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Equivalent legibility font size for traditional Chinese character compared to early treatment diabetic retinopathy study near visual acuity

Chia-Yu Wang[1], Elizabeth P. Shen[1,2,3], Shu-Ya Wu[1], Wei-Cherng Hsu[1,2*]

Abstract:

PURPOSES: To investigate the legibility of a standardized logarithmic print size of traditional Chinese (TC) characters and compare it with Early Treatment Diabetic Retinopathy Study (ETDRS) near chart.

MATERIALS AND METHODS: A total of 1243 commonly used TC characters were chosen and divided into three groups according to its stroke complexity: Group A with 2–9 strokes, Group B with 10–17 strokes, and Group C with 18–25 strokes. For each group of characters, near charts were created using randomly chosen characters arranged in decreasing logarithmic size. In a well-illuminated room, healthy controls were fully corrected to test both ETDRS near chart and our set of TC near charts. The smallest legible font sizes (SLFS) in TC near charts were recorded and analyzed.

RESULTS: Forty-two healthy eyes (21 participants) (age 29 ± 8.9 years old) were included. The mean near best-corrected visual acuity (nBCVA) in ETDRS chart was 0.06 ± 0.05 logMAR. We found that the mean SLFS in TC charts (0.33 ± 0.09 logMAR) was significantly larger than the nBCVA in ETDRS chart ($P < 0.001$). The SLFS of Group B and the SLFS of Group C was significantly larger than that of Group A ($P < 0.001$).

CONCLUSION: According to our results, to recognize TC characters, normal-sight readers need a 0.22–0.30 logMAR (1.7–2.0 fold) enlargement of the acuity size measured by ETDRS near chart. The low-stroke TC charts may provide a new method to assess the postsurgical outcomes for comparable functional visual acuity in reading TC characters.

Keywords:

Character, early treatment diabetic retinopathy study visual acuity, legibility, near chart, traditional Chinese

[1]Department of Ophthalmology, Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, Taipei, Taiwan, [2]School of Medicine, Tzu Chi University, Hua-Liang, Taiwan, [3]Department of Ophthalmology, National Taiwan University Hospital, College of Medicine, National Taiwan University, Taipei, Taiwan

***Address for correspondence:**
Dr. Wei-Cherng Hsu, Department of Ophthalmology, Taipei Tzu Chi Hospital, No. 289, Jianguo Road, Xindian Dist., New Taipei City 23142, Taiwan.
E-mail: cyao@seed.net.tw

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Introduction

National examinations and school textbooks in Taiwan use BiauKai (BK, 標楷體) and MingLiU (ML, 新細明體) as standard font types. In fact, there are a wide variety of Traditional Chinese (TC) font types commercially available. However, there is no standardization of the spatial occupation of TC characters in an *em square* presently [Figure 1]. In Taiwan, taking into consideration, the legibility and readability of literatures for low vision populations and the elderly, government entities recommend publishers to use larger font sizes in their printed matter. However, different publishers utilize various spacing between the printed TC character and the surrounding space around each character resulting in a nonuniform actual font size of TC characters. In this study, we measured the actual printed font size of TC characters in near charts to decrease the bias caused

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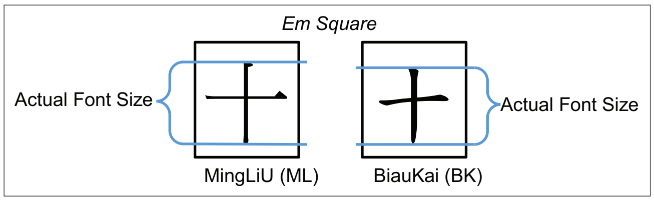

Figure 1: Two font types with the same *em square* size (pt) but different actual font size. Although the desktop publishing point (DTP pt) was defined as 0.353 mm in metric unit, the TC characters of a digital font type are designed around an imaginary space called an *em square*

by *em square*. We also investigated the legibility of TC characters in BK and ML fonts in normal-sighted subjects to find the relationship between the functional vision of TC language and the angular size of Early Treatment Diabetic Retinopathy Study (ETDRS) chart.

Materials and Methods

Subjects recruitment

Normal-sighted TC readers younger than 60 years old with best-corrected visual acuity (VA) better than 0.10 logMAR (0.8 decimal) and had at least a junior-high school education were included. Those who had any active ocular diseases (such as dense cataract, maculopathy, glaucoma, dry eye, etc.) or intraocular surgery were excluded. This study was approved by the Institutional Review Board of the Taipei Tzu Chi Hospital (IRB number: 07-XD-084), and written consent was obtained from all volunteers.

Development of traditional Chinese near charts

Selecting traditional Chinese characters as optotypes

We included TC characters with different degrees of spatial complexity from the most commonly used 5021 TC characters used in the general printed materials such as newspapers, textbooks, and magazines.[1] TC characters that were difficult to understand or hard to pronounce were excluded deriving at 1243 most popular TC characters. We divided the complexity of the strokes in these characters into three groups: Group A containing characters with 2–9 strokes (n = 526), Group B containing characters with 10–17 strokes (n = 642), and Group C containing 18–25 strokes (n = 75).

Fonts, sizes and arrangements

The size of TC optotype was defined by the longest width or height of the entire character composing of various number of strokes. To convert TC characters to corresponding logarithmic size, we printed the various sizes of each TC character to measure the actual visual angle [Supplement Table 1].

To avoid crowding phenomenon and better legibility, we followed Bailey-Lovie design principles[2] for spacing between each TC character and decreasing font size. There were 12 size levels separated by 0.10 logMAR, from 0.00 to 1.10 logMAR (corresponding to decimal VA of 1.0–0.08). Each size level is composed of 5 TC characters chosen from the same complexity. The spacing between adjacent TC character and between rows is at least one optotype to avoid the crowding effect. 60 TC characters were randomly extracted from each group and made into one chart. Each chart is printed into either BK font type or ML font type. These charts were printed in black on white paper at high contrast level (not below 90% Michelson contrast) and 1200 dots per inch (dpi) [Figure 2].

Visual acuity testing procedure

The subject was fully corrected to first test an ETDRS near chart. Then, TC near charts from each complexity group and with both ML font and BK font were tested for each eye at 40 cm distance in a well-illuminated room. The subject was asked to orally report the TC characters from left to right, from the largest to the smallest size. All legible characters correctly read out of 60 TC characters per chart were documented. If more than 3 s were spent differentiating a TC character, this TC character is not counted as a legible character. The number of correctly-identified optotypes was recorded. The smallest legible font size (SLFS) for each chart was derived by multiplying the number of characters read correctly to 0.02 logMAR and then subtracting 1.2 logMAR.

SLFS = 1.2 logMAR – 0.02 logMAR × (No. of characters read correctly).

Statistics

The logMAR VA between ETDRS near chart and TC near charts was compared and analyzed by the one-way repeated measurement analysis of variance (ANOVA). The correlation analysis between the number of strokes of TC characters and the SLFS of TC characters was also performed by Pearson r. Data are presented as mean ± standard deviation. All statistic assessments were two-sided and evaluated at the 0.05 level of significant difference. The discrepancy of the SLFS between ETDRS charts and three groups of TC near charts were scored and converted logMAR units into lines of magnification requirement in commonly-used Snellen acuity chart. Statistical analyses were performing using the SPSS 17.0 statistics software (SPSS lnc., Chicago, IL, USA).

Results

Participants

The demographics and near best-corrected near VA (nBCVA) is shown in Table 1.

Legibility

Table 2 shows the mean logMAR VA for all TC near charts is 0.33 ± 0.09 logMAR (= mean of SLFS)

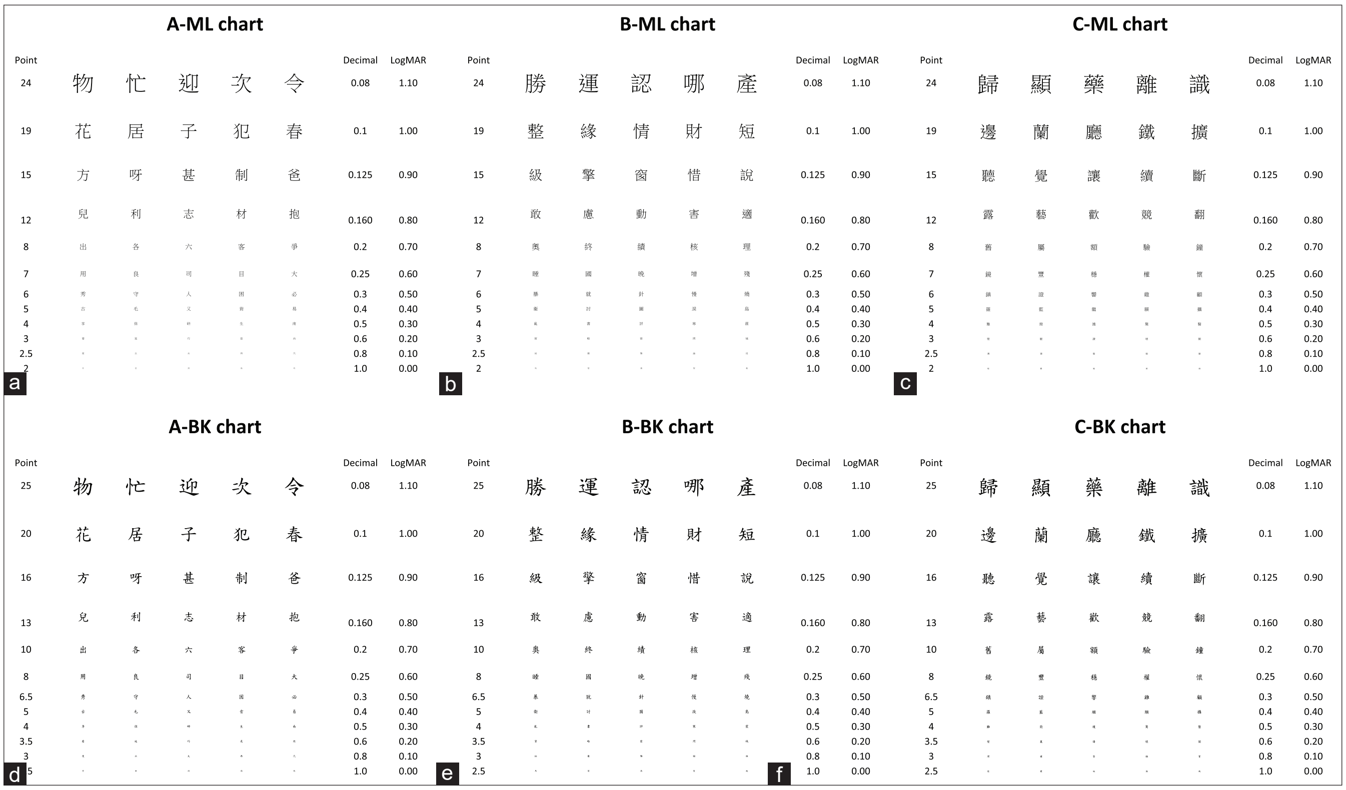

Figure 2: (a-c) show the Traditional Chinese near charts in low, medium and high stroke complexity, respectively, printed in ML font type. (d-f) show the Traditional Chinese near charts in low, medium and high stroke complexity, respectively, printed in BK font type

Table 1: Subject demographics of 21 participants (42 eyes)

	Mean±SD	Range
Age (years old)	29±8.9	15~54
Gender (male:female)	7:14	
Near BCVA by ETDRS (logMAR)	0.06±0.05	0.00~0.10
Spherical refractive error (diopters)	−3.30±2.00	−8.00~0.00
Astigmatism (diopters)	−0.46±0.48	−1.50~0.00

BCVA=Best-corrected visual acuity, SD=Standard deviation, LogMAR=Logarithm minimum angle of resolution, ETDRS=Early treatment diabetic retinopathy study

Table 2: Descriptive statistics for logarithm minimum angle of resolution visual acuity in various near charts

Near chart	*n*	Mean±SD
ETDRS	42	0.06±0.05
A-ML	42	0.28±0.09
A-BK	42	0.29±0.10
B-ML	42	0.34±0.07
B-BK	42	0.36±0.09
C-ML	42	0.36±0.07
C-BK	42	0.36±0.11

SD=Standard deviation, ETDRS=Early treatment diabetic retinopathy study

significantly different than the mean logMAR VA using ETDRS near chart for healthy eyes (ETDRS 0.06 ± 0.05 logMAR, $P < 0.01$, one-way ANOVA). This result indicates a larger font size for TC character is required for legibility. In addition, the mean of SLFS of Group A TC near chart for both ML and BK font type is significantly smaller compared to Group B and Group C ($P < 0.01$, one-way ANOVA) [Table 3]. The correlation between the number of stroke and logMAR VA of TC near charts is low-medium positive correlation ($R = 0.30$, $P < 0.001$).

The mean difference of logMAR VA: Between ETDRS and TC A-ML chart is 0.22 ± 0.01; between ETDRS and TC A-BK is 0.23 ± 0.01, between ETDRS and TC B-ML is 0.28 ± 0.01, between ETDRS and TC is B-BK 0.30 ± 0.01, between ETDRS and TC C-ML is 0.30 ± 0.01, between ETDRS and TC C-BK is 0.30 ± 0.01. These differences demonstrate that 3–4 lines enlargement of Snellen chart are required for TC character to be legible.

Discussion

VA is a measure of the ability to determine details. This is usually measured using VA charts with various angular size of detail (MAR, minimum angle of resolution). Universal standard VA charts like Landolt C and Snellen E utilize the break of the ring and the spacing of the adjacent strokes, respectively, to determine the VA. The break or the spacing is designed with one-fifth the optotype height which subtends 1 minarc, the resolution limit of human eyes.[3] These charts are useful and have claimed to be unaffected for testing subjects with various cultural background.

Table 3: The difference in logarithm minimum angle of resolution visual acuity between early treatment diabetic retinopathy study and various traditional chinese charts analyzed by the one-way repeated measurement analysis of variance (*P*<0.001)

	ETDRS	A-ML	A-BK	B-ML	B-BK	C-ML
A-ML	−0.22*					
A-BK	−0.23*	−0.01				
B-ML	−0.28*	−0.06*	−0.05*			
B-BK	−0.30*	−0.08*	−0.07*	−0.02		
C-ML	−0.30*	−0.08*	−0.07*	−0.01	0.002	
C-BK	−0.30*	−0.08*	−0.07*	−0.01	0.002	0.000

**P*<0.001. The multiple comparisons between various near charts for logMAR VA. LogMAR=Logarithm minimum angle of resolution, VA=Visual acuity

Accurate measurement of the functional vision for daily activity is essential as it is often required for certain job qualifications, disability benefits, and low vision rehabilitation. To approximate a person's visual tasks, the optotypes (visual targets) of a functional VA chart should be related to person's mother language and cultural background. Therefore, character charts are being taken more seriously and have become the dominant way to evaluate VA clinically around the world, such as the well-known ETDRS chart. The optotypes of ETDRS chart were made from Sloan's letters,[4] which are a set of 10 sans-serif capital English characters (C, D, H, K, N, O, R, S, V, Z) with specified angles and curvatures for each. Among the 26 capital English alphabet, these chosen English alphabetical letters had an intermediate legibility and were highly correlated to Landolt C (R = 0.90).[4] Therefore, the ETDRS chart became the most widely recommended system for near VA testing. The written Chinese language is a unique logographic pattern, composed of not only horizontal lines (一) and vertical lines (丨亅) but also variable types of right-falling diagonal lines (丿), left-falling diagonal lines (㇏), turning lines (□), raising lines (□), hooks (乚乙), and dots (丶) to compose one Chinese character. It is much more complex than the Latin or English linear alphabet. In addition, Chinese has a very wide range of spatial complexity varying from sparse strokes to dense strokes, up to 64 strokes to compose a single character.

Due to interaction effects in parafoveal letter recognition, the rate or speed of reading is dependent upon letter size and spacing.[5-7] Greater than 90% of TC characters contain more than 5 strokes that occupies the same square area. In a TC sentence, there is no interspace between TC words. All of these factors result in a heavy crowding effect which may affect reading speed. Therefore, people with low or poor vision have a greater difficulty in reading TC characters. Moreover, the database of TC is enormous, including characters from ancient times to the present, with approximately 16,700 characters applied to historical literary works.[8] Even in daily life, people use a large amount of these characters, recognizing approximately 5000 characters after graduating from elementary school.[9]

In this study, we found TC character required an increase in 0.22–0.30 logMAR font size to be comparable to equal VA using the ETDRS chart. Therefore, a much higher Snellen VA may be needed to achieve a functional VA for reading TC Chinese.

The association between the complexity of Chinese characters with English VA charts has been studied for years.[10-14] JY Zhang *et al*. divided SC characters into six groups from low to high spatial complexities and compared them with ETDRS Sloan letters.[15] Their results showed SC characters required a significantly larger font size (about 1.3–1.6-fold) than ETDRS letters (mean 4.68–5.99 vs. 3.68 arcmin).[15] The font size in arcmin was converted from the equation 10logMAR × 5. Recently, Wang *et al*. reported the threshold acuity for a set of SC characters was 1.16-fold higher than a set of lowercase English characters (mean 7.1 vs. 6.1 arcmin).[10] In this study, from the simplest to the most complicated TC groups, we found 1.7–2.0-fold increase in font size compared to ETDRS letters. TC characters generally also need a larger font size compared to SC character. This is because the crowding effect induced by the higher complexity of TC.[12,13,16] In real life scenario, if a road sign is designed to be recognized at 100 meters away by a normal-sighted driver, the TC characters on the sign need to be at least 2.0 × 100 × tan (5 arcmin) = 29.15 cm in height. It is essential to double the size of the public signs in TC language compared to those in English for better legibility.

Previously, Trauzettel–Klosinski *et al*. mentioned recognition of a Chinese character is by its pattern instead of counting the number of strokes. Therefore, they proposed that that reading performance for Chinese characters is not affected by the spatial complexity of strokes.[17] Chinese character might be identified through its spatial appearance without actually seeing the details of every stroke. This idea was also supported by Zhang *et al*. who reported the discrimination of fine details may not fully explain the physiology of character recognition.[15] Nonetheless, complexity of strokes could affect the legibility of characters to some extent, apart from their pattern recognition. Zhang *et al*. also illustrated the acuity size of SC characters increased steadily accompanied with the spatial complexity (0.1 logMAR increase in acuity size per 2.5-fold increase in stroke frequency).[15] In this study, TC characters can be divided into two levels of legibility by the number of strokes. Those with the number of strokes under 10 were considered to be easy to read (Group A, 2–9 strokes, 0.28 logMAR), whereas those with the number of strokes greater or equal to 10 were considered to be difficult (Group B and C, 10–25 strokes, about 0.35 logMAR). The legibility between low stroke and medium-to-high stroke was significantly different indicating greater complexity could affect the legibility. As the complexity of stroke increases, the difference in legibility diminishes. Therefore, stroke complexity affects general legibility of TC characters. These findings remind us to use the synonyms with sparse strokes instead of those with dense strokes in instructional guidance like hazard or road signs. For example, Group B word "注意 (pay attention)" could be substituted by easy-to-read synonym Group A word "小心;" Group C word "禮讓座位 (yield your seat)" could be substituted by its easy-to-read synonym Group A word "空出座位."

Since no significant difference was found between Group B and C TC characters in regards to equivalent ETDRS VA, complexity using the number of strokes may not be the only way to classify the spatial complexity of TC characters. Previously, Zhang *et al*. proposed using stroke frequency instead to quantify the spatial complexity of SC characters.[15] This method provides a more objective measurement, whereas the stroke number method chosen by us is a more intuitive and commonly accepted classification. Current evidence suggests that a new method is needed in classifying TC complexity. It may not be totally based on the visual angle theory (discrimination of finest details). In the other words, VA measured with Snellen E or Landolt C may not be equivalent actual VA for TC readers. The low-stroke TC charts (A-ML and A-BK) may more closely resemble the ETDRS chart VA result. We thus recommend using the low-stroke TC chart to better access surgical success, especially in a practical clinical scenario such as a patient who had undergone cataract surgery with premium multifocal intraocular lens insertion.

Interestingly, Group B and Group C had the same level of legibility (P = 1.0). This result supports the opinion reported by Trauzettel-Klosinski *et al*. When recognizing a more complex TC character, the pattern of the character gives greater impact than the detail of the stroke.[17] Most TC characters were an adaptation from a picture of object from ancient times to the present, such as "龍 (dragon)" and "龜 (turtle)". During language learning, TC readers must spend longer time practicing how to write characters with high complexity, after which, they could probably use less time to recognize them by their unique pattern. Therefore, the correctly-reported rate would increase and led to an underestimation of the SLFS in Group C. It seems that visual angular size is not the only factor that would influence the legibility of TC characters. The factors such as character's pattern and the utilization rate could have some effects.

To allow comfortable reading for a prolonged duration without a reduction of reading speed, further magnification of the SLFS was required. When the font size enlarges from the threshold level, reading speed rapidly increases, and the maximal reading speed plateaus at large font sizes.[10,18,19] In alphabetic language, Subramanian and Pardhan established the reading parameters in young adults by the MNREAD acuity chart.[20] According to their results, alphabetic readers required a 0.18 logMAR (1.5-fold) enlargement of the SLFS for fluent reading (from-0.13 to 0.05 logMAR). For SC readers, Han *et al*. reported 0.08 logMAR (1.2-fold) enlargement by C-READ charts in young adults (from 0.16 to 0.24 logMAR)[11] and Lu *et al*. found 3-fold enlargement in normal-sight population.[21] For TC readers, the crowding effect may therefore affect the reading speed.[13] A higher magnification of text is required to achieve an equivalent functional reading speed.

The font size and shape of characters are the crucial factors determining the legibility of print products.[22] Although a magnification of texts seems to resolve the reading difficulty, preserving the original typesetting format of a product requires a precise point (pt) for printing. Currently, the Ministry of Examination in Taiwan set ML 14 pt (0.8–0.9 logMAR) for content texts and BK 18 pt (0.9–1.0 logMAR) for title texts as the national examination format for low vision population based on the consideration of maintaining the alignment of texts in a well-composed layout.[23] School textbooks were regulated to use BK font not smaller than 14 pt (0.8–0.9 logMAR).[24] Newspapers in TC using 10.5 pt (about 0.8 logMAR) could be challenging for the elderly. When the font size is close to VA limit, reading speed shows a greater dependence on the font size.[25] Current regulations for these products were too small to achieve comfortable reading for the low vision population with BCVA below 0.52 logMAR (below 0.3 in decimal). The SLFS to cover all the ranges of complexity of TC characters would be 0.52 + 0.30 = 0.82 logMAR. However, the critical printed size for comfortable reading should be much larger: 0.82 + 0.18 = 1.00 logMAR corresponding to BK 20 pt and ML 19 pt. According to our study, printing size adjustments in TC and extending examination time may be required for the visually impaired population.

Conclusions

Reading TC characters generally require a larger font size, even for healthy individuals without visual problems. A normal-sighted reader requires about a 0.22–0.30 logMAR (1.7–2.0 fold) enlargement of the letter size measured by ETDRS near chart to equivalently read TC characters. The low-stroke TC charts may provide a new method to assess post-surgical outcomes for comparable functional VA in reading TC characters.

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Conflicts of interest

The authors declare that there are no conflicts of interests of this paper.

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Supplement Table 1: Table converting traditional Chinese character font size to actual visual angular size

LogMAR notation	Decimal notation	X-height (mm at 40 cm)	BiauKai (point)	MingLiU (point)
0.00	1.00	0.58	2.5	2
0.10	0.80	0.73	3	2.5
0.20	0.63	0.92	3.5	3
0.30	0.50	1.16	4	4
0.40	0.40	1.45	5	5
0.50	0.32	1.82	6.5	6
0.60	0.25	2.33	8	7
0.70	0.20	2.91	10	8
0.80	0.160	3.64	13	12
0.90	0.125	4.65	16	15
1.00	0.100	5.82	20	19
1.10	0.080	7.27	25	24

LogMAR: Logarithm minimum angle of resolution