No Flexibility in Letter Position Coding in Korean

Kathleen Rastle,[1] Clare Lally,[1] and Chang Lee[2]

1. Royal Holloway, University of London
2. Sogang University, Korea

RUNNING HEAD: PRECISE POSITION CODING IN KOREAN

Abstract

Substantial research across Indo-European languages suggests that readers display a degree of uncertainty in letter position coding. For example, readers perceive transposed-letter stimuli such as *jugde* as similar to their base words (e.g. judge). However, tolerance to disruptions of letter order is not apparent in all languages, suggesting that critical aspects of the writing system may shape the nature of position coding. We investigated readers' tolerance to these disruptions in Korean, a writing system characterized by a high degree of orthographic confusability. Results of three Korean masked priming experiments revealed robust identity priming effects, but no indication of priming due to shared letters or syllables in different positions. Two further masked priming experiments revealed where the Korean findings deviate from English. These results support the claim that the nature of the writing system influences the precision of orthographic representations used in reading.

Public Significance Statement

It is widely reported that adults are tolerant to disruptions of letter order in reading. This research demonstrates that this tolerance does not extend to Korean reading. These data suggest that the reading system is shaped by fundamental characteristics of writing systems.

Keywords: orthographic representations, visual word recognition, cross-linguistic, masked priming, transposed-letter effect

Orthographic representations must encode information about *letter identity* and *letter position*. Having a stable representation of letter identity is critical for distinguishing words like PAT, BAT, and RAT, which differ only in terms of small alterations to the initial letter. However, having a stable representation of letter position is also critical, because without it, we would be unable to distinguish words like PAT and TAP, which consist of the same letters in different positions. Exactly how we code this positional information in reading has become a prime theoretical concern over the past decade (e.g. Davis, 2010; Gomez, Ratcliff & Perea, 2008; Grainger, Dufau, & Ziegler, 2016).

Until fairly recently, theories of reading have dealt with the problem of letter position through slot-based coding schemes, in which letter identity is tied to letter position (e.g. Coltheart et al., 2001; Grainger & Jacobs, 1996). For example, in a left-aligned slot-based coding scheme, the word PAT would be coded as $P_1A_2T_3$, whereas TAP would be coded as $T_1A_2P_3$. This type of coding means that although these words both use the letters 'T' and 'P', they do not count as similar because they are in different positions; in fact, TAP and PAT have the same degree of similarity as TAP and BAN (they share A_2).

Slot-based coding schemes allow us to distinguish anagrams like TAP and PAT. However, substantial evidence now suggests that readers find anagrams to be perceptually very similar, certainly much more similar than stimuli that do not overlap fully in terms of letter identity. For example, in unprimed lexical decision, nonwords that are anagrams of words such as AMINAL are more difficult to reject than non-anagram controls such as ARISAL (e.g. Lupker, Perea & Davis, 2008). Similarly, studies that have used masked priming (Forster & Davis, 1984) have shown that the recognition of a target word is speeded by the prior presentation of a prime in which the letters of the target are transposed (e.g.

sevrice-SERVICE) relative to a prime that substitutes different letters for the transposed letters (e.g. sedlice-SERVICE; Schoonbaert & Grainger, 2004). This *transposed letter benefit* extends to cases in which the transposition crosses a syllable boundary (e.g. caniso-CASINO versus caviro-CASINO; Perea & Lupker, 2004) and to even more extreme modifications (e.g. snawdcih-SANDWICH versus skuvgpah-SANDWICH; Guerrera & Forster, 2008; see also Adelman et al, 2014 for megastudy data). Effects of this nature have been reported across a number of languages, many of which do not use the Roman alphabet including Thai (Winskel, Perea & Ratitamkul, 2012) and Japanese (Perea & Perez, 2009). These findings indicate that stimuli that are indistinguishable on the basis of letter identity are perceptually similar, even if information about the positions of those letters is not shared.

These data have revealed the limitations of slot-based coding, and have inspired the development of a whole new generation of models of orthographic processing. These models include the spatial coding model (Davis, 2010), the Open Bigram model (Grainger & Whitney, 2004), the Noisy Channel model (Norris & Kinoshita, 2012a) and the Overlap model (Gomez, Ratcliff, & Perea, 2008), amongst others. Though these models have important differences, they all assert that the nature of orthographic representation yields uncertainty in the perception of letter position. It is because of this uncertainty in the perception of letter position that stimuli such as CANISO and CASINO are treated as more similar than stimuli such as CAVIRO and CASINO (Perea & Lupker, 2004). Further, in at least some of these models, this uncertainty is deemed to arise from low-level visual (Grainger, Dufau, & Ziegler, 2016; Norris & Kinoshita, 2012a) or neurobiological factors (Dehaene, Cohen, Sigman, & Vinckier, 2005).

Despite their success in accounting for findings in English and other Indo-European languages, these models have recently been challenged by evidence that perceptual uncertainty of letter position is not a universal characteristic of reading (Frost, 2012a). Specifically, in a series of studies on Hebrew word recognition, Velan and Frost (2007, 2011) showed that the recognition of target letter strings is *not* facilitated by the prior presentation of a transposed-letter prime relative to a substitution control (see also Perea, Abu Mallouh, & Carreiras, 2010, for similar findings in Arabic). Frost (2012a) argued that the reason for this can be traced to properties of the Hebrew writing system. Unlike English and other Indo-European languages, the Hebrew writing system is very dense orthographically, with many anagrams. Precise coding of letter position is therefore necessary to avoid activating the meaning of another word in error. The more general point of Frost's (2012a) argument is that reading is a learned skill, and the nature of reading acquisition is critically dependent on the statistical structure of the writing system. While the more recent models of orthographic processing do a good job of capturing phenomena in English and in other Indo-European languages, Frost (2012a) argues that they cannot be thought of as *universal* models of reading, because they fail to account for position coding phenomena in Hebrew.

Orthographic Density and the Korean Writing System

One important question is whether this apparent precision in letter position coding applies to other languages with orthographically dense writing systems, but which do not share other important properties of Semitic languages, principally the rich, non-concatenative morphological structure of these languages. Korean has a number of unique features that make it an interesting test case for such an assessment.

The Korean Hangul writing system was developed around 600 years ago, and is perhaps the only writing system in the world that is both alphabetic and syllabic – termed, *alpha-syllabic*. Most Korean words are polysyllabic, and in printed Hangul, syllables are separated by a physical gap. For example, the printed Korean word "한국" (meaning "Korea") is composed of two syllable blocks, with each syllable block comprising a consonant-vowel-consonant (CVC) structure. The physical demarcation of syllable blocks in Hangul has led a number of authors to suggest that the syllable is an important level of representation in Korean word recognition (e.g. Lee & Taft, 2009, 2011; Simpson & Kang, 1994). Prior to the widespread use of Hangul in the 19th and 20th centuries, literacy in Korean was dependent on knowledge of Hanja. The Hanja script refers to logographic characters borrowed from Chinese and pronounced in the Korean language. Despite the dominance of Hangul, school pupils still learn some Hanja, and Hanja characters appear in different types of printed material. The experiments in this article deal only with the Hangul script.

Our interest in Hangul derives from the highly-rigid internal structure of its syllable blocks. Syllables can comprise CV (e.g., 가 [meaning "go"]), CVC (e.g., 강 [meaning "river"]), or much less frequently, CVCC (e.g. 닭 [meaning "chicken"]) structures. Further, there are just 19 consonants and 10 vowels that can fill these slots (Sohn, 1999). This highly-rigid internal structure, together with the small number of letters in each syllable, necessarily means that syllable blocks are frequently indistinguishable from one another on the basis of letter identity. Of the 2,066 syllable blocks that occur at least once in the Korean Word Database (National Institute of the Korean Language, 2001), 32% are onset-coda anagrams of another syllable block. Thus, accurate information about letter position is *required* for accurate identification of the syllable blocks that make up all Hangul words. Following on from this, if flexibility in position coding is constrained by the orthographic density of a writing system, as claimed by Frost (2012a), then we should observe low tolerance to letter transpositions in Hangul word recognition.

One might wonder whether the Korean writing system is really any more dense than other writing systems. For example, it is easy to think of English examples in which different words are indistinguishable on the basis of letter identity (e.g. TOP, POT, OPT). In fact, Shillcock, Ellison, and Monaghan (2000) reported that anagrams are quite common in English three- and four-letter words (affecting 33% and 34% of English types, respectively). However, they also showed that words of this length are relatively rare in English (comprising 1.7% and 5.7% of English types, respectively). Anagrams are far less common in the longer words that make up most of the English vocabulary. This is very different from the Korean case in which *all* words are built from a set of highly-confusable syllables. Further, English syllables lack a rigid internal structure. For example, while TO, TOP and TOPS would be permissible structures for Korean syllables, English also allows syllables to be built using more complex structures, as in OPT, TOO, STOP, STOOD, STONE, STRAP, STRAPS, STRENGTHS. The relative absence of structural constraints means that lexical differentiation is much less reliant on letter transpositions in English than it is in Korean.

Position Flexibility and Precision in Korean Word Recognition

There has been relatively little research on the nature of Korean word recognition, but there are already indications that orthographic representations in Korean may be more precisely coded than they are in English. In particular, Lee and colleagues have conducted a series of studies investigating transposed-letter effects in unprimed visual lexical decision.

Lee and Taft (2009) created stimuli that had transpositions across the 1st and 2nd syllable of printed disyllabic words in both Korean and English (e.g., 문장, napkin). These transpositions involved swapping the onsets, the codas, or the codas for onsets across the syllable block boundary (e.g., 문장 ->준망[onset exchange condition]; napkin -> kapnin). They measured the time taken for participants to reject these new stimuli as nonwords in visual lexical decision. Results showed that transposed letter stimuli proved difficult for the English participants to reject as nonwords, but that this transposed-letter rejection disadvantage was considerably reduced for the Korean stimuli. In a subsequent study using the same nonword rejection paradigm, they showed no letter transposition effect when the onset and coda of a Korean word were exchanged within a syllable (e.g., 문장 ->눔장) (Lee & Taft, 2011). Further research has replicated the absence of a transposed-letter effect under these conditions, in both behavioural and ERP measures (Kwon, Lee, Tae & Lee, 2018).

These studies suggest that Korean readers may have relatively precise representations of letter position. However, these studies are all based on the time taken to reject nonwords in visual lexical decision. One weakness of this paradigm is that it is based on processes related to the rejection of nonwords (as opposed to the recognition of words). There is also evidence that these decisions can be influenced by strategic and post-perceptual processes (e.g. Forster & Davis, 1984). These aspects of the paradigm mean that the contribution of specific orthographic processes to an overall effect on rejection latency may be rather minor. For these reasons, most of the previous studies of letter position coding have used the masked priming technique. One might argue that the null to weak transposed-letter effects in the nonword rejection paradigm already reported by Lee and Taft (2009, 2011) suggest that the case is closed, and that there is no reason to conduct masked priming experiments probing the issue of letter position flexibility in Korean. We believe that this conclusion would be premature. For the reasons outlined above, masked priming is more likely to tap into the nature of orthographic representations than is the nonword rejection paradigm. Further, the conclusions of Lee and Taft (2009, 2011) are all based on null effects –and critically, without any supporting analysis of power or the strength of those null effects.

We therefore conducted a series of masked priming experiments in which we investigated whether the recognition of Korean words would be facilitated by the prior masked presentation of transposed-letter primes relative to replaced-letter primes. Further, we conducted analogous English experiments where these were not already available in the published literature. In the first two experiments, we investigated the impact of masked primes with onset-coda transpositions on recognition of three-letter monosyllabic words in Korean (Experiment 1) and English (Experiment 2). In the second two experiments, we conducted a similar manipulation, but with six-letter disyllabic primes and targets in Korean (Experiment 3) and English (Experiment 4). The transposed-letter primes in these initial four experiments were constructed by manipulating onsets and codas *within* a syllable. In our final experiment, we investigated the impact of masked primes that transposed intact whole syllables on target recognition. Our rationale for this final experiment was that that if the syllable is a particularly important unit in Korean reading (Simpson & Kang, 2004), and if Korean syllables are precisely coded as a result of their orthographic density, then perhaps a transposition effect will emerge whenever primes and targets share whole syllables, irrespective of their position.

Statistical power is a potentially important concern given previous null results reported by Lee and Taft (2009, 2011), and given that the prediction based on Frost (2012a) is that we may not observe the usual transposed letter masked priming effect in Korean. Previous research in this domain has shown wide variation in sample size: for example, Schoonbaert and Grainger (2004; 37 and 39 participants); Perea and Carreiras (2006; 33 participants); Duñabeitia, Perea & Carreiras (2007; 36, 38, and 32 participants); Lupker, Perea and Davis (2008, 52 and 78 participants); Velan and Frost (2009; 51, 80, and 84 participants). We designed our experiments to be in the upper end of this range (60, 81, 75, 80, and 80 participants), and consistent with the Hebrew work of Velan and Frost (2009). Formal power calculations using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007) were based on the number of participants needed to detect a difference between the transposed-letter versus replaced-letter conditions (a within-subjects factor). With an alpha level of 0.05, and assuming a medium effect size (d=0.50), these calculations showed that with 34 participants, we would have 80% power to detect a true effect. However, recent recommendations suggest to assume a lower, more conservative effect size (e.g. d=0.40; Brysbaert & Stevens, 2018), yielding a suggested minimum sample of 52.

One problem with conducting power analyses in this manner is that masked priming designs used in cognitive psychology typically have multiple observations per participant and/or per condition. The process of averaging across multiple observations (e.g. comparing 40 high-frequency words to 40 low-frequency words for each participant) provides a better estimate of the magnitude of an effect than basing that estimate on a single value (e.g. comparing a single high-frequency word to a single low-frequency word for each participant; Brysbaert & Stevens, 2018). Thus, Brysbaert and Stevens (2018) have made the case that the number of observations (based on the numbers of participants * number of items) is a preferable guide to achieving adequate power in repeated measures designs in which reaction time is the dependent variable. Based on typical effect sizes for masked orthographic priming experiments, they recommend a minimum of 1600 observations per condition, and they note that the vast majority of published masked priming research falls well below this recommendation. Though we conducted these studies before this guideline was published, we are reassured that our experiments largely meet or exceed this threshold, as we demonstrate in the presentation of each experiment. Overall, based on this discussion of different means of estimating power, we believe that the experiments presented here are sufficiently powered to detect a difference between transposed-letter and replaced-letter priming conditions, and we believe that they compare favourably in terms of their power to previously-published research.

Experiment 1

Experiment 1 tested the impact of onset-coda transposition masked primes on the recognition of Hangul monosyllabic words. Although monosyllabic words are relatively rare in Korean (accounting for 2.6% of types) they are used frequently in daily life (accounting for 19.5% of tokens; National Institute of the Korean Language, 2001), and over 20% of these stand-alone syllables are onset-coda transpositions of other words. Thus, accurate information about position is critical for accessing meaning. Because there is evidence that the lexical status of primes might impact on target recognition, with greater facilitation expected from nonword primes (Davis & Lupker, 2006), we investigated these transposed-letter priming effects using both word and nonword primes.

Method

Participants

Participants were 60 native Korean speakers who were undergraduate students at Sogang University. They had normal or corrected-to-normal vision, and had no history of reading or language impairment. They received a course credit for their participation. Though we did not collect gender information, participants were from a sample that was approximately 68% women.

Materials

Seventy-eight monosyllabic words with a consonant-vowel-consonant (CVC) structure were selected as targets from the Korean Word Database (National Institute of the Korean Language, 2001). Each target was paired with three types of prime: (a) an identity prime (ID); (b) a transposed letter (TL) prime; and (c) a replaced letter (RL) prime. This design yielded 1,560 observations per condition according to the metric proposed by Brysbaert and Stevens (2018) [(60 participants * 78 targets) / 3 conditions]. TL primes were constructed by transposing the target's onset and coda consonants, while RL primes were constructed by replacing the target's onset and coda consonants with different letters. Half of the TL primes and half of the RL primes were words, while half of each type of prime were nonwords. In this and all subsequent experiments, stimuli are available in the Open Science Framework storage for this project (see author note).

TL and RL primes were closely matched on neighborhood size (M = 11.64 [std = 5.00], M=11.31 [std=4.25] for word TL and RL primes; M=5.85 [std = 3.06], M=5.49 [std=3.18] for nonword TL and RL primes). We also matched the frequency of TL (M = 2889.6 [std = 2861.5]) and RL (M = 2811.9 [std = 3514.2]) word primes (calculated using Korean Word Database; National Institute for the Korean Language, 2001). Though neighborhood size for word and nonword primes could not be matched, the neighborhood size of the targets for these primes was matched (targets for word primes: M=11.51 [std = 5.51]; targets for nonword primes: M=11.95 [std=4.58]).

Seventy-eight monosyllabic nonword targets with CVC structure were created for the lexical decision task. Nonword targets were also matched closely to word targets on neighborhood size (M = 11.47 [std] = 4.89]). One third of these targets were paired with an ID prime, one third were paired with a TL prime, and one third were paired with an RL prime. The neighborhood size of these primes was similar to those in the word target condition (M=5.09 [std=3.18]).

The assignment of primes to targets was counterbalanced across participants such that all participants received all prime conditions but saw each target only once.

Procedure

Participants were seated in a dimly lit room about 60 cm from a computer monitor. They were advised to decide as quickly and as accurately as possible whether letter strings presented on the monitor were real Korean words. Participants indicated their responses via button box.

Each trial consisted of a sequence of three visual events: (1) a row of four hash marks for 570 msec; (2) a prime presented for 50 ms (3 ticks on a 60Hz monitor); and (3) a target presented for 2000 ms. Participants were told that the target would be preceded by a row of hash marks, but were not told of the existence of the prime. Font size and style differed across primes and targets in order to reduce perceptual overlap between them (prime: 12 font size with “dokum” style Korean letter; target: 15 font size with “batang” style Korean letter). Trials were presented in a different random order for each participant, and the inter-trialinterval was 1 second. The experimental session was preceded by eighteen practice trials.

Stimulus presentation and data recording were controlled by DMASTR software (see Forster & Forster, 2003). Participant responses were recorded by a two-button response box, with the ‘yes’ button controlled by the participant’s dominant hand.

Results and Discussion

Reaction time (RT) and accuracy data were cleaned based on visual inspection of the subject, item, and data-point distributions for each experiment individually. This cleaning procedure was always applied prior to the calculation of condition means. Performance varied substantially across experiments, and thus the thresholds for identifying outliers also varied. In this experiment, one participant was excluded because of an error rate over 35%; data from 9 targets were excluded due to error rates over 40% (these targets were 능, 굽, 령, 평, 굽, 명, 압, 갱, 졸, 항); and six individual data points over 2000 ms were removed. RT data for incorrect responses were also excluded.

We conducted two analyses of variance (ANOVAs) on the RT and error data. In the principal analysis, we sought to identify whether there was an overall effect of prime condition on the recognition of targets, and thus considered Prime Condition (ID, TL, RL) and List (3 levels) as factors. In a secondary analysis, we sought to determine whether prime lexicality in the TL and RL conditions had an impact on target recognition. Thus, we included Prime Condition (TL vs RL), Prime Lexicality (Word vs Nonword) and List (3 levels) as factors. We note that the addition of a condition means that this comparison has less power than the principal analysis (Brysbaert & Stevens, 2018). The mean decision times and error rates by participants are shown in Table 1.

Insert Table 1 about here

The principal ANOVA revealed a significant effect of Prime Condition in the RT data, (F_1 [2,112] = 28.60, p < .001, *MSE* = 1902.83, η_p^2 = .34; F_2 [2,150] = 14.62, p < .001, *MSE* = 5615.24, η_p^2 = .16). Target recognition in the identity condition was faster than that in the TL condition, (t_1(58)=6.48, p < .001; t_2(77)=4.91, p < .001) and in the RL condition (t_1(58)= 6.11, p < .001; t_2(77)=4.81, p < .001). There was no numerical or statistical indication of a TL benefit relative to the RL condition (t_1(58)=0.76, p=.45; t_2(77)=0.37, p=.71). There was no effect of prime condition in the analysis of accuracy, (F_1[2,112] = 3.78, p = .03, *MSE* = .004, η_p^2 = .06; F_2[2,150] = 1.25, p = .29).

The secondary ANOVA including only TL and RL conditions revealed no effect of Prime Lexicality (F_1 [1,56]=1.45, p =.23; F_2 [1,73]=1.47, p=.23), no effect of Prime Condition (F_1 [1,56]=0.62, p=.44; F_2 [1.72]=0.14, p=.71), and no interaction between these variables (F_1 [1,56]=0.80, p=.38; F_2 [1.72]=0.95, p=.33) in the analysis of RT. Similarly, there was no effect of Prime Lexicality (F_1[1,56] = 5.22, p =.03, *MSE* = .008, η_p^2 = .09; F_2 (1,72)=0.02, p=.90), no effect of Prime Condition (F_1[1,56] = 2.10, p = .15; F_2 (1,72)=0.85, p=.36), and no interaction between these variables (F_1(1,56)=0.44, p=.51; F_2 (1,72)=0.23, p=.64) in the analysis of accuracy.

The absence of an effect of Prime Condition in the secondary ANOVA is theoretically important because it suggests that there is no transposed letter effect in Korean.

However, conventional inferential statistics cannot assess the strength of evidence in favour of the null hypothesis. Thus, we used a Bayesian alternative to null hypothesis significance testing described by Masson (2011) to compute the posterior probability of the null hypothesis (H_0) being true given the observed data. These values are available in Table 2. The Bayesian posterior probabilities provide an indication of the strength of evidence in favour of the null hypothesis and the alternative hypothesis (H_1; the probability values here are simply 1 minus the probability values for H_0). Raftery (1995) further classifies probability-based evidence into “weak” (0.5-0.75), “positive” (0.75-0.95), “strong” (0.95-0.99) and “very strong” (over 0.99). For reference, values associated with “positive” evidence are analogous to Bayes factors between 3 and 20; values associated with “strong” evidence are analogous to Bayes factors between 20 and 150; and values associated with “very strong” evidence are analogous to Bayes factors over 150 (Raftery, 1995). Thus, the values in Table 2 indicate positive evidence for a null effect of transposed-letter priming in this experiment (particularly in the RT data), and less than weak evidence for an effect of transposed-letter priming.

Insert Table 2 about here

To summarize, the results of this experiment produced no numerical or statistical evidence for a transposed-letter benefit in masked priming of Korean monosyllabic words. Bayesian analyses confirmed positive support for the null effect of transposed-letter priming. The absence of a transposed-letter benefit held across word and nonword primes, and arose in spite of an identity priming effect of a typical magnitude, approaching 50ms.

Experiment 2

Experiment 1 found no evidence for masked transposed-letter priming in Korean monosyllabic words. However, the monosyllables in Experiment 1 consisted of only three letters, meaning that the overall match between primes and targets in the transposed-letter conditions may have been too small to yield a priming effect (i.e. the transposition manipulation affected 2 out of the 3 letters). These three-letter primes and targets were also from very dense orthographic neighborhoods; research suggests that masked form priming effects may not be found in English either for these types of stimuli (Forster & Davis, 1991). Thus, it is not clear whether a transposed-letter priming benefit would be observed in English or other Indo-European languages in conditions similar to Experiment 1. In order to determine whether the results of Experiments 1 diverge from the expected range of outcomes in transposed-letter priming phenomena, we conducted an analogous experiment in English. Experiment 2 tests whether masked transposed-letter priming effects are observed in English when targets are 3-letter monosyllables with a CVC structure.

Method

Participants

Participants were 81 native English speaking adults from the Royal Holloway, University of London community (age M = 22.63 years, range 19-39). They had normal or corrected-to-normal vision, and had no history of reading or language impairment. Participants were paid £5 for their time. Though we did not collect gender information, participants were from a sample that was approximately 78% women. The majority of participants (71) also participated in Experiment 4. The order of these experiments was counterbalanced across participants.

Materials

Target stimuli comprised 78 three-letter words with a CVC structure. Each target was paired with three types of prime in the same manner as for Experiment 1: (a) an ID prime; (b) a TL prime; and (c) an RL prime. This design yielded 2,106 observations per cell [(81 participants * 78 targets) / 3 conditions] (Brysbaert & Stevens, 2018). TL primes were constructed by transposing the target's onset and coda consonants, while RL primes were constructed by replacing the target's onset and coda consonants with different letters. It was not possible to replicate the prime lexicality variable in Experiment 1 fully. However, 27 of the targets were preceded by TL or RL primes that were existing words (e.g. gum-MUG versus sun-MUG), while 51 of the targets were preceded by TL or RL primes that were nonwords (e.g. gip-PIG versus nid-PIG).

TL and RL primes were closely matched on neighbourhood size (TL word primes M=14.11 [std]=3.71; RL word primes M=14.44 [std]=3.49; TL nonword primes M=13.51 [std]=2.73; RL nonword primes M=14.02 [std]=1.81). We also matched TL (M = 34.98 [std = 76.76] and RL (M= 34.35 [std = 54.34]) word primes on frequency using N-Watch (Davis, 2005). The neighborhood size of targets preceded by word (M=15.63 [std]=5.34) and nonword primes (M=15.10 [std]=4.47) was matched.

Seventy-eight monosyllabic nonword targets with the same CVC structure as word targets were created for the lexical decision task. Nonword targets were also matched closely to word targets on neighborhood size (M =14.65 [std]=4.23). One third of these targets were paired with an ID prime, one third were paired with a TL prime, and one third were paired with an RL prime. The neighborhood size of these primes was similar to those in the word target condition (M=14.32 [std]=3.68).

The assignment of primes to targets was counterbalanced across participants such that all participants received all prime conditions but saw each target only once.

Procedure

The procedure was virtually identical to that used in Experiment 1. The only differences were use of DMDX software to control data recording and stimulus presentation (as opposed to DMASTR software; Forster & Forster, 2003), and the implementation of a small change to the duration of the forward mask. Trials began with a forward mask consisting of six hash symbols presented for 566 ms (34 ticks on a 60Hz monitor), followed by a lower-case prime displayed for 50ms (3 ticks), followed by the corresponding target in upper-case presented for 2000ms (120 ticks), or until the participant made a button-box response.

Results and Discussion

RT and accuracy data were cleaned in the same way as for Experiment 1. These procedures led to the exclusion of data from one participant with an error rate over 35%. We also excluded data from five targets that yielded error rates greater than 40% (WAD, PAR, YAK, YEW, BOP). Finally, RT data for incorrect responses were excluded.

The analyses on RT and accuracy data were modelled on those conducted in Experiment 1. In the principal analysis, we sought to identify whether there was an overall effect of prime condition on the recognition of targets, and thus considered Prime Condition

(ID, TL, RL) and List (3 levels) as factors. In the secondary analysis, we sought to determine whether prime lexicality in the TL and RL conditions had an impact on target recognition. Thus, we included Prime Condition (TL vs RL), Prime Lexicality (Word vs Nonword) and List (3 levels) as factors. However, we note that this analysis is less powerful than the principal analysis (Brysbaert & Stevens, 2018). Mean decision times and error rates are shown in Table 3.

Insert Table 3 about here

The principal ANOVA revealed a significant effect of Prime Condition in the RT data, (F_1 [2, 154]=79.27, p <.001, MSE=1336.92, η_p^2= .51; F_2 [2, 140]=98.98, p < .001, MSE=1090.91, η_p^2=.59). Target recognition in the ID condition was faster than that in the TL condition, (t_1(79)=10.29, p <.001; t_2(72)=9.95, p<.001) and in the RL condition (t_1(79)=12.11, p <.001; t_2(72)=11.01, p <.001). However, though there was a numerical difference between TL and RL conditions, this was not confirmed as statistically robust, (t_1(79)=1.32, p=.19.; t_2(72)=1.54, p=.13). This general pattern was replicated in the analysis of accuracy. There was a significant effect of prime condition (F_1 [2, 154]=13.30, p <.001, MSE=.003, η_p^2=.15; F_2 [2, 140]=12.43, p < .001, MSE=.003, η_p^2=.15), reflecting more accurate target recognition in the ID condition than in the TL (t_1(79)=5.51, p <.001; t_2(72)=4.86, p<.001) and RL (t_1(79)=3.57, p <.001; t_2(72)=4.26, p <.001) conditions. There was no difference in accuracy between the TL and RL conditions (t_1(79)=0.90, p =.37; t_2(72)=0.77, p =.44).

The secondary ANOVA including only TL and RL conditions revealed no reliable effects of Prime Lexicality (F_1 [1,77]=6.33, p <.05, MSE=1749.36, η_p^2=.08; F_2 [1,67]=1.23, p=.27) or Prime Condition (F_1 [1,77]=1.85, p=.18; F_2 [1.67]=2.40, p=.13), and no interaction between these variables (F_1 [1,77]=0.12, p=.73; F_2 [1.67]=0.001, p=.97) in the RT data. These results were confirmed in the analysis of accuracy, which yielded no significant effects of Prime Lexicality (F_1 [1,77]=20.76, p <.001; F_2 [1,67]=2.40, p=.13), Prime Condition (F_1 [1,77]=0.72, p =.40; F_2 [1,67]=0.40, p=.53), or interaction between these variables (F_1 [1,77]=0.26, p =.61; F_2 [1,67]=0.13, p=.72).

Because it is not possible to interpret the critical null effect of Prime Condition in the secondary ANOVA using conventional statistics, we again used the Bayesian alternative described by Masson (2011) to compute the posterior probabilities of H_0 being true given the observed data. The values in Table 2 indicate positive evidence for H_0 in the accuracy data, and marginally positive evidence for H_0 in the RT data based on Raftery's (1995) classification. Both RT and accuracy analyses produced less than weak evidence for an effect of transposed-letter priming (H_1).

To summarize, the results of this experiment showed the same pattern as the analogous Korean experiment: robust identity priming accompanied by no evidence for transposed-letter priming.

Experiment 3

In Experiment 1, we found no evidence for a transposed-letter benefit in masked priming of Korean words. However, our analogous English experiment using three-letter monosyllabic primes and targets also yielded no transposed-letter benefit. Thus, so far there is no evidence that letter position coding in Korean is any more precise than that in English.

However, there are important reasons why transposed-letter priming might not be observed for short monosyllables, as previously discussed. Thus, we conducted a second Korean experiment, in which we investigated masked transposed-letter priming of six-letter disyllabic words. Though such words are built from the highly-confusable set of Hangul syllable blocks, onset-coda transpositions within a single syllable of a disyllabic word only infrequently yield another word (in 2.3% and 2.8% of cases for onset-coda transpositions in the first and second syllable, respectively). Further, onset-coda transpositions in a single syllable affect only one-third of target letters in a six-letter disyllabic word, as opposed to two-thirds in Experiment 1. Thus, if there is a transposed-letter benefit in Korean masked priming, it is more likely to be apparent in these disyllabic stimuli than in the monosyllabic stimuli of Experiment 1.

Method

Participants

Participants were 75 native Korean speakers who were undergraduate Psychology students at Sogang University (age M = 21.61, range 18-27). Participants had normal or corrected-to-normal vision, and had no history of reading or language impairment. They received a course credit for their participation. Though we did not collect gender information, participants were from a sample that was approximately 55% women.

Materials

120 disyllabic words with a CVC-CVC structure were selected as targets from the Korean Word Database (National Institute of the Korean Language, 2001). Each target was paired with five types of prime: (a) an ID prime; (b) a TL prime in the first syllable; (c) an RL prime in the first syllable; (d) a TL prime in the second syllable; and (e) an RL prime in the

second syllable. This design yielded 1,800 observations per condition [(75 participants * 120 targets) / 5 conditions] (Brysbaert & Stevens, 2018). TL primes were constructed by transposing the target's onset and coda consonants, while RL primes were constructed by replacing the target's onset and coda consonants with different letters. TL and RL primes were all nonwords.

Primes in the TL and RL conditions for each syllable were matched on neighborhood size (M=1.45 [std = 1.58], M=1.45 [std=1.46] for TL and RL primes in the 1st syllable; M=1.45 [std=1.68], M=1.45 [std=1.42] for TL and RL primes in the 2nd syllable).

120 disyllabic nonword targets with the same CVC-CVC structure were created for the lexical decision task. Nonword targets were matched to word targets on neighborhood size (M=4.79, [std]=3.44 for the word targets; M=4.75, [std]=3.49 for the nonword targets). Nonword targets were preceded by primes that mirrored those for the word targets (e.g. ID, TL, RL in the same proportions as for the word targets). Primes for the nonword targets were matched to those for the word targets on neighborhood size (M=1.46, [std]=1.53 for the word targets; M=1.45, [std]=1.66 for the nonword targets).

The assignment of primes to targets was counterbalanced across participants such that all participants received all prime conditions but saw each target only once.

Procedure

The experimental procedure was identical to that of Experiment 1.

Results and Discussion

RT and error data were cleaned in the same manner as for Experiment 1. These cleaning procedures resulted in the exclusion of one participant due to an error rate over 30%, three items with error rates over 18% (인근, 발간, 삼진), and one data point over 1950ms.

Mean RT and error rates are shown in Table 4. RT and error data were analysed by subjects and by items via ANOVAs that treated Prime Condition (5 levels) and List (5 levels) as factors.

Insert Table 4 about here

The analysis of the RT data revealed an effect of Prime Condition, (F_1 [4, 276] = 48.01, p < .001, MSE = 677.38, η_p^2 = .41; F_2 [4, 460] = 17.11, p < .001, MSE = 3365.74, η_p^2 = .13). Planned comparisons revealed that this effect arose because target recognition in the ID condition was faster than in every other condition (against TL-first syllable, (t_1(73) = 10.61, p < .001; t_2(119) = 6.61, p < .001; against RL-first syllable, t_1(73) = 10.37, p < .001; t_2(119) = 7.06, p < .001; against TL-second syllable, t_1(73) = 9.69, p< .001; t_2(119) = 6.40, p < .001; against RL-second syllable, t_1(73) = 9.27, p < .001; t_2(119) = 6.55, p < .001.

In order to ascertain whether targets were recognized more quickly when preceded by TL rather than RL primes, we conducted a secondary ANOVA with Prime Type (TL versus RL) and Syllable (2 levels) as factors. This analysis revealed no effect of Prime Type, (F_1[1,69]=0.15, p=.70; F_2[1,115]=0.20, p=.65), no effect of Syllable (F_1[1,69]=2.38, p=.13; F_2[1,115]=0.35, p=.56), and no interaction between these factors, (F_1[1,69]=0.01, p=.92; F_2[1,115]=0.10, p=.76).

The analysis of the error data yielded an effect of Prime Condition, (F_1 [4, 276] =

8.20, $p < .001$, $MSE = .001$, $\eta_p^2 = .11$; $F_2[4, 460] = 5.39$, $p<.001$, $MSE = .003$, $\eta_p^2 = .05$), as target recognition was more accurate in the ID condition than in every other condition (against TL-first syllable, ($t_1(73) = 4.97$, $p < .001$; $t_2(119) = 4.77$, $p < .001$; against RL-first syllable, $t_1(73) = 4.38$, $p < .001$; $t_2(119) = 3.55$, $p = .001$; against TL-second syllable, $t_1(73) = 2.79$, $p = .007$; $t_2(119) = 2.32$, $p = .02$; against RL-second syllable, $t_1(73) = 3.01$, $p = .004$; $t_2(119) = 2.91$, $p = .004$).

In order to ascertain whether targets were recognized more accurately when preceded by TL rather than RL primes, we conducted a secondary ANOVA with Prime Type (TL versus RL) and Syllable (2 levels) as factors. This analysis revealed an effect of Syllable (F_1 [1, 69] = 8.30, p =.005, $MSE = .001$, $\eta_p^2 = .11$; $F_2[1, 115] = 4.29$, p=.04, $MSE = .004$, $\eta_p^2 = .04$), but no effect of Prime Type (F_1 [1, 69] = 0.22, $p = .64$; F_2 [1, 115] = 0.18, $p = .67$, or interaction between these variables (F_1 [1, 69] = 1.98, p =.16; F_2 [1, 115] = 1.70, p =.20).

Once again, we used the method described by Masson (2011) to test the strength of the critical null effect of Prime Type in the secondary ANOVAs conducted for RT and accuracy data. These Bayesian posterior probabilities are available in Table 2. On Raftery's (1995) classification, these values indicate positive evidence for the null effect of transposed-letter priming, and less than weak evidence for an effect of transposed-letter priming.

Overall, as in Experiment 1, despite an identity priming effect approaching 50ms in magnitude, we found no numerical or statistical evidence for transposed-letter priming of Korean disyllabic words. Bayesian analyses confirmed the strength of this null effect.

Experiment 4

Experiment 3 revealed no evidence for masked transposed-letter priming when targets were six-letter disyllabic Korean words. This experiment used the longer stimuli that are typical of those used in transposed-letter priming experiments in other languages; however the transpositions always involved an initial or final letter. It has sometimes been argued that such transpositions do not yield a transposed-letter priming effect in other languages either (Perea & Lupker, 2007). Thus, to investigate whether the lack of a transposed-letter effect in Experiment 3 can be attributed to cross-linguistic differences, Experiment 4 therefore replicates exactly these conditions using English stimuli.

Participants

Participants were 80 native English speaking adults from the Royal Holloway, University of London community (age M = 22.46 years, range 19-39). They had normal or corrected-to-normal vision, and had no history of reading or language impairment. Participants were paid £5 for their time. Though we did not collect gender information, participants were from a sample that was approximately 78% women. The majority of participants (71) also participated in Experiment 2. The order of these experiments was counterbalanced across participants.

Materials

Target stimuli comprised 120 disyllabic, six-letter words with a CVCCVC structure. Like Experiment 3, each target was paired with five types of prime: (a) an ID prime; (b) a TL prime in the first syllable; (c) an RL prime in the first syllable; (d) a TL prime in the second syllable; and (e) an RL prime in the second syllable. This design yields 1,920 observations per condition [(80 participants * 120 targets) / 5 conditions] (Brysbaert & Stevens, 2018). TL primes were constructed by transposing the target's onset and coda consonants (e.g. ticrus-CITRUS), while RL primes were constructed by replacing the target's onset and coda consonants with different letters (e.g. kimrus-CITRUS). TL and RL primes were all nonwords.

Primes in the TL and RL conditions for each syllable were matched on neighborhood size (M=0.20[std =0.60], M=0.05 [std=0.22] for TL and RL primes in the 1st syllable; M=0.20 [std=0.72], M=0.13 [std=0.44] for TL and RL primes in the 2nd syllable).

120 disyllabic nonword targets with the same CVCCVC structure were created for the lexical decision task. Nonword targets were matched to word targets on neighborhood size (M=0.81, [std]=1.16 for the word targets; M=0.77, [std]=0.79 for the nonword targets). Nonword targets were preceded by primes that mirrored those for the word targets. Primes for the nonword targets were matched to those for the word targets on neighborhood size (M=0.14, [std]=0.53 for the word targets; M=0.38, [std]=0.65 for the nonword targets).

The assignment of primes to targets was counterbalanced across participants such that all participants received all prime conditions but saw each target only once.

Procedure

The procedure was identical to that of Experiment 2.

Results

RT and accuracy data were cleaned in the same way as for Experiment 1. These procedures led to the exclusion of data from one participant with an error rate of over 35%. We also excluded data from eleven targets that yielded error rates of 40% or more (PARKIN,

DICTUM, CONSUL, PULSAR, SIPHON, MUSLIN, SIGNET, PARSON, LIMPET, PUTRID, DISPEL). RT data for incorrect responses were also excluded.

Mean RT and accuracy data are shown in Table 5. RT and accuracy data were analyzed by subjects and by items via ANOVAs that treated Prime Condition (5 levels) and List (5 levels) as factors.

Insert Table 5 about here

The analysis of the RT data revealed an effect of Prime Condition (F_1 [4, 296]=23.30, p < .001, MSE=965.08, η_p^2 = .24; F_2 [4, 416]=17.04, p < .001, MSE=2140.20, η_p^2 = .14). Planned comparisons revealed that this effect arose because target recognition in the ID condition was faster than in every other condition (against TL-first syllable, (t_1(78)=4.04, p < .001; t_2(108)=3.87, p < .001; against RL-first syllable, t_1(78)=7.23, p < .001; t_2(108)=6.13, p < .001; against TL-second syllable, t_1(78)=6.91, p< .001; t_2(108)=5.90, p < .001; against RL-second syllable, t_1(78)=7.20, p < .001; t_2(108)=7.12, p< .001).

In order to ascertain specifically whether targets were recognized more quickly when preceded by TL rather than RL primes, we conducted a secondary ANOVA with Prime Type (TL versus RL) and Syllable (2 levels) as factors. Critically, this analysis revealed an effect of Prime Type (F_1 [1,74]=17.87, p < .001, MSE=653.71; η_p^2 = .19; F_2 [1,104]=11.82, p < .001, MSE=1773.58, η_p^2 = .10), as targets were recognized faster when preceded by TL primes as opposed to RL primes. There was no effect of Syllable (F_1 [1,74]=1.04, p=.31; F_2

[1,104]=1.20, p=.28), or interaction between Prime Type and Syllable (F_1 [1,74]=3.01, p=.09; F_2 [1,104]=2.99, p=.09).

The analysis of accuracy data revealed an effect of Prime Condition (F_1 [4, 296]=3.22, p =.01, MSE=.003, η_p^2 = .04; F_2 [4, 416]=2.57, p =.04, MSE=.004, η_p^2 = .02). This reflected more accurate recognition when targets were preceded by an identity prime than by a replaced letter prime in the second syllable (t_1(78)=3.24, p =.002; t_2(108)=3.32, p =.001); no other comparisons between the identity condition and other conditions reached significance in both analyses.

In order to ascertain specifically whether targets were recognized more accurately when preceded by TL rather than RL primes, we conducted a secondary ANOVA with Prime Type (TL versus RL) and Syllable (2 levels) as factors. This analysis revealed no effect of Prime Type (F_1 [1,74]=3.68, p = .06; F_2 [1,104]=3.15, p = .08), no effect of Syllable (F_1 [1,74]=2.17, p=.15; F_2 [1,104]=1.52, p=.22), and no interaction between these factors (F_1 [1,74]=1.97, p=.16; F_2 [1,104]=1.34, p =.25).

In contrast to the first three experiments, analysis of the RT data in this experiment yielded a significant effect of Prime Type in the secondary ANOVA comparing priming in the TL and RL conditions. In order to assess the strength of this effect of Prime Type, we used the same Bayesian approach described previously (Masson, 2011). In contrast to the previous experiments, the posterior probabilities for the null hypothesis available in Table 2 indicate strong evidence for H_1 in the analysis of RT (1 minus the probability for H_0 is >0.95). The posterior probabilities associated with the analysis of accuracy indicate weak support for the null hypothesis, suggesting that this analysis is inconclusive. Critically, however, there is no evidence of a speed-for-accuracy trade-off in this experiment; the accuracy data go in the same direction as the strong effect in the RT data.

To summarize, the results of this experiment diverged from the analogous experiment in Korean. Both experiments revealed a significant identity priming effect, but only the English experiment revealed a transposed-letter priming effect.

Experiment 5

The Korean experiments so far have produced typical identity priming effects but no evidence for a transposed-letter priming benefit. We have shown that these data diverge from the English case, at least where six-letter disyllabic targets with external onset-coda transpositions are concerned (e.g. pankin-NAPKIN). Our findings using English support research by Adelman et al. (2014), suggesting that transposed letter priming effects are observed in well-powered experiments when transpositions include initial and final letters.

The absence of transposed-letter priming in Korean would appear to support Frost's (2012a) claim that flexibility in letter position coding is a learned property constrained by the orthographic density of a writing system. However, one way in which Korean is very different from other alphabetic languages is with respect to the importance and rigid structure of the syllable. As explained, syllables are physically demarcated in Korean words, and the location of onset, vowel and coda within the syllable is fixed and unambiguous (Lee & Taft, 2009). Lee and Taft (2009) argued that this lack of ambiguity means that letters are assigned to onset, vowel, and coda sub-syllabic positions very rapidly. Because of the rapid assignment of letters to positions that is possible in Korean, Lee and Taft have argued that stimuli with onset-coda transpositions, whether these be within (Lee & Taft, 2011) or across (Lee & Taft, 2009) syllable blocks, do not generate confusion with their base words and hence do not yield a rejection disadvantage in unprimed lexical decision. On this logic, we might not expect a transposition effect to emerge in masked priming when onset-coda transpositions are used. That is, the results that we observed in Experiments 1 and 3 may have more to do with the syllabic structure of Korean writing than with its orthographic density.

Experiment 5 was conducted to assess this hypothesis. If Korean words are represented in terms of syllables with an unambiguous internal structure, then perhaps masked primes that include the target syllables will facilitate target recognition, irrespective of whether the *position* of the syllable is the same across prime and target. Alternatively, if the degree of precision observed in Experiments 1 and 3 reflects learned sensitivity to the orthographic density of Korean orthography, then perhaps this precision will also be observed when intact syllables are transposed. We have already discussed the relatively high proportion of anagrams that arise due to onset-coda transpositions within the syllable. Anagrams based on the transposition of whole syllables are also relatively common in Korean, with nearly 30% of disyllabic Korean words being transposed-syllable anagrams of another word (e.g. 개회, meaning “opening” yields another word, 회개, meaning “repentance” when the syllables are transposed). Thus, any flexibility in position coding would frequently lead to misidentifications.

The information contained within syllables varies across languages, although we are unaware of any evidence that this impacts on syllable transposition effects. In typical Korean words derived from Chinese, syllables often contain meaningful (morphemic) information, although it is also possible to create simple transliterations of foreign words in which syllables comprise no meaningful information. Lee et al. (2015) investigated transposed-syllable effects in both of these types of stimuli using four-syllable words in the the nonword rejection paradigm. They demonstrated that syllable transpositions within both of these types of Korean words yield longer rejection latencies in unprimed lexical decision than matched nonwords that are not syllable transpositions of another word, with no differences reported across these types of Korean words. Syllable transposition effects have also been reported in masked priming of Japanese Kana (Perea & Pérez, 2009; Witzel, Qiao, & Forster, 2011) and in unprimed lexical decision in Spanish (Perea & Carreiras, 2006), both cases in which syllables typically were not also morphemes. Finally, Crepaldi et al. (2013) reported two experiments investigating syllable transpositions in English using disyllabic compound words (e.g. honeymoon). In their first experiment, they reported that transpositions of these words (e.g. moonhoney) were harder to reject in unprimed lexical decision than matched control nonwords (e.g. moonbasin). In their second experiment, they reported that masked presentation of transpositions (e.g. moonhoney) facilitated recognition of their base words (e.g. honeymoon), and that this facilitation was greater than that observed in cases where blocks of letters were transposed (e.g. tiseprac-PRACTICE). This latter experiment was similar to a finding reported in Basque, in which masked presentation of a compound facilitated recognition of a target that shared one constituent in a different position relative to an unrelated baseline (e.g. as in casework-WORKSHOP; Duñabeitia, Laka, Perea & Carreiras, 2009).

This brief review demonstrates that syllable transposition effects occur across different languages and writing systems. They have also been reported in Korean using the nonword rejection paradigm (Lee et al., 2015). Thus, if we are to find any evidence of flexibility in position coding in the masked priming paradigm, then the situation in which primes and targets share whole syllables is a good target. In Experiment 5, we therefore investigated whether the recognition of Korean words is facilitated by masked transposed-syllable primes, in which the syllable blocks of a disyllabic target word are simply reversed to make a nonword prime. We measured the impact of these transposed-syllable (TS) primes against conditions in which primes were identical to targets (ID) or shared no syllables with targets (all syllables different; ASD). However, because we have so far failed to find any non-identity priming in Korean, we also included a condition in which primes and targets shared a single syllable in the same position (1SYL_SAMEPOS). Our reasoning was that if Korean word recognition is based on the analysis of syllables, then priming should surely be observed in this condition. Finally, the facilitation that we expected in this condition was compared to a condition in which primes and targets shared a single syllable in a different position (1SYL_DIFFPOS).

Method

Participants

Participants were 80 native Korean speakers who were undergraduate Psychology students at Sogang University (age M = 22.44 years, std 2.73, range 18-35). Participants had normal or corrected-to-normal vision, and had no history of reading or language impairment. They received a course credit for their participation. Though we did not collect gender information, participants were from a sample that was approximately 52% women.

Materials

120 disyllabic target words with a CVC-CVC structure were selected from the Korean Word Database (National Institute of the Korean Language, 2001). Five types of prime were created for each of these targets: (a) an identity prime (ID); (b) a syllable prime comprising the same first or second syllable of the target in the same syllabic position

(1SYL_SAMEPOS); (c) a syllable prime comprising the first or second syllable of the target but in a different syllabic position (1SYL_DIFFPOS); (d) a transposed syllable prime (TS); and (e) an all syllable different prime (ASD). This design yields 1,920 observations per condition [(80 participants * 120 targets) / 5 conditions] (Brysbaert & Stevens, 2018). For conditions (b) and (c), primes and targets shared the first syllable for half of the targets, and the second syllable for the other half of targets. The syllable that was not shared was completely unrelated. Primes in the non-identity conditions were all nonwords.

Primes across conditions were matched on the number of constituent letters. Further, we were able to match the neighborhood size of the four non-identity conditions (M=2.13 [std=2.04]; M=2.02 [std=2.62]; M=2.02 [std = 2.25]; M=2.05 [std=2.57], for conditions (b),(c),(d), and (e), respectively). The neighborhood size of the targets (and therefore, ID primes) was M=3.60 [std=3.63].

120 disyllabic nonword targets with the same CVC-CVC structure were created for the lexical decision task. Nonword targets were matched to word targets on neighborhood size (M=3.59, [std=3.34]), and were preceded by primes that mirrored those for the word targets (e.g. TS, ASD). Primes for the nonword targets were matched to those for the word targets in the four non-identity conditions on neighborhood size (M=2.19, [std=2.17]).

The assignment of primes to targets was counterbalanced across participants such that all participants received all prime conditions but saw each target only once.

Procedure

The experimental procedure was identical to that of Experiment 1.

Results and Discussion

Reaction time (RT) and error data were cleaned in the same manner as in Experiment 1. This process resulted in the exclusion of four participants with an error rate over 30% and nine items with an error rate over 18% (강행, 겨례, 새길, 볼모, 냅킨, 애물, 통속, 피겨, 잉꼬). No further data points were removed.

Mean RT and error rates are shown in Table 6. RT and error data were analysed by subjects and by items via ANOVAs that treated Prime Condition (5 levels) and List (5 levels) as factors.

Insert Table 6 about here

The analysis of RT revealed an effect of Prime Condition, (F_1[4, 284] = 53.35, p<.001, *MSE* = 602.06, η_p^2 = .43; F_2[4, 460] = 20.88, *MSE* = 2676.18, p<.001, η_p^2 = .15). This effect reflected faster target recognition in the ID condition than in all other conditions (ID versus 1SYL_SAMEPOS, t_1(75) = 12.05, p<.001; t_2(119) = 7.01, p<.001; ID versus 1SYL_DIFFPOS, t_1(75) = 10.24, p<.001; t_2(119) = 7.79, p<.001; ID versus TS, t_1(75) = 9.12, p< .001; t_2(119) = 6.59, p<.001; ID vs ASD, t_1(75) = 11.93, p<.001; t_2(119) = 8.02, p< .001). There were no other differences between conditions (all *ts* < 1.20). There was no effect of Prime Condition in the accuracy data (F_1[4, 284] = 2.74, p = .03, *MSE* = .002, η_p^2 = .04; F_2 [4, 460] = 1.72, p = .14, *MSE* = .004).

In order to test the strength of the null transposed-syllable priming effect in the same manner as in the other experiments, we conducted additional ANOVAs on the RT and accuracy data, specifically comparing the TS and ASD conditions (again, with List as a factor). We then used the method described by Masson (2011) to compute the posterior probability of H_0 being true given the observed data. These ANOVAs yielded no effect of transposed-syllable priming in the RT [$F_1(1,71)=1.23$, $p=.27$; $F_2(1,115)=0.81$, $p=0.37$)] or accuracy data [$F_1(1,71)=0.014$, $p=.91$; $F_2(1,115)=0.00$, $p=0.99$)]. The Bayesian posterior probabilities are available in Table 2. On Raftery's (1995) classification, these values indicate positive evidence for a null effect of transposed-syllable priming, and less than weak evidence for an effect of transposed-syllable priming.

The results of this experiment were consistent with Experiments 1 and 3. Despite identity priming approaching 50ms in magnitude, there was no evidence that syllable overlap between primes and targets facilitated word recognition, irrespective of whether the shared syllable was in the same or different position across primes and targets.

General Discussion

Skilled reading requires rapid access to phonological and semantic information from orthographic representations. One important challenge in reading research is therefore to understand the nature of orthographic representations. Extensive research has been dedicated to understanding aspects of these representations: for example, whether these representations are local or distributed (Rastle & Coltheart, 2006), whether they are abstract (Bowers, 2000), and how they are acquired (Castles & Nation, 2006). However, one question that has generated substantial interest within the word recognition community concerns the nature of letter position coding within these representations. Position coding is important because it defines lexical similarity; two letter strings that are highly similar on one position coding scheme may have no similarity on another coding scheme. The manner in which position is coded therefore determines which lexical representations might be activated by a printed letter string (e.g. Davis & Taft, 2005).

The demonstration that readers find transposed-letter stimuli (e.g. jugde) perceptually similar to their base words has played a very important role in this body of research (e.g. Perea & Lupker, 2004; Schoonbaert & Grainger, 2004). In addition to refuting slot-based coding schemes, these findings have led to the development of a new generation of computational models that propose mechanisms underlying this perceptual uncertainty (e.g. Davis, 2010; Gomez et al., 2008; Grainger et al., 2016; Norris & Kinoshita, 2012a). However, recent work demonstrating the absence of a transposed-letter effect in some languages (e.g. Hebrew, Arabic; Velan & Frost, 2007; Perea et al., 2010) has led to the claim that position flexibility is not a universal property of orthographic representations (Frost, 2012a). Instead, it may be that orthographic representations reflect critical aspects of writing systems, and that imprecise coding of letter position emerges only where it maximizes efficiency in accessing meaning (Frost, 2012a).

Summary of Findings

We capitalized on the special properties of the Korean writing system to test this hypothesis. We noted that the physical demarcation of syllables in Korean has led to proposals that the syllable plays a particularly important role in Korean word recognition (e.g. Lee & Taft, 2009, 2011; Simpson & Kang, 2004). Further, we showed that a substantial proportion of the syllables that make up all Korean words are onset-coda transpositions of other syllables. Thus, on the perspective put forward by Frost (2012a), this may be a writing system that requires particularly precise position coding. We conducted masked priming experiments investigating the impact of transposed-letter primes (involving onset-coda transpositions within syllables) on monosyllabic and disyllabic Korean targets. Despite observing identity priming effects approaching 50 ms in magnitude (a consistent benefit of around 8%), we observed no indication of any benefit from primes that shared all of the letters with the target, but in different positions. These were high-powered experiments and Bayesian analyses further confirmed the strength of these null effects. Our analogous English control experiments established that while similar transposed-letter priming effects do not arise in three-letter monosyllables (e.g. gip-PIG versus nid-PIG), these effects do arise in six-letter disyllables (e.g. ticrus-CITRUS vs kimrus-CITRUS). Bayesian analyses confirmed the strength of this positive result. In addition to demonstrating an important deviation from Korean word recognition, this latter finding challenges previous reports that letter transposition effects are not observed when transpositions involve external letters (Perea & Lupker, 2007; see also Adelman et al., 2014).

In our final experiment, we tested whether we would find evidence for position flexibility when masked primes and targets share whole intact syllables in different positions, as has been observed in English (Crepaldi et al., 2013) and Japanese (Perea & Perez, 2009). We reasoned that if letters are assigned to sub-syllabic slots very rapidly as a result of the rigid internal structure of Korean syllables (Lee & Taft, 2009), then primes with onset-coda transpositions may not be expected to activate their base words. If our failure to observe transposed letter priming effects in the initial Korean experiments were for this reason, then perhaps evidence of position flexibility would emerge when primes and targets shared whole syllables in different positions. However, again, despite an identity priming effect near 50 ms, we observed no evidence of a syllable priming effect, irrespective of whether shared syllables across primes and targets were in the same or different position. In fact, when primes comprised identical syllables to the target but in reverse order, there was no benefit for target recognition compared to a condition in which primes shared no syllables with targets.

Overall, across all three of our well-powered Korean experiments, the numerical transposition effect ranged from 5ms facilitation to 7ms inhibition, an effect of less than 1% in either direction around an effect of zero. These findings are broadly consistent with findings from the nonword rejection paradigm reported by Lee and Taft (2009, 2011), although there is a discrepancy between our failure to find a syllable transposition effect in Experiment 5 and Lee et al.'s (2015) observation of one. Further research is needed to understand the nature of this discrepancy. It could reflect a difference between the rapid processes reflected in masked priming and the more strategic processes reflected in the nonword rejection paradigm; or alternatively, it could reflect differences in the nature of items used (and notably, Lee et al., 2015 used four syllable words in comparison to our two-syllable words). However, in respect of the data reported in this article, particularly in the face of the substantial and consistent identity priming effect, and given the Bayesian analyses of these null effects, we are confident that there is no transposition effect lurking in these data.

Is there a cross-linguistic difference?

The results of the five experiments presented here indicate that the state of affairs is not as simple as arguing that there is position flexibility in English but not in Korean.

Indeed, we have seen that as in Korean, transpositions of three-letter English monosyllables (e.g. gip-PIG) do not facilitate recognition of their base words. If position flexibility were simply a matter of the global orthographic density of a writing system, then we would have observed priming in this condition, because we have argued that English orthography is globally relatively sparse. That fact that we did not observe priming indicates that there are other factors at play. We have mentioned several potential factors: (a) three-letter words typically come from very large neighborhoods, where masked form priming effects are not observed (Forster & Davis, 1991); (b) the overall match between transposed-letter primes and targets for three-letter words is low; (c) the *local* orthographic space is dense (i.e. three-letter English words have many anagrams). One further potential explanation is that the transpositions in this case involved external letters, which some have argued play a special role in word recognition (Perea & Lupker, 2007). However, we do not believe that this is a likely explanation given evidence of robust transposition effects involving external letters within the published literature (e.g. Adelman et al., 2014; Crepaldi et al., 2013) as well as our own Experiment 4. Overall, the fact that a transposition effect was not observed for three-letter English monosyllables indicates that even in writing system characterized by a high degree of position flexibility, there is still a limit to the imprecision that can be tolerated in visual word recognition. It is for further work to determine precisely where this limit lies, and the factors that contribute to it.

This article is concerned with the question of whether there are cross-linguistic differences in position flexibility across English and Korean. On the basis of the experimental work that we have presented, we argue that there are such differences. One such difference is revealed in the contrast between Experiments 3 (Korean) and 4 (English). These were analogous experiments using disyllabic targets with the same structure, and using precisely the same type of transpositions. In both cases, these transpositions involved external letters. Yet, conventional and Bayesian statistics revealed evidence for a null priming effect in Korean, and evidence for a positive priming effect in English. The fact that these experiments were so closely matched makes it difficult to ascribe the different results observed to general perceptual factors such as the overall match between prime and target, or to the disruption of external letters. Instead, we conclude that the results of these experiments constitute a genuine cross-linguistic difference. Similarly, we believe that the null syllable transposition effect observed for Korean disyllables (Experiment 5) departs from the published literature; for example, robust syllable transposition priming effects have been reported using disyllabic English targets (Crepaldi et al., 2013).

What is the locus of the cross-linguistic difference?

Having identified cases in which there appears to be position flexibility in English but not in Korean, it is important to consider what might be the locus of those differences. One possibility consistent with Frost (2012a) is that Hangul orthographic representations themselves are specified in a very precise manner, and that this precision arises during the acquisition of those representations as a result of the high orthographic density characteristic of the syllable blocks at the heart of Hangul word recognition. However, there are other potential explanations for the differences between Hebrew and English that have been reported, and we believe that those explanations may also apply to the differences that we have observed.

One possibility is that the cross-linguistic difference reflects different forms of processing in English and Korean word recognition. On the basis of data from English and other Indo-European languages, Grainger and Ziegler (2011) proposed a dual-pathway model of orthographic processing. On this model, course-grained and fine-grained analysis pathways are balanced depending on task demands. Notably, the course-grained process provides rapid access to semantics by capitalizing on subsets of letters *without regard to precise letter position* that are diagnostic of word identity. In contrast, the fine-grained process comprises more detailed orthographic, morphemic, and phonological analysis of the visual input. Grainger and Ziegler (2011) argued that the null transposition effects observed in Hebrew (Velan & Frost, 2009, 2011) might be the result of a balance more heavily weighted toward fine-grained processing. They speculated that efficiency of morphemic analysis in Hebrew, which they propose is part of the fine-grained analysis, means that rapid course-grained processing may never develop for Semitic root-derived words. On the basis of this reasoning, we might suggest that Hangul word recognition proceeds largely through the fine-grained pathway, with little or no contribution from the course-grained pathway. By analogy to the logic for Hebrew, one might speculate that the very tight relationship between spelling and sound in Hangul may underpin particularly efficient fine-grained processing, and compensate for the absence of the orthographic “fast track” to semantics though the course-grained process. Indeed, in addition to the near one-to-one mapping between letters and sounds, Hangul consonants are drawn in the shape of the articulatory organs used in their production, thereby providing a direct line into spoken language. Thus, in terms of the framework proposed by Grainger and Ziegler (2011), we might consider that rapid access to meaning in Korean is accomplished largely through fine-grained phonological recoding, without the need for a rapid course-grained process that is relatively insensitive to letter position.

One final possibility that has been articulated in the discussions around Hebrew is that position flexibility in the early stages of orthographic processing is universal, and that cross-linguistic differences may arise later during access to lexical information (e.g. Gomez & Silins, 2012; Norris & Kinoshita, 2012b). Theories such as the Overlap model (Gomez et al., 2008) and the Noisy Channel model (Norris & Kinoshita, 2012a) claim that position uncertainty is a fact about orthographic processing that arises due to noisy perceptual processes. These theories propose to account for cross-linguistic effects by proposing additional linguistic constraints on recognition. In a commentary on Frost (2012a), Gomez and Silins (2012) speculated that perhaps individual letters in Hebrew are more informative than in English, and that this reduces position uncertainty in Hebrew. Similarly, in their commentary on Frost (2012a), Norris and Kinoshita (2012b) argued that noisy sampling of letter identity and letter order information accumulates over time, and that because of the high orthographic density of Hebrew lexical space, more evidence must be accumulated for Hebrew than for a less dense orthography such as English. They argued, "…English readers can tolerate more slop in the system, but the underlying process of identifying the orthographic symbols remains the same." (p. 297). This account is consistent with the finding that transposed letter priming can be observed in Hebrew if the task reflects pre-lexical orthographic representations (Kinoshita, Norris, & Siegelman, 2012).

We believe that each of these proposals offers a potential way to think about the cross-linguistic observations that we have presented in this article. However, we also believe that each of them remains underspecified, and for that reason, we find it difficult to adjudicate between them. One problem with the process explanation (Grainger & Ziegler,

2011) is that it is *ad hoc*: one would need a much more detailed advance specification of the conditions that would be expected to yield fine-grained or course-grained processing. Similarly, the noisy sampling proposal (Norris & Kinoshita, 2012b) fails to specify where perceptual processing ends and linguistic processing begins (Frost, 2012b). Indeed, Frost (2012b) argued that even if universal visual processes are assumed – and at some level there must be universal visual processes – the main challenge for building a theory of reading is to identify how the linguistic environment shapes processing of that visual information. Our data contribute to the overall picture in demonstrating an absence of position flexibility in a non-Semitic writing system, and in beginning to unpick the linguistic characteristics that give rise to the degree of precision that we have observed. Nevertheless, as for the Hebrew case much further empirical and theoretical work is necessary to fully understand the basis for these differences.

Masked form priming in Korean word recognition

Perhaps the most striking aspect of our findings is the complete absence of any type of masked form priming in Korean. Despite robust masked identity priming effects in the usual numerical range, any deviation from identity completely nullified the priming effect. These null priming effects extended to cases in which primes and targets shared a syllable *in the same position*. These results may seem surprising given the very robust form priming effects observed in other writing systems. However, they are consistent with some previous research (Kim & Davis, 2002) showing an absence of masked form priming on the recognition of Korean monosyllables, when primes were just one letter different from targets.

Kim and Davis (2002) conducted two studies designed to investigate the impact of a variety of masked phonological primes on the naming and lexical decision of Korean Hangul and Hanja target words. They were interested specifically in rapid phonological processing; for example, they reported robust masked homophone priming effects for primes and targets that shared no orthographic overlap (a situation made possible through the use of Hangul primes and Hanja targets). Though they were interested in phonological processes, data from the lexical decision task of their first experiment may be relevant to our observations. In this experiment, Kim and Davis (2002) investigated the impact of a range of masked primes on the recognition of Hangul monosyllables. Primes and targets (a) shared all letters; (b) shared the onset consonant; (c) shared the onset consonant and vowel; (d) shared the vowel and second consonant; and (e) shared no letters. Results showed a significant 40ms identity priming effect, but no priming whatsoever for the different types of non-identical primes against the all letter different control. These observations seem to contrast with those from Indo-European languages (e.g. Adelman et al., 2014; Davis & Lupker, 2006). However, it is important to note that these were short monosyllables with large neighborhoods (M=12, range 6-21); as discussed previously, and as noted by Kim & Davis (2002, footnote 4), masked form priming effects may not be expected in this context (Forster & Davis, 1991). Further, the lexical status of primes was not well controlled, and there were no statistical tests of the strength of the null effects observed. Thus, further work is needed to confirm the absence of masked form priming in Hangul, and to define the range of conditions under which this absence departs from masked form priming in other languages.

Overall, our work together with the observations of Kim and Davis (2002) appears to indicate that briefly-presented Hangul letter strings may not activate words with similar form, irrespective of whether similarity is defined at the level of the letter or the syllable, and irrespective of whether similarity is defined in a position-specific manner. Thus far, the data indicate robust identity priming effects, but no transposed-letter priming effects (Experiments 1 and 3), no transposed-syllable priming effects (Experiment 5), no priming effects based on a shared single syllable in the same or different position (Experiment 5), and no form priming effects (one letter different; Kim & Davis, 2002). This body of work therefore points to a high degree of precision in the recognition of Korean words that may extend to the computation of both letter position and letter identity. We believe that this more general precision could be a learned consequence of the high degree of orthographic density that we have described, both within and across syllable blocks, although this speculation requires further evidence.

Conclusions

Our purpose in this work was to highlight conditions in which rapid word recognition processes in Korean differ from those in English, and to begin to identify why these differences arise. We have provided initial evidence that the orthographic representations used in Korean word recognition are specified more precisely than in many Indo-European languages. These findings enrich the debate first begun with respect to Hebrew word recognition, concerning the extent to which orthographic representation and processing can be considered a universal feature of skilled reading (Frost, 2012a). We have claimed that the precision observed is a learned consequence of the very high degree of orthographic density characteristic of Hangul. Yet, specifying how this precision is manifested in the reading system – whether through orthographic representations themselves (Frost, 2012a), through the processes enacted on orthographic representations in the service of lexical access (Norris & Kinoshita, 2012b), or through the characteristics of different pathways linking orthography to meaning (Grainger & Ziegler, 2011) – remains a question for future research. Likewise, further work defining the range of cases in which masked form priming is observed (or not observed) is needed to understand whether the position rigidity that we have reported is part of a more general form of precision characteristic of Korean word recognition.

References

Adelman, J. S., Johnson, R. L., McCormick, S. F., McKague, M., Kinoshita, S., Bowers, J. S., ... & Scaltritti, M. (2014). A behavioral database for masked form priming. *Behavior Research Methods*, *46*(4), 1052-1067. doi: 10.3758/s13428-013-0442-y.

Bowers, J. S. (2000). In defense of abstractionist theories of repetition priming and word identification. *Psychonomic Bulletin & Review*, *7*(1), 83-99. doi: 10.3758/BF03210726.

Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects Models: A tutorial. *Journal of Cognition*, *1*(1), 1-20. doi: 10.5334/joc.10.

Castles, A., & Nation, K. (2006). How does orthographic learning happen. In S. Andrews (Ed.) *From Inkmarks to Ideas: Current Issues in Lexical Processing*, 151-179. Psychology Press.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204-256. doi: 10.1037/0033-295x.108.1.204.

Crepaldi, D., Rastle, K., Davis, C., & Lupker, S. (2013). Seeing stems everywhere: Position-independent identification of stem morphemes. *Journal of Experimental Psychology: Human Perception and Performance, 39*(2), 510-525. doi: 10.1037/a0029713.

Davis, C.J. (2005). N-watch: A program for deriving neighborhood size and other psycholinguistic statistics. *Behavior Research Methods, 37(1),* 65-70. doi: 10.3758/BF03206399.

Davis, C. J. (2010) The spatial coding model of visual word identification. *Psychological Review*, *117*(3), 713-758. doi: 10.1037/a0019738.

Davis, C. J., & Lupker, S. J. (2006). Masked inhibitory priming in English: Evidence for lexical inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 32*(3), 668-687. doi: 10.1037/0096-1523.32.3.668.

Davis, C. J., & Taft, M. (2005). More words in the neighborhood: Interference in lexical decision due to deletion neighbors. *Psychonomic Bulletin & Review, 12*(5), 904-910. doi: 10.3758/bf03196784.

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Sciences.* 9(7), 335-341. doi: 10.1016/j.tics.2005.05.004.

Duñabeitia, J., Laka, I., Perea, M., & Carreiras, M. (2009). Is Milkman a superhero like Batman? Constituent morphological priming in compound words. *European Journal of Cognitive Psychology, 21*(4), 615-640. doi: 10.1080/09541440802079835.

Duñabeitia, J., Perea, M., & Carrerias, M. (2007). Do transposed-letter similarity effects occur at a morpheme level? Evidence for morpho-orthographic decomposition. Cognition, 105, 691-703. doi:10.1016/j.cognition.2006.12.001.

Faul, F., Erdfelder, E., Lang, A.G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39(2),* 175-191. doi: 10.3758/BF03193146.

Forster, K. I., & Davis, C. J. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. *10*(4), 680-698. doi: 10.1037/0278-7393.10.4.680.

Forster, K., & Davis, C. (1991). The density constraint on form-priming in the naming task: interference effects from a masked prime. *Journal of Memory and Language*, *30*(1), 1-25. doi: 10.1016/0749-596x(91)90008-8.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*(1), 116-124. doi: 10.3758/BF03195503.

Frost, R. (2012a). Towards a universal model of reading. Behavioral and Brain Sciences, 35(5). 263-329. doi:10.1017/S0140525X11001841

Frost, R. (2012b). A universal approach to modelling visual word recognition and reading: Not only possible, but also inevitable. *Behavioural and Brain Sciences, 35(5),* 310-329. doi: 10.1017/S0140525X12000635.

Gomez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review, 115*(3), 577-600. doi: 10.1037/a0012667.

Gomez, P. & Silins, S. (2012). Visual word recognition models should also be constrained by knowledge about the visual system. *Behavioral and Brain Sciences, 35(5),* 287. doi: 10.1017/S0140525X12000179.

Grainger, J., Dufau, S., & Ziegler, J.C. (2016). A vision of reading. *Trends in Cognitive Sciences*, *20*(3), 171-179. doi: 10.1016/j.tics.2015.12.008.

Grainger, J., & Jacobs, A.M. (1996) Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*(3), 518-565. doi: 10.1037/0033-295X.103.3.518.

Grainger, J., & Whitney, C. (2004). Does the huamn mnid raed wrods as a wlohe? *Trends in Cognitive Sciences, 8*(2), 58-59. 10.1016/j.tics.2003.11.006.

Grainger, J., & Ziegler, J. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology,* 2, 54. doi: 10.3389/fpsyg.2011.00054.

Guerrera, C., & Forster, K. (2008) Masked form priming with extreme transposition. *Language and Cognitive Processes, 23(1)*, 117-142. doi: 10.1080/01690960701579722.

Kim, J., & Davis, C. (2002). Using Korean to investigate phonological priming effects without the influence of orthography. *Language and Cognitive Processes, 17(6)*, 569-591. doi: 10.1080/01690960143000281.

Kinoshita, S., Norris, D., & Siegelman, N. (2012). Transposed-letter priming effect in Hebrew in the same-different task. *Quarterly Journal of Experimental Psychology, 65*(7), 1296-1305. doi: 10.1080/17470218.2012.655749.

Kwon, Y., Lee, C., Tae, J., & Lee, Y. (2018). Early effect of phonological information in Korean visual word recognition: an ERP investigation with transposed letters. *Journal of Psycholinguistic Research, 47(4)*, 817-831. doi: 10.1007/s10936-018-9561-z.

Lee, C., Kwon, Y., Kim, K., & Rastle, K. (2015). Syllable transposition effects in Korean word recognition. *Journal of Psycholinguistic Research, 44*(3), 309-315. doi: 10.1007/s10936-015-9353-7.

Lee, C. H., & Taft, M. (2009). Are onsets and codas important in processing letter position? A comparison of TL effects in English and Korean. *Journal of Memory and Language, 60*(4), 530-542. doi: 10.1016/j.jml.2009.01.002.

Lee, C. H. & Taft, M. (2011). Subsyllabic structure reflected in letter confusability effects in

Korean word recognition. *Psychonomic Bulletin & Review*, *18*(1), 129-134. doi: 10.3758/s13423-010-0028-y.

Lupker, S., Perea, M., & Davis, C. (2008). Transposed-letter effects: Consonants, vowels and letter frequency. *Language and Cognitive Processes*, *23*(1), 93-116. doi: 10.1080/01690960701579714.

Masson, M.E.J. (2011). A tutorial on a practical Bayesian alternative to null-hypothesis significance testing. *Behavior Research Methods, 43(3)*, 679-690. doi: 10.3758/s13428-010-0049-5

National Institute of the Korean Language (2001). *Korean Word Database*. *21st century Sejong Project Corpus*. The National Institute of the Korean Language, Seoul: Korea.

Norris, D., & Kinoshita, S. (2012a). Reading through a noisy channel: Why there's nothing special about the perception of orthography. *Psychological Review*, *119*(3), 517-545. doi: 10.1037/a0028450.

Norris, D., & Kinoshita, S. (2012b). Orthographic processing is universal: it’s what you do with it that’s different. *Behavioral and Brain Sciences, 35(5)*, 296-297. doi: 10.1017/S0140525X12000015

Perea, M., & Carreiras, M. (2006). Do transposed-letter effects occur across lexeme boundaries?. *Psychonomic Bulletin & Review*, 13(3), 418-422. doi: 10.3758/BF03193863.

Perea, M., & Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language, 51*(2), 231-246. doi: 10.1016/j.jml.2004.05.005.

Perea, M., & Lupker, S. J. (2007). The role of external letter positions in visual word recognition. *Psicothema, 19*(3), 559-564.

Perea, M., & Pérez, E. (2009). Beyond alphabetic orthographies: The role of form and phonology in transposition effects in Katakana. *Language and Cognitive Processes, 24*(1), 67-88. doi: 10.1080/01690960802053924.

Perea, M., Abu Mallouh, R., & Carreiras, M. (2010). The search for an input coding scheme: Transposed letter priming in Arabic. *Psychonomic Bulletin & Review*, *17*(3), 375–380. doi: 10.3758/PBR.17.3.375.

Raftery, A.E. (1995). Bayesian model selection in social research. *Sociological Methodology, 25*, 111-163. doi: 10.2307/271063.

Rastle, K., & Coltheart, M. (2006). Is there serial processing in the reading system; and are there local representations? In S. Andrews (Ed.) *From inkmarks to ideas: Current issues in lexical processing*. Hove: Psychology Press.

Schoonbaert, S., & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes*, *19*(3), 333-367. doi: 10.1080/01690960344000198.

Shillcock, R., Ellison, T.M., & Monaghan, P. (2000). Eye-fixation behavior, lexical storage, and visual word recognition in a split processing model. *Psychological Review, 107(4)*, 824-851. 10.1037/0033-295X.107.4.824.

Simpson, G. B., & Kang, H. (1994). Inhibitory processes in the recognition of homograph meanings. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory and language* (pp. 359-381). San Diego, CA, US: Academic Press.

Simpson, G. B., & Kang, H. (2004). Syllable processing in alphabetic Korean. *Reading and*

Writing, 17(1), 137-151. doi: 10.1023/b:read.0000013808.65933.al.

Sohn, H. (1999). *The Korean language*. Cambridge: Cambridge University Press.

Velan, H., & Frost, R. (2007). Cambridge University versus Hebrew University: The impact of letter transposition on reading English and Hebrew. *Psychonomic Bulletin & Review*, *14*(5), 913-918. doi: 10.3758/BF03194121.

Velan, H., & Frost, R. (2009). Letter-transposition effects are not universal: The impact of transposing letters in Hebrew. *Journal of Memory and Language, 61*(3), 285–302. doi: 10.1016/j.jml.2009.05.003.

Velan, H., & Frost, R. (2011). Words with and without internal structure: What determines the nature of orthographic and morphological processing? *Cognition, 118*(2), 141-156. doi: 10.1016/j.cognition.2010.11.013.

Winskel, H., Perea, M., & Ratitamkul, T. (2012). On the flexibility of letter position coding during lexical processing: Evidence from eye movements when reading Thai. *Quarterly Journal of Experimental Psychology, 65(8), 1522-1536.* doi: 10.1080/17470218.2012.658409.

Witzel, N., Qiao, X., & Forster, K. (2011). Transposed letter priming with horizontal and vertical text in Japanese and English readers. *Journal of Experimental Psychology: Human Perception and Performance, 37*(3), 914-920. doi: 10.1037/a0022194.

Author Note

This work was supported by a Global Research Network grant from the National Research Foundation of Korea (NRF-2014S1A2A2027754). Stimuli are available on the Open Science Framework https://osf.io/rez7d/?view_only=e0f8ea4e8f954c25812e1844de53b10f. We are grateful to Yuan Kwon for his insights concerning the structure of Korean writing.

Correspondence about this work may be addressed to Kathleen Rastle (Kathy.Rastle@rhul.ac.uk) or Chang Lee (changhwan4017@sogang.ac.kr).

Table 1. Mean Reaction Times (ms) and Error Rates (proportions) for the conditions in Experiment 1 . Standard deviations in parentheses.

Prime Condition		Example	RT		Error rate	
ID		겉-겉	665 (104)		0.11 (.08)	
TL			721 (108)		0.12 (.07)	
	Word Prime	닢-핀		723 (127)		0.15 (.13)
	NW Prime	먼-덤		720 (113)		0.12 (.09)
RL			714 (102)		0.14 (.09)	
	Word Prime	힐-핀		725 (125)		0.16 (.14)
	NW Prime	겆-덤		707 (101)		0.15 (.13)

Table 2. Bayesian posterior probabilities for the null hypothesis given the observed data in Experiments 1-5. Posterior probabilities are computed using the method described by Masson (2011).

	Analysis	RT	Accuracy
Experiment 1			
	F_1	0.85	0.72
	F_2	0.89	0.85
Experiment 2			
	F_1	0.78	0.86
	F_2	0.70	0.87
Experiment 3			
	F_1	0.89	0.90
	F_2	0.91	0.90
Experiment 4			
	F_1	0.002	0.56
	F_2	0.03	0.67
Experiment 5			
	F_1	0.82	0.90
	F_2	0.88	0.91

Table 3. Mean Reaction Times (ms) and Error Rates (proportions) in Experiment 2. Standard deviations in parentheses.

Prime Condition		Example	RT		Error rate	
ID		pit-PIT	581 (101)		0.05 (.07)	
TL			639 (89)		0.09 (.08)	
	Word Prime	gum-MUG		632 (91)		0.07 (.09)
	NW Prime	gip-PIG		646 (97)		0.11 (.09)
RL			647 (102)		0.08 (.08)	
	Word Prime	sun-MUG		642 (104)		0.06 (.09)
	NW Prime	nid-PIG		653 (108)		0.10 (.10)

Table 4. Mean Reaction Times (ms) and Error Rates (proportion) in Experiment 3

Prime Condition		Example	RT		Error Rate	
ID		심판-심판	510 (69)		0.01 (.03)	
TL			556 (60)		0.04 (.03)	
	1st Syllable	낭정-안정		559 (64)		0.04 (.05)
	2nd Syllable	정앗-정상		554 (60)		0.03 (.03)
RL			557 (64)		0.03 (.03)	
	1st Syllable	턱정-안정		559 (65)		0.04 (.04)
	2nd Syllable	정닥-정상		555 (68)		0.03 (.04)

Table 5. Mean Reaction Times (ms) and Error Rates (proportions) in Experiment 4. Standard deviations in parentheses.

Prime Condition		Example	RT		Error Rate	
ID		combat-COMBAT	601 (91)		0.07 (.09)	
TL			630 (81)		0.08 (.06)	
	1st Syllable	ticrus-CITRUS		624 (85)		0.08 (.06)
	2nd Syllable	pelsiv-PELVIS		635 (86)		0.08 (.08)
RL			642 (81)		0.09 (.07)	
	1st Syllable	kimrus-CITRUS		643 (85)		0.08 (.09)
	2nd Syllable	pelgid-PELVIS		640 (84)		0.10 (.08)

Table 6. Mean Reaction Times (ms) and Error Rates (proportions) in Experiment 5. Standard deviations in parentheses.

Conditions	ID 선장-선장	1SYL_SAMEPOS 삭청-삭발	1SYL_DIFFPOS 넘안-안경	TS 정안-안정	ASD 간먼-엄살
RT	515 (68)	562 (66)	564 (67)	557 (67)	561 (75)
Error rates	0.03 (.04)	0.05 (.06)	0.04 (.05)	0.04 (.06)	0.04 (.06)