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Korean reading speed: Effects of print size and retinal eccentricity

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ABSTRACT

Evaluating the effects of print size and retinal eccentricity on reading speed is important for identifying the constraints faced by people with central-field loss. Previous work on English reading showed that 1) reading speed increases with print size until a critical print size (CPS) is reached, and then remains constant at a maximum reading speed (MRS), and 2) as eccentricity increases, MRS decreases and CPS increases. Here we extend this work to Korean, a language with more complex orthography. We recruited 6 Korean native speakers (mean age = 22) and measured their reading speed in central vision (0°) and peripheral vision (10° in the lower field). 900 Korean sentences (average 8.25 words) were created with frequently-occurring beginner-level words, presented using a rapid serial visual presentation (RSVP) paradigm. Data for English reading were obtained from Chung, Mansfield & Legge, *Vision Research*, 1998, for comparison. MRS was similar for Korean and English at 0° (713 vs. 787 wpm), but decreased faster with eccentricity for Korean. CPS was larger for Korean than for English regardless of eccentricity, but increased with eccentricity similarly for both languages. From 0 to 10°, MRS decreased by a factor of 6.5 for Korean and 2.8 for English, and CPS increased by a factor of 11.7 for Korean and 10.2 for English. Korean reading speed is more affected by retinal eccentricity than English, likely due to additional within-character crowding from more complex orthography. Korean readers with central-field loss may experience more difficulty than English readers.

1. Introduction

Age-related macular degeneration (AMD) is a degenerative eye disease that causes damage to the central visual field. It is the third leading cause of moderate or severe visual impairment worldwide (Flaxman et al., 2017). One of the most valued activities impaired for people with AMD is reading (Mitchell & Bradley, 2006), because reading is typically slow and effortful in peripheral vision (Legge, Rubin, Pelli, & Schleske, 1985). The current study measured Korean reading speed in central and peripheral vision and compared it with English reading speed. In Korea, AMD affects approximately 1.54 million (7.4%) of the population who are 40 years or older (Cho, Heo, Kim, Ahn, & Chung, 2014). In the United States, the number of people aged 50 years or older with AMD has increased from 1.75 million in 2000 to 2.07 million in 2010, and is projected to reach 5.44 million by 2050 (National Eye Institute, n.d.). It is important to understand Korean and English reading in both central and peripheral vision.

One of the crucial factors influencing reading speed is the print size. Within a certain range, reading speed will first increase with print size until a *critical print size (CPS)* is reached, and then remain at a *maximum reading speed (MRS)* (Chung, Mansfield, & Legge, 1998; Mansfield, Legge, & Bane, 1996). The CPS increases with retinal eccentricity (Chung et al., 1998). The range of print sizes seen in daily reading materials generally exceeds the critical print size for normally-sighted young adults, but may be below the critical print size for people with central-field loss (Legge & Bigelow, 2011). One of the most common prescriptions for AMD patients is magnification using optical or digital devices.

But size is not the only factor limiting peripheral reading speed. Magnifying text size can equate the threshold duration for a 10-alternative forced-choice word-recognition task in peripheral vision to that in central vision (Latham & Whitaker, 1996). However, the speed of reading meaningful text in peripheral vision is still slower than in central vision (Chung et al., 1998; Latham & Whitaker, 1996). For normally-sighted readers, Chung et al. found a 6-fold decrease in maximum reading speed from 0° (central vision) to 20° in peripheral vision (Chung et al., 1998). In the current study, we were interested in how reading speed for Korean text is influenced by print size and eccentricity, and whether the relationship differs from the findings for English reading (Chung et al., 1998).

Korean (Hangul) and English writing systems are both alphabetic. There are 24 basic Korean letters (14 consonant letters and 10 vowel

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letters), 5 double consonants formed by two same consonant letters, and 11 compound vowels formed by two different vowel letters. But unlike English reading where letters are arranged in a linear fashion, Korean letters are arranged left-to-right, top-to-bottom in a block to form a character (Yoon, Bolger, Kwon, & Perfetti, 2002). Each character is one syllable. One or more characters are arranged left-to-right to form a word. For example, letters ㄱ("g"), ㅏ("ah"), and ㅁ ("m") are arranged into the character/syllable 감 ("gahm"), and this character could appear in words such as 감 (persimmon), 촉감 (touch), or 공포감 (fear).

This special letter configuration introduces within-character crowding for Korean reading (He, Kwon, & Legge, 2018). Identifying a Korean character involves identifying different crowded symbols with an inter-symbol spacing that is even smaller than the character spacing. Since crowding poses a major sensory limitation on reading (He & Legge, 2017; He, Legge, & Yu, 2013; Pelli et al., 2007), Korean reading, which is limited by both within-and between-character crowding, may exhibit different characteristics compared to English reading, which is limited mainly by between-character crowding. In our study, we compared Korean and English reading performance in central and peripheral vision.

2. Methods

2.1. Subjects

We recruited 6 normally-sighted (4 female and 2 male), Korean-English bilingual students from the University of Minnesota. These subjects were native Korean-speakers with English fluency sufficient to support college studies in the United States. Subjects were between 18 and 26 years old (mean = 22) and their average binocular letter acuity was −0.017 logMAR (Lighthouse Near Acuity Chart, Lighthouse Low Vision Products, Long Island City, NY). All subjects signed an IRB-approved consent form prior to the experiment, and received monetary compensation. Our experimental procedure was in compliance with the Declaration of Helsinki.

2.2. Stimuli and apparatus

900 Korean sentences were generated for measuring reading performance. The sentences were first extracted from elementary school-level reading materials and shortened to about 8 words. They were then altered to include words that appear on the lists of frequent words in the Korean language ("부록:자주 쓰이는 한국어 낱말 5800 [Appendix: 5800 Frequently used Korean words]," n.d.; National Institute of the Korean Language, 2005) and vocabulary words recommended for learning Korean (National Institute of the Korean Language, 2003). Some sentences were further changed according to the standardized Korean spell-checker tool ("네이버 맞춤법 검사기 [Naver Spell-Checker]," n.d.). The final set of sentences was 8.25 ± 1.02 words long, and 95.7% of the words were within the frequent or educational word lists. An example sentence is "우리는 호랑이가 보고 싶어서 동물원에 왔습니다" (25 characters including spaces, 6 words, read left-to-right; translation: "We came to the zoo because we wanted to see tigers").

For comparison, the English sentences used in Chung et al. (1998) had an average length of 11 ± 1.7 words, and all words came from the 5000 most frequent words in written English according to the British National Corpus. The English sentences are longer, but in general more words are needed for English compared to Korean to convey similar information. We compared the word count of the English and Korean versions of the Universal Declaration of Human Rights (http://www.ohchr.org/EN/UDHR/Pages/SearchByLang.aspx), excluding headings and numeration. The English version contained 1680 words, which is 1.55 times larger than the Korean version (1087 words). The average word count for the English sentences used in Chung et al. (1998) was 1.33 times larger than our Korean sentences.

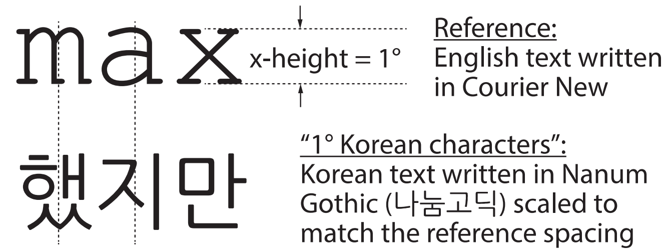

Fig. 1. Definition of Korean print size (details see text).

The Korean characters were rendered in *Nanum Gothic (나눔고딕)*, which is a fixed-width font for Korean. There are many potential ways to equate Korean and English text size, but we specified the print size for Korean text by equating the character spacing to the reference English text written in *Courier New* (also fixed-width; Fig. 1). For example, to create 1° Korean characters, we scaled Korean text (written in *Nanum Gothic* with its default spacing) so that the center-to-center spacing between characters matched that for the reference English text with an x-height of 1°. These "1° Korean characters" have an ink height of about 1.33°. Courier New was selected as the reference font because it is fixed-width and it has a stroke width similar to Korean text when scaled. We could not use the font used in Chung et al. (1998), Times-Roman, as the reference because it was a proportional-width font. While the stroke width may differ between Courier New and Times-Roman, English reading performance with normal vision remains unchanged for a range of stroke widths, in both central and peripheral vision (Bernard, Kumar, Junge, & Chung, 2013). We defined Korean print size by matching character spacing because x-height is a well-defined measurement for the size of English letters, and letter spacing is an important factor influencing letter-recognition and reading performance via influencing crowding (Chung, 2002, 2014; Levi & Carney, 2009; Pelli et al., 2007; Yu, Cheung, Legge, & Chung, 2007).

Our stimuli were black Korean characters on a white background (background luminance 102 cd/m^2; Weber contrast = 98%). The stimuli were generated and presented using MATLAB R2014b with Psychophysics Toolbox 3 (Brainard, 1997; Pelli, 1997). We used a NEC MultiSync CRT monitor (model FP2141SB-BK, NEC, Tokyo, Japan; refresh rate = 100 Hz) controlled by a Mac Pro Quad-Core computer (model A1186, Apple Inc., Cupertino, CA). The stimuli were either presented foveally or at 10° in the lower visual field. For measurements in central and peripheral vision, the viewing distance was 200 and 40 cm respectively, and the corresponding spatial resolution of the screen was 0.009°/pixel and 0.04°/pixel.

2.3. Procedure

The experiment required two 2-h sessions, scheduled on two different days at least one week apart. In each session reading speed was measured using Rapid Serial Visual Presentation (RSVP) (Forster, 1970; Rubin & Turano, 1992), similar to Chung et al. (1998). RSVP reading speed was measured in both central and peripheral visual fields (0° and 10° in the lower visual field), using 6 different print sizes each. The print sizes (in x-height) were 0.1, 0.14, 0.19, 0.26, 0.36, and 0.5° in central vision, and 1.2, 1.46, 1.78, 2.63, 3.55, and 5.01° in peripheral vision. The sets of print sizes were chosen based on pilot testing to cover both the rising and the flat part of the two-line reading curve. Each print size was tested in one block of 18 trials. The order of two visual fields and 6 print sizes was counterbalanced across subjects for the first daily session, and reversed in the second daily session.

2.4. RSVP reading speed measurement

In each RSVP trial, a sentence was randomly selected without