Effectiveness of Predominant Letterforms in Multi-Viewing Distances: Thai Universal Design Font Versus Familiar Thai Text Fonts

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Abstract

Background   In previous studies, researchers have explored ways to create legible Thai letterforms that eventually led to the development of the Thai universal design typeface (Thai UD typeface). This typeface was designed to support Thai readers and individuals with low visual acuity. Previous researchers utilized various psychological methodologies, including blur simulation and short exposure, to determine the effectiveness of legibility in the Thai UD typeface. To further investigate the capabilities of the Thai UD typeface, the present study uses the distance threshold method to compare it to familiar text typefaces. The present study aims to assess the performance in legibility of three different typefaces, FT Manifest UD (Thai UD typeface), Cordia New, and TH Sarabun New, when presented with 36 Thai consonants at 15 varying viewing distances.

Methods   We recruited a sample of 31 Thai volunteers, 12 males and 19 females aged between 18 and 60. We categorized participants into three groups: adolescent-young adults, older adults, and individuals working in graphic design and related fields. Our findings yielded distinct results for each of these groups.

Results   Based on the Wilcoxon Signed Ranks Test at a significance level of 0.05, the FT Manifest UD typeface was superior in overall effectiveness when compared to the Cordia New and TH Sarabun New typefaces. This finding was consistent across the adolescent-young adult, older adult, and graphic designer groups, where the FT Manifest UD typeface was deemed more effective than the other two typefaces.

Conclusions   This study focuses on the Thai UD font, also known as FT Manifest UD, specifically designed to assist individuals with low visual acuity. Through our research, the unique letter features of FT Manifest UD not only benefit individuals with low visual acuity, but also improve legibility for others under different visual angles and viewing distances. Our study suggests that FT Manifest UD is more effective than other typefaces regarding various visual angles and distances. However, our research also shows that some letterforms need improvement to ensure legibility under varying visual angles and distances.

Keywords   Universal Design Font, Legibility, Letter Features, Multi-Viewing Distances, Visual Angles

1. Introduction

There have been numerous studies on the legibility of various typefaces in developed countries, with a particular focus on Roman typefaces. However, there remains a notable gap in research on the legibility of Thai typefaces. Specifically, there has yet to be a comprehensive and in-depth analysis that can generate new knowledge to meet the requirements of the current situation, particularly concerning individuals with low visual acuity and the aging population in Thailand. As such, our understanding of the aspects of Thai letterforms that are suitable for diverse readers remains limited. This is particularly true for the individuals with low visual acuity. Although psychological studies on the efficacy of Thai typefaces have been conducted (e.g., Rattanakasamsuk, 2013; Teeravarunyou & Laosirihongthong, 2003; Waleetorncheepsawat et al., 2012), these studies have not yielded recommendations on how to improve and develop suitable legibility of Thai letterforms. Instead, their authors have primarily focused on presenting results that compare the efficacy of different typefaces or typeface sizes. Consequently, there is a need for further literature to elucidate the aspects of character morphology that influence visual letter recognition under different testing conditions for Thai typefaces.

According to Punsongserm et al. (2017a), the effectiveness or performance of letterforms is often reflected by their legibility and visibility, which are two functions that are closely related yet distinct. In this study, legibility refers to the ease with which individual letters can be distinguished from one another, and it is concerned with each letter's form and essential characteristics. On the other hand, visibility is determined by factors that can either enhance or obstruct visibility entirely. Visibility not only takes into account the negative space of a character, such as the closed and opened counters, but also has implications for external factors that can interfere with the visibility of a character. These external factors include low pass filtering, reduced print type and background contrast, varying viewing distances, and more. When visibility is inadequate, it can lead to misinterpretations of characters, which can ultimately affect legibility.

Researchers have employed various methodologies to measure the legibility of typefaces in psychological studies. Tinker (1963) extensively described these methodologies, including the short-exposure method, distance method, focal variator method, blinking method, speed of reading, and measurement of eye movements. Traditionally, researchers of typeface legibility have focused on visual letter recognition, and the short-exposure and distance methods have been the most commonly employed techniques for examining letter identification and recognition (Banister, 1927; Bouma, 1971; Fisher et al., 1969; Geyer, 1977; Phillip et al, 1983; Sanford, 1888; Townsend, 1971; van der Heijden et al, 1984). Others have examined the legibility of types under low-visibility conditions, such as Brown (1963), Uttal (1969), and Loomis (1982). However, these studies produced different findings, possibly due to the use of different typefaces (Milloy, 1978).

The short-time exposure method serves as a prevalent means to assess the effectiveness of individual letterforms within the parafoveal view, a crucial aspect in reading continuous text

(Beier & Larson, 2010). This method has proven useful in evaluating how well letterforms are perceived in peripheral vision, which is an essential factor in visual processing during reading. Furthermore, the distance threshold method is utilized to analyze the legibility of letterforms in typefaces that are displayed on signs viewed from a distance (Beier & Larson, 2010). This method helps to determine how well the letterforms can be identified from afar, considering various visual factors such as font size, contrast, and color. Overall, these methods provide valuable insights into different typefaces' legibility and suitability for particular scenarios.

Punsongserm et al. (2015, 2017a, 2017b, 2018a, 2018b) extensively analyzed Thai typefaces and their legibility in conditions of low visual acuity, using a blur simulation and a short-exposure test method. They aimed to develop a fundamental understanding of typeface design principles that would facilitate reading for individuals with low visual acuity, with the ultimate goal of creating a prototype for the Thai universal design font (UD). This prototype was specifically designed based on character morphology, with a view to effectively aiding visual letter recognition under low visual acuity conditions. Subsequently, Punsongserm (2019a, 2019b, 2020) measured the legibility of Thai UD letterforms under low visual acuity conditions (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 demonstrated that the overall effectiveness of the Thai UD font under low visual acuity conditions offers advantages over conventional text fonts.

In this study we aimed to evaluate the legibility of the Thai UD typeface across various viewing conditions. By employing the distance method, we aimed to gauge its efficacy compared to other commonly used and recognized typefaces. Our primary aim was to showcase the typeface's ability to retain its legibility, even when viewed from a distance.

According to Punsongserm (2019a, 2019b, 2020) and Punsongserm et al. (2017b, 2018a), the legibility and visibility of Thai letterforms are supported by certain key characteristics. These include the appearance of the typeface, character width, character shape, stroke shapes, and characteristics at the end of the line. The clarity of jagged lines, the protrusion of loops and terminals, and their size are crucial elements of type anatomy that affect legibility. Furthermore, appropriate character width, which is either narrow or wide, impacts the size of the counter or negative space. The shape of the characters, whether square or rounded, also plays a role in their legibility. The stroke shapes, such as the upper, lower, and front lines of the characters, can be either straight or curved. Finally, horizontal or straight downward characteristics at the end of the line, also known as the terminal aspect, are essential in improving legibility. By utilizing these different attributes or elements, the legibility of Thai letterforms can be enhanced, as illustrated in Figure 1.
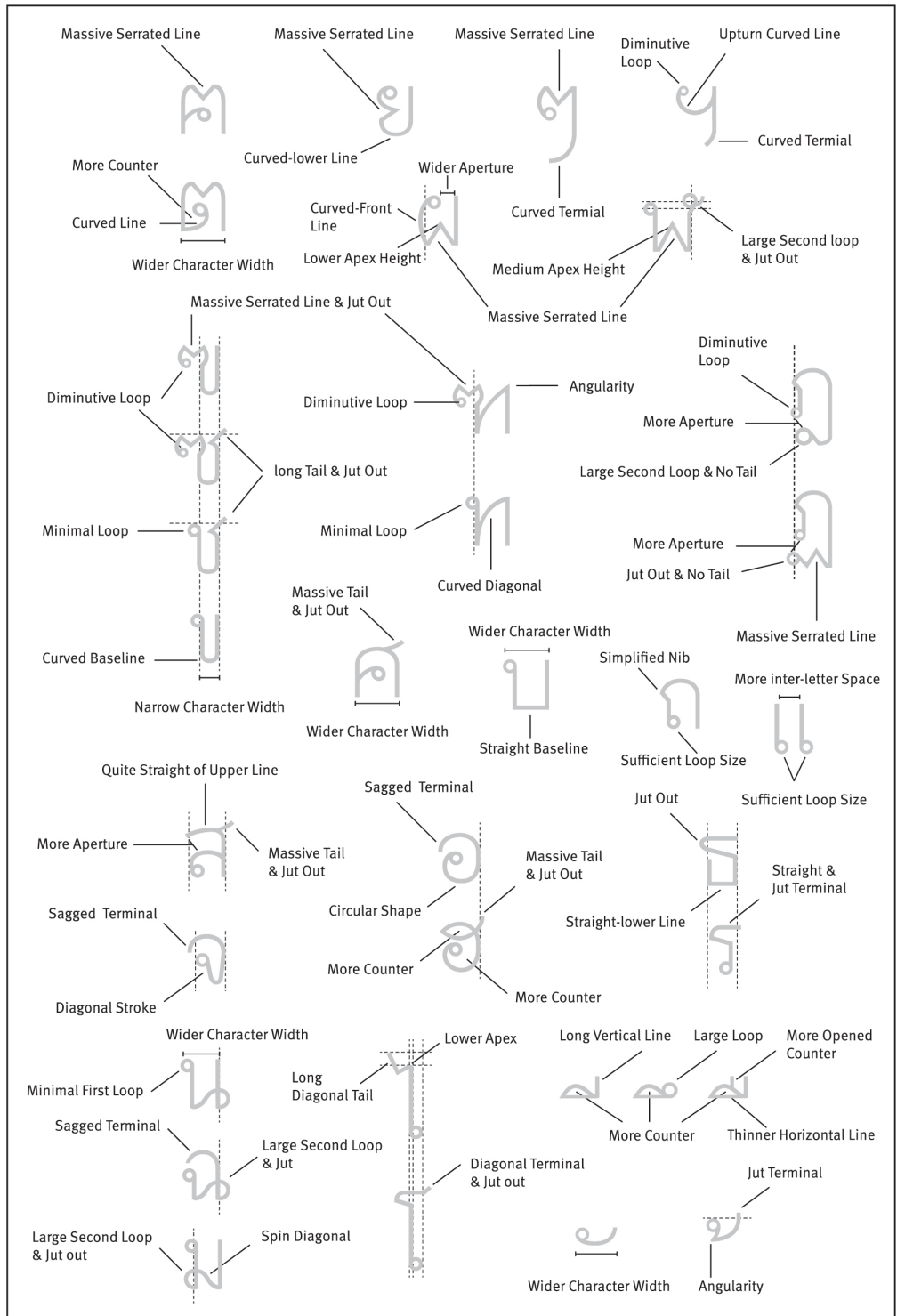
Figure 1 Key Characteristics of Thai Letterforms for Legibility Improvement (Source: Punsongserm, 2019a)

2. Method

2. 1. Test Materials

1) Selected Letters

In this study, we utilized 36 consonant letters listed in Table 1. We chose these letters for their similarities, including ก-ถ-ภ (Ko Kai-Tho Thung-Pho Samphao), ค-ต-ศ (Kho Khwai-Kho Khon-So Sala), ด-ต (Do Dek-To Tao), น-ฉ-ม-ฆ (No Nu-Cho Ching-Mo Ma-Kho Rakhang), ข-ข-ช-ซ (Kho Khai-Kho Khuat-Cho Chang-So So), ท-ฑ (Tho Thahan-Tho Nangmontho), ล-ส (Lo Ling-So Sua), อ-ฮ (O Ang-Ho Nokhuk), ฎ-ฏ (Do Chada-To Patak), บ-ป (Bo Baimai-Po Pla), ผ-ฝ (Pho Phung-Fo Fa), พ-ฟ-ฬ (Pho Phan-Fo Fan-Lo Chula), and ธ-ร (Tho Thong-Ro Rua). We also included characters that need clarification, such as ห (Ho Hip), ย (Yo Yak), and จ (Cho Chan), particularly in conditions of low visual acuity. These findings are consistent with previous research conducted by Punsongserm et al. (2017a, 2017b).

2) Selected Typefaces

To evaluate the effectiveness of letter features in Thai Universal letterforms (FT Manifest UD), we conducted a comparative examination of the legibility of two Thai typefaces, Cordia New (Regular) and TH Sarabun New (Regular), that are well-known typefaces that have been used for a significant period.

The origin of Cordia New can be traced back to a font known as Tom Light, which was created during the late stages of the hot metal typesetting era and had widespread use during the phototypesetting era (Punsongserm, 2010; Suveeranont, 2002). Tom Light was transformed into a digital font compatible with Mac and Windows OS during the digital typesetting era. The font was named EAC Tom Light on Mac OS and renamed Cordia New (Cordia UPC) on Windows OS. These fonts have been bundled with computers for several decades and are widely utilized in document typing. (Punsongserm, 2019a; 2019b).

In 2007, the Department of Intellectual Property (DIP) and Software Industry Promotion Agency (SIPA) held a Thai font competition. Among the thirteen successful fonts, TH Saraban PSK font emerged as one of the winners (Suveeranont, 2017). Later on, in 2010, the Council of Ministers officially announced the thirteen fonts, including TH Sarabun PSK, as the public fonts. Public agencies were directed to use these fonts, especially TH Sarabun PSK, in their official documents (NSTDA, 2018; Suveeranont, 2017). In 2011, the TH Saraban PSK font underwent some modifications and was re-released under the name 'TH Sarabun New' (beartai, 2016).

Table 1 The 36-Characters Set Varied by Three Typefaces Used in the Experiment

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	ศ (Kho Khon)	ฅ	ฅ	ฅ	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	ฑ (Tho Thahan)	ฑ	ฑ	ฑ	35	ย (Yo Yak)	ย	ย	ย
18	ฒ (Tho Nangmontho)	ฒ	ฒ	ฒ	36	จ (Cho Chan)	จ	จ	จ

3) Type Sizes

In this study, we defined a fixed size for each selected character as a physical size of 5 mm in Bo Baimai height measurement for displaying on a monitor. To determine the distances for viewing, we divided the distances into 15 ranges, with each range being 40 cm in length. The total length covered was 600 cm, ranging from the farthest distance to the nearest distance from the monitor. Figure 2 and Table 2 illustrate this, where the maximum length represents the smallest visual angle of 0.0477° at a distance of 600 cm from the monitor, and the largest length represents the largest visual angle of 0.7162° at a distance of 40 cm from the monitor.
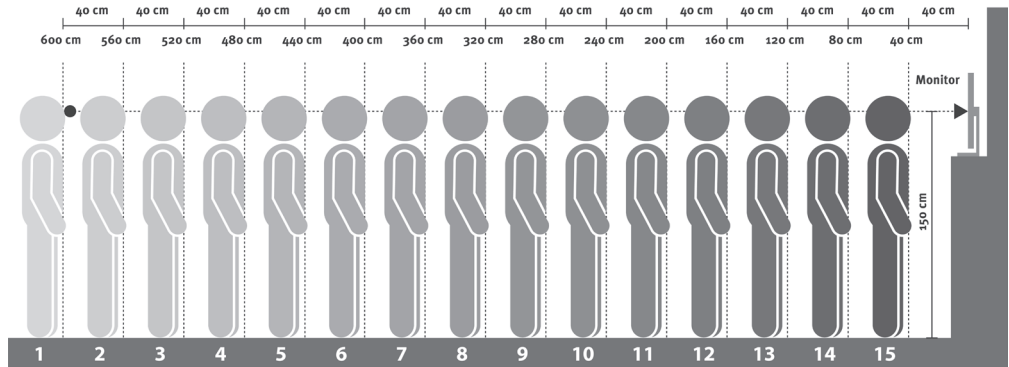
Figure 2 Steps of Viewing Distances From Human Eyes to Monitor, Range From Farthest 600 cm (Step 1) Approach to Nearest 40 cm (Step 15)

4) Apparatus

During the experiment setting, we employed a range of equipment to ensure the accuracy and reliability of the findings. This equipment consisted of a controller laptop computer and an observer monitor (BenQ PD3200U) featuring a 32-inch display and incorporating advanced features, such as eye care mode, flicker-free technology, and low blue light reduction. The monitor was configured to a resolution of 3840 x 2160 pixels and a refresh rate of 60 Hz, with a luminous intensity of 258 cd/m². The observer monitor was positioned on a concrete ridge of the wall, and we adjusted the monitor's height at eye level, approximately 150 cm measured from the floor to the center of the monitor (Figure 2). In addition to this, we utilized a set of 15 linear markers in the form of white marking tape, which we positioned on the dark grey floor at 15 different distances. This enabled us to maintain consistent viewing distances between the observer and the monitor, thereby facilitating precise and consistent results throughout the experiment.

In the present study we employed a test material that consisted of characters displaying variations in letters, typefaces, and visual angles, as delineated in Tables 1 and 2. Each character, exhibiting variations in letters and typefaces, was centrally presented on a monitor. The stimuli consisted of 36 characters, set in black (#000000) against a white (#FFFFFF) background, with distinctions in typeface (three typefaces) and visual angles (15 distances), resulting in a total of 1,620 trials per participant for the experiment.

2. 2. Participants

For the current investigation, we invited the 32 Thai participants to participate in the experiment. A total of 31 volunteers kindly agreed to participate in the experiment, and each of them signed a consent form after we thoroughly explained the objective and procedure of the study. The only exception was a single volunteer from the elderly group, aged 62, who declined to participate. As a result, the total number of participants involved in the current study was reduced to 31.

Table 2 The Comparison of Type Sizes Among Distances, Visual Angles, and Point Sizes

Step	Distance (cm)	Visual Angle (deg.)	Point Size (pt) at Bo Baimai Height of 5 mm		
			FT Manifest UD	Cordia New	TH Sarabun New
1	600	0.0477° (0° 2' 0.86")			
2	560	0.0512° (0° 3' 0.07")			
3	520	0.0551° (0° 3' 0.31")			
4	480	0.0597° (0° 3' 0.58")			
5	440	0.0651° (0° 3' 0.91")			
6	400	0.0716° (0° 4' 0.30")			
7	360	0.0796° (0° 4' 0.77")			
8	320	0.0895° (0° 5' 0.37")	42.50	35.50	36.18
9	280	0.1023° (0° 6' 0.14")			
10	240	0.1194° (0° 7' 0.16")			
11	200	0.1432° (0° 8' 0.59")			
12	160	0.1790° (0° 10' 0.74")			
13	120	0.2387° (0° 14' 0.32")			
14	80	0.3581° (0° 21' 0.49")			
15	40	0.7162° (0° 42' 0.97")			

A total of 31 Thai volunteers with varying levels of far visual acuity (distance acuity) participated in this study, including 12 males and 19 females ranging in age from 18–60 years old (mean age = 38.52 years). The average far visual acuity of the participants was LogMAR 0.047. We divided the participants into three groups for analysis: the adolescent-adults group, the older adults group, and the graphic designers and related fields group. The adolescent-adults group consisted of five males and seven females, all with normal visual acuity (mean LogMAR 0.008), ranging from 18–40 years old (mean age = 28.30 years). The older adults group included one male and nine females (mean LogMAR 0.078), ranging in age from 52–60 (mean age = 55.33 years). The graphic designers and related fields group consisted of six males and four females with either normal or slightly low visual acuity (mean LogMAR 0.06), ranging in age from 25–55 years old (mean age = 35.60 years). Table 3 displays the age, gender, educational background, occupation, and visual acuity of each participant. Given that graphic designers and related fields professionals are more likely to use and read different typefaces in their work, we hypothesize that they possess higher letter recognition abilities compared to other individuals.

Table 3 Age, Gender, Educational Background, Occupation, and Visual Acuity of Participants

Participant No.	Sub– Participant No.	Age	Gender	Highest Educational Qualification Obtained	Occupation	Far 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	0.1
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 Center Staff	0.0
12	12	40	Female	Junior High School, Grade 9	Cleaning Staff	0.0
		_28.3_		_Average of Age and Visual Acuity_		_0.008_
Older Adults					
13	1	52	Female	Late Elementary School, Grade 6	Cleaning Staff	0.2
14	2	53	Female	Junior High School, Grade 9	Book Center Staff	0
15	3	53	Female	High School, Grade 12	Cleaning Staff	0
16	4	54	Male	Bachelor's Degree (Marketing)	Churchwarden	0
17	5	55	Female	Junior High School, Grade 9	Housewife	0.1
18	6	56	Female	Junior High School, Grade 9	Housewife	0.1
19	7	57	Female	High School, Grade 12	Member of Agricultural Cooperatives Board	0
20	8	58	Female	Late Elementary School, Grade 6	Former Book Salesman	0.1
21	9	60	Female	Late Elementary School, Grade 6	Unemployed	0.2
		_55.33_		_Average of Age and Visual Acuity_		_0.078_
Graphic Designers and Related Fields					
22	1	25	Female	Bachelor's Degree (Multimedia Design)	Freelance Graphic Designer	0.0
23	2	25	Female	Bachelor's Degree (Information Technology)	Publication Designer	0.0
24	3	30	Female	Bachelor's Degree (Industrial Crafts Design)	Corporate Communication Media Designer	0.0
25	4	32	Male	Bachelor's Degree (Industrial Crafts Design)	Freelance Designer	0.0
26	5	32	Male	Bachelor's Degree (Animation Design)	Graphics and Animation Teacher	0.0
27	6	34	Male	Bachelor's Degree (Computer Graphics)	Publication Design Teacher	0.2
28	7	35	Female	Master's Degree (Public Relations)	Publicist/Public Media Creator	0.0
29	8	42	Male	Bachelor's Degree (Business Computer)	Publication/Sign Graphic Designer	0.2
30	9	46	Male	Junior High School, Grade 9	Sign Graphic Designer	0.0
31	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_
		38.52		Average of Age and Visual Acuity (Overall)		0.047

2. 3. Procedure

In the present study we initiated the experimental process by conducting a distance acuity test to measure the quality of far vision among the participants. We conducted the acuity test using a mobile application, Peek Acuity (Bastawrous et al., 2015; Kawamoto et al., 2021), which was utilized for eye measurement. The viewing distance between the mobile phone and the participants' eyes was approximately 200 cm. The results of the study revealed that adolescents-adults (aged between 18 and 40 years) had eye quality in the range of LogMAR 0.0–0.7, seniors (aged between 52 and 60 years) had eye quality in the range of LogMAR 0.0–0.2, and graphic designers (aged between 25 and 55 years) had visual quality value in the range of LogMAR 0.0–0.3 (as illustrated in Table 3).

To assess the inherent efficacy of different typefaces on varying levels of visual acuity among study participants, we employed a range of visual acuity levels that were not normalized to standard visual acuity, including both normal and low visual acuity.

When determining the experimental conditions, we found that a farthest distance of 600 cm from the eyes of the participants to the monitor was most suitable. To ensure the accuracy of data collection, we used a dark room that was dimly lit. This helped us eliminate any luminous disturbances that may have come from sources other than the monitors. By doing this, we could gather accurate data without any interference.

During the experiment, we followed a specific method to gather data on character reading at different distances. First, we asked a participant to stand at the step 1 mark with their toes aligned with the marked line. Then, we displayed a letter on the monitor and asked the participant to read it aloud. We repeated this process for each distance, starting from the farthest distance of 600 cm and moving closer to the monitor with 40 cm steps until we reached the closest distance of 40 cm at the step 15 mark. We recorded the participant's character reading data for each distance, totaling 15 steps for each character. If a participant could not identify any letter, they were allowed to inform us that they "cannot read." Following the same procedure, we collected data using 36-character sets to cover the three selected typefaces. We recorded and analyzed the experiment results to determine the effectiveness of the typefaces at different distances.

3. Result

3. 1. Comparative Effectiveness: Overall

In this study we aimed to test the hypothesis that different typefaces have varying levels of effectiveness. To do this, we utilized the Wilcoxon Signed Ranks Test, a two-way discriminant nonparametric statistical analysis. Our sample consisted of 31 participants, and we tested each typeface in pairs. For instance, we tested Cordia New against FT Manifest UD and TH Sarabun New against FT Manifest UD. Table 4 shows the results for all participants, while Tables 5, 6, and 7 present the findings for the different groups of participants. These groups include adolescent-young adults, older adults, and graphic designers and related fields. The

findings show which typefaces are most effective in different contexts and can inform design decisions moving forward.

We analyzed the results of 31 participants and used a paired test by Wilcoxon Signed Ranks Test to compare the different fonts. According to Table 4 in the Ranks and Test Statistics section, at a significance level of 0.05, the FT Manifest UD typeface was found to be more effective overall than the Cordia New and TH Sarabun New typefaces.

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]	21.9	525.5
	Positive Ranks	12[b]	11.71	140.5
	Ties	0[c]		
	Total	36		
TH Sarabun New − FT Manifest UD	Negative Ranks	30[d]	19.4	582
	Positive Ranks	6[e]	14	84
	Ties	0[f]		
	Total	36		

a. Cordia New 〈 FT Manifest UD
b. Cordia New 〉 FT Manifest UD
c. Cordia New = FT Manifest UD
d. TH Sarabun New 〈 FT Manifest UD
e. TH Sarabun 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	−3.025[b]	−3.912[b]
Asymp. Sig. (2−tailed)	0.002	0.000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

We further grouped the participants into three categories based on age and profession. The results in Table 5, Table 6, and Table 7 show that at a significance level of 0.05, the FT Manifest UD typeface was more effective than the Cordia New and TH Sarabun New typefaces among the adolescent-young adults, older adults, and graphic designers and related fields, respectively.

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	24[a]	20.6	481.5
	Positive Ranks	12[b]	15.38	184.5
	Ties	0[c]		
	Total	36		
TH Sarabun New − FT Manifest UD	Negative Ranks	29[d]	17.1	496
	Positive Ranks	5[e]	19.8	99
	Ties	2[f]		
	Total	36		

a. Cordia New 〈 FT Manifest UD
b. Cordia New 〉 FT Manifest UD
c. Cordia New = FT Manifest UD

d. TH Sarabun New 〈 FT Manifest UD
e. TH Sarabun 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	−2.334[b]	−3.397[b]
Asymp. Sig. (2−tailed)	0.002	0.001

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

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	26[a]	20.33	528.5
	Positive Ranks	9[b]	11.28	101.5
	Ties	1[c]		
	Total	36		
TH Sarabun New − FT Manifest UD	Negative Ranks	23[d]	17.2	395.5
	Positive Ranks	7[e]	9.93	69.5
	Ties	6[f]		
	Total	36		

a. Cordia New 〈 FT Manifest UD
b. Cordia New 〉 FT Manifest UD
c. Cordia New = FT Manifest UD

d. TH Sarabun New 〈 FT Manifest UD
e. TH Sarabun 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	−3.502[b]	−3.363[b]
Asymp. Sig. (2−tailed)	0.000	0.001

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

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	21[a]	21.62	454
	Positive Ranks	12[b]	8.92	107
	Ties	3[c]		
	Total	36		
TH Sarabun New − FT Manifest UD	Negative Ranks	28[d]	19.79	554
	Positive Ranks	7[e]	10.86	76
	Ties	1[f]		
	Total	36		

a. Cordia New ‹ FT Manifest UD
b. Cordia New › FT Manifest UD
c. Cordia New = FT Manifest UD
d. TH Sarabun New ‹ FT Manifest UD
e. TH Sarabun 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	−3.101[b]	−3.919[b]
Asymp. Sig. (2−tailed)	0.002	0.000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

3. 2. Comparative Effectiveness: Classified by Letters

Based on the findings in Table 8, we compared the mean values of the percentage of correct response rates among FT Manifest UD, Cordia New, and TH Sarabun New. We calculated these values based on the percentage of correct response rate of each character's finding of visual angles from level 1–15 (0.0477°–0.7162°), as presented in Table 2. To test the differences among the typefaces, we applied the Wilcoxon Signed Ranks Test method at a significance level of 0.05, as shown in Table 9.

According to Table 9, the certain characters within the FT Manifest UD appear much more effective than those found in Cordia New and TH Sarabun New, including Kho Khwai /ค/, Kho Khon /ฅ/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, So So /ซ/, O Ang /อ/, Do Chada /ฏ/, To Patak /ฏ/, Lo Chula /ฬ/, Tho Thong /ธ/, and Ro Rua /ร/ (Table 9: No. 4, 5, 8, 10, 15, 16, 21, 23, 24, 31, 32, and 33). These findings support the research hypothesis (Figure 1) that particular letter features of Kho Khon /ฅ/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, So So /ซ/, O Ang /อ/, Do Chada /ฏ/, To Patak /ฏ/, Lo Chula /ฬ/, Tho Thong /ธ/, and Ro Rua /ร/, when designed based on a theoretical framework, offer improved legibility when compared to other typefaces in distance methodology testing. These results suggest that careful consideration of letterform design can significantly impact legibility and may be particularly important for individuals with low visual acuity or reading difficulties.

In addition, the characters Ko Kai /ก/, Kho Khai /ข/, Lo Ling /ล/, and So Sua /ส/ of FT Manifest UD were more effective than the characters of Cordia New, according to Table 9 data (No. 1, 13, 19, and 20). Additionally, the characters of FT Manifest UD, including So Sala /ศ/, No Nu /น/, Kho Rakhang /ฆ/, Tho Nangmontho /ฑ/, Ho Nokhuk /ฮ/, Po Pla /ป/, Pho Phan /พ/, and Cho Chan /จ/, also had higher effectiveness than the characters of TH Sarabun New (Table 9: No. 6, 9, 12, 18, 22, 26, 29, and 36).

According to Table 9, there were no significant differences in the findings of FT Manifest UD, Cordia New, and TH Sarabun New for the characters Tho Thung /ฐ/, Do Dek /ด/, Mo Ma /ม/, Kho Khuat /ฃ/, Tho Thahan /ท/, Bo Baimai /บ/, and Pho Phung /ผ/ (Table 9: No. 2, 7, 11, 14, 17, 25, and 27). This indicates that these fonts are equally effective in displaying these characters.

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)	<u>50.11</u>	41.94	48.17
2	ฐ (Tho Thung)	49.89	48.82	48.60
3	ภ (Pho Samphao)	52.26	57.85	<u>58.28</u>
4	ค (Kho Khwai)	<u>56.13</u>	50.2	50.32
5	ฅ (Kho Khon)	<u>44.73</u>	30.32	27.10
6	ศ (So Sala)	54.19	54.41	49.03
7	ด (Do Dek)	44.09	39.36	43.23
8	ต (To Tao)	<u>50.75</u>	38.71	44.30
9	น (No Nu)	58.71	<u>60.00</u>	55.30
10	ฉ (Cho Ching)	<u>56.77</u>	47.53	51.83
11	ม (Mo Ma)	56.56	54.2	56.34
12	ฆ (Kho Rakhang)	51.40	<u>52.47</u>	44.09
13	ข (Kho Khai)	<u>49.03</u>	38.06	44.95
14	ฃ (Kho Khuat)	<u>37.85</u>	29.68	31.83
15	ช (Cho Chang)	<u>47.31</u>	31.83	38.49
16	ซ (So So)	<u>44.30</u>	23.87	25.59
17	ท (Tho Thahan)	53.76	50.75	50.50
18	ฑ (Tho Nangmontho)	<u>55.33</u>	50.11	48.17
19	ล (Lo Ling)	53.12	50.11	50.97
20	ส (So Sua)	<u>56.77</u>	52.04	52.04
21	อ (O Ang)	53.12	40.00	48.82
22	ฮ (Ho Nokhuk)	<u>49.25</u>	46.45	45.59
23	ฎ (Do Chada)	<u>57.85</u>	53.12	49.25
24	ฏ (To Patak)	<u>46.45</u>	30.75	25.38
25	บ (Bo Baimai)	53.98	52.26	<u>55.70</u>
26	ป (Po Pla)	64.73	<u>66.88</u>	60.43
27	ผ (Pho Phung)	51.40	53.76	<u>54.84</u>
28	ฝ (Fo Fa)	58.28	<u>62.15</u>	56.56
29	พ (Pho Phan)	54.84	<u>55.70</u>	51.83
30	ฟ (Fo Fan)	57.42	<u>62.37</u>	59.79
31	ฬ (Lo Chula)	<u>53.55</u>	49.03	36.13

No.	Letter	Mean of Correct Response's Percentage		
		FT Manifest UD	Cordia New	TH Sarabun New
32	ฒ (Tho Thong)	<u>56.13</u>	47.10	50.54
33	ร (Ro Rua)	<u>58.92</u>	52.47	55.48
34	ห (Ho Hip)	48.60	<u>55.27</u>	50.54
35	ย (Yo Yak)	46.88	52.25	53.12
36	จ (Cho Chan)	58.06	<u>60.00</u>	54.19

In addition, based on the data presented in Table 9, FT Manifest UD font is just as effective as Cordia New and TH Sarabun New for certain characters. Specifically, for characters such as So Sala /ศ/, No Nu /น/, Kho Rakhang /ฆ/, Tho Nangmontho /ฌ/, Ho Nokhuk /ฮ/, Pho Phan /พ/, and Cho Chan /จ/ (Table 9: No. 6, 9, 12, 18, 22, 29, and 36), FT Manifest UD is comparable to Cordia New. Meanwhile, for characters such as Ko Kai /ก/, Pho Samphao /ภ/, Kho Khai /ข/, Lo Ling /ล/, So Sua /ส/, Fo Fa /ฝ/, Fo Fan /ฟ/, and Ho Hip /ห/ (Table 9: No. 1, 3, 13, 19, 20, 28, 30, and 34), FT Manifest UD is comparable to TH Sarabun New.

In contrast, when comparing the character Yo Yak /ย/ of FT Manifest UD to Cordia New and TH Sarabun New, we found that the latter two had a higher level of effectiveness (Table 9: No. 35). Similarly, the characters Pho Samphao /ภ/, Po Pla /ป/, Fo Fa /ฝ/, Fo Fan /ฟ/, and Ho Hip /ห/ of FT Manifest UD had lower effectiveness than their counterparts in Cordia New (Table 9: No. 3, 26, 28, 30, and 34).

According to Santayayon et al. (2011), young and older adults should be able to read a minimum size of 2 mm at a distance of 50 cm. This size is considered easy to read. The recommended type size by Santayayon et al. (2011) corresponds to a visual angle of 0.2292° (Punsongserm & Suvakunta, 2022). Meanwhile, Rattanakasamsuk (2013) suggested that the minimum size of Thai letters presented on an LED panel should be more significant than 0.1800°. The Department of Highways (2011) also stated that a minimum Thai letter height of 2 cm is necessary for road signs to support readers' reading at no more than a distance of 10 m. We calculated the letter's size and distance to conform to its visual angle and found that the visual angle equals 0.1146°. The results show that the visual angles of 0.1146°, 0.1800°, and 0.2292° approximately correspond to the visual angles of 0.1194°, 0.1790°, and 0.2387° (including visual angle of 0.1432°) in the current study, as shown in Table 2, step 10 (at a distance of 240 cm) to step 13 (at a distance of 120 cm). We selected the findings of these visual angles for reporting (see Table 10). The results showed that most letterforms of FT Manifest UD had a correct response rate similar to other typefaces, except for the characters Kho Khon /ฅ/, Kho Khuat /ฃ/, Cho Chang /ฌ/, So So /ซ/, and To Patak /ฏ/, which had a higher correct response rate than other typefaces.

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)	T	C	–
13	ข (Kho Khai)	C	T	–
14	ฃ (Kho Khuat)	–	C, T	–
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)	T	C	–
23	ฎ (Do Chada)	C, T	–	–
24	ฏ (To Patak)	C, T	–	–
25	บ (Bo Baimai)	–	C, T	–
26	ป (Po Pla)	T	–	C
27	ผ (Pho Phung)	–	C, T	–
28	ฝ (Fo Fa)	–	T	C
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)	–	T	C
35	ย (Yo Yak)	–	–	C, T
36	จ (Cho Chan)	T	C	–

C = Cordia New
T = TH Sarabun New

Table 10 Percentage of Correct Response at Visual Angle of 0.1194˚, 0.1432˚, 0.1790˚, and 0.2387˚, Classified by Letters

| No. | Letter | Percentage of Correct Response | | | | | | | | | | | |
| | | Visual Angle of 0.1194˚ | | | Visual Angle of 0.1432˚ | | | Visual Angle of 0.1790˚ | | | Visual Angle of 0.2387˚ | | |
		FT Manifest UD	Cordia New	TH Sarabun New	FT Manifest UD	Cordia New	TH Sarabun New	FT Manifest UD	Cordia New	TH Sarabun New	FT Manifest UD	Cordia New	TH Sarabun New
1	ก (Ko Kai)	77.42	61.29	67.74	80.65	80.65	74.19	90.32	77.42	87.10	93.55	96.77	93.55
2	ถ (Tho Thung)	70.97	70.97	70.97	77.42	77.42	74.19	87.10	87.10	90.32	96.77	93.55	93.55
3	ภ (Pho Samphao)	77.42	77.42	70.97	77.42	77.42	80.65	87.10	87.10	87.10	93.55	96.77	96.77
4	ค (Kho Khwai)	70.97	74.19	64.52	80.65	74.19	64.52	83.87	80.65	83.87	90.32	87.10	90.32
5	ฅ (Kho Khon)	64.52	32.26	12.90	74.19	48.39	38.71	83.87	70.97	54.84	87.10	90.32	87.10
6	ศ (So Sala)	74.19	77.42	70.97	80.65	83.87	80.65	87.10	90.32	96.77	90.32	96.77	90.32
7	ด (Do Dek)	58.06	67.74	64.52	70.97	74.19	70.97	80.65	77.42	87.10	93.55	93.55	87.10
8	ต (To Tao)	70.97	58.06	74.19	77.42	70.97	80.65	83.87	77.42	80.65	93.55	96.77	96.77
9	น (No Nu)	77.42	74.19	70.97	80.65	83.87	77.42	93.55	87.10	83.87	93.55	93.55	96.77
10	ฉ (Cho Ching)	67.74	74.19	64.52	80.65	74.19	70.97	93.55	83.87	90.32	96.77	93.55	96.77
11	ม (Mo Ma)	70.97	74.19	74.19	74.19	77.42	83.87	90.32	83.87	93.55	96.77	93.55	96.77
12	ฆ (Kho Rakhang)	77.42	70.97	61.29	77.42	77.42	70.97	83.87	83.87	77.42	96.77	93.55	93.55
13	ข (Kho Khai)	77.42	54.84	61.29	77.42	67.74	74.19	83.87	83.87	80.65	93.55	96.77	96.77
14	ฃ (Kho Khuat)	61.29	16.13	25.81	64.52	35.48	45.16	83.87	58.06	64.52	87.10	87.10	93.55
15	ช (Cho Chang)	74.19	32.26	38.71	74.19	48.39	54.84	83.87	67.74	74.19	87.10	90.32	87.10
16	ซ (So So)	64.52	19.35	19.35	70.97	25.81	35.48	80.65	38.71	45.16	93.55	70.97	70.97
17	ท (Tho Thahan)	74.19	74.19	67.74	77.42	83.87	74.19	90.32	93.55	83.87	93.55	96.77	93.55
18	ฑ (Tho Nangmontho)	70.97	67.74	64.52	80.65	70.97	70.97	83.87	87.10	83.87	90.32	93.55	93.55
19	ล (Lo Ling)	74.19	74.19	70.97	77.42	80.65	74.19	93.55	87.10	83.87	96.77	93.55	96.77
20	ส (So Sua)	70.97	74.19	74.19	77.42	74.19	80.65	87.1	80.65	83.87	96.77	90.32	96.77
21	อ (O Ang)	74.19	61.29	74.19	77.42	67.74	74.19	90.32	77.42	87.10	96.77	93.55	96.77
22	ฮ (Ho Nokhuk)	74.19	64.52	67.74	77.42	74.19	70.97	80.65	90.32	87.10	90.32	96.77	90.32
23	ฏ (Do Chada)	74.19	70.97	61.29	77.42	70.97	70.97	83.87	83.87	83.87	90.32	90.32	90.32
24	ฏ (To Patak)	67.74	32.26	25.81	70.97	29.03	25.81	80.65	29.03	32.26	90.32	58.06	58.06
25	บ (Bo Baimai)	74.19	64.52	74.19	80.65	80.65	74.19	83.87	87.10	80.65	93.55	96.77	93.55
26	ป (Po Pla)	77.42	80.65	77.42	83.87	80.65	80.65	93.55	93.55	90.32	96.77	96.77	96.77
27	ผ (Pho Phung)	74.19	70.97	70.97	77.42	77.42	80.65	90.32	87.10	83.87	93.55	93.55	96.77
28	ฝ (Fo Fa)	77.42	77.42	74.19	77.42	80.65	80.65	83.87	83.87	83.87	93.55	93.55	100
29	พ (Pho Phan)	74.19	70.97	70.97	80.65	74.19	80.65	93.55	87.10	87.10	96.77	96.77	90.32
30	ฟ (Fo Fan)	80.65	80.65	70.97	80.65	83.87	80.65	87.10	93.55	93.55	93.55	100	96.77
31	ฬ (Lo Chula)	74.19	67.74	41.94	77.42	70.97	64.52	83.87	87.10	77.42	90.32	90.32	90.32

No.	Letter	Percentage of Correct Response											
		Visual Angle of 0.1194°			Visual Angle of 0.1432°			Visual Angle of 0.1790°			Visual Angle of 0.2387°		
		FT Manifest UD	Cordia New	TH Sarabun New	FT Manifest UD	Cordia New	TH Sarabun New	FT Manifest UD	Cordia New	TH Sarabun New	FT Manifest UD	Cordia New	TH Sarabun New
32	ธ (Tho Thong)	77.42	67.74	74.19	80.65	74.19	77.42	87.10	87.10	90.32	93.55	96.77	96.77
33	ร (Ro Rua)	74.19	70.97	74.19	74.19	74.19	74.19	87.10	77.42	83.87	93.55	90.32	96.77
34	ห (Ho Hip)	61.29	74.19	74.19	70.97	77.42	74.19	83.87	87.10	80.65	93.55	96.77	87.10
35	ย (Yo Yak)	64.52	74.19	74.19	77.42	80.65	80.65	93.55	93.55	87.10	93.55	96.77	96.77
36	จ (Cho Chan)	77.42	70.97	67.74	77.42	70.97	80.65	90.32	83.87	80.65	93.55	96.77	96.77
	Average	72.31	64.61	62.90	77.06	70.97	70.79	86.83	80.92	81.18	93.19	92.47	92.29

4. Discussion

4. 1. The characters Kho Khwai /ค/, Kho Khon /ฅ/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, So So /ซ/, O Ang /อ/, Do Chada /ฎ/, To Patak /ฏ/, Lo Chula /ฬ/, Tho Thong /ธ/, and Ro Rua /ร/

In this study we found that the letterforms of FT Manifest UD, specifically the characters Kho Khwai /ค/, Kho Khon /ฅ/, To Tao /ต/, Cho Ching /ฉ/, Cho Chang /ช/, So So /ซ/, O Ang /อ/, Do Chada /ฎ/, To Patak /ฏ/, Lo Chula /ฬ/, Tho Thong /ธ/, and Ro Rua /ร/ (as shown in Table 9 and Figure 3), can support legibility across different visual angles and distance conditions. This suggests that the key characteristics of the Thai typeface, as outlined in the conceptual framework (top part of Figure 3), are effective in designing highly legible letterforms. These key features include various design elements such as character width, character shape, stroke shapes, and terminal.

1) Characters Kho Khwai /ค/ and Kho Khon /ฅ/
The characters Kho Khwai /ค/ and Kho Khon /ฅ/ have distinct features that set them apart from others. Notably, they have greater widths than other characters, with many spaces within them and more counters. Additionally, the Kho Khon /ฅ/ has a massive, serrated line that sets it apart further. Both characters also use an overturned curve that connects the first loop and the front line, adding to their unique appearance.

2) Character To Tao /ต/
Character To Tao /ต/ has distinct features that set it apart from other characters. One noticeable feature is its greater width, which gives it a more prominent appearance. Additionally, the character To Tao /ต/ has more space within its design, resulting in more counters. Another defining characteristic is the use of an upturned curve connecting the first loop and the front line, adding a unique flair to its overall appearance.

3) Character Cho Ching /ฉ/

Character Cho Ching /ฉ/ has distinct features that make it recognizable. One of its key features is a large second loop protruding from the main body. This loop is quite prominent and juts out noticeably. Additionally, the top line of the character is curved and bends down, creating a sagged terminal. However, this terminal does not jut out of the front vertical axis of the first loop, giving the character a unique appearance.

4) Character Cho Chang /ช/

Character Cho Chang /ช/ contains a minimal loop without a curve connecting the first loop. Additionally, it has a long diagonal tail that juts out from the character's main body and uses a curved line at the base of the character's bottom line.

5) Character So So /ซ/

Character So So /ซ/ is identifiable by several key features. First, it has a small loop, giving it a diminutive appearance. A sizeable serrated line also juts out from the main body, making it stand out visually. The character's base features a curved line, adding a unique touch to its overall design. Finally, the diagonal tail is notably long, jutting out from the main body and providing further distinction. These features all come together to create an unmistakable character that is easy to identify.

6) Character O Ang /อ/

Character O Ang /อ/ is characterized by several key features that distinguish it from other letters. First, it utilizes a curved line as a circular shape at its base. Additionally, it has a curved topline and a bent-down or sagged terminal that juts out from the front vertical axis of the first loop. Finally, the letter has more space, resulting in a greater counter.

7) Character Do Chada /ฎ/

Character Do Chada /ฎ/ has a unique design that differentiates it from other characters. It is characterized by a diminutive first loop and a large second loop that does not align or protrude out of the vertical axis of the first loop. Additionally, this character has a wider aperture than other characters, further contributing to its distinct appearance.

8) Character To Patak /ฏ/

The unique features of the character To Patak /ฏ/ are its small first loop and increased aperture. Additionally, it stands out due to its use of massive underside wavy lines, also known as serrated lines. Unlike other Thai characters, the To Patak /ฏ/ omits a tail and instead has the coil or second loop protrude out of the vertical axis of the first loop. These distinct characteristics make the To Patak /ฏ/ easily recognizable.

9) Character Lo Chula /ฬ/

Character Lo Chula /ฬ/ is a unique letterform with a significant second loop and tail-end protruding from the main body. It is defined by its massive, serrated line that forms up-down diagonals. Additionally, it has a pointed tip, which is ideal for a medium height and medium apex height. These features make Character Lo Chula /ฬ/ stand out among other letters and contribute to its distinct appearance.
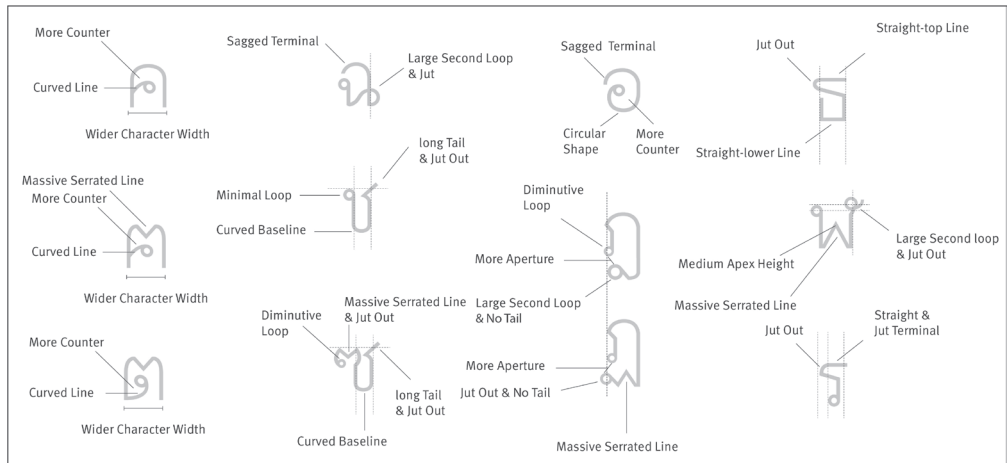
Figure 3 Key Characteristics of FT Manifest UD, Compared With Cordia New and TH Sarabun New (in Case of Letterforms ค, ศ, ต, ฉ, ช, ซ, อ, ฎ, ฏ, ธ, ฟ, and ร) (Source for top part: Punsongserm, 2019a)

10) Character Tho Thong /ธ/

When it comes to the character Tho Thong /ธ/, several key features make it stand out. First, it has a straight-lower baseline, which gives it a distinct shape. Additionally, the character's front part protrudes from the main body's vertical axis, creating a unique look. Finally, the top line of the character is straight and does not jut out from the back vertical axis of the main body, aligning with the backline.

11) Character Ro Rua /ร/

Character Ro Rua /ร/ has distinct features that make it stand out. One of its key characteristics is the front part of the character that protrudes or juts out from the stem and first loop. Additionally, the character utilizes a straight horizontal upper line that extends from the body line. These features give Ro Rua /ร/ an unmistakable appearance and make it easily distinguishable from other characters.

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

To enhance the legibility of 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 4) in different viewing distances, specific improvements in letterforms need to be implemented.

1) Character Pho Samphao /ภ/

It might be helpful to continue using a simpler nib and slightly widen the characters. It could also be beneficial to increase the size of the enlarged loop so that it protrudes more and is easier to identify.

2) Character Po Pla /ป/

The present study revealed that the Po Pla /ป/ characters in each of the typefaces we tested provided the most accurate responses. Interestingly, the Po Pla /ป/ letterform has been constructed with the same structure as the Bo Baimai /บ/ letter but with a vertical straight tail (ascender). To maintain the legibility of this character, it is essential to retain a straight baseline and a wider character width, which enhances visibility. Additionally, extending the size of the loop slightly can also improve legibility.

3) Character Fo Fa /ฝ/

The character Fo Fa /ฝ/ is similar in structure to the character Pho Phung /ผ/, but it has a tail (ascender) added. Although the curved front lines of these characters improved legibility in specific experiments, a study by Punsongserm (2019a, 2019b) showed that these characters' effectiveness in FT Manifest did not differ significantly from Codia New and TH Sarabun New. To make the character Fo Fa /ฝ/ more legible, it is recommended to adjust the curved frontal line to make the upper aperture wider while preserving the key letter features (see Figure 4). This will help improve the visibility and legibility of the characters Fo Fa /ฝ/ and Pho Phung /ผ/ at smaller visual angles.

4) Character Fo Fan /ฟ/

The finding in Table 9 (No.30) showed that the character Fo Fan /ฟ/ of Cordia New was more effective than the one in the FT Manifest UD. However, the effectiveness of the character Fo Fan /ฟ/ of the FT Manifest UD was not significantly different from that of TH Sarabun New. When comparing Cordia New and TH Sarabun New with the FT Manifest UD, we observed that the loops of Cordia New and TH Sarabun New are larger in size and have 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, it is suggested to expand its character width to more than Cordia New and TH Sarabun New to increase the counter space and enhance visibility.
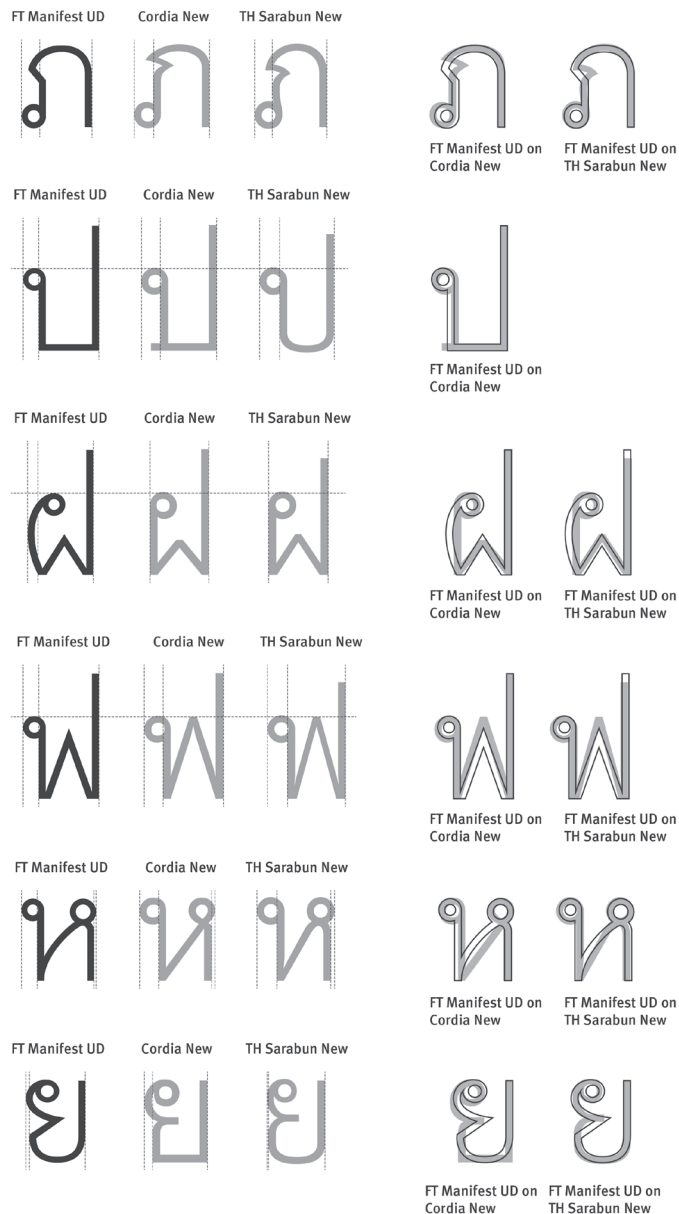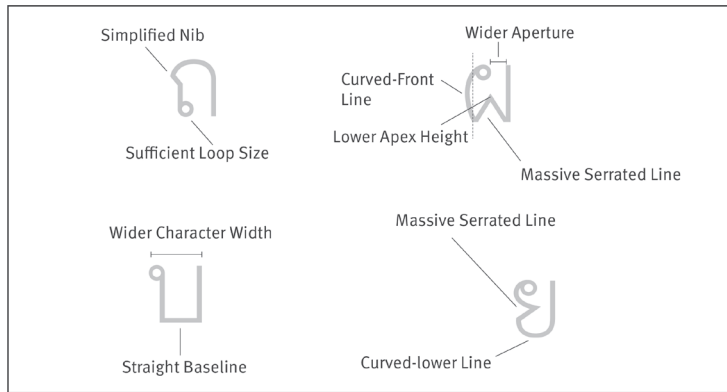
Figure 4 Key Characteristics of FT Manifest UD, Compared With Cordia New and TH Sarabun New (in Case of Letterforms ก, ป, ผ, ฟ, ห, and ย) (Source for top part: Punsongserm, 2019a)

5) Character Ho Hip /ห/

For the present study, we found that the effectiveness of the character Ho Hip /ห/ of the FT Manifest UD was not different from the character Ho Hip /ห/ of TH Sarabun New. Figure 4 compares the character Ho Hip /ห/ of Cordia New and TH Sarabun New with the FT Manifest UD, revealing a significant difference. The character Ho Hip /ห/ of FT Manifest UD has a diagonal curvature, which sets it apart from the straight diagonal of the Cordia New and TH Sarabun New. This diagonal curve design is influenced by the character Tho Thahan /ท/ structure of FT Manifest UD. To maintain this aspect, it is recommended to improve the legibility and visibility of the character Ho Hip /ห/ of FT Manifest UD by increasing its width and adjusting the curl (second loop) to further extend (jut) out the vertical axis of the back line to the righthand side.

6) Character Yo Yak /ย/

In our comparison of the character Yo Yak /ย/ of FT Manifest UD with those of Cordia New and TH Sarabun New, we found that the former was not as effective at different viewing distances. This was due to its use of a large, jagged line rather than horizontal lines protruding within the character (see Figure 4). To improve the legibility of Yo Yak /ย/ in FT Manifest UD, the current study suggest using a horizontal mid-body style instead of jagged curls, similar to Cordia New and TH Sarabun New. The current study also recommend reducing the size of the loop to increase the negative space within the letterform.

5. Conclusion

In our study we aimed to investigate the effectiveness of a new Thai UD typeface, FT Manifest UD, which was designed specifically for readers with low visual acuity. We compared this new typeface to two commonly used typefaces, Cordia New and TH Sarabun New, to determine its legibility. We tested 36 Thai consonants at 15 different distances and recruited 31 Thai volunteers with varying visual acuity, including adolescents, older adults, and professionals in graphic design.

The results of our study showed that the FT Manifest UD typeface had better overall effectiveness compared to the Cordia New and TH Sarabun New typefaces, with a significance level of 0.05. Additionally, our findings indicated that the character sets of FT Manifest UD performed better overall for all three groups of Thai volunteers. These results suggest the Thai UD typeface may offer a more effective and accessible option for Thai readers in the condition of multi-viewing distances.

The study on the legibility improvement of FT Manifest UD's letterforms revealed that the key characteristics of Thai letterforms contributed significantly to their legibility when viewed from various distances. However, the study suggests that improving letter features can enhance the legibility of FT Manifest UD's letterforms when identifying small visual angles at different distances. This improvement can be achieved by increasing the character width, providing more counter space, adjusting the loop and tail size, and adding a jutting part, as discussed in the study.

Apart from letter features, stroke weight size is another factor that affects legibility and visibility. Evidence suggests that greater boldness in medium-sized Roman letterforms, rather than regular boldness, can enhance legibility in smaller type sizes. However, ultra-boldness does not support recognition (Beier & Oderkerk, 2019). In addition, increased letter spacing, width, and boldness have been found to enhance performance in low-vision reading caused by age-related macular degeneration (Beier et al., 2021).

Further investigation is necessary to determine the effectiveness of thickness and broadness in Thai letterforms, particularly in different small sizes and multi-viewing distances. This insufficiency provides an opportunity for future studies. To broaden the extent of research on the efficacy of FT Manifest UD concerning the degree of visual angles, it is imperative to compare it with the effectiveness of Roman-like Thai typefaces, which are other commonly employed fonts in various media.

Regarding participants, we had the pleasure of employing only Thai volunteers for the present study. This included a diverse range of participants, from adolescents to older adults and even professionals in graphic design. However, to evaluate the legibility of FT Manifest UD for a more extensive range of readers, it is beneficial to include individuals with visual impairments, such as those with Cataracts and Glaucoma. Alternatively, we could use visual impairment simulation equipment for further research. This would ensure that the FT Manifest UD can support various reader groups more inclusively.

References

1. Banister, H. (1927). Block capital letters as tests of visual acuity. *British Journal of Ophthalmology, 11*(2), 49–62. https://doi.org/10.1136/bjo.11.2.49.
2. Bastawrous, A., Rono, H. K., Livingstone, I. A., Weiss, H. A., Jordan, S., Kuper, H., & Burton, M. J. (2015). Development and validation of a smartphone-based visual acuity test (Peek Acuity) for clinical practice and community-based fieldwork. *JAMA Ophthalmol, 133*(8), 930–937. https://doi.org/10.1001/jamaophthalmol.2015.1468.
3. Beartai, (2016). Why we should use the TH Sarabun New font instead of TH Sarabun PSK? *beartai Weekly.* Retrieved August 25, 2023. From https://www.beartai.com/article/tech-article/104166. (In Thai).
4. Beier, S., & Larson, K. (2010) Design improvements for frequently misrecognized letters. *Information Design Journal, 18*(2), 118–137. https://doi.org/10.1075/idj.18.2.03bei.
5. Beier, S., & Oderkerk, C. (2019). Smaller visual angles show greater benefit of letter boldness than larger visual angles. *Acta Psychologica, 199*, 102904. https://doi.org/10.1016/j.actpsy.2019.102904.
6. Beier, S., Oderkerk, C., Bay, B., & Larsen, M. (2021). Increased letter spacing and greater letter width improve reading acuity in low vision readers. *Information Design Journal, 26*(1), 1–16. https://doi.org/10.1075/idj.19033.bei.
7. Bouma, H. (1971). Visual recognition of isolated lower-case letters. *Vision Research, 11*(5), 459474. https://doi.org/10.1016/0042-6989(71)90087-3.
8. Brown, D. W. (1963). Recognition of typed letters in noise. *Information and Control, 6*(3), 301–305. https://doi.org/10.1016/S0019-9958(63)90370-X.
9. Department of Highways, Ministry of Transport. (2011). *Standard of letters, numerals, and traffic signs*. Bangkok: Department of Highways. Retrieved April 3, 2023 from http://phitsanulok.doh.go.th/phitsanulok/content/page/journals/13714 (In Thai).

10. Fisher, D. F., Monty, R. A., & Glucksberg, S. (1969). Visual confusion matrices: Fact or artifact? *The Journal of Psychology, 71*(1), 111–125. https://doi.org/10.1080/00223980.1969.10543077.

11. Geyer, L. H. (1977). Recognition and confusion of the lowercase alphabet. *Perception & Psychophysics, 22*(5), 487–490. https://doi.org/10.3758/BF03199515.

12. Kawamoto, K., Stanojcic, N., Li, J. P. O., & Thomas, P. B. (2021) Visual acuity apps for rapid integration in teleconsultation services in all resource settings: A review. *Asia–Pacific Academy of Ophthalmology, 10*(4), 350–354. https://doi.org/10.1097/APO.0000000000000384.

13. Loomis, J. M. (1982). Analysis of tactile and visual confusion matrices. *Perception & Psychophysics, 31*(1), 41–52. https://doi.org/10.3758/BF03206199.

14. Milloy, D. G. (1978). Comment on recognition and confusion of the lowercase alphabet. *Perception & Psychophysics, 24*(2), 190–191. https://doi.org/10.3758/BF03199550.

15. National Science and Technology Development Agency (NSTDA), (2018). *13 standard free fonts from the National Software Industry Promotion Agency (SIPA)*. Retrieved August 25, 2023. From https://www.nstda.or.th/home/news_post/thai-font/. (In Thai).

16. Phillips, J. R., Johnson, K. O., & Browne, H. M. (1983). A comparison of visual and two modes of tactual letter resolution. *Perception & Psychophysics, 34*(3), 243–249. https://doi.org/10.3758/BF03202952.

17. Punsongserm, R. (2010). *Glyph designing approach for Thai fonts*. Research Report, Faculty of Fine and Applied Arts, Thammasat University. (In Thai).

18. Punsongserm, R. (2019a). *Approach to design a Thai universal design font* (Doctoral thesis, Kyushu University).

19. Punsongserm, R. (2019b, September). *Thai universal design font versus familiar Thai text fonts: The role of distinctive letterforms and suitable inter-letter space influence in blurred words*. Heritage & Vision: Proceedings of the 2019 International Conference on Design for Experience and Wellbeing (143–202), Xi'an, Northwestern Polytechnical University. Retrieved January 30, 2023 from https://pure.tudelft.nl/ws/portalfiles/portal/67548586/2019_DEW_proceedings.pdf.

20. Punsongserm, R. (2020). Comparative effectiveness of homologous Thai letterforms on visual word recognition: Thai universal design font versus familiar Thai text fonts. *Archives of Design Research, 33*(3), 19–43. https://doi.org/10.15187/adr.2020.08.33.3.19.

21. Punsongserm, R., Sunaga, S., & Ihara, H. (2015, October). *The typeface priority of Thai characters for identification: Studying based on blurring tests*. Annual Conference of the 5th Branch of Japanese Society for the Science of Design (JSSD), Fukuoka, Kyushu University (Ohashi Campus).

22. Punsongserm, R., Sunaga, S., & Ihara, H. (2017a). Thai typefaces (part 1): Assumption on visibility and legibility problems. *Archives of Design Research, 30*(1), 5–23. https://doi.org/10.15187/adr.2017.02.30.1.5.

23. Punsongserm, R., Sunaga, S., & Ihara, H. (2017b). Thai typefaces (part 2): Criticism based on legibility test of some isolated characters. *Archives of Design Research, 30*(2), 23–45. https://doi.org/10.15187/adr.2017.05.30.2.23.

24. Punsongserm, R., Sunaga, S., & Ihara, H. (2018a, March). *Effectiveness of the homologous Thai letterforms on visibility under a simulated condition of low visual acuity*. Annual Conference of the 11th Typography Day, Mumbai: Industrial Design Centre (IDC) and Indian Institute of Technology Bombay (IIT Bombay). Retrieved January 30, 2023 from https://www.typoday.in/2018/spk_papers/rachapoom-punsongserm-typoday-2018.pdf.

25. Punsongserm, R., Sunaga, S., & Ihara, H. (2018b). Effectiveness of homologous Thai letterforms presented in parafoveal vision. *Information Design Journal, 24*(2), 92–115. https://doi.org/10.1075/idj.00002.pun.

26. Punsongserm, R., & Suvakunta, P. (2022). Optimal typeface and type size on Thai drug labeling and drug documentation: A recommendation for legal development. *Archives of Design Research, 35*(4), 49–71. https://doi.org/10.15187/adr.2022.11.35.4.49.

27. Rattanakasamsuk, K. (2013, December). *Elderly vision on legibility of Thai letters presented on LED panel*. ACA 2013 Thanyaburi: Blooming Color for Life (70–73), Thanyaburi: Asia Color Association and Rajamangala University of Technology Thanyaburi. Retrieved January 24, 2023 from http://www.repository.rmutt.ac.th/dspace/bitstream/123456789/1187/1/ELDERLY%20VISION%20ON%20LEGIBILITY%20OF….pdf.

28. Sanford, E. C. (1888). The relative legibility of the small letters. *The American Journal of Psychology, 1*(3), 402–435. https://doi.org/10.2307/1411012.

29. Santayayon, M., Pipitpukdee, J., & Phantachat, W. (2011, July). *A study of the legibility of Thai letters in Thai young adults aged 19–25 years old and older adults aged 60 years old and over*. The 5th International Conference on Rehabilitation Engineering & Assistive Technology, Bangkok, Swissotel Nai Lert Park.

30. Suveeranont, P. (2002). *Tracing of Thai font*. Bangkok. SC Matchbox. (In Thai).

31. Suveeranont, P. (2017). *Sarabun: A national font*. *Matichon weekly*. Retrieved August 25, 2023. from https://www.matichonweekly.com/art/article_20392. (In Thai).

32. Teeravarunyou, S., & Laosirihongthong, T. (2003, October). *Dynamic legibility of standard Thai fonts on traffic highway sign*. The 6th Asian Design International Conference, Tsukuba, Tsukuba International Congress Center.

33. Tinker, M. A. (1963). *Legibility of print*. Iowa State University Press.

34. Townsend, J. T. (1971). Theoretical analysis of an alphabetic confusion matrix. *Perception & Psychophysics, 9*(1), 40–50. https://doi.org/10.3758/BF03213026.

35. Uttal, W. R. (1969). Masking of alphabetic character recognition by dynamic visual noise (DVN). *Perception & Psychophysics, 6*(2), 121–128. https://doi.org/10.3758/BF03210695.

36. van der Heijden, A. H. C., Malhas, M. S. M., & van den Roovaart, B. P. (1984). An empirical interletter confusion matrix for continuous–line capitals. *Perception & Psychophysics, 35*(1), 85–88. https://doi.org/10.3758/BF03205927.

37. Waleetorncheepsawat, B., Pungrassamee, P., Obama, T., & Ikeda, M. (2012). Visual acuity of Thai letters with and without cataract experiencing goggles. *Journal of the Color Science Association of Japan, 36*, 216–217.