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Effectiveness of predominant letterforms in different small type sizes:

Thai Universal Design font versus familiar Thai text fonts

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Abstract: Earlier researchers have investigated and suggested how to design legibility for Thai letterforms that evolved into the Thai universal design typeface (Thai UD typeface), which supports Thai readers and visually impaired people. Prior researchers measured the letterforms of the Thai UD typeface for effectiveness on various psychological methodologies, such as blur simulation, short exposure, and distance threshold method. To continually investigate the effectiveness of the Thai UD typeface, in the present study, we tested its capability by adapting the methods involved in critical print size (CPS), letter acuity (LA), and reading acuity (RA) compared to familiar text typefaces. In the current study, we compared the effectiveness of three typefaces: FT Manifest UD (Thai UD typeface), Cordia New, and TH Sarabu New, which employed 36 Thai consonants in 15 different type sizes of the three typefaces. We presented the Thai characters to 32 Thai volunteers, including 12 males and 20 females between 18 and 62 years old, and we also divided the volunteers into three groups: adolescent adults, older adults, and graphic designers and related fields, into three different results. The Wilcoxon Signed Ranks Test showed that at a significance level of 0.05, the FT Manifest UD typeface was different in overall effectiveness from (better than) the Cordia New and TH Sara bun new typefaces. For the finding of each group, the FT Manifest UD typeface was different in effectiveness from (better than) the Cordia New and TH Sara bun new typefaces among the adolescent-young adults and the older adults. The finding for the graphic designers' group revealed that the FT Manifest UD typeface differed in effectiveness from (was better than) the TH Sarabu New typeface. However, the effectiveness of FT Manifest UD was similar to the Cordia New typeface. The study suggests that the most critical characteristics of FT Manifest UD provided better effectiveness than the other typefaces on various small type sizes. However, certain letterforms should be improved to enhance sufficient legibility for using the types in small and diminutive.

Keywords: Universal Design Font, Typeface, Font Sizes, Legibility, Letter Features, Design Evaluation

1. Introduction

There are several ongoing studies on the legibility of various typefaces in developed countries, especially Roman typefaces. However, the study of the legibility of the Thai typeface still needs to be made available. A comprehensive and in-depth analysis is needed to create new knowledge that meets the requirements of the current situation both in terms of people with visual impairment and the problem of the aging population in Thailand. There is still a lack of knowledge

to explain aspects of the Thai letterform that are suitable for diverse readers, especially those who are visually impaired and people with low vision. Although there are psychological studies on the efficiency of Thai typefaces (e.g., Rattanakasamsuk, 2013; Teeravarunyou & Laosirihongthong, 2003; Waleetorncheepsawat, Pungrassamee, Obama, & Ikeda, 2012), their authors did not discuss and recommend ways to improve and develop the suitable legibility of Thai letterforms. Such researchers only presented the results on which typefaces or typeface sizes were better than other typefaces. Notwithstanding, the literature needs more explanation concerning aspects of character morphology that influence visual letter recognition under different typefaces' testing conditions.

Research conducted by Punsongserm, Sunaga, & Ihara (2015, 2017a, 2017b, 2018a, 2018b) has shed light on the legibility of Thai typefaces, particularly in visually impaired conditions. Using a blur simulation and a short-exposure test method, the team analysed various typefaces and developed knowledge of letterform characteristics that facilitate reading under low visual acuity conditions. They also developed a basic understanding of typeface design principles for visually impaired individuals, leading to the creation of a prototype of the Thai universal design font (Thai UD font). The Thai UD font focuses on designing a specific character morphology that can aid visual letter recognition in low vision conditions. Following up on this research, Punsongserm (2019a, 2019b, 2020) measured the legibility of Thai UD letterforms using both a blur simulation and a short-exposure test method, with real words and pseudo-words, comparing them to Cordia New and TH Sarabun New typefaces. The results of this study showed that the Thai UD font was more effective in aiding legibility under low visual acuity conditions than conventional text fonts.

A recent study by Punsongserm (2023) compared the effectiveness of three typefaces (FT Manifest UD [Thai universal design font: Thai UD font], Cordia New, and TH Sarabun New) and used 36 Thai consonants in 15 different viewing distances (15 visual angles) of the three typefaces with the participation of various participant characteristics. The study suggests that the most critical characteristics of FT Manifest UD provided better effectiveness than the other typefaces on fixed font sizes varied by viewing distances. However, the studies did not encompass a comprehensive survey of other visual requirements, such as a study of the efficiency of differential print sizes from most minor to large. These factors may also impact legibility and demand further examination, which can provide valuable insights into the overall efficiency of the typefaces.

To further establish the legibility effectiveness of the Thai UD typeface in alternative conditions, in the present study, we aimed to measure the capability of the Thai UD typeface by adapting the methods involved critical print size (CPS), letter acuity (LA), and reading acuity (RA) throughout the measurement in different small type sizes compared to the same fonts used in the previous study (Cordia New and TH Sarabun New), as well as the same 36 Thai consonants and 15 visual angles (Punsongserm, 2023). This study will provide further insights into the effectiveness of the Thai UD typeface and its potential use in diverse contexts.

The key characteristics of Thai letterforms that support legibility and visibility include (Punsongserm, 2019a, 2019b, 2020; Punsongserm et al., 2017b, 2018a):

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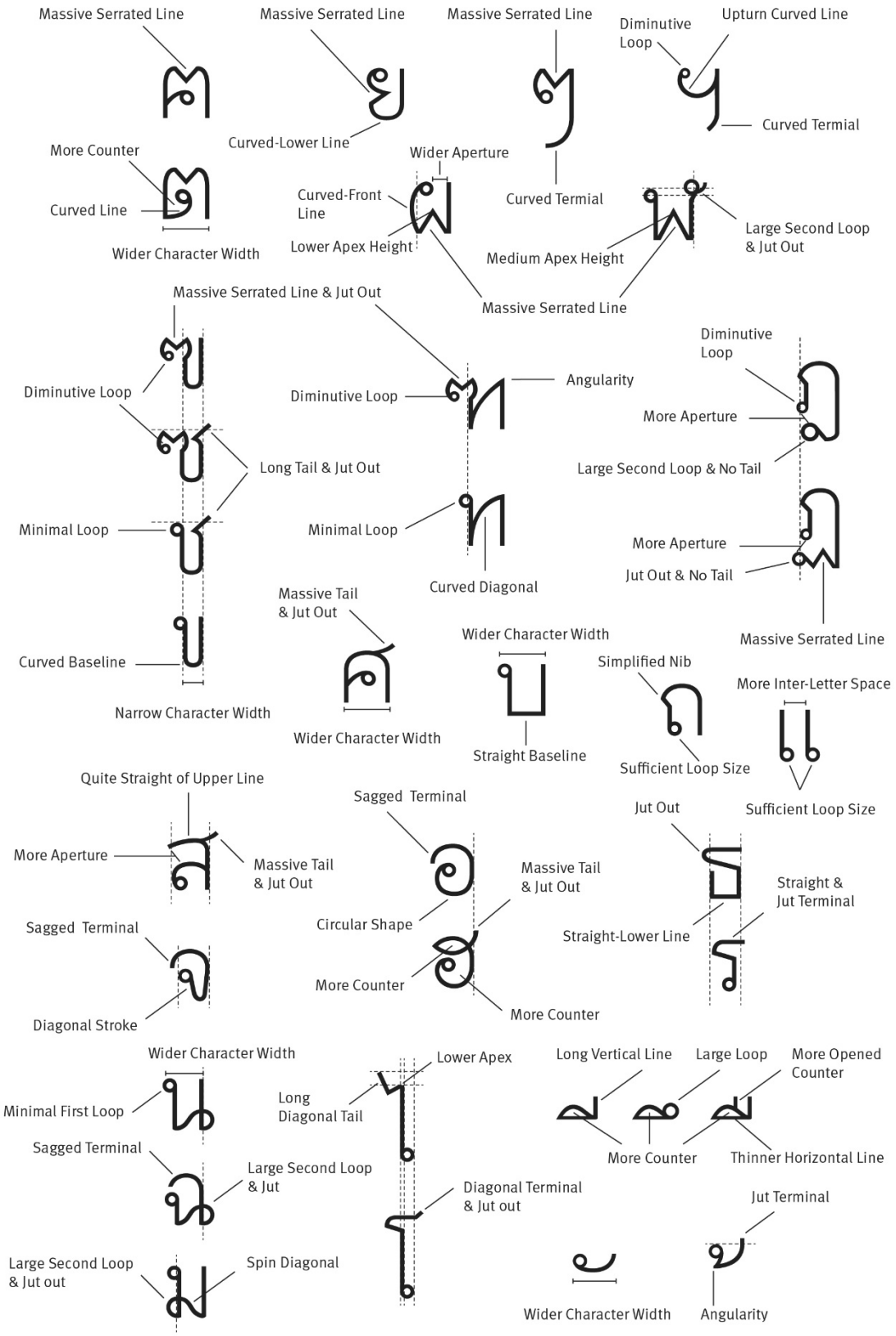
Figure 1. Key Characteristics of Thai Letterforms for Legibility Improvement.
(Source: Punsongserm, 2019a; Punsongserm, 2023)



- The character shape, square or rounded
- The appearance of the typeface (type anatomy) refers to the clarity of the jagged lines as well as the protrusion of a loop, the end of the letter (terminal), and the size of a loop
- The character width is appropriately narrow or wide, which also affects the size of the counter (negative space)
- The stroke shapes (e.g., the upper line, the lower line, and the front line of the characters), straight or curved
- Characteristics at the end of the line (terminal aspect), horizontal or straight downward

Each letterform has different requirements for these features. To help distinguish the characters from each other easily, these different attributes or elements can be utilized to improve the typeface's legibility, as shown in Figure 1.

2. Methods

The present study involved the altering of the critical print size (CPS), letter acuity (LA), and reading acuity (RA) techniques. Several studies have suggested that the critical print size (CPS) is the minimum print size at which maximum reading speed (MRS) or maximum reading rate (MRR) can be attained (Arango et al., 2020; Cheong, Lovie-Kitchin, & Bowers, 2002; Mansfield, Legge, & Bane, 1996; Mansfield, West, & Dean, 2018; Rae, Latham, & Katsou, 2015; Legge, 2007). According to Legge (2007), CPS corresponds to the smallest print size on the reading-speed plateau, which can be effortlessly determined by the eye, especially for individuals with normal vision who usually show only minor variations in reading speed at large sizes. Xiong et al. (2018) suggested that when a detailed reading assessment is not feasible, simpler clinical measures such as letter acuity (LA) and reading acuity (RA) can be employed to forecast reading performance. LA represents the threshold print size for single-letter recognition. Modern LogMAR charts measure the smallest print size at which letters can be identified and corrected for the number of errors made throughout the test (Xiong et al., 2018). RA corresponds to the threshold print size for word recognition (Xiong et al., 2018). RA can typically be obtained using standard clinical reading tests (Radner, 2017; Rubin, 2013).

To evaluate the legibility of isolated characters, this method involves starting with the smallest unidentifiable character size and gradually increasing it to the standard sizes typically used in general. Although we did not assess reading speed using the CPS method, adapting these approaches allowed us to understand the average legibility across different character sizes, reflecting their diverse usage in real-world scenarios.

In the methods section of the present study, provide details on the materials used in the experiment, including selected letters, typefaces, type sizes, and apparatus. Additionally, provide information on the participants and the procedure.

2.1. Test Materials

2.1.1. Selected Letters

In the present study, we used 36 consonant letters, as seen in Table 1. We employed the 36 letters based on their similarity, including Ko Kai /ก/-Tho Thung /ถ/-Pho Samphao /ภ/, Kho Khwai /ค/-Kho Khon /ฅ/-So Sala /ศ/, Do Dek /ด/-To Tao /ต/, No Nu /น/-Cho Ching /ฉ/-Mo Ma /ม/-Kho Rakhang /ฆ/, Kho Khai /ข/-Kho Khuat /ฃ/-Cho Chang /ช/-So So /ซ/, Tho Thahan /ท/-Tho

Nangmontho /ฑ/, Lo Ling /ล/-So Sua /ส/, O Ang /อ/-Ho-Nokhuk /ฮ/, Do Chada /ฎ/-To Patak /ฏ/, Bo Baimai /บ/-Po Pla /ป/, Pho Phung /ผ/-Fo Fa /ฝ/, Pho Phan /พ/-Fo Fan /ฟ/-Lo Chula /ฬ/, and Tho Thong /ธ/-Ro Rua /ร/, as well as characters that tend to be easily confused with other characters under specific conditions such as in low visual acuity, that is, Ho Hip /ห/, Yo Yak /ย/, and Cho Chan /จ/, as in the studies of Punsongserm et al. (2017a, 2017b).

2.1.2. Selected Typefaces

To assess the efficacy of Thai UD letterforms (FT Manifest UD), we conducted a comparative analysis of legibility, utilizing two commonly used Thai text fonts - Cordia New (Regular) and TH Sarabun New (Regular). These two fonts were also employed as comparative fonts in the previous study conducted by Punsongserm (2023).

Cordia New is derived from a font known as Tom Light, which was developed during the hot metal typesetting era and widely employed in the phototypesetting period (Punsongserm, 2010; Suveeranont, 2002). During the digital typesetting era, Tom Light was transformed into a digital font named EAC Tom Light on Mac OS and Cordia New (Cordia UPC) on Windows OS. These fonts have been incorporated into computers for decades and are extensively employed for document typing (Punsongserm, 2019a; 2019b).

In 2007, the Department of Intellectual Property (DIP) and Software Industry Promotion Agency (SIPA) held a Thai font competition. As a result, TH Saraban PSK font was one of the thirteen successful fonts chosen (Suveeranont, 2017). In 2010, the Council of Ministers officially recognized the thirteen fonts, including TH Sarabun PSK, as public fonts. They also instructed public agencies to use them, especially TH Sarabun PSK, in their official documents (NSTDA, 2018; Suveeranont, 2017). The TH Saraban PSK font was later modified in 2011 and released under a new name, 'TH Sarabun New' (Beartai, 2016).

2.1.3. Type Sizes

We measured the effectiveness of letterforms in a variety of different type sizes by using each typeface's 15 different physical sizes (Bo Baimai height), starting from 0.3339–5.0134 mm., as shown in Table 2. When designing typography, the point size measurement is commonly used to determine font-size units. However, different typefaces created in the same point size can impact the x-height size. To address this issue, Legge and Bigelow (2011: 19) have suggested using x-height measures, which are a convenient metric familiar to both typographers and vision researchers. Similarly, Punsongserm et al. (2017a) used Bo Baimai height measurements to define Thai-type sizes in their research. This method involves normalising by the character's height /บ/ (Bo Baimai) and accurately regulating the equalisation of character heights within any font. Therefore, we have also adopted the Bo Baimai height measurement (Punsongserm, 2019a; 2019b, 2020; Punsongserm et al., 2017a, 2017b, 2018a, 2018b; Punsongserm & Suvakunta, 2022a, 2022b) in millimetres to define physical type sizes. Table 2 shows the comparison of font sizes between physical sizes and visual angles calculated from the viewing distance from the monitor to the eyes at a distance of 400 mm, as well as the point sizes of the typefaces. Each step of the 15 physical sizes conformed to the visual angles in the previous study (Punsongserm, 2023), from the visual angle of 0.0477° (smallest, step 1) to the visual angle of 0.7162° (largest, step 15), as shown in Table 2.

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Table 1. The 36-characters set varied by three typefaces used in the experiment (Punsongserm, 2023).

No.	Letter	FT Manifest UD	Cordia New	TH Sarabun New	No.	Letter	FT Manifest UD	Cordia New	TH Sarabun New
1	ก (Ko Kai)	ก	ก	ก	19	ล (Lo Ling)	ล	ล	ล
2	ถ (Tho Thung)	ถ	ถ	ถ	20	ส (So Sua)	ส	ส	ส
3	ภ (Pho Samphao)	ภ	ภ	ภ	21	อ (O Ang)	อ	อ	อ
4	ค (Kho Khwai)	ค	ค	ค	22	ฮ (Ho Nokhuk)	ฮ	ฮ	ฮ
5	ต (Kho Khon)	ต	ต	ต	23	ฎ (Do Chada)	ฎ	ฎ	ฎ
6	ศ (So Sala)	ศ	ศ	ศ	24	ฏ (To Patak)	ฏ	ฏ	ฏ
7	ด (Do Dek)	ด	ด	ด	25	บ (Bo Baimai)	บ	บ	บ
8	ต (To Tao)	ต	ต	ต	26	ป (Po Pla)	ป	ป	ป
9	น (No Nu)	น	น	น	27	ผ (Pho Phung)	ผ	ผ	ผ
10	ฉ (Cho Ching)	ฉ	ฉ	ฉ	28	ฝ (Fo Fa)	ฝ	ฝ	ฝ
11	ม (Mo Ma)	ม	ม	ม	29	พ (Pho Phan)	พ	พ	พ
12	ฆ (Kho Rakhang)	ฆ	ฆ	ฆ	30	ฟ (Fo Fan)	ฟ	ฟ	ฟ
13	ข (Kho Khai)	ข	ข	ข	31	ฬ (Lo Chula)	ฬ	ฬ	ฬ
14	ฃ (Kho Khuat)	ฃ	ฃ	ฃ	32	ธ (Tho Thong)	ธ	ธ	ธ
15	ช (Cho Chang)	ช	ช	ช	33	ร (Ro Rua)	ร	ร	ร
16	ซ (So So)	ซ	ซ	ซ	34	ห (Ho Hip)	ห	ห	ห
17	ท (Tho Thahan)	ท	ท	ท	35	ย (Yo Yak)	ย	ย	ย
18	ฑ (Tho Nangmontho)	ฑ	ฑ	ฑ	36	จ (Cho Chan)	จ	จ	จ

Table 2. The comparison of type sizes among physical sizes, visual angles, and point sizes.

Step	Physical Size (mm)	Visual Angle (deg.) at Distance 400 mm	Point Size (pt)		
			FT Manifest UD	Cordia New	TH Sarabun New
1	0.3339	0.0477° (0° 2' 0.86'')	2.87	2.37	2.42
2	0.3584	0.0512° (0° 3' 0.07'')	3.05	2.54	2.58
3	0.3857	0.0551° (0° 3' 0.31'')	3.29	2.72	2.78
4	0.4179	0.0597° (0° 3' 0.58'')	3.54	2.95	3.03
5	0.4557	0.0651° (0° 3' 0.91'')	3.90	3.23	3.29
6	0.5012	0.0716° (0° 4' 0.30'')	4.25	3.54	3.61
7	0.5572	0.0796° (0° 4' 0.77'')	4.76	4.00	4.04
8	0.6265	0.0895° (0° 5' 0.37'')	5.31	4.43	4.53
9	0.7161	0.1023° (0° 6' 0.14'')	6.10	5.04	5.15
10	0.8358	0.1194° (0° 7' 0.16'')	7.10	5.90	6.00
11	1.0024	0.1432° (0° 8' 0.59'')	8.48	7.08	7.20
12	1.2530	0.1790° (0° 10' 0.74'')	10.66	8.87	9.06
13	1.6709	0.2387° (0° 14' 0.32'')	14.20	11.82	12.05
14	2.5067	0.3581° (0° 21' 0.49'')	21.25	17.70	18.05
15	5.0134	0.7162° (0° 42' 0.97'')	42.50	35.50	36.18

2.1.4. Apparatus

The equipment used in the experiment included:

- A controller laptop computer
- An observer 27-inch monitor (BenQ BL2711U) with eye care mode, flicker-free technology, and low blue light reduction displayed with a resolution of 1920 x 1080 pixels and a refresh rate of 60 Hz. The luminous intensity of the display was 258 cd/m^2
- A chinrest for maintaining the viewing distance between an observer and the monitor displaying the characters
- A standard working table for supporting installing a monitor and chin rest, with a comfortable chair

The test material contained characters differing in letters, typefaces, and type sizes (according to Table 1 and Table 2). Each character varied in letters, typefaces, and sizes and was displayed on the centre of the monitor. We displayed the 36 characters set in black (#000000) on a white (#FFFFFF) background as stimuli that differ in typeface (three typefaces) and type size (15 sizes), representing 1,620 trials in the experiment for each participant.

2.2. Participants

We have invited 32 Thai participants who had participated in a study conducted by Punsongserm (2023) for the current investigation. All 32 volunteers have kindly agreed to participate in the experiment, and after thoroughly explaining the study's objective and procedure, each one has signed a consent form.

A sample of 32 Thai volunteers with various near visual acuity (average = LogMAR 0.203), including 12 males and 20 females between 18 and 62 years old (average = 39.25 years), participated in this study. We divided the 32 volunteers into three groups, including the adolescent-adults group, the older adults group, and the graphic designers and related fields group. The adolescent-adults group with normal visual acuity included five males and seven females between 18 and 40 years old (average = 28.30 years). The older adults group with low visual acuity (average = LogMAR 0.59) included one male and nine females between 52 and 62 years old (average = 56 years). The graphic designers and related fields group with normal or slightly low visual acuity (average = LogMAR 0.06) included six males and four females between 25 and 55 years old (average = 35.60 years). Table 3 shows each participant's age, gender, educational background, occupation, and visual acuity. Graphic designers and related fields have a higher choice of using and reading typefaces in their work. Therefore, we infer that they have higher letter recognition than other people.

2.3. Procedure

The experimental process started by measuring the quality of near vision (near vision acuity test) of each participant with a mobile application for eye measurement, Smart Optometry. The viewing distance from the mobile phone to the participant’s eyes was approximately 400 mm. The results for adolescents-adults (between 18 and 40 years old) with eye quality in LogMAR 0.0 and seniors (between 52 and 62 years old) showed their visual quality value in the range of LogMAR 0.4–0.7, and the group of graphic designers (between 25 and 55 years old) had their visual quality value in the range of LogMAR 0.0–0.2 (as shown in Table 3).

We used multiple degrees of the participants' visual acuity without corrected-to-normal visual acuity to elicit the intrinsic effectiveness of the typefaces on various visual acuity in participants' normal and low visual acuity.

In determining the experimental conditions, the approximate distance from the eyes of the participants to the monitor was 400 mm, with the chin rest as a barrier. In conducting the experiment and collecting data, a dark room was used to eliminate luminous disturbances from sources other than monitors.

In the experiment, a participant sat on a comfortable chair and used the chin rest correctly. We randomly selected typefaces (one out of three) and a set of the same characters (varied in 15 different sizes). We asked the participants to look at the smallest character size (Bo Baimai height = 0.3339 mm, step 1) shown on the monitor, which was a size that could not be read. We asked a participant to look at a total of 15 sizes according to Table 2 (step 2) leading up to the largest size (Bo Baimai height = 0.3584–5.0134 mm, step 2–15). We asked participants to read aloud the letter shown for each character reading, and we recorded the participant's answers. If a participant could not identify any letter they saw, they could inform us that they "cannot read." We collected data with the other character sets in the same procedure, using 36-characters sets, to cover the three selected typefaces.

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Table 3. Age, gender, educational background, occupation, and visual acuity of participants.

Participant No.	Sub-Participant No.	Age	Gender	Highest Educational Qualification Obtained	Occupation	Near Visual Acuity (LogMAR)
				Adolescent-Young Adults		
1	1	18	Female	High School, Grade 12	Undergraduate Student	0.0
2	2	21	Female	High School, Grade 12	Undergraduate Student	0.0
3	3	22	Female	High School, Grade 12	Undergraduate Student	0.0
4	4	23	Male	High School, Grade 12	Factory Worker	0.0
5	5	23	Male	High School, Grade 12	Undergraduate Student	0.0
6	6	25	Male	High School, Grade 12	Supermarket Staff	0.0
7	7	28	Male	Bachelor's Degree (Political and Administrative Science)	Municipal Staff, Tax Improvement Department	0.0
8	8	30	Male	Junior High School, Grade 9	Self-Employed	0.0
9	9	34	Female	Bachelor's Degree (Business Administration)	Financial Staff	0.0
10	10	37	Female	Bachelor's Degree (Interdisciplinary Studies of Social Science)	Library Staff	0.0
11	11	39	Female	Bachelor's Degree (Accounting)	Book Centre Staff	0.0
12	12	40	Female	Junior High School, Grade 9	Cleaning Staff	0.0
		28.3		*Average of Age and Visual Acuity*		*0.0*

Table 3. Continued.

Participant No.	Sub-Participant No.	Age	Gender	Highest Educational Qualification Obtained	Occupation	Near Visual Acuity (LogMAR)
				Older Adults		
13	1	52	Female	Late Elementary School, Grade 6	Cleaning Staff	0.7
14	2	53	Female	Junior High School, Grade 9	Book Centre Staff	0.7
15	3	53	Female	High School, Grade 12	Cleaning Staff	0.7
16	4	54	Male	Bachelor's Degree (Marketing)	Churchwarden	0.7
17	5	55	Female	Junior High School, Grade 9	Housewife	0.5
18	6	56	Female	Junior High School, Grade 9	Housewife	0.4
19	7	57	Female	High School, Grade 12	Member of Agricultural Cooperatives Board	0.7
20	8	58	Female	Late Elementary School, Grade 6	Former Book Salesman	0.4
21	9	60	Female	Late Elementary School, Grade 6	Unemployed	0.7
22	10	62	Female	High Vocational Certificate (Accounting)	Grocer	0.4
		56		*Average of Age and Visual Acuity*		*0.59*

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Table 3. Continued.

Participant No.	Sub-Participant No.	Age	Gender	Highest Educational Qualification Obtained	Occupation	Near Visual Acuity (LogMAR)
				Graphic Designers and Related Fields		
23	1	25	Female	Bachelor's Degree (Multimedia Design)	Freelance Graphic Designer	0.0
24	2	25	Female	Bachelor's Degree (Information Technology)	Publication Designer	0.0
25	3	30	Female	Bachelor's Degree (Industrial Crafts Design)	Corporate Communication Media Designer	0.0
26	4	32	Male	Bachelor's Degree (Industrial Crafts Design)	Freelance Designer	0.0
27	5	32	Male	Bachelor's Degree (Animation Design)	Graphics and Animation Teacher	0.0
28	6	34	Male	Bachelor's Degree (Computer Graphics)	Publication Design Teacher	0.2
29	7	35	Female	Master's Degree (Public Relations)	Publicist/Public Media Creator	0.0
30	8	42	Male	Bachelor's Degree (Business Computer)	Publication/ Sign Graphic Designer	0.2
31	9	46	Male	Junior High School, Grade 9	Sign Graphic Designer	0.0
32	10	55	Male	Master's Degree (Art and Design)	Graphic Designer/ Guest Lecturer	0.2
		35.6		*Average of Age and Visual Acuity*		*0.06*
		39.25		**Average of Age and Visual Acuity (Overall)**		**0.203**

3. Results

The results section of our report comprises both the overall comparative effectiveness findings and the classified findings presented by each letter to demonstrate the relative effectiveness of the three typefaces.

3.1. Comparative Effectiveness: Overall

To test the hypothesis, we used Wilcoxon Signed Ranks Test, a two-way discriminant nonparametric statistical analysis used to test the differences between the two groups. In this study, we used it to test which typefaces had different levels of effectiveness, which were tested in pairs (e.g., Cordia New – FT Manifest UD and TH Sarabun New – FT Manifest UD). The result for all 32 participants is presented in Table 4, as well as the findings separated by groups of participants into:

- the adolescent-young adults (12 participants), Table 5,
- the older adults (10 participants), Table 6, and
- the graphic designers and related fields (10 participants), Table 7.

In the results for all participants (32 people), we considered using a paired test by Wilcoxon Signed Ranks Test to test which fonts have different levels of effectiveness. The results in Table 4 in the Ranks and Test Statistics section show that at a significance level of 0.05, the FT Manifest UD typeface was different in overall effectiveness from (better than) the Cordia New and TH Sarabun New typefaces.

The data presented in Table 4 suggests that the FT Manifest UD typeface may have performed better than the Cordia New and TH Sarabun New typefaces. Negative ranks (Cordia New < FT Manifest UD) indicate that Cordia New received higher values (N=24, Mean Rank = 20.25, Sum of Ranks = 486), while positive ranks (Cordia New > FT Manifest UD) received lower values (N=12, Mean Rank = 15, Sum of Ranks = 180). Similarly, negative ranks (TH Sarabun New < FT Manifest UD) show that TH Sarabun New received higher values (N=28, Mean Rank = 19.57, Sum of Ranks = 548), while positive ranks (TH Sarabun New > FT Manifest UD) received lower values (N=7, Mean Rank = 11.71, Sum of Ranks = 82). These results suggest that the FT Manifest UD typeface could have been more effective than either Cordia New or TH Sarabun New typefaces.

When splitting the results into three case-specific groups of participants, the findings showed that at a significance level of 0.05, the FT Manifest UD typeface was different in effectiveness from (better than) the Cordia New and TH Sarabun New typefaces among the adolescent-young adults and the older adults (see Table 5 and Table 6, respectively). In contrast, the finding for the graphic designers and related fields revealed that the FT Manifest UD typeface differed in effectiveness from (was better than) the TH Sarabun New typeface. However, the effectiveness of FT Manifest UD was similar to the Cordia New typeface (see Table 7).

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Table 4. The overall results of ranks and test statistics for FT Manifest UD compared with Cordia New and TH Sarabun New.

Ranks				
		N	Mean Rank	Sum of Ranks
Cordia New - FT Manifest UD	Negative Ranks	24[a]	20.25	486
	Positive Ranks	12[b]	15	180
	Ties	0[c]		
	Total	36		
TH Sarabun New - FT Manifest UD	Negative Ranks	28[d]	19.57	548
	Positive Ranks	7[e]	11.71	82
	Ties	1[f]		
	Total	36		
a. Cordia New < FT Manifest UD	d. TH Sarabun New < FT Manifest UD			
b. Cordia New > FT Manifest UD	e. TH Sarabun New > FT Manifest UD			
c. Cordia New = FT Manifest UD	f. TH Sarabun New = FT Manifest UD			

Test Statistics[a]		
	Cordia New – FT Manifest UD	TH Sarabun New – FT Manifest UD
Z	-2.404[b]	-3.818[b]
Asymp. Sig. (2-tailed)	0.016	0.000
a. Wilcoxon Signed Ranks Test		
b. Based on positive ranks		

Based on the results in Table 5, it can be inferred that the FT Manifest UD typeface was more effective for adolescent-young adults compared to Cordia New and TH Sarabun New typefaces. This is supported by the negative ranks (Cordia New < FT Manifest UD), where Cordia New received more values (N=25, Mean Rank = 20.34, Sum of Ranks = 580.50), while the positive ranks (Cordia New > FT Manifest UD) received fewer values (N=10, Mean Rank = 12.15, Sum of Ranks = 121.50). A similar pattern is observed between TH Sarabun New and FT Manifest UD, where the negative ranks (TH Sarabun New < FT Manifest UD) showed that Cordia New received more values (N=29, Mean Rank = 17.91, Sum of Ranks = 519.50), whereas the positive ranks (TH Sarabun New > FT Manifest UD) received fewer values (N=5, Mean Rank = 15.10, Sum of Ranks = 75.50).

Table 6 reveals that the FT Manifest UD typeface was more effective for older adults than the Cordia New and TH Sarabun New typefaces. This is supported by the negative ranks (Cordia New < FT Manifest UD), where Cordia New received more values (N=23, Mean Rank = 19.24, Sum of Ranks = 442.50), while the positive ranks (Cordia New > FT Manifest UD) received fewer values (N=11, Mean Rank = 13.86, Sum of Ranks = 152.50). Similarly, the negative ranks (TH Sarabun New < FT Manifest UD) showed that Cordia New received more values (N=29, Mean Rank = 20.07, Sum of Ranks = 582), and the positive ranks (TH Sarabun New > FT Manifest UD) received fewer values (N=7, Mean Rank = 12, Sum of Ranks = 84).

Table 7 suggests that, when comparing Cordia New and FT Manifest UD, Cordia New received more values (N=20, Mean Rank = 19.93, Sum of Ranks = 398.50) in the negative ranks (Cordia New < FT Manifest UD), whereas it received fewer values (N=16, Mean Rank = 16.72, Sum of Ranks = 267.50) in the positive ranks (Cordia New > FT Manifest UD). Similarly, when comparing TH Sarabun New and FT Manifest UD, TH Sarabun New received more values (N=24, Mean Rank = 20.13, Sum of Ranks = 483) in the negative ranks (TH Sarabun New < FT Manifest UD), whereas it received fewer values (N=12, Mean Rank = 15.25, Sum of Ranks = 183) in the positive ranks (TH Sarabun New > FT Manifest UD). These findings suggest that the FT Manifest UD typeface was more effective than the TH Sarabun New typeface for graphic designers and related fields. However, the effectiveness of FT Manifest UD was similar to that of the Cordia New.

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Table 5. The results of ranks and test statistics for FT Manifest UD compared with Cordia New and TH Sarabun New, the adolescent-young adults.

Ranks				
		N	Mean Rank	Sum of Ranks
Cordia New - FT Manifest UD	Negative Ranks	25[a]	20.34	508.50
	Positive Ranks	10[b]	12.15	121.50
	Ties	1[c]		
	Total	36		
TH Sarabun New - FT Manifest UD	Negative Ranks	29[d]	17.91	519.50
	Positive Ranks	5[e]	15.10	75.50
	Ties	2[f]		
	Total	36		
a. Cordia New < FT Manifest UD	d. TH Sarabun New < FT Manifest UD			
b. Cordia New > FT Manifest UD	e. TH Sarabun New > FT Manifest UD			
c. Cordia New = FT Manifest UD	f. TH Sarabun New = FT Manifest UD			

Test Statistics[a]		
	Cordia New – FT Manifest UD	TH Sarabun New – FT Manifest UD
Z	-3.172[b]	-3.798[b]
Asymp. Sig. (2-tailed)	0.002	0.000
a. Wilcoxon Signed Ranks Test		
b. Based on positive ranks		

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Table 6. The results of ranks and test statistics for FT Manifest UD compared with Cordia New and TH Sarabun New, the older adults.

Ranks				
		N	Mean Rank	Sum of Ranks
Cordia New - FT Manifest UD	Negative Ranks	23[a]	19.24	442.50
	Positive Ranks	11[b]	13.86	152.50
	Ties	2[c]		
	Total	36		
TH Sarabun New - FT Manifest UD	Negative Ranks	29[d]	20.07	582
	Positive Ranks	7[e]	12	84
	Ties	0[f]		
	Total	36		
a. Cordia New < FT Manifest UD	d. TH Sarabun New < FT Manifest UD			
b. Cordia New > FT Manifest UD	e. TH Sarabun New > FT Manifest UD			
c. Cordia New = FT Manifest UD	f. TH Sarabun New = FT Manifest UD			

Test Statistics[a]		
	Cordia New – FT Manifest UD	TH Sarabun New – FT Manifest UD
Z	-2.483[b]	-3.923[b]
Asymp. Sig. (2-tailed)	0.013	0.000
a. Wilcoxon Signed Ranks Test		
b. Based on positive ranks		

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Table 7. The results of ranks and test statistics for FT Manifest UD compared with Cordia New and TH Sarabun New, the graphic designers and related fields.

Ranks				
		N	Mean Rank	Sum of Ranks
Cordia New - FT Manifest UD	Negative Ranks	20[a]	19.93	398.50
	Positive Ranks	16[b]	16.72	267.50
	Ties	0[c]		
	Total	36		
TH Sarabun New - FT Manifest UD	Negative Ranks	24[d]	20.13	483
	Positive Ranks	12[e]	15.25	183
	Ties	0[f]		
	Total	36		
a. Cordia New < FT Manifest UD	d. TH Sarabun New < FT Manifest UD			
b. Cordia New > FT Manifest UD	e. TH Sarabun New > FT Manifest UD			
c. Cordia New = FT Manifest UD	f. TH Sarabun New = FT Manifest UD			

Test Statistics[a]		
	Cordia New – FT Manifest UD	TH Sarabun New – FT Manifest UD
Z	-1.030[b]	-2.359[b]
Asymp. Sig. (2-tailed)	0.303	0.018
a. Wilcoxon Signed Ranks Test		
b. Based on positive ranks		

3.2. Comparative Effectiveness: Classified by Letters

The findings of each letter are in Table 8, which shows the mean values of the percentage of correct response rates comparing FT Manifest UD, Cordia New, and TH Sarabun New. We calculated each mean value from the percentage of correct response rate of each character's finding of visual angles from levels 1–15 (0.0477°–0.7162°), as shown in Table 2. We applied the Wilcoxon Signed Ranks Test method at a significance level of 0.05 (see Table 9) to test the differences among the typefaces.

Table 8. Mean of correct response's percentage, classified by letters.

No.	Letter	Mean of Correct Response's Percentage		
		FT Manifest UD	Cordia New	TH Sarabun New
1	ก (Ko Kai)	38.96	33.75	36.04
2	ถ (Tho Thung)	35.83	34.58	33.75
3	ภ (Pho Samphao)	39.17	41.25	32.92
4	ค (Kho Khwai)	35.63	34.36	36.88
5	ฅ (Kho Khon)	33.54	26.25	22.09
6	ศ (So Sala)	43.33	40.84	38.33
7	ด (Do Dek)	32.50	30.83	32.08
8	ต (To Tao)	34.38	27.71	24.79
9	น (No Nu)	42.71	43.55	41.04
10	ฉ (Cho Ching)	40.63	34.17	36.25
11	ม (Mo Ma)	42.92	38.96	41.04
12	ฆ (Kho Rakhang)	31.67	31.46	29.79
13	ข (Kho Khai)	30.42	31.46	32.71
14	ฃ (Kho Khuat)	25.83	22.71	17.50
15	ช (Cho Chang)	40.84	26.67	30.63
16	ซ (So So)	30.41	21.25	24.79
17	ท (Tho Thahan)	30.41	21.25	24.79
18	ฑ (Tho Nangmontho)	36.04	35.63	28.54
19	ล (Lo Ling)	32.09	35.21	35.83
20	ส (So Sua)	39.79	37.29	37.50
21	อ (O Ang)	33.75	27.71	36.46
22	ฮ (Ho Nokhuk)	34.58	36.46	32.92
23	ฎ (Do Chada)	30.84	32.29	28.96
24	ฏ (To Patak)	37.71	30.84	29.58
25	บ (Bo Baimai)	38.13	36.25	35.21
26	ป (Po Pla)	52.09	51.88	47.50
27	ผ (Pho Phung)	36.25	38.75	35.63
28	ฝ (Fo Fa)	42.08	40.63	38.13
29	พ (Pho Phan)	37.50	38.70	31.88
30	ฟ (Fo Fan)	47.29	50.42	43.75
31	ฬ (Lo Chula)	44.17	40.83	26.46
32	ธ (Tho Thong)	37.29	31.46	32.92
33	ร (Ro Rua)	41.46	32.09	36.53
34	ห (Ho Hip)	33.96	36.88	36.67
35	ย (Yo Yak)	29.79	36.26	34.17
36	จ (Cho Chan)	38.54	41.25	38.96

Table 9 shows the summary of FT Manifest UD effectiveness by letter, indicating that the characters of the FT Manifest UD are more effective than Cordia New and TH Sarabun New, such as Kho Khon /ต/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, To Patak /ฏ/, Lo Chula /ฬ/, and Ro Rua /ร/ (Table 9: No.5, 8, 10, 15, 24, 31, and 33).

These results are consistent with the research hypothesis, specifically in the letter features of Kho Khon /ต/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, To Patak /ฏ/, Lo Chula /ฬ/, and Ro Rua /ร/, that design of letters based on the theoretical framework can provide better legibility than other typefaces in the test.

Also, the characters Ko Kai /ก/, Mo Ma /ม/, So So /ซ/, So Sua /ส/, O Ang /อ/, and Tho Thong /ธ/ of FT Manifest UD had higher effectiveness than the characters of Cordia New (Table 9: No. 1, 11, 16, 20, 21, and 32), besides the characters Pho Samphao /ภ/, So Sala /ศ/, No Nu /น/, Kho Khuat /ข/, Tho Nangmontho /ท/, Bo Baimai /บ/, Po Pla /ป/, Pho Phan /พ/, and Fo Fan /ฟ/ of FT Manifest UD that had higher effectiveness than the characters of TH Sarabun New (Table 9: No. 3, 6, 9, 14, 18, 25, 26, 29, and 30).

There was no difference in the findings of FT Manifest UD, Cordia New, and TH Sarabun New for the characters Tho Thung /ถ/, Kho Khwai /ค/, Do Dek /ด/, Kho Rakhang /ฆ/, Kho Khai /ข/, Tho Nangmontho /ท/, Lo Ling /ล/, Ho Nokhuk /ฮ/, Do Chada /ฎ/, Pho Phung /ผ/, Fo Fa /ฝ/, Ho Hip /ห/, and Cho Chan /จ/ (Table 9: No. 2, 4, 7, 12, 13, 17, 19, 22, 23, 27, 28, 34, and 36).

In addition, the effectiveness of FT Manifest UD was equivalent to Cordia New for the characters Pho Samphao /ภ/, So Sala /ศ/, No Nu /น/, Kho Khuat /ข/, Tho Nangmontho /ท/, Bo Baimai /บ/, Po Pla /ป/, and Pho Phan /พ/ (Table 9: No. 3, 6, 9, 14, 18, 25, 26, and 29), whereas the effectiveness of FT Manifest UD was equivalent to TH Sarabun New for the characters Ko Kai /ก/, Mo Ma /ม/, So So /ซ/, So Sua /ส/, O Ang /อ/, and Tho Thong /ธ/ (Table 9: No. 1, 11, 16, 20, 21, and 32).

In contrast, the character Yo Yak /ย/ of FT Manifest UD had a lower effectiveness than the character Yo Yak /ย/ of Cordia New and TH Sarabun New (Table 9: No. 35). The character Fo Fan /ฟ/ of FT Manifest UD also had a lower effectiveness than the character Fo Fan /ฟ/ of Cordia New (Table 9: No. 30).

Santayayon et al. (2011) suggested that the minimum size for young and older adults should be 2 mm at a viewing distance of 50 cm. This type of size is easy to read. The recommended type size corresponds to the visual angle of 0.2292° (Punsongserm & Suvakunta, 2022b). The visual angle of 0.2292° approximates to a visual angle of 0.2387° in the current study, as shown in Table 2, step 13 (physical sizes = 1.6709 mm). We selected the findings of the visual angle of 0.2387° (Table 10). The results showed that most letterforms of FT Manifest UD had a higher correct response rate than the other typefaces, particularly in the characters Kho Khuat /ข/, Cho Chang /ช/, So So /ซ/, and To Patak /ฏ/.

Table 9. Summary of the effectiveness of FT Manifest UD (Thai UD typeface), classified by letters.

No.	Letter	Effectiveness of FT Manifest UD		
		Higher (than)	No Difference (with)	Lower (than)
1	ก (Ko Kai)	C	T	-
2	ถ (Tho Thung)	-	C, T	-
3	ภ (Pho Samphao)	T	C	-
4	ค (Kho Khwai)	-	C, T	-
5	ต (Kho Khon)	C, T	-	-
6	ศ (So Sala)	T	C	-
7	ด (Do Dek)	-	C, T	-
8	ต (To Tao)	C, T	-	-
9	น (No Nu)	T	C	-
10	ฉ (Cho Ching)	C, T	-	-
11	ม (Mo Ma)	C	T	-
12	ฆ (Kho Rakhang)	-	C, T	-
13	ข (Kho Khai)	-	C, T	-
14	ฃ (Kho Khuat)	T	C	-
15	ช (Cho Chang)	C, T	-	-
16	ซ (So So)	C	T	-
17	ท (Tho Thahan)	-	C, T	-
18	ฑ (Tho Nangmontho)	T	C	-
19	ล (Lo Ling)	-	C, T	-
20	ส (So Sua)	C	T	-
21	อ (O Ang)	C	T	-
22	ฮ (Ho Nokhuk)	-	C, T	-
23	ฎ (Do Chada)	-	C, T	-
24	ฏ (To Patak)	C, T	-	-
25	บ (Bo Baimai)	T	C	-
26	ป (Po Pla)	T	C	-
27	ผ (Pho Phung)	-	C, T	-
28	ฝ (Fo Fa)	-	C, T	-
29	พ (Pho Phan)	T	C	-
30	ฟ (Fo Fan)	T	-	C
31	ฬ (Lo Chula)	C, T	-	-
32	ธ (Tho Thong)	C	T	-
33	ร (Ro Rua)	C, T	-	-
34	ห (Ho Hip)	-	C, T	-
35	ย (Yo Yak)	-	-	C, T
36	จ (Cho Chan)	-	C, T	-
	C = Cordia New T = TH Sarabun New			

Table 10. Percentage of correct response at visual angle of 0.2387°, classified by letters.

No.	Letter	Percentage of Correct Response at Visual Angle of 0.2387°		
		FT Manifest UD	**Cordia New**	**TH Sarabun New**
1	ก (Ko Kai)	93.75	81.25	84.37
2	ถ (Tho Thung)	87.50	87.50	90.63
3	ภ (Pho Samphao)	87.50	93.75	87.50
4	ค (Kho Khwai)	90.63	90.63	87.50
5	ฅ (Kho Khon)	87.50	81.25	68.75
6	ศ (So Sala)	93.75	87.50	90.63
7	ด (Do Dek)	90.63	87.50	90.63
8	ต (To Tao)	93.75	84.38	71.88
9	น (No Nu)	93.75	93.75	90.63
10	ฉ (Cho Ching)	93.75	78.13	90.63
11	ม (Mo Ma)	90.63	93.75	93.75
12	ฆ (Kho Rakhang)	93.75	81.25	87.50
13	ข (Kho Khai)	87.50	84.38	75
14	ฃ (Kho Khuat)	**93.75**	68.75	43.75
15	ช (Cho Chang)	**90.63**	71.88	68.75
16	ซ (So So)	**90.63**	53.13	50
17	ท (Tho Thahan)	87.50	90.63	90.63
18	ฑ (Tho Nangmontho)	90.63	90.63	84.38
19	ล (Lo Ling)	84.38	84.38	90.63
20	ส (So Sua)	93.75	93.75	93.75
21	อ (O Ang)	93.75	81.25	90.63
22	ฮ (Ho Nokhuk)	93.75	90.63	81.25
23	ฎ (Do Chada)	75	75	75
24	ฏ (To Patak)	**81.25**	50	62.50
25	บ (Bo Baimai)	90.63	81.25	90.63
26	ป (Po Pla)	93.75	96.88	90.63
27	ผ (Pho Phung)	90.63	93.75	93.75
28	ฝ (Fo Fa)	93.75	93.75	93.75
29	พ (Pho Phan)	90.63	90.88	87.50
30	ฟ (Fo Fan)	96.88	93.75	93.75
31	ฬ (Lo Chula)	93.75	93.75	84.38
32	ธ (Tho Thong)	87.50	87.50	87.50
33	ร (Ro Rua)	93.75	87.50	87.50
34	ห (Ho Hip)	90.63	93.75	84.38
35	ย (Yo Yak)	90.63	90.63	90.63
36	จ (Cho Chan)	93.75	93.75	93.75

4. Discussion

In this segment, we will discuss the confirmation of the most prominent letterforms of FT Manifest UD, which are crucial in enhancing legibility in small type sizes. Additionally, we will provide recommendations for refining certain letterforms of FT Manifest UD that are particularly useful for small type sizes.

4.1. The characters Kho Khon /ค/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, To Patak /ฏ/, Lo Chula /ฬ/, and Ro Rua /ร/

The results of the characters Kho Khon /ค/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, To Patak /ฏ/, Lo Chula /ฬ/, and Ro Rua /ร/ (Table 9) indicated that the design of the letterforms of FT Manifest UD (as shown in Figure 2) could support legibility in terms of different physical type sizes. This finding confirmed that the key characteristics of the Thai typeface, according to the conceptual framework in this section (top part of Figure 2), can be used to design high-legibility letterforms that correspond to the previous study of Punsongserm (2023); the key features of each letterform in FT Manifest UD include the following:

- Character Kho Khon /ค/
  - Wider character width
  - Many spaces within characters, more counter
  - Presence of a massive, serrated line
  - Use of an overturned curve connecting the first loop and the front line
- Character To Tao /ต/
  - Wider character width
  - Many spaces within characters, more counter
  - Use of an upturned curve connecting the first loop and the front line
- Character Cho Ching /ฉ/
  - Second loop that is large enough and protruding from the main body (large second loop and juts out)
  - Curved topline and bent-down (sagged terminal) and does not jut out of the front vertical axis of the first loop
- Character Cho Chang /ช/
  - A minimal loop without a curve connecting the first loop
  - Long diagonal tail that juts out from the main body
  - Use of a curved line at the base (bottom line)
- Character To Patak /ฏ/
  - Diminutive first loop
  - More aperture
  - Use of massive underside wavy lines (serrated lines)
  - Omits a tail and has the coil (second loop) protrude out of the vertical axis of the first loop of the character To Patak /ฏ/

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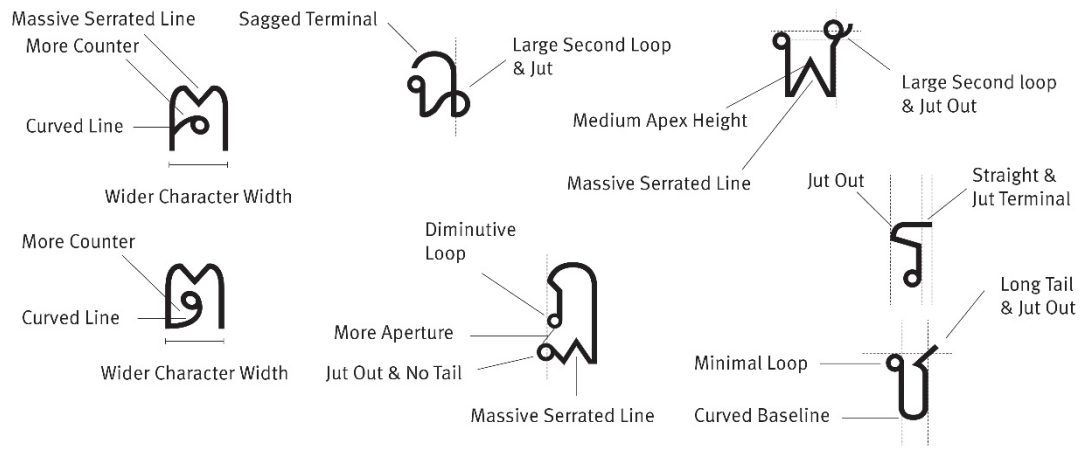
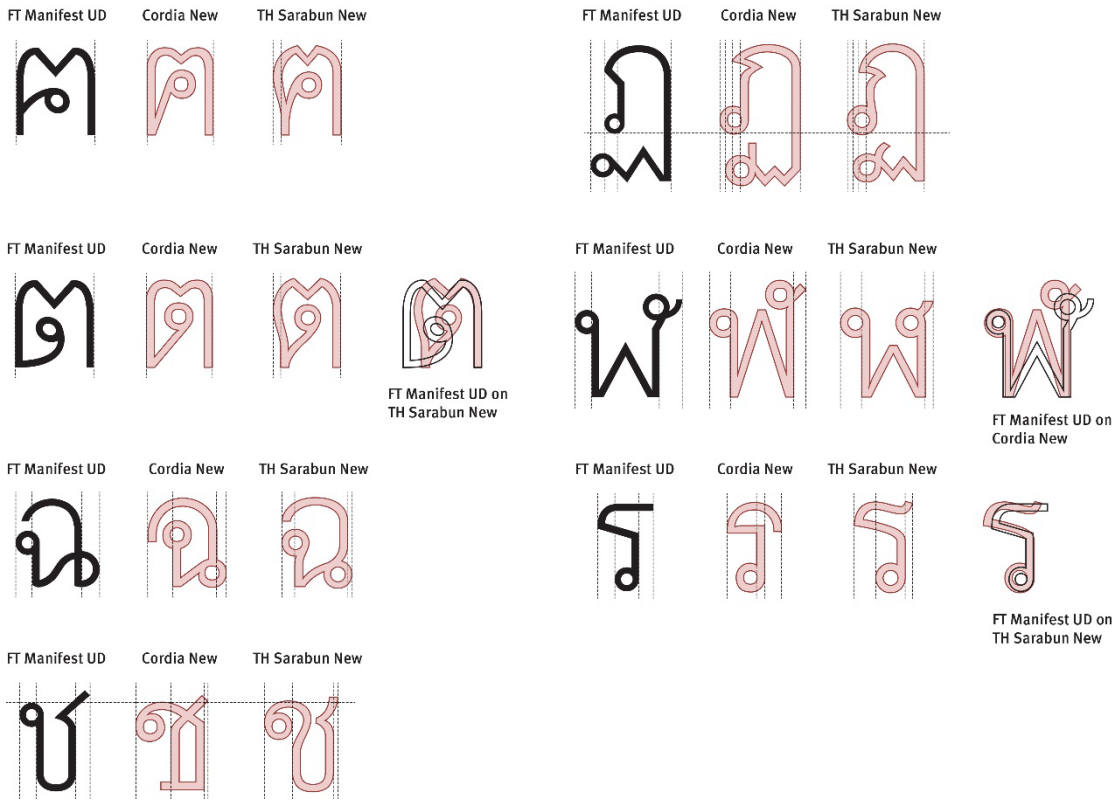
- Character Lo Chula /ฬ/
  - Sizeable second loop and tail-end juts out of the main body
  - Defining up-down diagonals, to be precise (massive, serrated line)
  - Pointed tip for a medium height, medium apex height
- Character Ro Rua /ร/
  - Front part of the character that protrudes (juts out) from the stem and first loop
  - Use of the straight horizontal upper line extending from the body line.

Figure 2. Key characteristics of FT Manifest UD, compared with Cordia New and TH Sarabun New (in case of letterforms ค, ต, ฉ, ป, ฏ, ฬ, and ร) (source for top part: Punsongserm, 2019a)





4.2. The characters Kho Khwai /ค/, So So /ซ/, Do Chada /ฎ/, and Tho Thong /ฐ/

To improve the legibility of the letterform of the FT Manifest UD for the characters Kho Khwai /ค/, So So /ซ/, Do Chada /ฎ/, To Patak /ฏ/, and Tho Thong /ฐ/ to reinforce more effectiveness in small type sizes, we suggest as follows:

- Character Kho Khwai /ค/: The improvement must maintain broader character width, more counter space, and a curved line connecting its first loop to the front line (Figure 4). However, it could improve the part of the diagonal curve line connecting the front line to the first loop, which can be lowered to enhance recognition.
- Character So So /ซ/: The improvement must retain key features of providing a diminutive loop; having a massive, serrated line; and jutting out of the front of the main body, as well as having a curved baseline and a long diagonal tail that juts out of the main body (Figure 4). To enhance legibility, it should increase the length of the character's tail, So So /ซ/, to make it longer than before.
- Character Do Chada /ฎ/: The improvement must retain key characteristics of having a diminutive loop, a large second loop with no tail, and a broader aperture (Figure 4). To improve legibility, the lower part of the character Do Chada /ฎ/ could be adjusted downward to make the aperture wider and make an observable vertex for the lower part, as well as increase the counter space of the character Do Chada /ฎ/, as suggested by Punsongserm et al. (2018b) (see Figure 3).
- Character Tho Thong /ฐ/: The improvement must keep the use of a horizontal top line and protrusion of the front part by increasing the protrusion of this front part slightly (Figure 4).

Figure 3. Improving approach for Do Chada /ฎ/ letterform. (source: Punsongserm et al., 2018b)

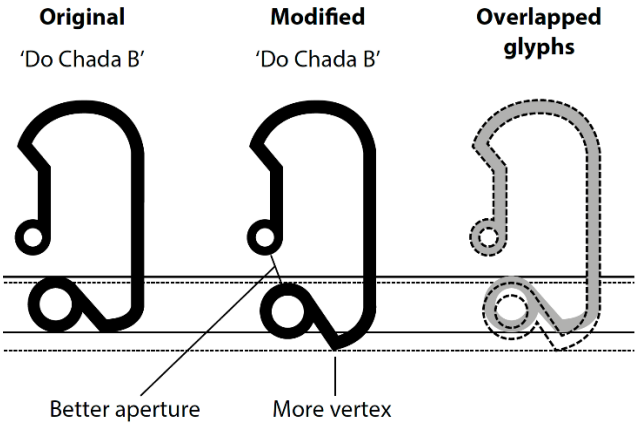


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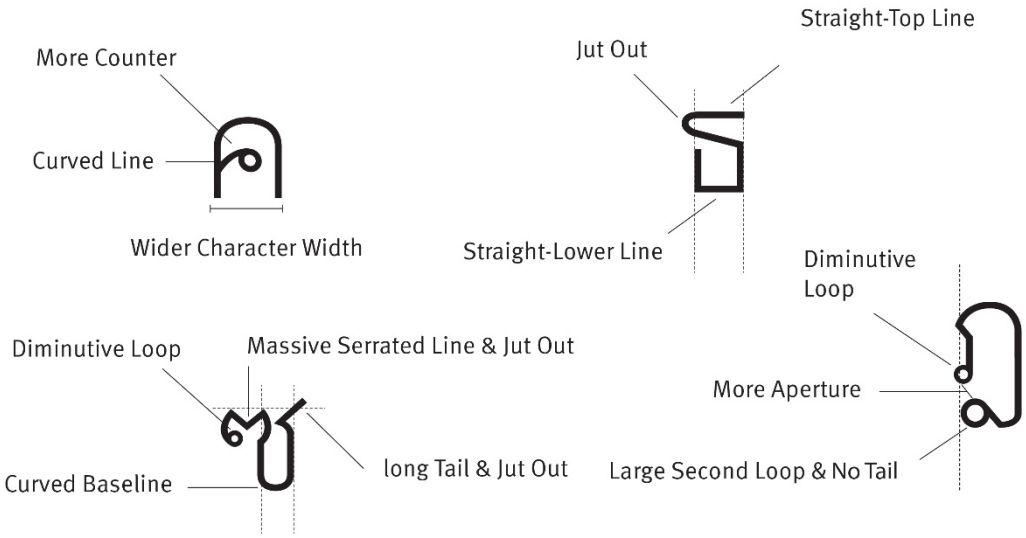
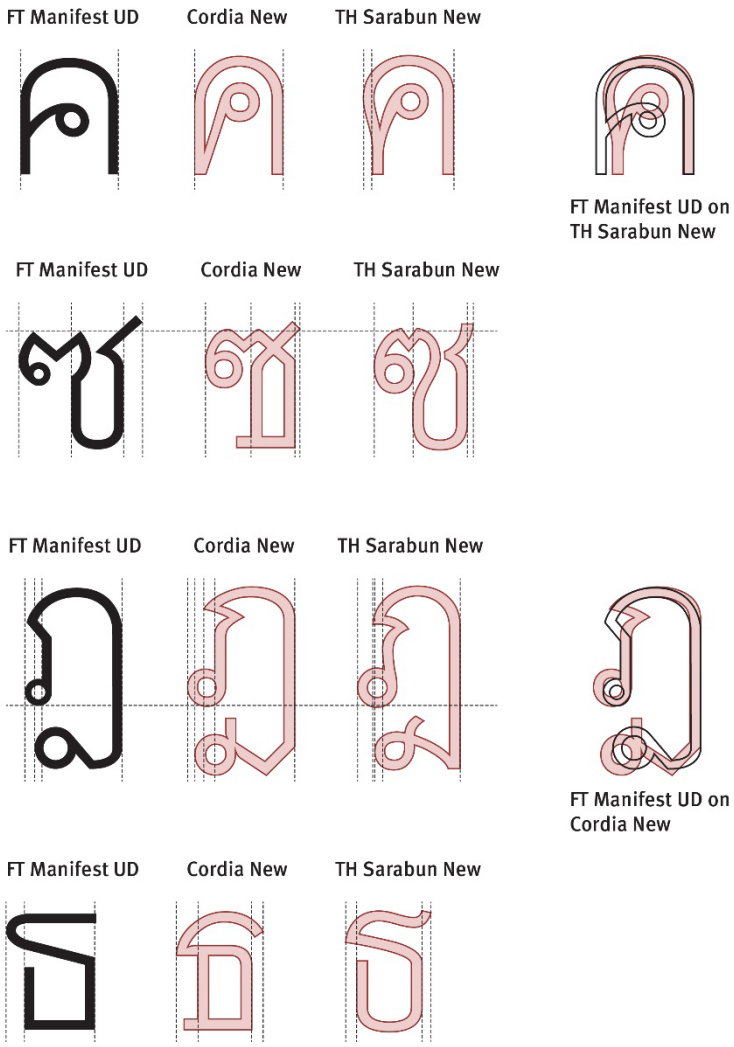
Figure 4. Key characteristics of FT Manifest UD, compared with Cordia New and TH Sarabun New (in case of letterforms ค, ช, ฎ, and ฮ). (source for top part: Punsongserm, 2019a)





4.3. The characters Pho Samphao /ภ/, Po Pla /ป/, Fo Fa /ฝ/, Fo Fan /ฟ/, Ho Hip /ห/, and Yo Yak /ย/

The present study suggests that the letterforms improvement for the characters Pho Samphao /ภ/, Po Pla /ป/, Fo Fa /ฝ/, Fo Fan /ฟ/, Ho Hip /ห/, and Yo Yak /ย/ (as shown in Figure 5) to have better legibility. The following suggestions conforming to the previous study (Punsongserm, 2023) may improve clarity and legibility.

- Character Pho Samphao /ภ/: The suggestion is to keep using a simplified nib and slightly increase the character width, including possibly increasing the size of the enlarged loop to ensure the loop has more protrusion to enhance better legibility.
- Character Po Pla /ป/: In this study, we found that the characters Po Pla /ป/ of each typeface provided a higher percentage of correct answers than the other characters tested. The letterform of the letter Po Pla /ป/ has used the same structure as the letter Bo Baimai /บ/, and then added a vertical straight tail (ascender). To maintain legibility, a straight baseline and a wider character width must be retained to enhance visibility. For better legibility, the character width should be slightly broader, including extending the size of the loop slightly.
- Character Fo Fa /ฝ/: The character Fo Fa /ฝ/ applied the same structure as the character Pho Phung /ผ/ and then added a tail (ascender). Although the use of curved front lines for the characters Pho Phung /ผ/ and Fo Fa /ฝ/ provided the benefit of enhancing legibility in blur simulation (fovea vision) and short-exposure (parafovea vision) experiments, according to the results of the Punsongserm (2019a, 2019b) study, the results in this study showed that the effectiveness of characters Pho Phung /ผ/ and Fo Fa /ฝ/ of FT Manifest UD did not differ from Codia New and TH Sarabun New. To improve the legibility of the character Fo Fa /ฝ/ (including character Pho Phung /ผ/), in addition to preserving the key letter features (see Figure 5), the curved frontal line should be adjusted to make the upper aperture wider. This way helps support legibility and visibility to make it easier to identify the characters Fo Fa /ฝ/ and Pho Phung /ผ/ at various small type sizes.
- Character Fo Fan /ฟ/: The character Fo Fan /ฟ/ of the FT Manifest UD was less effective than the character Fo Fan /ฟ/ of Cordia New in the experiment. The effectiveness was not different from the character Fo Fan /ฟ/ of TH Sarabun New. When comparing Cordia New and TH Sarabun New with the FT Manifest UD (see Figure 5), we found that the loops of Cordia New and TH Sarabun New are more prominent in size. It has a higher serrated line (apex) than the serrated line of the FT Manifest UD, with similar character widths. To improve the character Fo Fan /ฟ/ of the FT Manifest UD, its character width may be expanded to more than Cordia New and TH Sarabun New to increase the counter space and enhance visibility.

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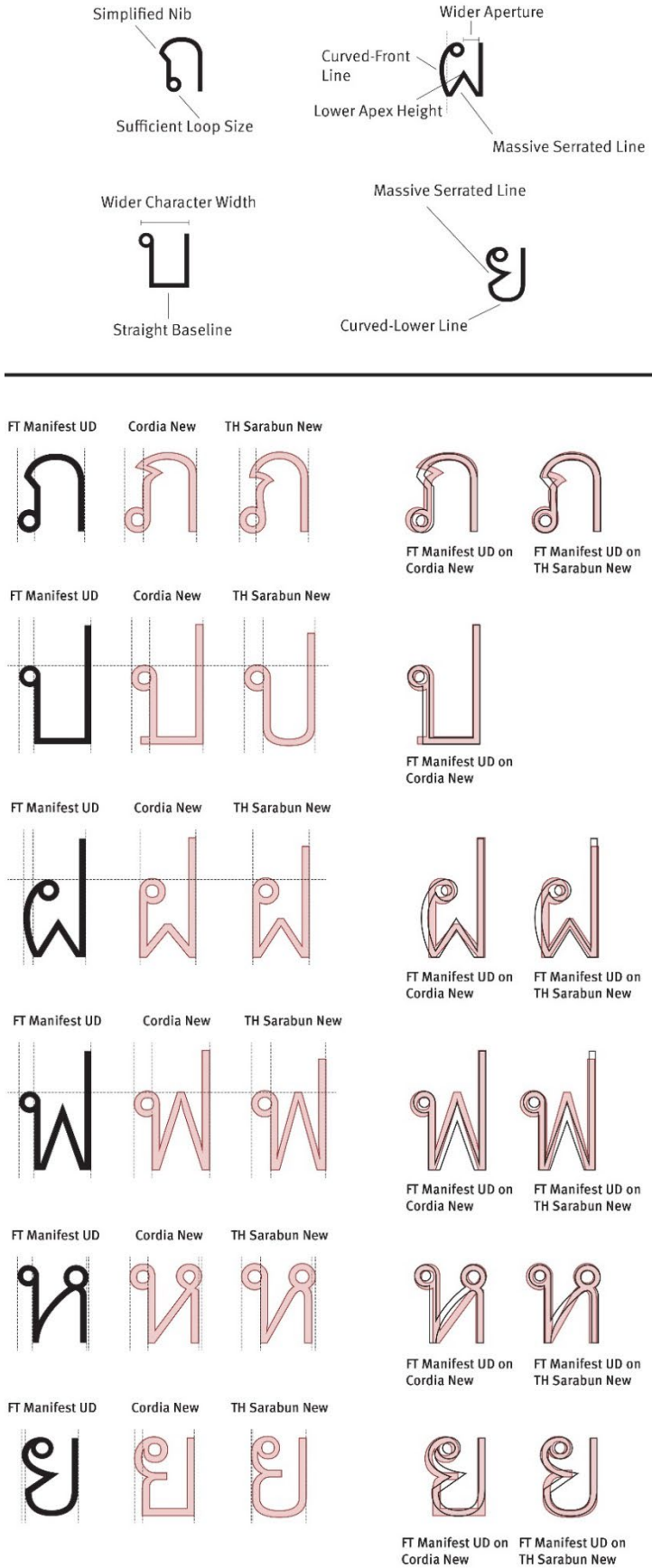
Figure 5. Key Characteristics of FT Manifest UD, compared with Cordia New and TH Sarabun New (in case of letterforms ก, ป, ฝ, พ, ห, and ย). (Source for top part: Punsongserm, 2019a)



- Character Ho Hip /ห/: The effectiveness of the character Ho Hip /ห/ of the FT Manifest UD was not different from the character Ho Hip /ห/ of Cordia New for the present study. In Figure 5, the character Ho Hip /ห/ of Cordia New and TH Sarabun New is compared with the FT Manifest UD and shows a significant difference. The character Ho Hip /ห/ of FT Manifest UD has a diagonal curvature, which differs from a straight diagonal of the Cordia New and TH Sarabun New. The use of diagonal curves for the character Ho Hip /ห/ of FT Manifest UD derives from the character Tho Thahan /ท/ structure of FT Manifest UD. To maintain this aspect, improving the legibility and visibility of the character Ho Hip /ห/ of the FT Manifest UD may increase the character width and adjust its curl (second loop) to extend (jut) out the vertical axis of the back line to the righthand side more.
- Character Yo Yak /ย/: FT Manifest UD's character Yo Yak /ย/ was inferior in performance to the characters Yo Yak /ย/ of Cordia New and TH Sarabun New. When comparing the character of FT Manifest UD with that of other typefaces, we found that the characters of other typefaces used more horizontal lines protruding within the character than the jagged lines (see Figure 5). The results indicated that using a massive serrated line following the FT Manifest UD approach was ineffective in identifying small type sizes. Also, omitting the presence of the loop of the character Yo Yak /ย/ may not affect the legibility in small print sizes. To improve the legibility of the character Yo Yak /ย/ of the FT Manifest UD, we may apply this horizontal at mid-body style instead of jagged curls similar to the letter feature of Cordia New and TH Sarabun New, including reducing the size of the loop to increase the negative space (counter space) within letterform.

5. Conclusion

In the current study, we conducted a study to evaluate whether the Thai UD typeface (FT Manifest UD) can improve legibility for Thai readers of varying ages and visual acuities. We compared the legibility of the Thai UD typeface with two other familiar text typefaces. Based on the test statistics, the FT Manifest UD (Thai UD typeface) demonstrated better overall effectiveness than the Cordia New and TH Sarabun New typefaces. These results were obtained at a significance level of 0.05 and are consistent with the findings of the previous study (Punsongserm, 2023), in which the effectiveness of the typefaces was measured using the distance threshold method under the same conditions of Thai consonants and visual angles. However, among individuals in graphic design and related fields, the FT Manifest UD outperformed the TH Sarabun New typeface overall, except the Cordia New typeface, which produced a similar effect as the FT Manifest UD. It is worth noting that these results differ from those of the previous study (Punsongserm, 2023), which found that FT Manifest UD had significantly better effectiveness in each group of volunteers when compared to the Cordia New and TH Sarabun New typefaces.

Most results revealed that key characteristics of Thai letterforms for legibility improvement contributed to the legibility of FT Manifest UD's letterforms when used in different small print sizes. However, the present study suggested that improving letter features could provide better legibility in identifying small print sizes for the FT Manifest UD's letterforms, such as developing broader character width and providing more counter space, increasing or decreasing the size of the loop and the length of the tail, and adding the presence of a jutting part, as we presented in the Discussion section.

Other factors besides letter features affect legibility and visibility, such as the size of stroke weight. We found evidence that greater boldness, or visual angles rather than regular boldness,

in medium size for Roman letterforms can enhance legibility in smaller type sizes. In contrast, ultra-letter boldness does not support recognition (Beier & Oderkerk, 2019). In addition, increased letter spacing, letter width, and letter boldness enhance performance in low-vision reading owing to age-related macular degeneration (Beier et al., 2021). There is a need to investigate the effectiveness of thickness and broadness in Thai letterforms, especially in small sizes. This insufficiency is an opportunity for further study.

To expand the scope of studies on the effectiveness of FT Manifest UD related to the degree of visual angles, it is imperative to compare it with the efficacy of Roman-like Thai typefaces, which are other commonly employed fonts in various media. To achieve this, it is recommended that the adapted distance threshold methodology utilized in a prior study by Punsongserm (2023) be employed in conjunction with the method in the present study. This methodological approach can elicit the effectiveness of letterforms through varying visual angles based on physical sizes and distances.

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