Visual Demand and Acuity Reserve of Chinese versus English Newspapers

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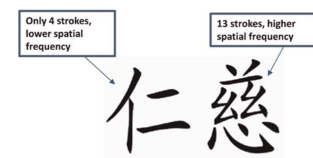
SIGNIFICANCE: This study suggests that Chinese newspaper characters are more legible than English newspaper letters. Characters in Chinese newspapers have higher acuity reserve than English newspapers.

PURPOSE: The purpose of this study was to evaluate visual demand and acuity reserve for Chinese newspapers in comparison with published data on U.S. newspapers.

METHODS: The test distances for visual acuity in Chinese clinical studies were reviewed systematically. Characters from different sections of newspapers printed in simplified Chinese were evaluated. The character height, frequency, and visual demand and acuity reserve of each newspaper section were determined for Chinese characters of the six different levels of complexity.

RESULTS: More than 70% of Chinese clinical studies measure near visual acuity at either 33 or 40 cm. The height of Chinese characters ranged from 1.95 to 3.28 mm across different sections of five newspapers compared with 1.0 to 2.0 mm for English letters. The frequency of Chinese characters from least to most complex ranged from 7 to 34% across 12 sections of one Chinese newspaper. The angular threshold across the six complexity levels of Chinese characters ranged from 4.62 to 5.93 arcmin (0.54 to 0.69 mm at 40-cm reading distance) with a weighted angular threshold of 5.18 arcmin compared with 3.37 arcmin (0.39 mm) for the English letters. For Chinese newspapers, at 40-cm reading distance, the acuity reserve for the smallest and largest median size was 3.55 and 4.61, respectively.

CONCLUSIONS: Chinese characters are larger than English characters in all newspaper sections newspapers by a factor of 1.60 to 2.34. Given that Chinese characters need to be 1.54 times larger than English letters to provide the same acuity reserve, on average, Chinese newspapers are more legible than U.S. English newspapers.



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Visual acuity testing is the standard evaluation of visual function and the first step in the clinical management of ophthalmic conditions. Visual acuity is typically measured using standardized charts comprising various letter sizes. Although visual acuity testing in the clinic informs on how the eye functions, it is equally important for the visual acuity measurement to be functionally relevant, that is, to perform vision-related activities. In this regard, most people list reading as their primary visual requirement.[1]

Reading is an essential skill, a basic near visual task that requires a complex integration of visual acuity, visual fixation, accommodation, binocular fusion, saccades, convergence, field of vision, and form perception.[2] Factors such as language skills, visual perception and cognition, character type, style, spacing, contrast, and reading distance add to the complexity of reading proficiently.[3–6] Accordingly, populations in different cultural or demographic areas, with different languages/script, may differ in their reading skills.

Unlike English, the Chinese language does not have an alphabet but uses a logographic system where one or two characters may stand for one word. Chinese and English characters also differ significantly with respect to their spatial structure.[7] Written Chinese characters contain a large range of spatial complexities, and there are more than 2500 frequently used characters. English characters vary in width and height. While around half are the same height as an x or o, the remainder have either ascenders (e.g., b or d) or descenders (e.g., p or q). In contrast, Chinese characters with the same font type and size occupy a constant square area and consist of anywhere between 1 and 52 strokes within a letter, making them more complex and less legible as the visual angle decreases.[8] Furthermore, a Chinese word typically consists of only one or two characters. Ma et al.[9] showed that the visual configuration of such a word contributes to the retrieval of the word's meaning. On the other hand, the average word length in English language is approximately 4.7 characters. Pitt and Samuel[10] showed that longer English words allow for better lexical activation and thereby better retrieval of a word's understanding and meaning. These differences between the languages may also add to the variability in visual acuity demand and thereby influence reading ability and performance.

Reading speed is related to how large the print size is relative to threshold size. As size increases above threshold, reading speed improves steadily until maximum speed is reached at a critical print size. At still larger sizes, reading speed remains relatively constant. Whittaker and Lovie-Kitchin[3] coined the term *acuity reserve*, defined as the ratio between the font size being read and the threshold size, and proposed that the acuity reserve should be at least 3 for highly fluent reading.

Zhang et al.[8] systematically studied common Chinese characters and demonstrated that the threshold size of Chinese characters increased linearly with their spatial complexity. Nonetheless, there are few studies that assess the demands and acuity reserve for Chinese and how it compares with English.[6,11] Evaluating the demands of newspapers not only requires consideration of character style and print size but also the reading distance. In U.S. Food and Drug Administration clinical trials, measurement of near visual acuity is usually performed at a distance of 40 cm, a distance commonly used to perform near visual tasks, although there is considerable between-subject variation.[12,13] Considering the fundamental differences between Chinese and English reading material, it is important to understand the relationship between commonly encountered print sizes and the visual acuity demand to read Chinese.

In this study, newspapers were used as a medium to understand the visual acuity demand of the Chinese population. First, the test distance of near, intermediate, and distance visual acuity in clinical studies in China was reviewed systematically. Second, the sizes of Chinese newspaper characters were measured and compared with the previously published data for U.S. newspapers. Finally, the visual demand and acuity reserve of these Chinese newspaper characters were determined and compared with that for English newspapers.

METHODS

Systematic Literature Search

To understand reading distances in China, a literature search was conducted in PubMed and the Chinese databases (CNKI [China Academic Journals full-text database], CqVIP [Chongqing VIP Information Co., Ltd., China's first Chinese journal database research institution under the Chongqing Branch of the Institute of Scientific and Technical Information of China], and Wanfang Med Online). The PubMed search was conducted to identify articles published in the last 5 years using the following keywords: "near visual acuity" AND (China OR Chinese), "intermediate visual acuity" AND (China OR Chinese), "distance visual acuity" AND (China OR Chinese)." Chinese databases were also searched for articles with keywords "near visual acuity" ("近视力"), "intermediate visual acuity" ("中视力" or "中间视力"), "distance visual acuity" ("远视力"). Abstracts retrieved from the search were screened to include articles either on ophthalmological clinical studies conducted in China or those in which near, intermediate, or distance vision was measured. Articles that did not report visual acuity test distances were excluded (Fig. 1).

Character Selection

The most common Chinese characters used by Zhang et al.[8] were selected, given that their visual demand had been well characterized. Briefly, among a linguistic corpus of 138 million, the 500 most frequently used Chinese characters were selected from

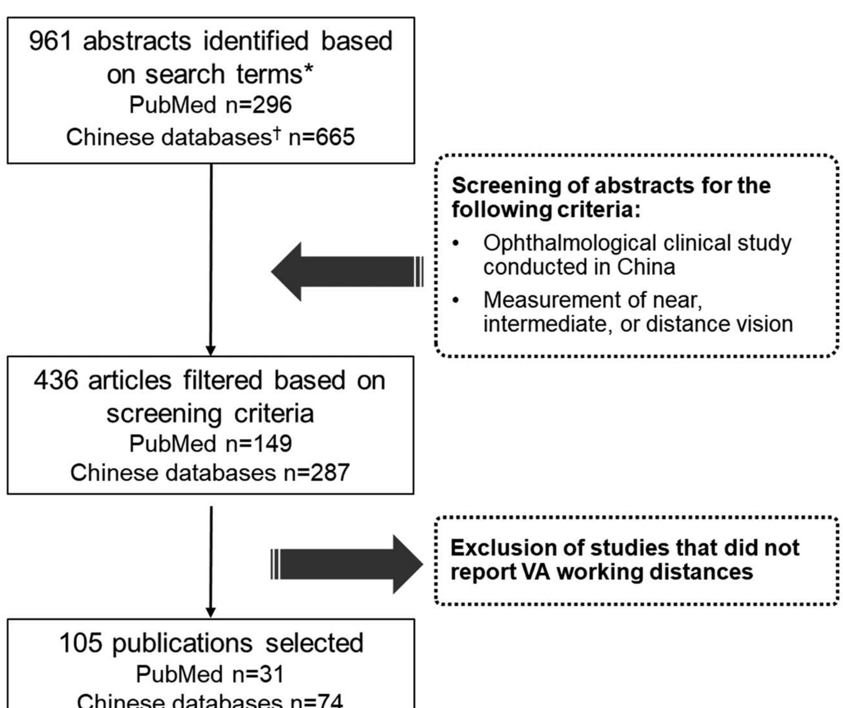

FIGURE 1. Flowchart of the systematic literature review. *For PubMed: "near visual acuity" AND (China OR Chinese), "intermediate visual acuity" AND (China OR Chinese), "distance visual acuity" AND (China OR Chinese); for Chinese databases: "near visual acuity" ("近视力"), "intermediate visual acuity" ("中视力" or "中间视力"), "distance visual acuity" ("远视力"). †CNKI (China Academic Journals full-text database), CqVIP (Chongqing VIP Information Co., Ltd.), and Wanfang Med Online.

an official character-frequency table (Modern Chinese Character Frequency Table).[14] These were then screened based on the number of strokes and categorized into six groups (2 to 4, 5 to 6, 8 to 9, 11 to 12, 13 to 15, and 16 to 18 strokes). Zhang et al.[8] used the distances between strokes to further refine character complexity. The final six groups, each with defined levels of complexity, were used as the sample Chinese characters measured in the current study (Fig. 2A).

Measurements and Data Analysis

Five local newspapers printed in simplified Chinese were chosen for the study. Given that the requirements are specified by the government, print sizes across Chinese newspapers were not expected to vary significantly, so only five newspapers were measured. In each newspaper, five sections (sports, weather, classified advertisements, syndicated columns, and front-page articles) were selected for evaluation. A Peak Scale Lupe (10×, GWJ Company, La Quinta, CA) was used to measure the samples.

Character Height

An investigator read through every section from the beginning, and the first appearance of any character from each complexity group (Fig. 2A) was selected and measured. Each character sample was measured vertically from its highest to lowest point (example shown in Fig. 2B) and expressed in millimeter. The second investigator repeated the measurement, and the mean of these measurements was used as the print size of each complexity level for each section. Data from DeMarco and Massof,[15] summarizing English characters from newspapers in the United States, were converted into millimeter based on the following formula: 1 M = 1.45 mm. The range of the median Chinese character print size in each section was calculated and compared with the published values for English characters in U.S. newspapers.[15]

A

CC1	个文么山少之十力人天
CC2	州月占只无区以世风任
CC3	条名抓电各好取医非多
CC4	益售很资建做学深张事
CC5	势数想续验率常群策领
CC6	需感题路德增解就赛整

B

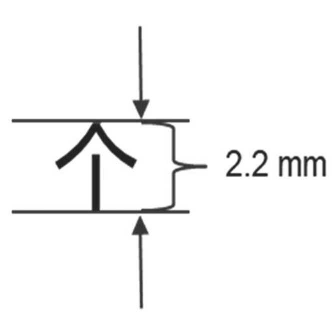

FIGURE 2. (A) Six groups of Chinese characters based on complexity. Adapted with permission of Association for Research in Vision & Ophthalmology (ARVO), from Zhang et al.[8]; permission conveyed through Copyright Clearance Center, Inc. (B) Illustration for character height measurement.

Angular Threshold and Size Threshold

Size threshold is the height in millimeter of the smallest character/letter that people can read at a given distance. Likewise, angular threshold is the corresponding angular subtense in minutes of arc (arcmin). Angular threshold is related to visual acuity, but for complex Chinese characters, the relationship is not as straightforward as it is for Sloan letters and similar optotypes where the visual acuity is the stroke width, that is, one-fifth the angular subtense. Zhang et al.[8] determined the angular threshold for six groups of Chinese characters (Fig. 2A) from low to high spatial complexities and Sloan letters (C, H, K, O, R, S, V, and Z) in six normal-sighted Chinese observers.[8] It should be noted, however, that there may not be a one-to-one relationship between thresholds for Sloan letters and newspaper print.

Using the near reading distance of 40 cm, the print height was calculated using the following formula:

$$\text{Print height at 40 cm (in mm)} = \tan(\text{acuity size in arcmin}/60) \times 400$$

Weighted Mean of Angular Threshold

To calculate the mean angular threshold across the six complexity levels, the frequency of each one was determined. The frequency of Chinese characters in each complexity-level group (from least complex to most complex) across all 12 sections of one Chinese newspaper was assessed to reflect how often characters of each complexity appear in a newspaper. The weighted mean angular threshold for Chinese characters was calculated, with their relative frequency as weights, using the following formula:

$$\sum_{i=1}^{6} w_i a_i$$

where i is the complexity level from 1 to 6, w_i is the frequency/weight for each complexity, and a_i is the angular threshold for each complexity level.

Acuity Reserve

The acuity reserve is the ratio of the angular subtense of print to the angular threshold. It was calculated using the weighted mean of angular threshold based on the comprehensive data of Zhang et al.[8] for Sloan letters and Chinese characters.

RESULTS

Literature Review

The test distance of near, intermediate, and distance visual acuity measurement in clinical studies in China was reviewed systematically to better understand visual acuity testing in China (Fig. 1). The preliminary search of PubMed and Chinese databases retrieved 296 and 665 abstracts, respectively. Further screening of these abstracts based on the applied criteria identified 105 publications that reported the distance for visual acuity measurement in Chinese studies. Among the 67 studies that test near visual acuity (10 to 40 cm), the majority (~72%) are measured at 33 cm (n = 21), at 40 cm (n = 24), or between (n = 3). Of the 47 studies reporting at intermediate visual acuity (40 to 125 cm), 36% are commonly reported at 60 cm. Of the studies that report on testing

TABLE 1. Height and ratio of Chinese characters and English letters in newspapers

Newspaper section	Character height, median (range) (mm) China	Character height, median (range) (mm) U.S.*	Ratio of print size (China/U.S.)
Sports	2.8 (2.7–2.8)	1.2 (1.0–1.4)	2.3
Weather	2.7 (1.9–3.3)	1.3 (1.1–2.0)	2.1
Classifieds	2.1 (2.0–2.3)	1.2 (1.0–1.5)	1.8
Syndicated	2.8 (2.7–2.8)	1.7 (1.5–2.0)	1.7
Front page	2.8 (2.8–2.8)	1.7 (1.3–1.9)	1.6

*Data from the height of letter *o* of 100 newspapers in the United States.[15]

at distant visual acuity (3 to 6 m, n = 80), 80% (n = 64) test distant visual acuity at 5 m.

Character Height

The median height of Chinese characters in newspapers ranged from 1.95 to 3.28 mm across all sections. The median height of characters was 2.8, 2.7, 2.1, 2.8, and 2.8 mm in the sports, weather, classified advertisements, syndicated columns, and front-page sections, respectively. The corresponding values for angular subtense at 40 cm are 23.9, 23.5, 18.4, 23.9, and 23.9 arcmin, respectively.

In comparison, letters in U.S. newspapers range from 1.0 to 2.0 mm with medians of 1.2, 1.3, 1.2, 1.2, and 1.7 mm for the corresponding sections.[15] The corresponding values for angular subtense at 40 cm are 10.2, 11.0, 10.0, 14.4, and 15.0 arcmin, respectively. Overall, Chinese characters across multiple sections were 1.6 to 2.3 times larger than English characters in the same section (Table 1).

Angular Threshold (α_i) and Size Threshold

The angular threshold across the six Chinese character complexity levels ranged from 4.62 to 5.93 arcmin (Table 2).[8] This corresponds to size thresholds of 0.54 to 0.69 mm for a 40-cm reading distance. The corresponding values for English characters are 3.37 arcmin and 0.39 mm for a 40-cm reading distance.

Weighted Mean of Angular Threshold

The frequency of each complexity level assessed in all 12 sections of one Chinese newspaper is summarized in Table 2. Among the characters in this pool, the frequencies of Chinese characters from the least to the most complex were 34, 17, 16, 12, 7, and 14%. Based on the angular threshold (a_i) and frequency/weight (w_i) for each complexity group (Table 2, respectively), the weighted mean of angular threshold for Chinese characters was 5.18 arcmin. This corresponds to a size threshold of 0.60 mm for a 40-cm reading distance.

Acuity Reserve

The acuity reserve is the ratio of print size to size threshold.[3] It can also be expressed as the ratio of the angular subtense of print to the angular threshold. For Chinese newspapers, the acuity reserve is 3.55 (18.4/5.18) for the smallest median size and 4.61 (23.9/5.18) for the largest median size assuming a reading distance of 40 cm. The smallest Chinese character measured was 1.95 mm or, at 40 cm, 16.8 arcmin, giving an acuity reserve of 3.24 (16.8/5.18; Table 2).

For U.S. newspapers, the acuity reserve is 2.96 (10.0/3.37) and 4.44 (15.0/3.37) for the smallest and largest median sizes, respectively. The smallest U.S. character reported was 1 mm or, at 40 cm, 8.6 arcmin, giving an acuity reserve of 2.55 (8.6/3.37).

DISCUSSION

The medium used for testing (including the character style and print size) and testing distance are two important aspects of ophthalmic assessment. Previous studies have underscored the importance of character print size and shape that, together with the reader's viewing distance, determine the angular print size or the visual angle, thereby affecting letter recognition and reading performance.[5,16,17] Hence, different languages and their script may influence visual acuity and thereby their readability.

TABLE 2. Size threshold for Chinese characters of six levels of complexity and their ratio to the threshold of English letters

Character complexity level	Sample character	Frequency (%)	Angular threshold (arcmin)*	Size threshold at 40 cm (mm)	Acuity reserve: Smallest character (2.14 mm)	Acuity reserve: Largest character (2.78 mm)
CC1	个 文 么 山 少 之 十 力 人 天	34.2	4.62	0.54	3.96	5.15
CC2	州 月 占 只 无 区 以 世 风 任	17.0	4.88	0.57	3.75	4.88
CC3	条 名 抓 电 各 好 取 医 非 多	15.7	5.38	0.63	3.40	4.41
CC4	益 售 很 资 建 做 学 深 张 事	12.0	5.66	0.66	3.24	4.21
CC5	势 数 想 续 验 率 常 群 策 领	7.2	5.90	0.69	3.10	4.03
CC6	需 感 题 路 德 增 解 就 赛 整	13.9	5.93	0.69	3.10	4.03
Weighted mean			5.18	0.61	3.55	4.61

*Data extracted from figures in Zhang and colleagues'[8] study on legibility variations of Chinese characters.

Chinese and English fonts vary significantly, but there is limited literature comparing Chinese and English print size in newspapers and comparing them with established thresholds. In this study, Chinese and English newspaper character sizes were compared, and Chinese characters were found to have larger characters across all sections of newspapers (vs. English letters in U.S. newspapers).

Furthermore, comparison of their visual demand showed that Chinese characters with complexities ranging from 0.54 (least complex character) to 0.69 mm (most complex character) are readable at 40 cm. However, English letters need to be larger than 0.39 mm to be readable at 40 cm. The visual demand was also assessed based on the frequency of each complexity level in all 12 sections of one Chinese newspaper. Consistent with the current observations, it was noted that Chinese characters need to be larger than English letters to have the same visibility from the same distance. It is worth noting that the measuring distance used (40 cm) is aligned with the near-vision testing distance from the systematic literature review, which showed that 70% of the clinical studies in China test near visual acuity at 33 or 40 cm. This result is also consistent with global procedures and guidelines for standardized visual acuity testing.[18–20]

Unlike previous studies that used standardized eye charts to compare visual acuity demand between Chinese and English characters, the current study used newspapers to compare the ability of subjects to perform a common visual task in both Chinese and English and is therefore reflective of individuals' quality of life. Zhang et al.[8] investigated the legibility of written Chinese characters and developed a reliable way to evaluate functional vision in Chinese readers. Their data were used to predict subjects' ability to read Chinese newspapers. Print size for Chinese newspapers was compared with DeMarco and Massof[15]; newsprint sizes are variable across different sections, including from headline to main text.[15] Therefore, the selection of newspapers as a medium for near visual testing also allowed for visual acuity assessment across different character sizes in the current study.

Interestingly, Wang et al.[6] recently evaluated Chinese and English reading performance by measuring reading speed as a function of font size in a group of Chinese college students fluent in both languages. The investigators designed and used equivalent visual acuity charts in Chinese and English and measured reading speed in both languages. Although reading speed in Chinese was faster than in English, the critical acuity reserve was identical at 3.4 in both languages. In other words, regardless of language, maximum reading speed was attained for character sizes 3.4 times larger than the size threshold.[6] The acuity reserve for the Chinese newspapers evaluated in the present study ranged from 3.55 to 4.61. This implies that the median character size in Chinese newspapers is always greater than the critical acuity reserve reported by Wang et al.,[6] and thus, maximum reading speed should be possible for patients with normal visual acuity. Likewise, Cheung et al.[11] developed and evaluated a Chinese reading chart for children. In 169 children, they found that mean reading acuity was 0.05 logMAR and critical print size for reading was 0.35 logMAR. In other words, acuity reserve would need to exceed 0.3 log units or 2.0 for maximum reading speed. Again, the acuity reserve for the Chinese newspapers evaluated in the present study exceeded this value. The acuity reserve calculated for U.S. newspapers ranges from 2.96 to 4.44, which is similar but slightly lower than that for Chinese newspapers. A reasonable inference from our comparison of acuity reserve is that print in Chinese newspapers should be at least as legible as that in U.S. newspapers and likely more legible, although we did not make our subject comparisons with statistical analysis. Data collected from English-speaking subjects can thus be applied to Chinese populations—reading performance and satisfaction should be at least as good.

This study is not without limitations. The angular thresholds for Chinese and English characters are based on a previous study of young subjects. It is important to note, however, that the thresholds were measured in the same subjects. Although the data might reasonably be extrapolated to older subjects with normal vision, extending our findings to visually impaired patients might require some caution. Another limitation of this study is the assumption of no general differences in the resolution acuity of a subject who reads Chinese versus English. In this study, the acuity was referring only to symbol acuity. The font type of the newspapers measured in this study was Songti (宋体), which is commonly used in most of newspapers in China for historical reasons—Songti was originally named and used for printing in old China. In contrast, the font used by Zhang et al.[8] was standard bold Heiti font, which has a relatively constant stroke width, although is thinner for more complex characters (Fig. 2). Thus, the main difference between Songti and Heiti is evenness of the stroke width. The potential impact on legibility is likely to be minimal based on previous research on English text,[21,22] although it needs to be evaluated for Chinese characters. Newspaper was the medium used in this study because it represents a basic daily activity with easy access; however, the contrast of the print and crowding might have an impact on legibility and reading speed, although the effect is likely to be modest.[23] As previously noted, thresholds for Sloan letters and newspaper print may not be identical, although the difference is in the order of 0.02 logMAR.[24] Further studies might include testing multiple reading materials and making direct comparisons within a group of subjects. Finally, we did not measure reading performance in the present study. Although reading speed shows a robust relationship with font size, future studies could measure it to validate the conclusions based on acuity reserve.

China is the most populous nation in the world and has a large aging population.[25,26] Age-related visual decline is common and will also bring about increased usage of intraocular lenses and other vision aids. For such interventions to be useful, it is important that they be tested appropriately, especially for performing daily visual activities including reading. Results from the current study demonstrate that, irrespective of the language, the visual acuity testing approach and distance adopted in the United States may be applied to the Chinese population. Furthermore, although Chinese characters are more complex (vs. English), they are usually printed larger than standard English characters.

Although Snellen charts are widely used, the majority of ophthalmologists prefer logMAR visual acuity charts instead.[20,27,28] Therefore, in the current study, the visual acuity for each Chinese character complexity level was converted and presented as logMAR. Also, despite the rise in the use of digital media, we chose to use print newspapers to evaluate visual acuity demand in Chinese. The current study used five local newspapers printed in simplified Chinese from Tianjin, which were evaluated by only two investigators. These factors may present some variations, and therefore, the results should be interpreted appropriately. It is, however, important to note that the simplified (versus traditional) Chinese characters used in the study are widely used in mainland China.

Overall, results from the current study show that characters in Chinese newspapers are larger than English letters in U.S. newspapers at the same reading distance. Assuming the same reading distance, the larger character size compensates for the greater complexity of Chinese characters leading to an acuity reserve that is similar to that for U.S. newspaper print. Furthermore, with respect to clinical studies, data on visual performance from English-speaking populations might be reasonably applied to the Chinese population.

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REFERENCES

1. National Research Council. Visual Task Performance. In: Lennie P, Hemel SB, eds. Visual Impairments: Determining Eligibility for Social Security Benefits. Committee on Disability Determination for Individuals with Visual Impairments. Washington, DC: National Academy Press; 2002:126–98.

2. Flax N. Visual Factors Which Affect Reading Achievement. St. Louis, MO: American Optometric Association; 1968.

3. Whittaker SG, Lovie-Kitchin J. Visual Requirements for Reading. Optom Vis Sci 1993;70:54–65.

4. McMonnies CW. Chart Construction and Letter Legibility/Readability. Ophthalmic Physiol Opt 1999; 19:498–506.

5. Legge GE, Bigelow CA. Does Print Size Matter for Reading? A Review of Findings from Vision Science and Typography. J Vis 2011;11:8.

6. Wang CX, Lin N, Guo YX. Visual Requirement for Chinese Reading with Normal Vision. Brain Behav 2019; 9:e01216.

7. Jackson NE, Lu WH, Ju D. Reading Chinese and Reading English: Similarities, Differences, and Second-language Reading. In: Berninger VW, ed. The Varieties of Orthographic Knowledge. I: Theoretical and Developmental Issues. Dordrecht, The Netherlands: Kluwer Academic Publishers; 1994:73–109.

8. Zhang JY, Zhang T, Xue F, et al. Legibility Variations of Chinese Characters and Implications for Visual Acuity Measurement in Chinese Reading Population. Invest Ophthalmol Vis Sci 2007;48:2383–90.

9. Ma B, Wang X, Li D. The Processing of Visual and Phonological Configurations of Chinese One- and Two-character Words in a Priming Task of Semantic Categorization. Front Psychol 2016;6:1918.

10. Pitt MA, Samuel AG. Word Length and Lexical Activation: Longer Is Better. J Exp Psychol Hum Percept Perform 2006;32:1120–35.

11. Cheung JP, Liu DS, Lam CC, et al. Development and Validation of a New Chinese Reading Chart for Children. Ophthalmic Physiol Opt 2015;35:514–21.

12. Bababekova Y, Rosenfield M, Hue JE, et al. Font Size and Viewing Distance of Handheld Smart Phones. Optom Vis Sci 2011;88:795–7.

13. Rah MJ, Mitchell GL, Bullimore MA, et al. Prospective Quantification of Near Work Using the Experience Sampling Method. Optom Vis Sci 2001;78:496–502.

14. State Language Work Committee, Bureau of Standards. Modern Chinese Character Frequency Table. Beijing, China: Beijing Language Press; 1992.

15. DeMarco LM, Massof RW. Distributions of Print Sizes in US Newspapers. J Visual Impair Blin 1997; 91:9–13.

16. Arditi A, Cho J. Letter Case and Text Legibility in Normal and Low Vision. Vision Res 2007;47:2499–505.

17. Lages M, Boyle SC, Jenkins R. Illusory Increases in Font Size Improve Letter Recognition. Psychol Sci 2017;28:1180–8.

18. Recommended Stardard Procedures for the Clinical Measurement and Specification of Visual Acuity. Report of Working Group 39. Committee on Vision. Assembly of Behavioral and Social Sciences, National Research Council, National Academy of Sciences, Washington, D.C. Adv Ophthalmol 1980;41:103–48.

19. Ferris FL, 3rd, Bailey I. Standardizing the Measurement of Visual Acuity for Clinical Research Studies: Guidelines from the Eye Care Technology Forum. Ophthalmology 1996;103:181–2.

20. Ricci F, Cedrone C, Cerulli L. Standardized Measurement of Visual Acuity. Ophthalmic Epidemiol 1998;5:41–53.

21. Rubin GS, Feely M, Perera S, et al. The Effect of Font and Line Width on Reading Speed in People with Mild to Moderate Vision Loss. Ophthalmic Physiol Opt 2006;26:545–54.

22. Bernard JB, Kumar G, Junge J, et al. The Effect of Letter-stroke Boldness on Reading Speed in Central and Peripheral Vision. Vision Res 2013;84:33–42.

23. Johansson J, Pansell T, Ygge J, et al. The Effect of Contrast on Monocular versus Binocular Reading Performance. J Vis 2014;14:8.

24. Rae S, Latham K, Katsou MF. Distance Word Acuity, Critical Print Size and Driving Vision Standards. Clin Exp Optom 2015;98:459–63.

25. Wang B, Congdon N, Bourne R, et al. Burden of Vision Loss Associated with Eye Disease in China 1990–2020: Findings from the Global Burden of Disease Study 2015. Br J Ophthalmol 2018;102:220–4.

26. Chen R, Xu P, Song P, et al. China Has Faster Pace than Japan in Population Aging in Next 25 Years. Biosci Trends 2019;13:287–91.

27. Pascolini D, Mariotti SP. Global Estimates of Visual Impairment: 2010. Br J Ophthalmol 2012;96:614–8.

28. Johnston AW. Near Visual Acuity Tests Using Chinese Characters and the LogMAR Principle. Singapore Med J 1985;26:448–55.