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Lexical properties influencing visual word recognition in Hangul

Hye K. Pae[1] · **Sungbong Bae**[2] · **Kwangoh Yi**[2]

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Abstract
This study examined how lexical properties, such as word frequency, word length, and morphological features, affect the word recognition of Korean Hangul among adult readers. Ninety-four native Korean students performed a lexical decision task on disyllabic and trisyllabic words and nonwords. Results of cross-classified and hierarchical linear modeling showed a significant frequency effect but null effects of word length and their interactions on word recognition. The null syllable effect might be contributable to the block structure of syllables, which does not require syllabic decomposition in recognition. Given that Chinese-derived Sino-Korean words account for about 70% of the Korean lexicon, morphological features embedded in the word were examined in order to further understand the morphological undercurrent of multisyllabic word recognition. Word type (bound-morphemic words vs. compound words), word origin (native or semi-native words vs. Chinese-derived words), and morphemic transparency (opaque morpheme vs. transparent morpheme) were significant predictors of the speed of visual word recognition. An analysis of frequency split showed that compound words and morpheme transparency facilitated word recognition for high frequency words, while the number of morphemes within the word, Korean native and semi-native words, and morphemic transparency facilitated word recognition for low frequency words. These results suggest that high and low frequency words function differently according to morphological information available within the multisyllabic word in visual word recognition in Hangul.

Keywords Korean Hangul · Lexical decision · Morphological features · Word frequency · Word length

✉ Hye K. Pae
hye.pae@uc.edu

✉ Kwangoh Yi
yiko@yu.ac.kr

Extended author information available on the last page of the article

Introduction

Given that reading is a multifaceted cognitive process and that efficient word recognition is a foundational skill of reading, an identification of the mechanism behind the proficient recognition of isolated words has been of crucial interest in reading science. The robust effects of word frequency and word length on word recognition have been well documented especially in Roman alphabetic orthographies (Barton, Hanif, Björnström, & Hills, 2014; Carreiras, Álvarez, & de Vega, 1993; Conrad & Jacobs, 2004; Ferrand & New, 2003). General findings point to the significant effects of word frequency and word length in varying degrees in Roman orthographies. Hangul provides a unique ground to expand on the literature due to being an alphabet in endogeneity (as an operating principle) and a syllabary in exogeneity (in appearance). In other words, Hangul conforms to the alphabetic principle such that graphs represent phonemes and that multiple graphs are grouped together to form a syllable, which is the intrinsic or endogenous nature of the script. However, graphs are written in square blocks, showing a structural autonomy of the syllable, which is the extrinsic or exogenous appearance similar to Chinese characters. This unique feature of Hangul is a departure point from Roman alphabets and Chinese morphosyllabary. Drawing upon Hangul's characteristics that cannot be found in other orthographies, this study investigated the effects of lexical properties, including word frequency, word length, and morphological features, as well as their interactions in visual word recognition among adult readers of Korean. Given that research on Korean has been built upon research on Roman alphabets, we review research findings in Roman script first before moving on to Korean studies.

The effects of word frequency, length, and morphological features on word recognition in Roman script

Irrespective of the theory of serial letter recognition or parallel letter recognition, word frequency and word length have been extensively examined with respect to relationships between these variables and response time (RT). Research shows that words that frequently appear in text are easier and are more accurately and even quickly recognized than words that appear less frequently. Murray and Forster (2004) asserted that the most important variable in word recognition was the "frequency of occurrence of the pattern" (p. 721) among lexical variables of concreteness, length, regularity or consistency, homophony, number of meanings, and neighborhood density. Brysbaert et al. (2011) analyzed RTs of both lexical decision and naming[1] of 40,481 English words with a wide range of variables, including

[1] Although this study examined lexical decision data, a small number of studies reporting naming data was reviewed in this article only when naming data were presented in comparison to lexical decision data in the studies reviewed. In addition, the literature review is based on adult data because children's reading is still in the (transient) developmental stage, as Beyersmann, Castles, and Coltheart (2012) indicate that reading automization does not appear until a relatively late stage in reading development.

word frequency, a series of orthographic, phonological, and phonographic characteristics, and the numbers of phonemes, morphemes, and syllables within the word (see p. 412 for the variable descriptions). The results of multiple regression analyses showed that the most important variable predicting lexical decision latency was word frequency, explaining 41% of the variance in RT (Brysbaert et al., 2011; see Table 1). The results of naming tests also showed a similar pattern, although the magnitude of the explained variance in RT was smaller than that in lexical decision. Another study showed a very similar result. Brysbaert, Stevens, Mandera, and Keuleers (2016) reported in a large-scale study of a lexicon project that word frequency accounted for 42% of the variance in English word recognition (see Table 4) and 33% of the variance in Dutch word recognition (see Table 10).

Another important variable affecting RT in word recognition is word length, which is typically defined as the number of letters (Brysbaert et al., 2011; New, Ferrand, Pallier, & Brysbaert, 2006) or the number of syllables (Ferrand & New, 2003). In English, the number of letters within the word rarely aligns with the number of syllables due in part to the inconsistency of the number of letters involved in a syllable (e.g., three-letter-one-syllable word *cat* vs. nine-letter-one-syllable word *strengths*) or silent letters (e.g., *though, knee*). The varying degrees of length effects have been found depending on the different number of letters and syllables used in studies (Barton et al., 2014; New et al., 2006; Samuel, van Santen, & Johnston, 1982). Samuel et al. (1982) examined length effects in word perception using one-letter, two-letter, three-letter, and four-letter strings and words. The one-letter word "I" (pronoun) and "A" (indefinite article) did not show an advantage despite their independent lexical status. They also found lower accuracy of letter recognition for two-letter words than for three- to four-letter words. This result can be attributable to the fact that two-letter words tend to be function words which carry little lexical meaning and express grammatical relationships with other words within the sentence (e.g., *to, on, at*), while three- to four-letter words tend to be content words (e.g., nouns, verbs).

New et al. (2006) examined word length effects in visual word recognition, using 33,006 English monosyllabic and disyllabic words ranging from 3 to 12 letters in length from the English Lexicon Project. Overall, a U-shaped length effect was found; that is, a facilitatory effect was observed for words that had from three to five letters, a null effect for words that had from five to eight letters, and an inhibitory effect for words that had from 8 to 13 letters within the word. They also reported that word frequency, the number of syllables, and the number of orthographic neighbors explained unique variances in visual word recognition, but the length effect was independent of word frequency, the number of syllables, and the number of orthographic neighbors of monomorphemic nouns and bisyllabic words.

Also reported was a significant length effect on the performance of visual word recognition and naming in French. Ferrand and New (2003) found a significant effect of syllabic length on naming RT for nonwords and very low-frequency words (but not for high frequency words; Experiment 1) and a significant syllabic length effect on lexical decision for very low-frequency words (but not for high-frequency words and nonwords; Experiment 2). The common thread of the findings from their naming and lexical decision data was the robust effect of syllabic length for low-frequency words. They also explained that high-frequency words were processed through a global and parallel procedure, while low-frequency words were processed via an analytic and sequential procedure in both naming and visual recognition. They also noted that syllabic decomposition was required for processing very low-frequency words, as the syllable served as an important unit of reading in French.

Balota et al. (2004) investigated visual word recognition of 2428 single-syllable words among young adults and healthy older adults using word naming and lexical decision tasks in English. Examined were the phonological features of onsets, lexical features including consistency, frequency, familiarity, neighborhood size, and length, and semantic features including imageability and semantic connectivity. The semantic-level variables associated with imageability and semantic connectivity accounted for a unique variance in both speeded naming and lexical decision performance, but greater semantic-level effects were found in lexical decision. Yap and Balota (2009) also reported that the variance explained by similar variables to those of Balota et al. (2004) in monomorphemic multisyllabic words was greater than the variance explained in monosyllabic words in lexical decision.

Readers seem to segment words based on a morpho-orthographic unit. Beyersmann, Castles, and Coltheart (2012) examined, using the masked priming paradigm, the mechanism of morpho-orthographic decomposition in visual word recognition among adult readers and children. In a masked primed lexical decision, they compared prime-target pairs in three conditions, including related word stem (*golden–GOLD*), pseudo-stem (*mother–MOTH*), and unrelated form control (*spinach–SPIN*) conditions. Their adult data showed significant priming effects in the conditions of related word stem and pseudo-stem in high-frequency words. Similar priming effects were found in first and second language word recognition. Diependaele, Duñabeitia, Morris, and Keuleers (2011) tested native English speakers as well as Spanish–English and Dutch–English bilinguals using a masked morphological priming lexical decision task. They used related (or transparent) word stem pairs (e.g., viewer–view), pseudo-stem pairs (e.g., corner–corn) and form control pairs (e.g., freeze–free). They noted that bilinguals made use of morphological information in a similar way to monolinguals' in word recognition. Priming effects were the greatest with the related primes, followed by the pseudo-stem primes, and the form control primes. Their findings suggest that semantic transparency effects occur in the initial stages of word recognition in both first and second languages.

The effects of word frequency, length, and morphological features on word recognition in Korean Hangul

Korean Hangul demonstrates idiosyncratic features because it is an alphabetic orthography but shows a distinct syllabic unit, as graphs are packaged within square blocks (e.g., {한글}[2] <Hangul> rather than {ㅎ ㅏ ㄴ ㄱ ㅡ ㄹ}). This is different from English and other alphabetic orthographies in which not only are syllabic boundaries ambiguous, but also graphs are arranged in a linear fashion.

There have been much fewer studies conducted with regard to the role of word frequency in visual word recognition in Hangul than in English and other alphabetic scripts. The existing studies of Korean Hangul show inconsistent results on the effect of word frequency with one line of studies showing significant frequency effects (Bae, Park, Lee, & Yi, 2016; Oh, Choi, Yi, & Lee, 2007; Park, 1993) and another line of studies showing null or marginal effects (Lee, Lee, & Kim, 2016; Simpson & Kang, 1994). Specifically, Lee et al. (2016) reported that a by-item analysis showed no significant frequency effect (Experiment 1). Simpson and Kang (1994) also suggested that Hangul might exert smaller frequency effects than Chinese or English because Hangul's mapping of graphemes to phonemes is consistent. They found that the frequency effect was affected by the composition of the list in which stimulus words were embedded. Specifically, the frequency effect was large when Hangul words were embedded in Hanja words (traditional Chinese characters used in Korea), but significantly diminished when the list included Hangul words only. Simpson and Kang (1994) further raised the possibility that even the small frequency effect in the Hangul-only condition (approximately 20 ms) might have stemmed from the syllabic characteristics. These results warrant further research on the effect of word frequency in Hangul word recognition.

Regarding word-length effects, Park (1993) examined the effects of one-syllable, two-syllable, three-syllable, and four-syllable words and nonwords on word recognition employing both naming and lexical decision tasks. There was a linear relationship among the different syllabic lengths in naming, indicating that the more syllables, the slower naming (Experiment 1). However, data from the lexical decision task showed a different pattern. There was a judgment disadvantage for one-syllable words, which was consistent with previous research (Samuel et al., 1982). The word recognition of two-syllable, three-syllable, and four-syllable words was faster than that of one-syllable words, but did not show significant differences among them (Experiment 2; see Table 3). When word frequency was broken down into high and low bands, one-syllable words took the longest time for high frequency words, while two-syllable words took the shortest time. For low frequency words, the one-syllable disadvantage was not observed, although RT did not show a linear pattern demonstrating four-syllable words being the fastest, followed by three-syllable words, one-syllable words, and two-syllable words (see Table 4). A mega-study of the Korean Lexicon Project conducted in accordance with the lexicon projects of

[2] In this article, curly brackets { } are used for orthographic representations and angle brackets < > for semantic explanations.

other languages, such as English, French, and Dutch, showed a similar pattern of syllabic length effects. Yi et al. (2017) used one-, two-, three-, four-, and five-syllable 30,930 words in lexical decision tasks, and found that three-syllable words were recognized at the fastest rate (605 ms), followed by two-syllable words (618 ms) and four-syllable words (619 ms). One-syllable words showed a disadvantage (622 ms), along with five-syllable words (623 ms). Oh and colleagues (2007) also showed one-syllable word disadvantage in Korean word recognition. Globally, this result was in line with the U-shaped length effects found in English (New et al., 2006).

A recent study by Bae and colleagues (2016) reported a consistent finding with monosyllabic and disyllabic Korean words in a lexical decision task performed in two experiments using mixed and block presentations. The results of the two presentations were not significantly different from each other. Although they eliminated semantic ambiguity from the stimuli, most of disyllabic words used in the stimuli were Sino-Korean words which were of Chinese origin and morpheme-based. Therefore, it was possible that morphological information that disyllabic words embedded within the word might have facilitated the speed of word judgment. Bae et al. (2016) concluded that morphological activation and its resultative competitions among activated candidates for the target might be the source of the monosyllabic word disadvantage effect.

Beyond word frequency and word length, the Korean lexicon has another layer that affects word recognition. Korean words are classified into three kinds of words based on the origin of the word: (1) words of native Korean origin, (2) Sino-Korean words (Chinese-derived words in Korean pronunciation), and (3) loanwords. Native-Korean words and loanwords are written only in Hangul because there are no corresponding references to Hanja (e.g., {방울} in Hangul only), while Sino-Korean words can be written in both Hangul and Hanja due to the availability of the shared reference (생일 in Hangul; {生日}in Hanja). The distribution of words classified in this way can be slightly different depending on the corpus on which the classification is based and methodology used, but what is consistent is the largest portion of Sino-Korean words in the Korean lexicon. Lee (1980) reported the makeup of Korean vocabulary as follows: 25.9% native words, 67.9% Sino-Koreans, and 7.1% loanwords. Another distribution shows 24.4% native words, 69.3% Sino-Korean words, and 6.3% loanwords (Kim, 1993). A study showed that Korean readers were able to classify words into these three kinds of vocabulary even though the target words were written in Hangul only with about 90% of accuracy, regardless of their Hanja knowledge (see Yi, 2003).

Differences between Sino-Korean and native Korean words are two-fold in a related way. First, each syllable represents a free morpheme in the Sino-Korean word, but not necessarily so in the native Korean word. In other words, due to having Chinese origin, each syllable of the Sino-Korean word corresponds to a morpheme. For example, the disyllabic word {직선} meaning <straight line> comprises two morphemes, {직} meaning <straight> {선} meaning <line>, each of which represents a morpheme at the syllabic level. In contrast, the Korean native word {방울} <(tiny) bell> takes two syllables to gain a lexical status with no Hanja equivalent. Another example is the monosyllable Sino-Korean word {인} meaning a <human being>. The corresponding referent in the native Korean word is {사람} in which the two syllables are inseparable to mean the same meaning. Second, the number of syllables required for free lexical status varies. In other words, most disyllabic Sino-Korean words consist of two constituent morphemes within the word (e.g., {낙엽}, the first syllable meaning *fall* and the second *leaf*, <fallen leaf>). Korean native words are less likely to have constituent morphemes than Sino-Korean words and tend to have words that take more than one syllable to gain their independent lexical status (i.e., bound-morphemic words). For instance, the word {아침} meaning <morning> consists of two syllables (아 + 침) which are bound to each other to gain the lexical referent and each syllable has little to do with the meaning of the given word when separated.

Due to the difference in the lexical property embedded within the word, the processing of the three different kinds of words might be different. Yi (2003) conducted a study to determine whether or not word origins made a difference in word recognition, using native words, Sino-Korean words, and loanwords in lexical decision and naming tests with two different presentation manipulations. Results showed that native words were consistently recognized the fastest, followed by Sino-Korean words, with loanwords the slowest in both lexical decision and naming. However, the different proportion of these three kinds of words presented in the experimental condition affected only lexical decision, not naming.

Present study and hypotheses

This study was motivated by the unique characteristics that Hangul manifests in at least four ways. First, unlike other writing systems that have evolved over time, Hangul was invented by King Sejong in the fifteenth century. The specific purpose for the invention was to develop a writing system that was easy to learn to read and that was compatible to the spoken Korean language. Hangul has 40 graphs which correspond to 40 phonemes (i.e., one grapheme represents one phoneme without the consideration of sound variations in multisyllabic words; Pae, Bae, & Yi, 2020). This makes Hangul easy to learn to read. This might lead to no or reduced word frequency effect because Hangul has a comparatively regular grapheme-phoneme correspondence (Lee et al., 2016; Simpson & Kang, 1994). However, salient frequency effects have also been found (Bae et al., 2016; Oh et al., 2007; Park, 1993; Yi et al., 2017). Therefore, more research is needed using homogeneous syllabic structures to resolve the inconsistent findings. Second, Hangul conforms to the alphabetic principle as an alphabetic orthography using non-Roman graphs. Under the alphabetic principle, graphs represent phonemes rather than morphemes, and syllables comprise multiple graphs as in English. This shared principle may result in similar research findings in Korean and English. Third, graphs are written in square-blocks rather than in left-to-right sequence, which yields visual autonomy of syllabic units. Reflecting the characteristics of an alphabet and a syllabary, Hangul is dubbed an *alphasyllabary* (Taylor & Taylor, 2014). Thus, syllabic parsing or decomposition that is necessary for Roman alphabetic orthographies (Ferrand & New, 2003) is not mandatory for Hangul. This feature may exert minimal or no word length effects in word recognition in Hangul. Fourth, as indicated earlier, the high proportion of

Sino-Korean words in the lexicon may yield significant morphological effects on word recognition. This may lead to a salient role of morphology in Hangul word recognition.

Two research questions were examined in this study to address those features of Hangul by investigating the degree to which word frequency and word length affected word recognition as well as the role of morphological features in Hangul word recognition.

1. To what extent do word frequency and word length affect word recognition in Korean disyllabic and trisyllabic words among adult readers?
2. Which morphological feature facilitates visual word recognition in Korean Hangul among the number of morphemes, word type (bound-morphemic words vs. compound words), word origin (i.e., native and semi-Korean words vs. Sino-Korean words), and morphemic transparency (i.e., opaque morpheme vs. transparent morpheme)?

The first research question was posed to examine the extent to which word frequency and word length affect word recognition of uniform consonant–vowel–consonant (CVC) disyllabic and trisyllabic words. Monosyllabic words were not included in this study because they have already sufficiently examined in the literature (Bae et al., 2016; Lee et al., 2016; Oh et al., 2007; Park, 1993). We used both disyllabic and trisyllabic words containing CVC syllables for comparison because they contained six and nine graphs in total, respectively. These numbers of graphs were large enough to accord with the numbers of letters used in studies of English (e.g., New et al., 2006). In addition, since Yi et al.'s (2017) study used a mixture of CV and CVC syllables in the stimuli, we used only CVC syllables for the stimuli to examine length effects within the same syllabic structure. Another reason for the inclusion of disyllabic and trisyllabic words in this study was the fact that they allowed for an examination of the multiple dimensions of morphological properties, such as the number of morphemes, word type, and morphemic transparency. Although some studies found marginal or null effects of frequency (Lee et al., 2016; Simpson & Kang, 1994), it was hypothesized that there would be a significant frequency effect given that Hangul is an alphabetic orthography and that other alphabetic orthographies showed a significant frequency effect (Brysbaert et al., 2011, 2016; Murray & Foster, 2004; Samuel et al., 1982). In addition, previous studies also found significant frequency effects in the stimuli of mixed syllabic structures (Oh et al., 2007; Park, 1993; Yi et al., 2017). Since that disyllabic words comprise six graphemes and trisyllablic words consist of nine graphs, it is possible that disyllabic words would be read faster than trisyllabic counterparts based on the results found in English (New et al., 2006). However, we hypothesized that word length effect would be marginal or nonsignificant because Hangul does not require syllabic parsing due to the syllabic autonomy provided in blocks.

The second research question was formulated because Sino-Korean words account for the largest portion in the Korean lexicon, as indicated earlier, especially in disyllabic and trisyllabic words. Given this linguistic characteristic in the Korean lexicon, it was hypothesized that morphological features would facilitate the speed of lexical decision.

In other words, the morphological properties, such as the number of morphemes within the word, word type (i.e., bound-morphemic word vs. compound word), word origin (i.e., native and semi-Korean words vs. Sino-Korean words), and morphological transparency (opaque morphemes vs. transparent morphemes within the word), would influence word recognition in Hangul.

Method

Participants

A total of 94 university students participated in a lexical decision test from a co-ed comprehensive university in Korea. The mean age of the participants was 23.34 (SD = 1.97), ranging from 20 to 28. Male students comprised 39%. All of them were Korean native readers of Korean. Their vision or corrected vision and motor skills were self-reported to be in the normal range. Neither reading disabilities nor neurological problems were reported.

Stimuli and variables

The stimuli included 240 letter strings in total, including 120 words (60 disyllabic and 60 trisyllabic words) and 120 nonwords with the equal number of disyllabic and trisyllabic nonwords (see Appendix). The mean of word frequency was 41.41 per million words ($SD = 57.13$), ranging from 1 to 299 (Kim, 2005[3]); the mean frequency of disyllabic words was 47.98 ($SD = 66.36$) and that of trisyllabic words was 34.84 ($SD = 45.16$). For disyllabic words, the mean of high frequency words was 84.28 ($SD = 78.52$), while that of low frequency words was 11.77 ($SD = 4.86$). For trisyllabic words, the mean of high frequency words was 62.35 ($SD = 54.15$), while that of low frequency words was 10.76 ($SD = 4.02$). The high and low frequency counts were significantly different: $t(5638) = 8.69$, $p = .000$.

DMDX (Foster & Foster, 2003) was utilized for the random presentation of the stimuli. Four lists were constructed for each syllabic length to counterbalance the presentation such that each participant saw each item only once in the experiment.

Based on the stimulus features, four morphology-related variables were constructed. First, the number of morphemes within the multisyllabic word was counted to form a variable used for this study. Second, each stimulus was determined as either a bound-morphemic word (i.e., as each syllable cannot stand alone to refer to a given meaning, both syllables are bound together to gain a lexical status; e.g., {방울}) or a compound word (i.e., each syllable within the compound word is a free morpheme but two morphemes are combined to form a new word; e.g., {직선}). Third, word origin was determined based on whether the target is of native or

[3] The word frequency measure, based on a corpus of three million words that were published in print materials since 1990, includes frequencies of segments (i.e., consonants and vowels), syllables, words, particles, suffixes, and phrases.

semi-Korean origin[4] or of Chinese origin, as explained earlier. Lastly, morphological transparency was determined by whether or not the individual morpheme within the syllable was clear or unclear, as some words have an unstraightforward combination of morphemes in disyllabic words. For example, the first syllable of the word {곶감} <dried persimmon> is opaque because it does not have a reference to <dry>, while the second syllable is transparent because it is a discrete referent to a kind of fruit <persimmon>.[5] In order to ensure the coding of the morphological properties, three researchers completed coding independently first, and the interrater reliability coefficients were computed. The agreement rates of coding across the variables ranged from 88 to 93% in the first round of coding. After discussing the intricacies, the agreement reached 100% in the second round.

Procedure

The participant individually performed a lexical decision task in a quiet laboratory. A fixation point "*" appeared on the computer screen for 500 ms, followed by a blank screen of 300 ms, and then the target was displayed for 2000 ms or until a response was provided. Each participant completed 30 practice items, which were not included in the main experiment, before moving on to the main experimental items.

Analysis

A technical concern has arisen regarding the traditionally performed separate by-item and by-subject analyses because they tend to inflate a Type I error or overestimate parameters. Separate single-level analyses entail aggregation bias, misestimated standard errors, the heterogeneity of regression slopes, and the systematic misestimation of group effects, which can mislead the interpretations of study results (Baayen, Davidson, & Bates, 2008; Yan & Tourangeau, 2008). It can be viewed that, due to the interdependent nature between subjects and items, RT is nested within the cell formed by cross-classified subjects and items. The intra-subject and intra-item correlations and the cross-classified structure of subjects and items need to be considered in order to avoid inflated variances estimated for parameters (Baayen et al., 2008; Yan & Tourangeau, 2008). So as to address the limitations of separate by-subject and by-item analyses, a two-level cross-classified model (CCM) and a

[4] The determination of the morphological properties of the stimuli was complicated to some degree. Some Korean words have a mixture of a native Korean word and a Sino-Korean word; for example, The word {강물} <river (water)> has one Chinese-origin syllable {강} <river> and another native one-syllable word {물} <water> in the first and the second position, respectively. We classified the mixture of a Korean morpheme and a Sino-Korean morpheme as a semi-Korean word because the focus of the classification was whether the word was of Chinese-origin or not in order to tease apart the role of morphological information.

[5] To be consistent with the coding scheme for the determination of the word origin, the mixture of an opaque and a transparent morpheme was considered opaque because the purpose of the study was to examine the role of clear morphological information.

Table 1 Means and standard deviations in milliseconds by word length

	2-Syllable target		3-Syllable target	
	Word	Nonword	Word	Nonword
Mean	642	750	636	724
SD	164	201	158	207

SD standard deviation

two-level hierarchical linear model (HLM) were tested for this study, using HLM 7.0 (Raudenbush, Bryk, & Congdon, 2010). In other words, the effects of both item and subject characteristics on RT were examined concurrently.

Results

Given that they were all university students in Korea, the participants recognized the stimuli efficiently. Due to the near ceiling effect, accuracy data were not analyzed. Regarding RTs, data trimming took place with the criteria of below 300 ms (ms) and above 1700 ms to be deleted. For disyllabic words, of 11,280 cases, 369 incorrect cases (3.27%) and 40 cases (0.4%) of outside the range were deleted. For trisyllabic words, of 11,280 words, 305 incorrect cases (2.7%) and 25 cases (0.2%) of outside the range were deleted. The software HLM 7.0 (Raudenbush et al. 2010) takes care of missing cases and uneven cases across cells adequately.

Table 1 displays the means and standard deviations of RTs measured with two-syllable and three-syllable targets. The mean difference in RT between two-syllable and three-syllable words was 6 ms, and was not significantly different from each other: $t(5466) = 1.276$, $p = .202$). Note that the two-syllable word comprised six graphs, while the three-syllable word consisted of nine graphs.

Research question 1: effects of word frequency and word length

A two-level CCM was tested. RTs to all items by all subjects were specified as level-1 data (a within-cell model that represents relationships among RTs). The subject characteristics (age and gender) and item characteristics (word frequency and length) were entered into the model as level-2 data (between-cell model that captures the influences of items- and subjects-level factors) with items as column variables and subjects as row variables. First, an unconditional model (a.k.a., a null model which is akin to a one-way ANOVA with random effects; Model 1) was tested using the restricted maximum likelihood estimation with no predictor variables entered into the model. The level-1 model was $RT_{ijk} = \pi_{0jk} + e_{ijk}$, where RT_{ijk} was the *i*th RT for item *j* to subject *k*; π_{0jk} was the mean (or expected RT) for cell *jk* cross-classified by item *j* and subject *k*; and e_{ijk},was the random effect of individual response time. The level-2 model was $\pi_{0jk} = \theta_0 + b_{00j} + c_{00k}$, where θ_0 is the grand mean RT; b_{00j} is the random main effect for item *j*; c_{00k} is the random main effect for subject *k*.

Table 2 Fixed and random effects of cross-classified models for research question 1

Model	Component	Coefficient	SE	*t*	*df*	*p*
Fixed effects						
Model 1	RT, $\theta 0$	641.25	8.67	73.94	5134	< 0.001
Model 2	RT, $\theta 0$	653.71	96.03	6.08	5134	< 0.001
	Gender, γ_{01}	– 1.06	16.71	– 0.06	92	0.949
	Age, γ_{02}	0.53	4.17	0.13	92	0.898
	Frequency, β_{01}	– 43.27	8.19	– 5.28	238	< 0.001
	Length, β_{01}	– 5.77	8.17	– 0.71	238	0.481
Model 3	RT, $\theta 0$	696.88	98.97	7.04	5132	< 0.001
	Gender, γ_{01}	1.82	17.19	0.11	92	0.916
	Age, γ_{02}	– 1.17	4.29	– 0.27	92	0.786
	Frequency split, β_{03}	– 128.33	47.45	– 2.71	238	0.007
	Length, β_{03}	– 14.67	11.57	– 1.27	238	0.206
	Frequency × length, β_{03}	17.63	16.34	1.08	476	0.282
	Gender × length, γ_{04}	– 5.65	7.87	– 0.72	5132	0.473
	Age × length, γ_{05}	3.36	2.01	1.67	5132	0.094
Model	Component	SD	Variance component	df	χ^2	*p*
Random effects						
Model 1	Row, b_{00j}	72.89	5313.48	93	1782.04	< .001
	Level-1, *e*	131.34	17248.89			
	Col, c_{00k}	60.96	3715.99	239	1349.55	< .001
	Deviance	69,556		# Parameter		4
Model 2	Row, b_{00j}	72.94	5319.69	89	1786.54	< .001
	Level-1, *e*	131.33	17247.48			
	Col, c_{00k}	56.92	3240.44	235	1221.37	< .001
	Deviance	69,529		# Parameter		8
Model 3	Row, b_{00j}	73.01	5330.23	86	1791.50	< .001
	Level-1, *e*	131.29	17236.38			
	Col, c_{00k}	56.80	3226.18	232	1217.66	< .001
	Deviance	69,525		# Parameter		11

SE standard error, *SD* standard deviation

Overall, the mixed model was $RT_{ijk} = \theta_0 + b_{00j} + c_{00k} + e_{ijk}$. Model 1 showed that the variance of RT was significantly different from zero and that further CCMs with predictor variables would be necessary. The variance components of the row and column variables were significant: $\chi^2(93) = 1782$, $p < .001$. This indicated that it was appropriate to test further CCMs to statistically justify the variance of RT explained by the level-2 variables. The residual variance component was large, demonstrating that there was a considerable residual variation in RT yet to be accounted for with additional predictors in the model.

Based on the results of the unconditional model, predictor variables were added to the null model equation. The predictor variables were the subject variables and the item variables. For the first CCM, the frequency count and the syllable count for each stimulus were entered. When the subject characteristics and the item characteristics were crossed, only word frequency was a significant predictor of the outcome variable RT (Model 2): $b = -43.27$, $p < .001$. The level-1 intercept, which was a function of the grand mean and a level-1 residual error term, was 654 ms. This indicated that RT could be 611 ms, which was reduced by 43 ms from the intercept, depending on the frequency counts. Table 2 shows the fixed effects of the CCMs tested for Research Question 1. Concerning random effects, both column and row variables showed significant variance components (see the bottom part of Table 2). With the predictor variables entered into the model, the CCM became a better model fit, as indicated by the reduced deviance and the reduced residual variance component from Model 1.

Another CCM was tested to further examine interaction effects. In order to accord with previous studies (Ferrand & New, 2003; Park, 1993), the frequency data were split into high and low bands (Model 3). The same subject and item variables (except for the frequency split) were entered into the model, along with interaction terms. The results were consistent with Model 2, showing only the frequency split variable being significant: $b = -128.33$, $p = .007$. The t-ratio was the regression coefficient divided by its standard error. The group of high frequency words used in this study could be processed at the rate of 569 ms, reduced by 128 ms from the grand mean of 697 ms.

In the two models tested in Models 2 and 3, word length showed neither main effects nor interaction effects with the frequency variable and the subject characteristics. In order to better understand the undercurrent of Hangul word recognition, the morphological features were examined in the second research question due to the heavy presence of Sino-Korean words in vocabulary.

Research question 2: morphological predictor(s) influencing word recognition in Hangul

Research Question 2 was posed to examine the role of morphological features, including frequency, the number of morphemes within the word, word type (bound-morphic word vs. compound word), word origin (native and semi-Korean word vs. Sino-Korean word), and morphemic transparency (morphologically opaque vs. morphologically transparent within the multisyllabic word). Since we were interested in the main effect of each variable building upon the results of Research Question 1, we adopted an HLM with the outcome variable RT being nested within the subject.

The null model indicated that an HLM would be tenable and would better fit the data with additional predictors, as indicated by the variance component: $\chi^2(93) = 1449$, $p < .001$ (see Model 1 in Table 3). Model 2 was specified using the individual item's frequency as a predictor, along with the other morphological variables that were used as dummy variables except the number of morphemes within the word. We compared the mean RT of each dummy explanatory variable (coded 1)

Table 3 Fixed effects and random effects of hierarchical linear models including morphological features for research question 2

Component	Coefficient	SE	t	df	P
Fixed effects					
Model 1					
RT, $\theta 0$	638.66	7.73	82.62	93	< 0.001
Model 2					
RT, $\theta 0$	670.81	15.01	44.69	93	< 0.001
Frequency, γ_{10}	– 0.30	0.03	– 10.92	5369	< 0.001
# Morphemes within word, γ_{20}	– 9.20	5.65	– 1.63	5369	0.104
Bound-morphemic or compound word, γ_{30}	– 20.94	15.53	– 1.35	5369	0.177
Native or Sino-Korean, γ_{40}	17.34	5.81	2.99	5369	0.003
Opaque or transparent, γ_{50}	– 3.59	4.52	– 0.79	5369	0.428
Model 3					
RT, $\theta 0$	701.96	15.01	46.77	93	< 0.001
Frequency split, γ_{10}	– 43.50	3.77	– 11.53	5369	< 0.001
# Morphemes within word, γ_{20}	– 7.32	5.62	– 1.30	5369	0.193
Bound-morphemic or compound word, γ_{30}	– 31.02	15.31	– 2.03	5369	0.043
Native or Sino-Korean, γ_{40}	18.12	5.61	3.23	5369	0.001
Opaque or transparent, γ_{50}	– 9.56	4.53	– 2.11	5369	0.035
Component	SD	Variance component	df	χ^2	
Random effects					
Model 1					
Intercept u_0	72.94	5320.15	93	1448.81	< .001
Level-1, e	144.04	20746.76			
Deviance	70,122		# Parameter		2
Model 2					
Intercept u_0	73.04	5334.84	93	1510	< .001
Level-1, e	142.88	20414.31			
Deviance	70,015		# Parameter		2
Model 3					
Intercept u_0	73.25	5365.86	93	1529.69	< .001
Level-1, e	142.32	20254.74			
Deviance	69,964		# Parameter		2

SE standard error, *SD* standard deviation

to that of the reference group (i.e., variables coded 0). In other words, we assigned the constant term to the intercept for the reference group and the constant term *plus* the coefficient for the dummy explanatory variable. Word type (bound-morphemic word = 0; compound word = 1), word origin (native and semi-Korean word = 0; Sino-Korean words = 1), and morphemic transparency (opaque morpheme = 0;

Table 4 The estimates of the fixed effects of morphological variables by frequency split

	High frequency		Low frequency	
	B	*p*	*b*	*p*
RT, *θ0*	642.57	< .001	720.00	< .001
# Morphemes within word, γ_{10}	7.53	0.177	− 14.53	0.020
Independent or compound word, γ_{20}	− 71.40	< .001	[a]	[a]
Native or Sino-Korean, γ_{30}	12.89	0.073	16.57	0.020
Opaque or transparent, γ_{40}	− 20.77	0.003	− 44.24	< .001

[a]The parameter could not be estimated due to multicollearity resulted from a constant being all compound words in the low frequency cell

transparent morpheme = 1). Table 3 shows the estimates of the fixed effects with the robust standard error. The results showed that the frequency counts and being native and semi-Korean words were significant predictors of the outcome variable. The variables of morpheme numbers within words and the presence of morphemic transparency were not significant (see Model 2 in Table 3).

Following previous studies that have employed frequency split (Ferrand & New, 2003; Park, 1993; Perea & Careiras, 1998), word frequency was broken down into high- and low-frequency bands with each band including 60 items in order to further examine the function of word frequency. Model 3 was tested with the frequency breakdown (low frequency = 0, high frequency = 1; see Model 3 in Table 3). Importantly, Model 3 showed a better fit than the null model, as indicated by the reduced residual component. Specifically, the residual component decreased by 492 from 20,747 to 20,255 in the regression model. A better model fit was also demonstrated by the drop of the deviance by 158 from the null model to Model 3. The random effect on the grand mean of RT by the frequency grouping variable was computed to be 21% based on Model 3 in Table 3. This meant that there was a significant tendency for low frequency words to have slower RT than the high frequency counterpart. The variables of word type and morphemic transparency were significant. However, the number of morphemes within the word was still nonsignificant. The most conspicuous result was the magnitude of effects of the frequency grouping variable, word type, and word origin. Specifically, the frequency split resulted in the difference by 44 ms between high and low frequency bands. The effects of word type, word origin, and morphemic transparency became larger in this model. This suggests that morphological information might have been involved in decoding. This prompted a further analysis so as to disentangle the role of the morphological properties in RT by using the frequency grouping variable as a dummy variable.

When the morphological variables were fit into an HLM model by the frequency grouping variable, the parameter estimates were different across high and low frequency bands. For the high frequency words, the intercept was 643 ms. The status being compound words was associated with processing at 572 ms which was 71 ms faster than the grand mean, when other variables were controlled in the model. The variables of being compound words and transparent morphemes were significant. For the low frequency words, the results painted a different picture. Interestingly, the number of morphemes within the word showed a significant effect, along with the variables of being native and semi-Korean and having transparent morphemes within the word. The compound-word variable did not account for the variance because of having a constant number of compound words in the low frequency cell. Table 4 displays the results of the fixed effects by high and low frequency split.

Discussion

This study investigated the roles of word frequency and word length as well as morphological features in visual word recognition in Korean Hangul. Two research questions were addressed using CCM and HLM modeling to overcome the shortcomings of separate by-subject and by-item analyses. Drawing upon the unique characteristics that Hangul demonstrates in comparison to other orthographies, such as Chinese, Japanese, and English, the results of this study offer a better understanding of the role of salient syllabic boundaries in blocks as well as lexical properties in Hangul word recognition. The first research question addressed this matter by focusing on word frequency and the length of words as well as their interactions. Based on significant frequency effects and length effects previously found in Roman alphabetic orthographies, hypothesized were significant frequency effects in consideration of Hangul being an alphabetic orthography, despite slightly inconsistent findings of frequency effects with null or marginal effects (Lee et al., 2016; Simpson & Kang, 1994). The results showed significant word frequency effects, which were consistent with previous studies of Korean (Bae et al., 2016; Oh et al., 2007; Park, 1993) and other alphabetic orthographies (Samuel et al., 1982; Brysbaert et al., 2011, 2016; Murray & Forster, 2004; Schilling, Rayner, & Chumbley, 1998).

However, a significant word length effect was not found. This finding supported our hypothesis that a length effect would be hardly observed due to the syllabic autonomy and graphemes packaged in blocks in orthography, despite the difference in number of graphs in disyllabic and trisyllabic stimuli (i.e., 6 graphs in disyllabic word vs. 9 graphs in trisyllabic word). The result was also consistent with those of previous studies which showed no significant differences in recognition between disyllabic and trisyllabic words (Park, 1993; Yi et al., 2017). The null effect might also have resulted from the function of morphology because Korean vocabulary includes both Korean-native and Sino-Korean words as well as bound-morphemic words and compound words.

The null length effect was slightly different from those of studies in English showing null effects for five- to eight-letter words and inhibitory effects for words from nine letters and above (New et al., 2006). Since the stimuli used in this study embedded lexical properties other than frequency and word length, it was still unknown whether other lexical properties masked the nonsignificant effects of word length. In order to unpack the morphological contributions to lexical decision, the second research question sought to examine the role of different morphological features in word recognition in Hangul. The results of HLM showed that compound words, Korean native words, and morphological transparency within the multisyllabic word facilitated visual Hangul recognition. When word frequency was split, the predictive patterns were slightly different between high and low frequency words.

Taken together, the results of this study can be summarized in four ways. First, Simpson and Kang (1994) speculated that word frequency effects in Hangul would be minimal, if any, because the Hangul orthography allows for regular letter-sound mapping in decoding (i.e., 40 graphs–40 phonemes) and because syllables are represented in blocks. However, this study showed that significant word frequency effects. This finding is consistent with those of previous research (Oh et al., 2007; Park, 1993; Yi et al., 2017). This means that, regardless of the degree of letter-sound regularity and different syllabic structures, frequency might be a universal predictor of word recognition, although the magnitude of frequency effects varies across scripts.

Second, word length effects were not significant in any model tested in this study. One explanation is Hangul's relatively simple syllabic structure. The positions of consonants and vowels are prescribed in a restricted way to yield discrete CV, CVC, or CVCC syllables. This characteristic might lead to efficient word recognition regardless of word length. Another explanation is the function of morphology. The results suggest that the different levels of morphological information have an impact on Hangul word recognition. Another explanation has to do with grapheme packages within the syllable block. As indicated earlier, the stimuli used in this study included six graphemes for disyllabic words and nine graphemes for trisyllabic words. Due to the graphemes bundled within blocks, however, the span of graph representation within the word is much narrower than that of English words. Since the stimuli had the comparable number of graphemes to that of New et al.'s study (2006), the null results might be attributable to the unelongated syllabic configuration or a shorter word span due to graphs packaged within the block rather than graphemes spread in a left-to-right linear sequence. Given that our result is somewhat different from those of other alphabetic orthographies, the syllable length effect in Roman orthographies seems to be more complex than that in Korean (for more information about the U-shaped syllabic effects, see New et al., 2006). Specifically, Ferrand and New (2003) reported that the syllabic length effect was found only in very low frequency words with non-significant effects with high frequency words and nonwords in lexical decision. In an Italian study, Spinelli et al. (2005) reported that proficient readers' RTs were independent of word length for three- to five-letter words, while RTs increased linearly in the five-letter to eight-letter range. Based on the null effect found in this study, it seems that the nature of Hangul's unelongated syllabic block may be the source of the syllabic length independency.

Third, multisyllabic native and semi-native words were recognized faster than multisyllabic Sino-Korean words. This finding is consistent with previous evidence (Yi, 2003). As briefly indicated earlier, native words bear one morpheme regardless of the number of syllables used as a unit (e.g., the two-syllable word {소리}<sound>has one morpheme), while Sino-Korean disyllabic and trisyllabic words tend to bear more than one morpheme as compound words (e.g., the two-syllable word {부모} <parents> has two morphemes meaning <father> in the first syllable and <mother> in the second syllable).

Fourth, the last interpretation involves the morphological intricacy. As indicated earlier, Korean multisyllabic words included a mixture of pure native Korean words, Sino-Korean words, and mixed native and Sino-Korean words. Given the significant frequency effect, a frequency split was used to further examine the function of frequency in the morphological features. It seemed that the participants were more sensitive to morphological information when recognizing low frequency words. The number of morphemes and native words did predict RTs for high frequency words.

Overall, the findings of this study were consistent with previous studies in the significant effect of word frequency. Word length was independent of lexical decision RTs to disyllabic and trisyllabic words in Hangul. The source of the null length effect may lie in the morphological features embedded within the multisyllabic word. In short, the intricacies of lexical properties, especially morphological features, seemed to affect the lexical decision of low frequency words more than that of high frequency words.

In conclusion, one of merits that this study entails is the use of CCM and HLM analyses, which provides more confidence in the interpretation of results, in order to combat overestimation or a Type I error. As indicated earlier, there has been a relative paucity in studies of Hangul, especially in the role of morphology. This study provides an additional perspective in understanding visual word recognition in Hangul. The findings of this study indicate that morphological information plays a significant role in different dimensions of word recognition in Hangul. These results potentially endorse a new proposal for referring Korean Hangul to be a *morphosyllabic alphabet* as a collective or comprehensive term (Pae, Bae, & Pae, 2020). This goes beyond the term *alphasyllabary* (Taylor & Taylor, 2014), which has been used in the literature and properly encompasses the nature of Hangul being an alphabet and a syllabary in exogeneous appearance. Importantly, the term *alphasyllabary* leaves out the morphological features embedded in the Korean language and Hangul. The significant role of morphology in Hangul word recognition adds more weight to the neologism of *morphosyllabic alphabet* for Hangul in order to capture the characteristics of Hangul in its entirety.

The findings of this study have orthography-universal and orthography-specific implications. Orthography-universal has to do with word frequency, which suggests that it be one of universal lexical properties affecting visual word recognition, although the magnitude of frequency effects can vary. Orthography-specific lexical properties involve the functions of word length and morphological intricacies that each orthography entails, because the orthographic inner structures and the composition of the lexicon are different across orthographies.

Limitations and future directions

Future directions are noted in relation to the limitations of this study. First, morphological variables were not manipulated in this study because we were initially interested in more global lexical properties than morphological features per se. A follow-up study focusing on morphological features only is necessary to fully understand the function of morphology in Hangul word recognition.

Second, we used only CVC syllables to have the homogenous syllabic structure in the current study. Follow-up studies that include a wider range of syllabic types (CV vs. CVC; e.g., 기자 vs. 간단) and syllabic formats (left-to-right vs. top-down; e.g., 가마 vs. 고무) would be useful to better identify significant variables impacting Hangul word recognition.

Third, relatedly, the effect of word structures resulted from the combination of syllables, such as CV–CV, CV–CVC, or CVC–CV words, is also worth investigating because we used the uniform CVC syllables only in this study. Although there is no solid protocol for the syllabic combination in words, there are several combinatory patterns in Korean. In order to tease apart the dimensions of the mechanism involved in word recognition, future studies need to consider syllabic combinatory patterns when stimuli are constructed. Similarly, since this study used only two- and three-syllable words, an investigation of CVC syllables in more inclusive syllabic lengths will broaden our understanding of the role of lexical properties in word recognition in Hangul.

Fourth, another area of focus would be an investigation as to how the processing of Korean native words and Sino-Koreans are mediated or modulated by mediators and/or moderators in visual word recognition, because we did not examine direct and indirect relationships among variables. The morphology-derived results of this study suggest that morphological effects be examined more systematically by controlling for intervening variables or by identifying moderators (as an explanatory variable) or mediators (to determine the strength of relationships), such as semantic transparency, the structure of compound words (e.g., Sino-Korean only, Sino-Korean + native words, or native + Sino-Korean words), and other morpheme-based variables.

Last, the Korean syllabic configuration allows for flexible orientation for printing; that is, it can be written horizontally and vertically. Although the left-to-right orientation of printing is currently the norm (vertical orientation used to be the norm in the old age), a comparison of vertical and horizontal printing may provide another insight into word recognition of Hangul. Addressing these variables not only would corroborate the findings of this study, but also expands on our understanding of the intricacies behind word recognition.

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Appendix

Stimuli Used

Disyllabic stimuli		Trisyllabic stimuli	
Words	Nonwords	Words	Nonwords
강물 견학 곶감 군복 극장	국송 긴점 철국 달쿨 독굴	갈림길 건망증 걸림돌	감식울 골식인 농균말
낙엽 낙찰 논점 단팥 달님	말실 면별 밀동 박언 복진	경영진 곁눈질 골격근	등은성 물박판 생잣성
당첨 돌풍 동참 등불 면담	속품 실석 웅학 장분 집짓	궁금증 금융업 냉동실	손양문 실산력 일용문
밀렵 반찬 발탁 밥솥 방울	강억 건틀 국설 난압 민진	동영상 말장난 발돋움	장풍필 종면물 출문점
벌집 북극 불법 살균 생일	색검 융금 입변 축녹 콩착	방문객 방법론 방송국	친상물 평찰실 할짐법
손톱 솔잎 순찰 압축 약국	탄본 판복 폭림 합통 헌낙	법률안 분식집 살림집	경독성 날상날 눈승심
언덕 언행 연못 연필 열량	골전 근양 낙격 답용 동냉	삼각형 삼겹살 생물학	맞분색 발목전 설민학
염색 옥상 운행 입금 입실	맹탄 몰전 밑인 방격 성륙	선입견 선진국 설렁탕	신장승 얼망선 장열식
존엄 중립 직선 책장 총탄	식즙 압피 율립 준입 착빈	성냥갑 성장률 손놀림	정반정 중절샘 충통량
출장 친절 침술 침입 탐험	객민 결줄 눈장 만북 분능	식중독 신입생 양복점	판착금 폭병촌 행산복
통근 통역 특강 특급 평일	식실 졸약 철압 출난 탄밭	얼음물 연락망 연속극	감연눈 결산당 국널통
필통 학업 핵심 행군 협력	털용 폭근 필탁 합발 훈변	연장선 연합군 운동장	농근률 달발음 등복품
		운전석 작업복 작품전	명학등 눈업난 불은심
		장난감 장년층 장학금	생걸길 연경빛 응급증
		적응력 전문직 정상급	책전불 한행문 합록범
		준결승 준공식 중금속	건설목 경정점 난작객
		중산층 직장인 참을성	달굴감 동상액 말경생
		출근길 통신망 특별법	백홍등 불문감 색임력
		편집장 한방약 합창단	식등물 옹장감 응춤잎
		헌책방 현행범 혈액형	천력성 함국집 혼문형

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Affiliations

Hye K. Pae[1] **· Sungbong Bae**[2] **· Kwangoh Yi**[2]

Sungbong Bae
sbongbae@gmail.com

[1] School of Education, University of Cincinnati, 615R Teachers-Dyer Complex, Cincinnati, OH 45221-0022, USA

[2] Department of Psychology, Yeungnam University, 280 Daehak-Ro, Gyeongsan 38541, Gyeongbuk, Korea