, particularly for longer texts with smaller font sizes. Therefore, the decision to use conventional Thai text is the optimal choice.

Additionally, the optimal type sizes for Thai government mobile applications are determined by the selection of typefaces with high legibility and the differences in readers' eyesight that define the range of viewing distances. Roman-like Thai typefaces may be used for titles, headings, or short words, which require larger character sizes than the type sizes recommended in the previous study (Punsongserm & Suvakunta, 2022b).

In addition, it is essential to consider the complexity of Thai letterforms and writing systems and their impact on contrast ratios when designing applications. To ensure better legibility and accessibility, the present study suggests using higher contrast ratios than the minimum ones suggested by WCAG guidelines, especially when dealing with longer text or unfamiliar content.

Designers and developers should consider the typeface, type size, and contrast ratio when designing applications to ensure they are easily readable and comprehensible for all users. However, using small type sizes and contrast ratio variations necessitates a case-by-case evaluation by the mobile application developers or owners based on legibility, readability, and accessibility.

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<Appendix 1> Selected words and texts, type sizes, colors, and contrasts used in the **ทางรัฐ** (Thang Rath) mobile application

Word/ Text Code	Selected Word/Text	Type Size (Bo Baimai Height) (Millimeter)	Color and Contrast				
			Foreground (Hex color)	Background (Hex color)	Contrast Ratio	WCAG 2.1 Results	
						AA (Regular Text)	AAA (Regular Text)
W/T 01	กำลังหาอะไรอยู่	1.926	#797979	#FFFFFF	4.4:1	Not Pass	Not Pass
W/T 02	รับประโยชน์ได้มากขึ้น จากบริการที่คุณชื่นชอบ	1.923	#2F6447	#FBFFFB	6.9:1	Pass	Not Pass
W/T 03	สมัครสมาชิก / เข้าสู่ระบบ	1.744	#FFFFFF	#3D855C	4.461:1	Not Pass	Not Pass
W/T 04	เรารักษาความปลอดภัยข้อมูลของท่านอย่างไร	1.477	#FEFEFE	#78C07C	2.2:1	Not Pass	Not Pass
W/T 05	หมวดหมู่	2.345	#262626	#FFFFFF	15.1:1	Pass	Pass
W/T 06	สวัสดิการ	1.722	#262626	#FFFFFF	15.1:1	Pass	Pass
W/T 07	บริการ	1.286	#3D855D	#FFFFFF	4.457:1	Not Pass	Not Pass
W/T 08	แจ้งเตือน	1.286	#797979	#FFFFFF	4.4:1	Not Pass	Not Pass
W/T 09	ข้อมูลทะเบียนรถ	1.983	#262626	#FFFFFF	15.1:1	Pass	Pass
W/T 10	บริการตรวจสอบข้อมูลเครดิตบูโร จำนวนบัญชีสินเชื่อ และ...	1.983	#262626	#FFFFFF	15.1:1	Pass	Pass

<Appendix 2> Selected words and texts, type sizes, colors, and contrasts used in the **สมุดสุขภาพ** (Smud Sukhaphap) mobile application

Word/ Text Code	Selected Word/Text	Type Size (Bo Baimai Height) (Millimeter)	Color and Contrast				
			Foreground (Hex color)	Background (Hex color)	Contrast Ratio	WCAG 2.1 Results	
						AA (Regular Text)	AAA (Regular Text)
W/T 01	ของขวัญจากกรมอนามัยกับสมุดสุขภาพรูปแบบใหม่ ง่าย สะดวก ครอบคลุมทุกบริการครบครันเหมือนมีหมออยู่เป็นเพื่อนคู่ใจตลอด 24 ชม. กับแอปพลิเคชัน สมุดสุขภาพ	1.862	#24413E	#FFFFFF	11:1	Pass	Pass
W/T 02	ถ่ายรูปบัตรประชาชน	1.989	#305E46	#FAFAFA	7.1:1	Pass	Pass
W/T 03	สำหรับใช้ในการยืนยันตัวตน เพื่อความปลอดภัย ในการเข้าใช้งานครั้งถัดไป	1.990	#000000	#FAFAFA	20.1:1	Pass	Pass
W/T 04	แนะนำให้วางบัตรบนโต๊ะหรือบนพื้นราบและถ่ายรูปให้เห็นทั้งตัวบัตร	1.860	#262626	#FAFAFA	14.5:1	Pass	Pass
W/T 05	*ระบบไม่ทำการจัดรูปถ่ายบัตรประชาชนของท่าน	1.859	#E05244	#FAFAFA	3.7:1	Not Pass	Not Pass
W/T 06	ข้อมูลส่วนตัว	1.991	#4E4E4E	#FBFBFB	8:1	Pass	Pass
W/T 07	วันนัดหมาย	1.605	#747474	#FFFFFF	4.7:1	Pass	Not Pass
W/T 08	กรอกข้อมูลสุขภาพของคุณ	1.475	#4E4E4E	#FFFFFF	8.3:1	Pass	Pass
W/T 09	วัยทำงาน	1.476	#9D9D9D	#FAFAFA	2.6:1	Not Pass	Not Pass
W/T 10	ข้อมูลสุขภาพ	1.734	#FFFFFF	#2F5D46	7.6:1	Pass	Pass
W/T 11	ความเครียด	1.025	#262626	#FAFAFA	14.5:1	Pass	Pass
W/T 12	ภาพรวมจากแบบประเมินสุขภาพ	1.991	#4F4F4F	#FAFAFA	7.8:1	Pass	Pass
W/T 13	ไม่พบแบบประเมิน	1.861	#262626	#FAFAFA	14.5:1	Pass	Pass
W/T 14	หน้าแรก ติดตามเรื่องร้องเรียน	1.990	#FFFFFF	#428459	4.491:1	Not Pass	Not Pass
W/T 15	ประเภทการแจ้งเรื่องร้องเรียน / แสดงความคิดเห็น*	1.922	#26292C	#FFFFFF	14.6:1	Pass	Pass
W/T 16	โปรดระบุรายละเอียดของเหตุการณ์ที่เกิดขึ้น พยานบุคคลหรือพยานหลักฐานอื่น ๆ ที่สามารถตรวจสอบได้	1.926	#6D747C	#FFFFFF	4.7:1	Pass	Not Pass
W/T 17	ศูนย์ให้ความช่วยเหลือ	1.862	#000000	#FAFAFA	20.1:1	Pass	Pass
W/T 18	ปรึกษาปัญหาท้องไม่พร้อม	1.414	#000000	#FFFFFF	21:1	Pass	Pass
W/T 19	เพื่อประชาชน	1.672	#252221	#EBD5CF	11.2:1	Pass	Pass
W/T 20	ข้าราชการ / รัฐวิสาหกิจ	1.861	#000005	#E7C9C1	13.5:1	Pass	Pass
W/T 21	ค่ารักษาพยาบาล	1.411	#000000	#FFFFFF	21:1	Pass	Pass
W/T 22	เจ็บป่วยทั่วไป หมายความว่า อาการเจ็บป่วย ที่ไม่ใช่อาการฉุกเฉิน ซึ่งอาจรอรับหรือเลือกสรรบริการสาธารณสุขในเวลาทำการปกติได้ โดยไม่ก่อให้เกิดอาการที่รุนแรงขึ้น หรือภาวะแทรกซ้อนตามมา	1.861	#272727	#FFFFFF	14.9:1	Pass	Pass
W/T 23	วันที่ทำแบบประเมิน	1.412	#9D9D9D	#FFFFFF	2.7:1	Not Pass	Not Pass
W/T 24	ประเมินพฤติกรรมการนอนหลับพักผ่อน	1.154	#306640	#FFFFFF	6.8:1	Pass	Not Pass

<Appendix 3> Selected words and texts, type sizes, colors, and contrasts used in the RD Smart Tax mobile application

Word/ Text Code	Selected Word/Text	Type Size (Bo Baimai Height) (Millimeter)	Color and Contrast				
			Foreground (Hex color)	Background (Hex color)	Contrast Ratio	WCAG 2.1 Results	
						AA (Regular Text)	AAA (Regular Text)
W/T 01	1. คำนิยาม	1.670	#747474	#FFFFFF	4.7:1	Pass	Not Pass
W/T 02	2.2 ห้ามผู้ขอใช้บริการแอบอ้างข้อมูลที่เป็นเท็จเพื่อการแสดงตัวตนใน การเปิดใช้บริการใด ๆ กับกรมสรรพากร หากพบว่าผู้ขอใช้บริการแสดง ข้อมูลอันเป็นเท็จ กรมสรรพากรสามารถระงับการให้บริการได้ทันที โดยมิต้องแจ้งให้ทราบล่วงหน้า	1.605	#747474	#FFFFFF	4.7:1	Pass	Not Pass
W/T 03	ปฏิทินภาษี	1.666	#5EAA43	#FFFFFF	2.9:1	Not Pass	Not Pass
W/T 04	ด้วยฟังก์ชันทดลองคำนวณภาษี ให้คุณลดหย่อนอย่างคุ้มค่า พร้อมเตรียม แบบแสดงรายการภาษี ให้นำไปใช้ยื่นแบบฯผ่านแอปพลิเคชันได้เลย	1.348	#666666	#FFFFFF	5.7:1	Pass	Not Pass
W/T 05	เหลือเวลายื่นแบบอีก	1.798	#3E3E3E	#FFFFFF	10.7:1	Pass	Pass
W/T 06	นาที	1.413	#3E3E3E	#FFFFFF	10.7:1	Pass	Pass
W/T 07	ยื่นแบบออนไลน์	1.413	#000000	#FFFFFF	21:1	Pass	Pass
W/T 08	ตรวจสอบใบเสร็จรับเงิน	1.798	#3E3E3E	#FFFFFF	10.7:1	Pass	Pass
W/T 09	ข่าวประชาสัมพันธ์	1.413	#5DA942	#FFFFFF	2.9:1	Not Pass	Not Pass
W/T 10	15 ม.ค. 66	1.413	#6D6D6D	#FFFFFF	5.2:1	Pass	Not Pass
W/T 11	ขณะนี้กรมสรรพากรได้จัดส่งจดหมายแจ้งเตือนการยื่นแบบฯ ภ.ง.ด.90 ในปีภาษี 2566	1.606	#5B5B5B	#FFFFFF	6.8:1	Pass	Not Pass
W/T 12	ร้อยเรื่องลดหย่อน	1.798	#5DA943	#FAFAFA	2.8:1	Not Pass	Not Pass
W/T 13	คำถามที่ถามบ่อยที่เกี่ยวข้องกับลดหย่อนภาษีเงินได้บุคคลธรรมดา	1.413	#5DA943	#FAFAFA	2.8:1	Not Pass	Not Pass
W/T 14	หมวดค่าลดหย่อนเบี้ยประกันสุขภาพบิดามารดา	1.604	#3E3E3E	#FFFFFF	10.7:1	Pass	Pass

<Appendix 4> Selected words and texts, type sizes, colors, and contrasts used in the PEA Smart Plus mobile application

Word/ Text Code	Selected Word/Text	Type Size (Bo Baimai Height) (Millimeter)	Color and Contrast				
			Foreground (Hex color)	Background (Hex color)	Contrast Ratio	WCAG 2.1 Results	
						AA (Regular Text)	AAA (Regular Text)
W/T 01	บ้าน	1.679	#B89C57	#7E3AA4	2.6:1	Not Pass	Not Pass
W/T 02	หมายเลขผู้ใช้ไฟฟ้า 020024946305 รหัสเครื่องวัด 6300910353 ประเภทอัตรา 1125	1.291	#DEC8EA	#7E3AA4	4.5:1	Pass	Not Pass
W/T 03	วันที่ครบกำหนดตามใบแจ้งค่าไฟฟ้า 03/05/2566	1.225	#DEC8EA	#7E3AA4	4.5:1	Pass	Not Pass
W/T 04	แสดงทั้งหมด	1.099	#70407B	#FFFFFF	7.8:1	Pass	Pass
W/T 05	ขอขยายเขตไฟฟ้า	1.034	#70407B	#FFFFFF	7.8:1	Pass	Pass
W/T 06	หน้าแรก	1.033	#70407B	#FFFFFF	7.8:1	Pass	Pass
W/T 07	แจ้งไฟฟ้าขัดข้อง	1.033	#BBBBBB	#FFFFFF	1.9:1	Not Pass	Not Pass
W/T 08	ยอดที่ต้องชำระ	1.413	#272727	#FFFFFF	14.9:1	Pass	Pass
W/T 09	*แตะที่แต่ละรายการเพื่อดาวน์โหลดหนังสือแจ้งค่าไฟฟ้า หรือ e-Tax Invoice/ e-Receipt	1.221	#6F6F71	#F3F0FE	4.466:1	Not Pass	Not Pass
W/T 10	สถานะ	1.411	#FFFFFF	#763D86	7.5:1	Pass	Pass
W/T 11	วันที่ครบกำหนดตามใบแจ้งค่าไฟฟ้า 29/04/2566	1.155	#6F6F75	#F4F0FE	4.455:1	Not Pass	Not Pass
W/T 12	เงื่อนไขการขอใช้ไฟฟ้าใหม่	1.866	#FFFFFF	#642D71	9.7:1	Pass	Pass
W/T 13	ขอใช้ไฟฟ้าใหม่สำหรับบุคคลธรรมดา	1.668	#262628	#F3F0FE	13.5:1	Pass	Pass
W/T 14	ทั้งนี้ การไฟฟ้าส่วนภูมิภาคจะดำเนินการจ่ายกระแสไฟฟ้าให้เมื่อ ชำระค่าบริการการใช้ไฟฟ้า และหลักการประกันการใช้ไฟฟ้าครบถ้วน ตามที่การไฟฟ้าส่วนภูมิภาคกำหนดแล้ว	1.411	#6F6F6F	#F3F0FE	4.476:1	Not Pass	Not Pass

<Appendix 5> Selected words and texts, type sizes, colors, and contrasts used in the PWA Plus Life mobile application

Word/ Text Code	Selected Word/Text	Type Size (Bo Baimai Height) (Millimeter)	Color and Contrast				
			Foreground (Hex color)	Background (Hex color)	Contrast Ratio	WCAG 2.1 Results	
						AA (Regular Text)	AAA (Regular Text)
W/T 01	หน้าหลัก	1.917	#25489A	#FFFFFF	8.5:1	Pass	Pass
W/T 02	โปรไฟล์	1.634	#FFFFFF	#4F53BF	6.3:1	Pass	Not Pass
W/T 03	เลขมิเตอร์	1.798	#272727	#FFFFFF	14.9:1	Pass	Pass
W/T 04	ขอบเขตการบังคับใช้	0.642	#000000	#FFFFFF	21:1	Pass	Pass
W/T 05	4. การเก็บรวบรวมข้อมูลส่วนบุคคล กปภ. จะจัดเก็บรวบรวมข้อมูลส่วนบุคคลของพนักงาน ผู้สมัครงาน ลูกจ้าง และคู่ค้า ของ กปภ. รวมถึงผู้ซึ่งได้รับความยินยอมให้ปฏิบัติงานหรือทำประโยชน์ให้แก่ กปภ. หรือในสถานประกอบกิจการของ กปภ. ไม่ว่าจะเรียกชื่ออย่างไรก็ตาม โดยมีแหล่งที่มา หลักการ และวัตถุประสงค์ในการเก็บรวบรวมข้อมูลส่วนบุคคลดังต่อไปนี้	0.642	#000000	#FFFFFF	21:1	Pass	Pass
W/T 06	PWA Plus Life+ เพิ่มความสะดวกรวดเร็ว ครบจบในแอปเดียวให้แก่ประชาชนที่เป็นผู้ใช้น้ำของการประปาส่วนภูมิภาค พัฒนาโดยการประปาส่วนภูมิภาค	1.413	#363636	#FFFFFF	12.1:1	Pass	Pass
W/T 07	เสนอแนะเพื่อพัฒนาระบบเพิ่มเติม	1.413	#4878B1	#FCFEFF	4.5:1	Pass	Not Pass
W/T 08	วิธีการลงทะเบียน	1.992	#F5F9FC	#59A6C9	2.6:1	Not Pass	Not Pass
W/T 09	เลขประจำตัวประชาชน	1.670	#282A2D	#FFFFFF	14.4:1	Pass	Pass
W/T 10	ตัวเลขที่เห็นในภาพ	1.670	#6C747C	#FFFFFF	4.7:1	Pass	Not Pass
W/T 11	ค้นหาข้อมูลคำขอติดตั้ง	1.477	#363636	#FFFFFF	12.1:1	Pass	Pass
W/T 12	ตรวจสอบค่าน้ำสูงผิดปกติ	1.668	#24282D	#FFFFFF	14.8:1	Pass	Pass
W/T 13	ตรวจสอบเรื่อง	1.862	#363636	#FFFFFF	12.1:1	Pass	Pass
W/T 14	ระบบลงทะเบียนขอรับใบกำกับภาษีอิเล็กทรอนิกส์	0.897	#FFFFFF	#3572D1	4.7:1	Pass	Not Pass
W/T 15	เงื่อนไขการขอรับเอกสารอิเล็กทรอนิกส์	1.030	#FFFFFF	#4370A6	5.1:1	Pass	Not Pass
W/T 16	3. ภายหลังจากลงทะเบียนแล้ว การประปาส่วนภูมิภาคจะส่งข้อความยืนยันไปยังอีเมลที่ลงทะเบียนไว้ และผู้ลงทะเบียนจะต้องยืนยันตอบรับการลงทะเบียนขอรับเอกสารอิเล็กทรอนิกส์ อีกครั้งหนึ่ง หากไม่ยืนยันจะถือว่าการลงทะเบียนไม่สมบูรณ์	1.027	#363636	#FFFFFF	12.1:1	Pass	Pass