Journal of Memory and Language 60 (2009) 530–542

Contents lists available at ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

Are onsets and codas important in processing letter position? A comparison of TL effects in English and Korean

Chang H. Lee [a], Marcus Taft [b,*]

[a] Sogang University, Seoul, South Korea
[b] University of New South Wales, School of Psychology, Sydney NSW 2052, Australia

ARTICLE INFO

Article history:
Received 19 March 2008
revision received 18 December 2008
Available online 14 February 2009

Keywords:
Korean lexical processing
Letter position
Onsets and codas
Orthographic processing
Subsyllabic processing
Transposed letter effect

ABSTRACT

When two consonants within an English word were transposed to create a nonword, difficulty in lexical decision responses to that nonword was revealed, most strongly when the coda of the first syllable was exchanged with the onset of the second (e.g., *nakpin* derived from *napkin*), but also when onsets were exchanged between syllables (e.g., *kapnin*) as well as codas (e.g., *nankip*). The latter findings are incompatible with current models of letter processing. Moreover, such transposed letter (TL) effects were shown to be considerably reduced in Hangul, the alphabetic script used in Korean. Because Hangul physically demarcates the onset and coda positions for every consonant, it is argued that it is ambiguity in assignment of a consonant to an onset or coda slot that leads to the TL effect in a linear script such as English. Such a conclusion implies that models of letter processing should incorporate the involvement of subsyllabic structure, something that is currently lacking.

Introduction

When a nonword is created from an English word by transposing two of its interior letters (e.g., *nakpin*), it is hard to distinguish from its baseword (*napkin*). This has been amply demonstrated in lexical decision experiments where such "transposed letter" (TL) nonwords are erroneously classified as words more often than nonTL nonwords (e.g., *nagbin*) and/or have longer response times when being correctly classified as nonwords (e.g., Andrews, 1996; Chambers, 1979; Frankish & Turner, 2007; O'Connor & Forster, 1981; Perea & Lupker, 2004; Perea, Rosa, & Gómez, 2005). Such a finding has implications for the issue of how information about letter position is encoded during reading because it suggests that the exact position of a letter in the middle of a presented letter-string is not very important when that letter-string is encoded.

There are several recent accounts of letter position coding that readily handle the TL effect, namely, "open-bigram coding", "spatial coding", and "overlapping distributions". In the first of these (e.g., Grainger & van Heuven, 2003; Grainger & Whitney, 2004; Schoonbaert & Grainger, 2004; Whitney, 2001; Whitney & Cornelissen, 2008), a word is coded in terms of the correctly ordered pairs of letters (i.e., bigrams) that are found within it, both adjacent and nonadjacent (though distant letter pairings only make a weak contribution, if any). For example, *napkin* would be coded at the bigram level as *na, np, nk, ak, pk, pi, kn, in*, and so on. When *nakpin* is presented, units representing the bigrams *np* and *nk* are activated while the unit representing *pk* is not, thus providing a slightly different coding to that associated with *napkin*, but with considerable overlap. In contrast, none of the bigrams relevant to *napkin* that contain *k* or *p* will be activated by *nagbin* and, therefore, it is less confusable with the baseword.

In the spatial coding account (e.g., Davis, 2006a; Davis & Bowers, 2004, 2006), words are coded in terms of their individual letters, but are maximally responsive to a specific pattern of activation within the letter-level nodes. The amount of activation generated within a letter node is determined by its position in the letter-string, with the

* Corresponding author. Fax: +61 2 9385 3641.
E-mail address: M.Taft@unsw.edu.au (M. Taft).

0749-596X/$ - see front matter Crown Copyright © 2009 Published by Elsevier Inc. All rights reserved.
doi:10.1016/j.jml.2009.01.002

highest activation for initial letters and the lowest for final letters. For example, the lexical representation for *napkin* will be maximally responsive when the amount of activation in the *p* unit is appropriate for the third letter of a letter-string and the amount of activation for the *k* unit is slightly less. The stimulus *nakpin* will activate the *p* and *k* letter nodes, but with the latter being activated somewhat more than the former. Thus, the pattern of activation in the letter nodes will not quite match the expected pattern for *napkin*, but will match it more closely than that generated by a stimulus that does not activate the *p* and *k* letter nodes at all (e.g., *nagbin*).

The final account has coding in terms of slots, but letter identification for a particular slot is imprecise (Gómez, Ratcliff, & Perea, 2008). While the first letter of a stimulus is quite precise in its association with the initial slot, other letter identities activate a range of slots with a decreasing level of probability the further away those slots are from their correct position. Thus, although the *k* and *p* of the TL stimulus *nakpin* are most strongly associated with the third and fourth slot respectively, the *k* will also be associated to some extent with the fourth slot and *p* with the third slot. As a result, the lexical representation for *nakpin* will be partly activated because it is responsive to having a *k* and *p* in those positions. Hence, TL interference will ensue.

All of these accounts of letter position coding assume that the only sublexical structure to play a role in orthographic processing is at the level of the single letter or the bigram. What is not taken into account is the fact that some letters are consonants and some are vowels (or "nuclei"), and moreover that, within a syllable, some consonants precede the nucleus (i.e., are "onsets") while others follow the vowel (i.e., are "codas"). For example, *n* is the onset and *p* is the coda of the first syllable of *napkin*, while *k* is the onset and *n* is the coda of its second syllable. The differential impact of the onset and coda in English orthographic processing is evidenced by the fact that the coda is processed more closely with the vowel than is the onset, creating an orthographic onset + body structure (where a "body" is the combination of the vowel and coda, e.g., the *ap* of *nap*). The analysis of a letter-string into its onset + body (such as *n* + *ap*, as opposed to an "antibody" + coda analysis, such as *na* + *p*[1], cf. Forster & Taft, 1994) has been revealed in a number of studies using a wide range of paradigms (e.g., Andrews & Scarratt, 1998; Bowey, 1990; Kay & Marcel, 1981; Taraban & McClelland, 1987; Treiman & Chafetz, 1987; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995; Treiman & Zukowski, 1988).

As an example, Taraban and McClelland (1987) observed more irregular pronunciations to *jead* (i.e., saying /dʒɛd/ rather than /dʒi:d/) when preceded by an irregular word that shared its body (e.g., *head*) than when preceded by an unrelated control. In contrast, when the target shared its antibody with the irregular prime word (e.g., *heam* primed by *head*), the bias toward an /ɛ/ pronunciation was far weaker. Thus, there is priming on the basis of the pronunciation of the body, and not on the basis of the pronunciation of the antibody. This has been shown to be true not only with monosyllabic words, but with the first syllable of polysyllabic words as well (Taft, 1992). That is, *meadow* also primes the irregular pronunciation of *jead*, whereas *jealous* does not, and this indicates that the body of the first syllable (*ead*), and not its antibody (*jea*), plays a role in the processing of the letter-string. The models of letter position outlined above fail to incorporate the fact that words have an internal orthographic structure whereby the body of a syllable forms a unit of processing separate from the onset.

While the function of a letter as an onset, nucleus, or coda may only be determined after it has been assigned to its position in the letter-string, it is worth pursuing the possibility that the function of the letter plays a role in the actual assignment of that letter to its positional slot. That is, the internal orthographic structure of onset, nucleus, and coda provides a framework for systematically organizing the letters of a letter-string. The model put forward by Plaut, McClelland, Seidenberg, and Patterson (1996) is an account of this type because letter-strings are initially coded in terms of their onset, vowel, and coda. For a complex onset that is composed of more than one letter (e.g., the *pl* of *plant*), each of those letters will activate an onset unit (representing *pl*), and the equivalent is true for a complex coda (e.g., the *nt* of *plant*]. The correct order of those letters will be specified by the fact that they only have one possible combination as an onset (i.e., *lp* is not a possible onset, even though it is a possible coda). The major problem for the account of Plaut et al. (1996), however, is that it is impossible to differentiate a word with a complex onset or coda from the nonsense letter-string that has the letters of its onset or coda transposed (Davis & Bowers, 2006). For example, the letter-string *lpatn* should be totally indistinguishable from its baseword *plant* because *lp* will be re-organized to coincide with the existing onset *pl*, and *tn* with the existing coda *nt*.

It would be premature, however, to reject the idea of an onset/vowel/coda analysis merely on the basis of this particular instantiation of it. Alternatives can be envisaged. For example, words might be represented with an onset + vowel + coda structure and activated when the appropriate letters fill each type of slot. This is illustrated in Fig. 1 using the example of *plant*. The whole-word representation for *plant* is activated via sublexical units representing the

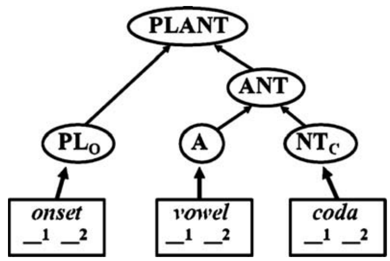

Fig. 1. A possible hierarchical framework for representing letter position in the lexical processing system using the word plant as an example. The subscript "o" refers to an onset and the subscript "c" refers to a coda.

[1] Confusion in terminology can arise here because linguists sometimes refer to the combination of onset and nucleus as the "body" of the syllable. In relation to visual word recognition, however, the term "body" is typically used to refer to the orthographic representation of the nucleus plus coda, which leads to the use of "antibody" to refer to the onset plus nucleus.

onset and body, with the latter activated via units representing the vowel and coda. The onset unit *pl* is maximally responsive when the first onset slot is filled with a *p* and the second with an *l*, and the coda unit *nt* is maximally responsive when the second coda slot is filled with a *t* and the first with an *n*. In this way, the nonsense string *lpatn* would not be confused with the word *plant* because the onset slot would be filled with *lp* rather than *pl* and the coda slot with *tn* rather than *nt*.

In order that the assignment of a consonant to an onset slot or coda slot can take place, the consonant/vowel structure of a presented letter-string must be identified (see e.g., Berent, Bouissa, & Tuller, 2001). Because of their distinctive physical position in the letter-string, it is easy to identify the initial consonant as filling the first onset slot and the last consonant as filling the final coda slot. However, assignment of any remaining consonants will be less straightforward and can be achieved in two different ways.

First, the consonant might be simultaneously "tried out" in both the remaining onset slot and the remaining coda slot[2], which in most cases will ultimately succeed in activating the appropriate representation at the whole-word level. That is, if the *l* of *plant* is tried out in both the second onset slot and the first coda slot, only the former will lead to activation of the correct word. However, such a process means that presentation of the nonsense string *pnalt* will also lead to its recognition as *plant*, and the existence of TL interference effects provides evidence that this can happen.

The second approach to assigning any remaining consonants to their correct slots involves greater attentional control. A consonant that is identified as being to the left of the vowel (or immediately to the right of the initial consonant) is assigned to the vacant onset slot, and a consonant identified to the right of the vowel (or immediately to the left of the final consonant) is assigned to the vacant coda slot. This second, more conscious process, allows any TL confusion to be overcome. In the normal course of reading, such a strategy will only be required when assignment of a consonant to both the onset and coda slots leads to competing lexical representations (e.g., *slept* and *spelt*, or *salt* and *slat*). In a lexical decision task, it allows the participant to correctly reject a TL nonword, albeit delayed by the interference arising from the more automatic process of concurrent onset/coda assignment.

In relation to polysyllabic words like *napkin*, it can be suggested that syllables are included within the sublexical hierarchy (see e.g., Taft, 1991, 2003). In this way *napkin* is activated via the syllable representations for *nap* and *kin*, each of which is in turn activated via units representing their onset and body. When presented with the letter-string *napkin*, it is easy to assign the initial *n* to the onset slot for the first syllable and the final *n* to the coda slot of the second syllable. Where there is uncertainty is in the assignment of the medial consonants *p* and *k* to their appropriate subsyllabic slots. For instance, placing the *p* in the coda slot for the first syllable will activate the appropriate syllable *nap*, but *p* could also be erroneously placed in the onset slot of the second syllable, or even the second onset slot of the first syllable. Only the first option leads to the recognition of *napkin*. Given that the same choices of assignment are available for the TL nonword *nakpin*, lexical information for *napkin* will be activated, leading to an incorrect or delayed lexical decision response to the TL nonword.

The issue being raised here is the possible need for models of letter position assignment to consider incorporating onset and coda structure into their conceptualization. The purpose of the framework outlined above is not so much to advocate a specific instantiation of this subsyllabic structure, but to indicate that it is possible to present an account that can handle the effects of transposed letters while capturing the involvement of onset/coda information. The experiments to be reported here aim to provide empirical evidence that onset/coda information might indeed play a role in the processing of letter position.

The present research

While the coda of the first syllable and the onset of the second might be hard to identify on physical grounds in a linear script such as English, there exists a script that physically demarcates all onsets and codas. This is "Hangul", the primary orthographic system of Korean. All Hangul characters correspond to an individual phoneme and, as such, are letters within an alphabetic script. However, syllabic structure is also represented in the orthography because the letters of each individual syllable are formed into their own block-shaped cluster, with consonants centered around the letter representing the vowel. This vowel is always depicted as a variation of either a horizontal or a vertical line. For example, the syllable 물 ("mool") is composed of the consonants ㅁ ("m") and ㄹ ("l") centered around the horizontal vowel ㅜ ("oo").

Every syllable possesses a consonantal onset (even if it is a letter representing a silent consonant) and, of most relevance here, the position of this onset is entirely predictable: It appears at the top of the block above the vowel when that vowel is horizontal, and it appears at the upper left-hand corner of the block to the left of the vowel when that vowel is vertical. Any coda that the syllable might have also has a predictable position, always appearing at the bottom of the block. Take the example 한글, which is the Korean spelling of the word "Hangul". The first syllable 한 ("han") is composed of onset ㅎ ("h"), vowel ㅏ ("a"), and coda ㄴ ("n"), and because the vowel is vertical, the onset is placed in the upper left-hand corner with the coda at the bottom. The second syllable 글 ("gul") is composed of onset ㄱ ("g"), vowel ㅡ ("u"), and coda ㄹ ("l"), and because the vowel is horizontal, the onset and coda are placed above and below it respectively.

The fact that the location of the onset and coda of each syllable of a word can be identified purely on a physical basis, means that the assignment of a consonant to its onset or coda slot lacks the ambiguity that is found in English. When confronted with a word in Hangul, the Korean speaker can place every letter in its appropriate slot prior to accessing the lexical representation, presumably via representations of the component syllables (see Simpson

[2] There would actually have to be three potential onset slots (as in *spray*) and coda slots (as in *world*), but only two are presented here for the sake of simplicity.

& Kang, 2004, for evidence of syllabic representation in Hangul). Given this, a test of the general involvement of onset/coda structures in the processing of letter position can be made by examining TL nonwords in Hangul. If letters are assigned to an onset or coda position early in processing, Korean speakers should have little or no difficulty in classifying a TL nonword in Korean when the coda of the first syllable is swapped with the onset of the second syllable (e.g., 학늘, "hagnul"), even though an English speaker will have considerable difficulty classifying a similar TL nonword in English. In other words, the conclusion that the basis of TL effects in English (and other linear scripts) is ambiguity in the assignment of letters to their onset and coda slots can be inferred from a marked reduction in TL confusion when such ambiguity is eliminated.

It is the medial coda–onset swap condition where the greatest contrast is likely to be found between Korean and English. When it comes to swapping an onset with an onset (e.g., *kapnin*) or swapping a coda with a coda (e.g., *nankip*), it is possible that TL effects will be evident in both Korean and English. In both languages, it is possible that the onset of the first syllable will activate a unit representing the onset of the second syllable, and the coda of the first syllable will activate a unit representing the coda of the second syllable. That is, confusion might arise as a result of the assignment of a consonant to its appropriate slot in the wrong syllable. Even here, though, a stronger TL effect might be expected in English than in Hangul. The identity of a letter as the coda of the first syllable or as the onset of the second syllable is not physically demarcated in English, unlike Hangul, and this is likely to make that letter more prone to mis-assignment. On the other hand, it is possible that neither script will reveal TL effects for onset–onset or coda–coda swap items on account of the fact that the onset or coda identity is physically defined for at least one of the two transposed letters.

Experiment 1

In order to establish whether TL effects arise primarily when there is ambiguity in the assignment of a consonant to its onset or coda slot, it is necessary to compare a situation where such ambiguity exists with a situation where it does not. Thus, TL effects were sought in English, using materials for which the same TL manipulation could be made in Hangul. To this end, it was necessary to find English words that, like Korean, had a clear-cut boundary between their first and second syllable, with the first syllable having a coda and the second syllable having an onset (e.g., *napkin*, *walrus*).

Although the expected difference between English and Korean should be seen most clearly when the medial coda and onset are transposed (the C–O condition), an examination was also made of the transpositions between the two onsets (the O–O condition) and between the two codas (the C–C condition). The aim was not to compare the three TL conditions to each other directly, but rather to specify as much as possible where there might be differences in the processing of English and Hangul. It was predicted that, in English, a coda–onset swap would generate clear interference because the transposition was between two adjacent internal letters where assignment to the appropriate slot is ambiguous. It was also possible that interference would be observed when there was both an onset–onset swap and a coda–coda swap because the two consonants fill the same slot. However, the TL effect in these conditions might be tempered by the fact that the appropriate slot for one of those consonants is clearly defined by the physical presence of a word boundary, and also by the fact that the transposed letters are not adjacent.

Method

Participants

Participants were 24 native English speakers who were all first-year Psychology students at the University of New South Wales. They received course accreditation for their participation.

Materials

The TL nonwords were created by transposing two consonants within a baseword that had a clear boundary between its first and second syllable. A boundary was considered to be clear when the two medial consonants could not form a complex coda; that is, they could never occur together at the end of a monosyllabic word (e.g., the *pk* of *napkin* or the *lr* of *walrus*). Some of the basewords were actually compound words, though not highly transparent in their relationship to their constituent morphemes (e.g., *hardware, jaywalk, runway*) and sometimes they contained one meaningful and one meaningless component (e.g., *cobweb, nutmeg, steadfast*). TL effects have been found even across the constituents of a compound word (e.g., Christianson, Johnson, & Rayner, 2005; Perea & Carreiras, 2006a), so the morphological structure of the baseword should not compromise the effects being examined.

There were 16 items generated for each of the three TL conditions. For the O–O condition, each syllable of the baseword had a simple onset (i.e., composed of a single consonant) and these onsets were transposed (e.g., *pagmie* from *magpie*, *wardhare* from *hardware*). For the C–C condition, codas were transposed (e.g., *nankip* from *napkin*, *wimwag* from *wigwam*), and for the C–O condition, the coda of the first syllable was transposed with the onset of the second (e.g., *widsom* from *wisdom, semgent* from *segment*).

To generate control items against which TL effects can be gauged, most studies replace the transposed letters with letters that do not occur in the baseword at all (e.g., *nagbin* from *napkin*). This approach is problematical, however, when the TL items have letters transposed across syllables because the TL item and its control will have a different first syllable. The nature of the first syllable is likely to have a considerable impact on the identification of a letter-string as a nonword (e.g., Taft & Forster, 1976), so it is important that each control item maintains the same first syllable as its matching TL nonword. This was achieved in the present research by substituting another consonant in the TL item for the second transposed letter only (e.g., *pagnie* as the O–O control for *pagmie, nankid* as the C–C control for *nankip*, and *widrom* as the C–O control for *widsom*). Thus the TL nonword and its paired control differed by only one letter. For each condition, the TL nonwords and their controls were matched on the number of one-letter-different neighbors (the N measure of Coltheart, Davelaar, Jonasson, & Besner, 1977) which was close to zero in each condition. They were also matched on mean bigram frequency (obtained from Davis, 2005), with $|t| < 1$ for all three types of TL pairs. The mean log frequency of the baseword was also closely matched between the three types of TL item, $F < 1$, with mean antilog being 2.72 (based on the CELEX norms of Baayen, Piepenbrock, & van Rijn, 1995). When the second syllable created by transposition corresponded to a real word, an attempt was made to use a real word in the second syllable of the control item as well (e.g., *wardmare* as the O–O control for *wardhare*, *wimway* as the C–C control for *wimwag*, and *semrent* as the C–O control for *semgent*).

A Latin-Square design was used in order to avoid having the same participant see both a TL word and its similar-looking control. The 16 item pairs in each TL condition (see Appendix A) were split into two lists such that eight TL items were placed in one list and the other eight were placed in the second list. Each control item was placed in the opposite list from its TL partner. The two lists also included the same set of 40 filler words. These were words that had not been used as basewords for the TL nonwords, but which had a similar structure (e.g., *chimney, fanfare, goblin*). There were also 12 practice items, half being bisyllabic words and half bisyllabic nonwords (none of which were TL items).

Procedure

Items were presented one by one using DMDX display software (Forster & Forster, 2002). In order to optimize the potential for TL interference, a relatively short exposure time was adopted, namely, 250 ms. Participants were instructed to respond as quickly but as accurately as possible by pressing a "yes" button when the letter-string was a real English word and the "no" button when it was not.

Results and discussion

Two of the C–O items had very high error rates (*porftolio* and *widsom*), so in order to avoid the potentially unreliable mean RTs arising from this, the RTs of those items (but not their error rates) were removed from the analysis, along with the RTs for their controls. For each participant, response times exceeding the mean by two standard deviations were replaced by that cut-off value. This occurred on 4.50% of trials. Table 1 presents the mean lexical decision times and error rates for the three TL conditions and their controls.

As required by the Latin-Square design, the two subgroups of participants were treated as a between-groups factor in the analysis, but the statistics from this are meaningless and hence not reported. Because the three TL conditions were not being compared to each other, only to their respective controls, separate ANOVAs were carried out for the three comparisons.

Table 1
Mean lexical decision times (RT in ms) and % error rates (ER) based on the participant analysis of English nonwords in Experiment 1. Confidence intervals (CI) are given in parentheses.

Condition	Example	RT	ER
O–O Swap	pagmie	673	8.88
O–O Control	pagnie	635	4.17
TL effect		+38 (±23.8)	+4.71 (±6.04)
C–C Swap	nankip	703	12.17
C–C Control	nankid	640	6.77
TL effect		+63 (±36.2)	+5.40 (±7.59)
C–O Swap	widsom	697	41.15
C–O Control	widrom	653	12.50
TL effect		+44 (±40.8)	+28.65 (±17.66)

The effect of onset transposition proved to be significant on RT, $F_1(1,22) = 11.23$, $p < .01$; $F_2(1,15) = 4.51$, $p = .052$; min$F'(1,27) = 3.22$, $p < .1$, though not on error rates, $F_1(1,22) = 2.62$, $p > .1$; $F_2(1,15) = 3.30$, $p < .1$; min-$F'(1,37) = 1.46$, $p > .1$. Swapping codas produced significant interference on the RT measure, $F_1(1,22) = 12.93$, $p < .01$; $F_2(1,15) = 7.16$, $p < .02$; min$F'(1,30) = 4.61$, $p < .05$, but only for the item analysis on the error measure $F_1(1,22) = 2.18$, $p > .1$; $F_2(1,15) = 10.22$, $p < .01$; min$F'(1,30) = 1.79$, $p > .1$. The effect of coda–onset transposition was significant on RT, $F_1(1,22) = 5.16$, $p < .05$, $F_2(1,13) = 7.38$, $p < .02$; min-$F'(1,35) = 3.04$, $p < .1$, and highly significant on error rates, $F_1(1,22) = 45.27$, $p < .001$; $F_2(1,15) = 21.49$, $p < .001$; min-$F'(1,28) = 14.57$, $p < .001$.

Consistent with other studies in English (e.g., Andrews, 1996; Chambers, 1979; Frankish & Turner, 2007; O'Connor & Forster, 1981; Perea & Lupker, 2004), it is shown that lexical decision responses to a nonword are disrupted when transposition of two of its consonants creates a real word. Such interference is greatest when neither of the two consonants are the first nor last letter of the string, with the coda–onset swap condition producing over 40% errors. It is apparent that the lexical representation for a word is accessed with little regard to the position of its internal consonants.

It is also shown, however, that interference still occurs even when the first or last letter is disrupted by the transposition; that is, there are also significant difficulties in responding to the Onset swap and Coda swap conditions. Such a finding is consistent with Chambers (1979) who reported a reduced, though significant, TL effect for initial transpositions relative to medial transpositions. In fact, the finding of TL interference when two letters are swapped over a distance of at least three characters (as in the O–O swap and C–C swap conditions) is inconsistent with the current models of letter position coding.

Take for example the C–C swap item and its control, *wasrul* vs *wasrud* (based on *walrus*). Because neither the bigrams *sl, rl, ul*, nor *sd, rd, ud* exist in *walrus*, the open-bigram coding approach could only potentially explain the observed difference between *wasrul* and *wasrud* in terms of the existence of *wl* and *al* relative to *wd* and *ad*. However, all recent versions of this approach (e.g., Grainger & van Heuven, 2003; Grainger & Whitney, 2004; Schoonbaert & Grainger, 2004; Whitney, 2001, 2008; Whitney & Cornelissen, 2008) give very little weight, if any, to the bigrams *wl* and *al* in *wasrul* because they are separated by too many letters. The same holds for O–O swap items (e.g., *pagmie*) relative to their controls (*pagnie*). On top of this, the most recent versions give more weight to the initial and final letters of a word than any other letters (e.g., Whitney, 2008; Whitney & Cornelissen, 2008), so disruption of the initial and final letters of the baseword (as in *pagmie* and *wasrul*) reduce the likelihood of TL effect even further. While it might be possible to point to the fact that the effect for the O–O condition was not quite significant in the item analysis of RT at the .05 level, there is no doubting the TL effect for the C–C condition. Furthermore, when the actual match scores between a nonword stimulus and its baseword are quantified (using values provided by Davis, 2006b and Whitney, 2008), no version of the open-bigram approach shows anything close to a correlation for the size of the TL effect across these conditions between the calculated scores and either the observed RTs or error rates (with the highest r being .14 for the correlation between error rates and the values based on the Binary Open Bigram model of Schoonbaert & Grainger, 2004).[3]

According to the spatial coding account (e.g., Davis, 2006a; Davis & Bowers, 2004, 2006), a match is attempted between the presented letter-string and the stored representation, with a weaker amount of matching the further away the letter in the stimulus is from that of the stored representation. According to the parameters for calculating the match value, when a letter is more than three letters away from its correct position ("sigma" = 3, see Davis & Bowers, 2004), it fails to register as a match. This is confirmed when match scores are calculated (using Davis, 2006b) inasmuch as all but four of the O–O and C–C items have the same value as their controls. As such, it is hard to explain the existence of a TL effect across three letter positions as in the O–O and C–C conditions.

Finally, in the overlapping distributions model that is used to successfully simulate a large body of data (Gómez et al., 2008), there is negligible activation when a letter is in a position three letters away from its position in the baseword. As a result, *wasrul* should be little different to *wasrud* when it comes to activating the baseword *walrus*: Activation of the *s* of *walrus* will be the same for both items, and the *l* of the former will only activate the *l* of *walrus* to a very small degree. The overlap model therefore needs to adopt the rather tenuous argument that the tiny amount of overlap between distant positions is enough to generate TL interference in the C–C swap condition. In relation to the O–O swap items, positional coding is far more precise for initial letters than for letters in other positions, so the *m* of *magpie* will not be activated at all by the *m* of *pagmie*, which means that there should be no difference whatsoever between *pagmie* and *pagnie*. As in the case of open-bigram coding, it might be argued that the O–O priming effect was not quite significant in the item analysis of RTs and, hence, not really an effect at all. However, there was also no statistical difference in magnitude between the O–O TL effect and the C–C TL effect (with no sign of an interaction on either RT or error rates, all F's < 1, despite a highly significant main effect of TL on RTs across the two types of transposition, $F_1(1,22) = 37.62$, $p < .001$; $F_2(1,30) = 11.54$, $p < .01$; $\min F'(1,45) = 8.83$, $p < .01$). So, the O–O TL effect cannot be dismissed so readily. The overlap model would have considerable difficulty explaining how there could be an effect of O–O transposition of the same magnitude as the effect of C–C transposition.

It is therefore seen that the English results are problematical for current models of letter position, but can be accommodated within an account that tries to identify consonants as being onsets or codas. That is, medial codas and onsets are confused because there is ambiguity in their assignment to their appropriate slot, hence producing a large TL effect for the C–O condition. Interference in the O–O and C–C conditions can be explained in terms of there being some confusion in the assignment of the onset or coda to its appropriate syllable. Consistent with such an account would be the finding that TL effects are weakened when assignment of a consonant to its appropriate slot is relatively unambiguous. Such a situation is examined in Experiment 2 where Hangul is tested.

Experiment 2

The fact that TL interference is observed in English across clear syllable boundaries allows a comparison to be made with Hangul, where the onset and coda positions are physically demarcated in the script. If onset-vowel-coda structure is important in providing letter position information, the weakest interference in Korean should arise from a coda–onset swap, which is the condition that showed the greatest interference in the linear script of English. This is because there should be little confusion in assigning the coda of the first syllable to its coda slot and the onset of the second syllable to its onset slot. Whether any interference is observed for the onset–onset and coda–coda conditions will depend on how well the slots for the two syllables are differentiated within the letter processing system.

Method

Participants

Participants were 72 native Korean speakers recruited from the undergraduate population of Pusan National University, South Korea.

Materials

Fourteen two-syllable words (e.g., 남북, "nambuk") were found for which transposition of the two onsets, transposition of the two codas, and transposition of first coda with second onset created a nonword. These nonwords constituted the O–O condition (e.g., 밤눅, "bam-

[3] When a TL item gives a notably higher match score than its control in the open-bigram models, it is primarily the spurious outcome of the item having repeated letters (cf. Guerrera & Forster, 2007). Thus, the C-C item *casvan* matches the baseword *canvas* more closely than does its control *casvat* because the final *an* of the former also happens to exist in the baseword. It is apparent that such items did not carry the TL effect for the O-O and C-C conditions because the magnitude of the effect remains much the same when these items are removed (consistent with the lack of correlation between match scores and the size of the TL effect).

nuk"), C–C condition (e.g., 낙붐, "nakbum"), and C–O conditions (e.g., 납묵, "nabmuk") respectively. As in the English experiment, each TL nonword was matched to a control item whereby the second transposed consonant was replaced with another consonant such that the resultant letter-string was not related to a real word through transposition (e.g., 납눅, "nabnuk" being the control for 납묵, "nabmuk"). Each of the three TL conditions was closely matched to its control on N, being less than a single neighbor on average per condition (all t's < 1), as well as on syllable frequency (based on the Korean Word Database, 2001), all t's < 1. There was also no significant difference between a TL condition and its control on bigram frequency (according to the Korean Word Database, 2001), with the trend being for the TL nonwords to have a lower bigram frequency than their controls: $t(13) = 1.80$, $p > .05$ for O–O; $t(13) = 0.80$, $p > .05$ for C–C; and $t(13) = 1.64$, $p > .05$ for C–O. The basewords from which the TL nonwords were derived were all of sufficient frequency to be within the standard vocabulary of Korean undergraduate university students.[4] All of the items (see Appendix A) were pronounceable and orthographically legal.

As in Experiment 1, the items were split into two sublists for use in a Latin-Square design whereby an individual participant did not see both a TL item and its orthographically similar control. Each sublist also included the same set of filler items, which were 42 bisyllabic Korean words. There were also 30 practice items, half of which were words and half nonwords.

Procedure

Items were presented using the DMDX display software (Forster & Forster, 2002) at an exposure rate of 300 ms. Participants were asked to press the appropriate button as quickly but as accurately as possible depending on whether the stimulus was real Korean word or not.

Results and discussion

One pair of items in each condition was excluded from the RT analysis because of very high error rates to one member of the pair (i.e., 준망: O–O, 형산: C–C, and 식명: C–O Control). RTs that exceeded two standard deviation points from the mean were replaced by that cut-off value (5.11% of trials). Table 2 presents the mean lexical decision times and error rates.

No TL interference was found in the Onset swap condition, $F_1(1,70) = 1.24$, $p > .1$; $F_2(1,12) = 0.71$, $p > .1$; min-$F'(1,28) = 0.45$, $p > .1$ for RT, and $F_1(1,70) = 1.01$, $p > .1$; $F_2(1,13) = 0.15$, $p > .1$; min$F'(1,17) = 0.13$, $p > .1$ for error rate. Although there was a significant TL effect for Coda swap items in the participant analysis for both speed and accuracy, this was far from significant in the item analyses, $F_1(1,70) = 4.11$, $p < .05$; $F_2(1,12) = 0.69$, $p > .1$; min-$F'(1,16) = 0.59$, $p > .1$ for RT, and $F_1(1,70) = 5.03$, $p < .05$;

Table 2
Mean lexical decision times (RT in ms) and % error rates (ER) based on the participant analysis of Hangul nonwords in Experiment 2. Confidence intervals (CI) are given in parentheses.

Condition	Example	RT	ER
O–O Swap	밤눅, "bamnuk"	669	3.39
O–O Control	밤룩, "bamluk"	660	2.42
TL effect		+9 (±17.5)	+0.97 (±1.97)
C–C Swap	낙붐, "nakbum"	685	7.81
C–C Control	밤룩, "nakbun"	668	5.20
TL effect		+17 (±16.4)	+2.61 (±2.32)
C–O Swap	납묵, "nabmuk"	676	2.20
C–O Control	납눅, "nabnuk"	663	7.83
TL effect		+13 (±14.4)	−5.63 (±2.41)

$F_2(1,13) = 0.73$, $p > .1$; min$F'(1,17) = 0.64$, $p > .1$ for error rate. Coda–Onset transposition produced a trend toward interference in the participant analysis of RT, but a reverse effect for error rate, with neither being significant in the item analyses, $F_1(1,70) = 3.34$, $p < .1$; $F_2(1,12) = 0.19$, $p < .1$; min$F'(1,13) = 0.18$, $p > .1$ for RT, and $F_1(1,70) = 21.78$, $p < .001$; $F_2(1,13) = 2.98$, $p > .1$; min-$F'(1,17) = 2.62$, $p > .1$ for error rate.

Where English materials produced TL interference for all three types of exchanges, Korean materials only showed very weak effects, if any. Although it is possible that an effect on latencies may have been observed in Korean if there had have been more items, particularly in the C–C and C–O conditions, there is a striking difference between the two scripts in terms of accuracy in the C–O condition. English TL nonwords were frequently identified as words when transposition of the coda of their first syllable and the onset of their second syllable produced a word (with over 40% errors), whereas there was no evidence of this happening in Hangul (with only about 2% errors). Clearly, information about letter position is used very differently depending on the nature of the orthographic structure of the language.

Such a conclusion concurs with that drawn by Velan and Frost (2007) who found that consonant transpositions in Hebrew disguise the identity of the baseword, unlike in English. Hebrew orthographic structure centers upon a three-consonant root whose identification depends upon each of the consonants equally. Disruption to the order of those consonants is therefore detrimental to their recognition. Thus, the argument can be made that TL effects only occur for consonants when there is confusion in assigning them to an onset or coda slot, as in English. In Hebrew, there are no such slots because categorization of consonants into an onset and a coda requires a dichotomy and this is incompatible with the root having three consonants. In Korean, the slots exist, but assignment to the appropriate slot can be readily made on the basis of physical cues, hence reducing confusion.

Experiment 3

Before accepting that the difference between the English and Hangul findings arose from a difference in orthographic structure, however, there are two discrepancies between the procedure of the two experiments that

[4] According to the Korean Word Database (2001), the mean word frequency was 85 per million phrases, but no indication is given of the mean number of words in a phrase.

need to be dismissed as possible confounds. First, an exposure duration of 300 ms was employed in the Korean study, with 250 ms being adopted in the English study. While the former is a fast presentation rate, it is nevertheless conceivable that the extra 50 ms gave the Korean readers time to process the letter position information accurately enough to avoid an erroneous response. Second, the same basewords were used in the Korean study for each of the three TL conditions, whereas different basewords were used in the English study. It is possible that TL effects were attenuated in Korean because of the fact that each participant saw three variants on the same baseword. Perhaps participants became aware that they should respond "no" when they had already experienced another nonword that was similar to the same baseword.

In order to eliminate these trivial possibilities for the observed cross-language differences, Experiment 3 was carried out using English materials. This time an exposure duration of 300 ms was used and three different nonwords were generated from the same baseword. Only the C–O condition and its control were examined because this is where the greatest contrast was observed between the two experiments. If exposure duration and repetition of nonwords with the same baseword were the factors that led to the difference between the English and Hangul studies, the TL effect should be greatly reduced in Experiment 3, as it was in Experiment 2 (relative to Experiment 1).

Method

Participants

There were 34 participants recruited from the same pool of students as in Experiment 1.

Materials

The same items used in the C–O condition of Experiment 1 and their controls were examined in Experiment 3. For each C–O item, there were always two other TL nonwords generated from the same baseword and each of these nonwords was paired with a nonTL item that was one letter different from it. These TL filler items often involved an onset swap or a coda swap, but it was not always possible to achieve this for the basewords used in the C–O condition (e.g., a coda exchange for the baseword *dogma* was replaced by a vowel–coda exchange, giving *dgoma*). In addition, many of the onset and coda transpositions involved the exchange of a digraph (e.g., when transposing the codas *g* and *nt* of *segment* to produce *sentmeg*).

Again, a Latin-Square design was used to ensure that the C–O item was not seen by the same participant as its control. So, for example, half of the participants saw *widsom* (C–O) and *semrent* (C–O control) along with *diswom* and *wimdos* (both based on "wisdom") as well as *sentmed* and *meglent* (both one letter different from TL versions of "segment"). The other half of participants received *semgent* (C–O) and *widrom* (C–O control) along with *sentmeg, megsent, disvom* and *wintos*. Both sublists contained the same 40 filler words that were used in Experiment 1, as well as the same 12 practice items.

Procedure

The procedure was the same as in Experiment 1 except that each item was presented for 300 ms.

Results and discussion

The data were treated in the same way as in Experiment 1, with the mean response time for three items with over 75% error rates removed from the RT analysis (*porftolio, feebdack*, and *chuntey*). The 2 s.d. cut-off was applied on 4.17% of trials.

It was clear from the results that the modification to the methodology of Experiment 1 did not attenuate the TL effect at all. If anything, the effect was greater. The mean RTs (based on the participant analysis) for the C–O items and their controls were 724 ms and 651 ms, respectively, a significant 73 ms difference, $F_1(1,32) = 10.10$, $p < .01$; $F_2(1,12) = 8.88$, $p < .02$; $\min F'(1,33) = 4.73$, $p < .05$, CI ± 46.74. The effect on accuracy was again massive, a 37.13% difference arising from error rates of 44.33% for the TL items and 7.19% for their controls, $F_1(1,32) = 97.97$, $p < .001$; $F_2(1,15) = 24.72$, $p < .001$; $\min F'(1,23) = 19.74$, $p < .001$, CI ± 7.64.

From these data it can be confidently concluded that the lack of a C–O interference effect in Hangul cannot be explained in terms of the experimental procedure adopted in Experiment 2. It is apparent, then, that information about the position of medial consonants in English is less readily processed than the same information in Hangul.

There is, however, an obvious difference between the structure of Hangul and English words, unrelated to onsets and codas that could explain the relative lack of TL effects for the former. Words written in Hangul have a physical gap between their syllables, even if a small one, and it might be that such a gap simply provides a barrier to TL effects. That is, syllables might form two distinct perceptual units with such independent processing that there is no leakage of letter-level information between them. In terms of the overlapping distributions account (Gómez et al., 2008), for example, the overlap in activation across letter positions might not occur across a physical gap, with no overlap between the final position of the first unit and the initial position of the second.

Although there can be letter migration across a physical gap between words in English (see e.g., Davis & Bowers, 2004), this has been demonstrated under far more degraded conditions than used in the present research. Furthermore, transposition of a medial coda and onset in Hangul not only requires the crossing of a physical gap, but a diagonal exchange between the bottom position of the first syllable and the top position of the second. Thus, it needs to be established whether TL effects in Hangul and English differ simply on the basis of the physical distance between the transposed letters rather than the specificity of onset and coda locations. To this end, a further experiment was carried out using English materials structured in a similar way to Hangul.

Experiment 4

In order to construct English stimuli that paralleled the structure of Hangul, syllables were physically separated within the word, and each syllable was vertically structured with onsets placed at the top, vowels in the middle, and codas at the bottom. An example of each of three TL conditions in such "Hangulized" form is seen in Fig. 2. The way in which the stimuli were constructed was clearly explained to participants and enough practice was given with both words and nonwords for them to know how to perform the task.

In addition to increasing the physical distance between the two transposed letters, the use of Hangulized English provides positional slots for all onsets and codas. If it is the case, as argued here, that the TL effect arises largely from uncertainty in the assignment of consonants to their onset or coda slot, the specification of such slots might eliminate the TL effect altogether. If so, it would still be unclear whether the contrast between normal English (Experiments 1 and 3) and Hangul (Experiment 2) arose on the theoretically interesting grounds of onset/coda ambiguity or merely on the grounds of physical distance between letters. However, it was thought that a more likely outcome of specifying the onset and coda location in English would be the reduction of the TL effect rather than its complete elimination. This is because strategies appropriate to reading linear script are likely to be so entrenched that it would require considerable experience with a Hangulized script to overcome them. If significant TL effects are indeed observed with Hangulized English materials, it would mean that the Hangul results could not merely be explained in terms of perceptual distance.

Method

Participants

There were 32 participants recruited from the same pool of students as in Experiment 1 and 3.

Materials

The stimuli used in Experiment 1 were re-structured according the principles of Hangul. Because there were onsets, vowels, and codas composed of more than one letter (e.g., the *shr* of *shralnep*, the *ie* of *pagmie*, and the *ck* of *tockcail*), it was most practical to adopt a vertical syllable structure for all items (as used in Hangul when the vowel is horizontally oriented). This is illustrated in Fig. 2, where it can be seen that the syllables were separated by a space and the letters of each syllable were spread over three rows. The top row contained the onset, the middle row the vowel, and the bottom row the coda (if there was one). Thus, the basic shape was two columns with three rows. Letters that occurred beyond the second coda (e.g., the *e* of *fonbire* and *fonlire*) were placed in a third column with the vowel positioned in the middle row. All such cases were O–O items, except one.

O-O Swap		C-C Swap		C-O Swap	
p	**m**	**n**	**k**	**w**	**s**
a	**ie**	**a**	**i**	**i**	**o**
g		**n**	**p**	**d**	**m**

Fig. 2. Examples of "Hangulized" English stimuli used in Experiment 4.

Procedure

Because of the unusual presentation format, it was thought that participants would need considerable time to process each stimulus. For this reason, a 2500 ms target duration was employed. A further 10 practice items were also included, making 22 in total. The following written instructions were provided prior to the experiment:

"In this experiment you will see letter-strings (both real words and nonsense words) presented in an unusual formation. For example:

bl	m
a	ai
ck	l

Each letter string will be divided into syllables (e.g., "black" and "mail"), with each syllable presented side by side from left to right. However, each syllable will be presented vertically (i.e., in a downward column) with three rows within each column. The first row gives the initial consonants of the syllable if there are any, (e.g., the "bl" of "black" and the "m" of "mail"), the second row gives the vowel (e.g., the "a" of "black" and the "ai" of "mail"), and the third row gives the final consonants if there are any (e.g., the "ck" of black" and the "l" of "mail").

Other examples:

k		r		l		l	st
a	a	oo	a	e	e	i	i
ng			th	t		p	ck

Your task is to decide whether each letter string is a word or a nonsense word, e.g.,

"Yes" for	t	l	"No" for	gr	m
	a	e		a	a
	b	t		d	r

Please respond as quickly, but as accurately as you can by pressing the "Yes" or "No" key".

Results and discussion

No items were removed from the analysis because none exceeded a 50% error rate. The 2 s.d. cut-off was applied on 3.58% of trials. Table 3 presents the mean RTs and error rates.

It is apparent from the results that error rates were a more sensitive measure than were the long and variable response times. There were no significant differences on RT between the TL and control conditions, all F's < 1, apart from the item analysis of the C–O comparison which showed a strong trend toward a TL effect, $F_2(1,15) = 3.97$, $p = .065$. On error rates, however, there was a TL effect for both the C–C and C–O Swap conditions, $F_1(1,30) = 8.26$, $p < .01$; $F_2(1,15) = 8.64$, $p = .01$; $\min F'(1,41) = 4.22$, $p < .05$, and $F_1(1,30) = 13.11$, $p = .001$; $F_2(1,15) = 5.18$, $p < .05$; $\min F'(1,27) = 3.71$, $p = .065$, respectively. There was no TL effect for the onset swap condition, both F's < 1.

It can be seen, then, that TL effects can still be found when English is structured in the same way as Hangul. Although some of the effects are diminished compared to normal lin-

Table 3
Mean lexical decision times (RT in ms) and % error rates (ER) based on the participant analysis of Hangulized English nonwords in Experiment 4. Confidence intervals (CI) are given in parentheses.

Condition	Example	RT	ER
O–O Swap	pagmie	1661	2.35
O–O Control	pagnie	1674	1.99
TL effect		−13 (±66.3)	+0.36 (±2.47)
C–C Swap	nankip	1635	6.74
C–C Control	nankid	1663	1.15
TL effect		−28 (±73.5)	+5.49 (±3.97)
C–O Swap	widsom	1682	14.91
C–O Control	widrom	1650	4.98
TL effect		+32 (±67.6)	+9.93 (±5.60)

ear English (i.e., Experiment 1), with the effect for onset transposition disappearing altogether, there is nevertheless a significant TL effect on error rates when two codas are transposed or the coda of the first syllable is transposed with the onset of the second. This contrasts markedly with the findings for Hangul (Experiment 2), particularly for the coda–onset transposition. The O–O and C–O Swap effects were weaker with Hangulized English than with normal English, though the C–C Swap effect remained the same at least on the accuracy measure. What is important about this experiment, however, is simply the fact that TL effects could still be observed across syllables that were physically separated. It eliminates the perceptual explanation for the lack of TL effects in Korean because it shows that TL effects are possible when the transposition crosses a physical space.

There are several possible reasons why the impact of letter transpositions might have been reduced in the Hangulized English experiment compared to the normal English experiment. First, there might have been at least a partial contribution of having a physical gap, particularly when the exchange had to traverse rows as well as columns (as in the C–O Swap condition). Second, the much longer presentation time used in Experiment 4 potentially allowed for more accurate responding, reducing the overall error rate, and particularly so in the case of the most confusing items, namely, those in the TL conditions. Third, participants may have been able to develop a more Hangul-like strategy for processing the Hangulized English words, hence overcoming their normal English processing strategies. That is, participants may have made use of the lack of ambiguity in the assignment of consonants to their onset or coda slots. The maintenance of TL confusion when codas were transposed, but not when onsets were transposed, suggests that processing of the top row of the Hangulized English stimuli had greater priority than that of the bottom row. Indeed, it was the Coda swap condition that showed the greatest tendency toward a TL effect in Korean itself.

The finding of a C–C effect with no O–O effect, is actually consistent with the predictions of the overlap model in relation to normal English script (as long as the tiny overlap beyond two letter positions is able to produce sufficient activation in the baseword to produce interference). So, while the overlap model had difficulty handling the findings of Experiment 1 with normal English script, it is compatible with the findings of Experiment 4 with Hangulized script. The problem with this, however, is that it is hard to see how positional overlap should be instantiated within the artificial Hangulized structure, particularly in such a way that the coda of the first and second syllable overlap more than their onsets, while not overlapping more than the coda of the first syllable with the onset of the second syllable.

General discussion

The orthographic structure of a language is shown in the research reported here to have an impact on the way in which letter position is processed in reading. When a nonword is created from a baseword through the transposition of two consonants, particularly the coda of the first syllable and the onset of the second, there is more of a confusion with the baseword in the linear script of English than in the blocked script of Korean. What is argued is that Hangul provides physical cues for the appropriate positioning of consonants because onset and coda slots can be filled without confusion, unlike English script. Even when English is structured in the same way as Hangul, such confusions are still observed even if reduced.

There is an important factor, however, that needs to be considered as a potential explanation for the difference between the Korean and English results, and that is the relationship between the pronunciation of the TL nonword and its baseword. All three TL nonwords generated from the Korean baseword 남북, “nambuk” retained the phonemes of their baseword, albeit in a transposed position (e.g., the C–O item 납묵, “nabmuk”). As it happens, though, this was not the case for any of the other C–O items. In Korean, the pronunciation of a coda often assimilates to the pronunciation of the onset that follows it within a word (see e.g., Kim, Taft, & Davis, 2004), which means that the pronunciation of at least one of those consonants is modified when their positions are exchanged. As an example, syllable-final ㄱ is canonically pronounced /g/, but is nasalized to becomes /ŋ/ when followed by the onset ㄹ (“l”). Thus, transposition of the coda ㄹ and onset ㄱ of the baseword 물건 [5](“mulgeon”) produces a C–O item (묵런) where one of those letters has a different pronunciation (i.e., “mungleon” instead of “mugleon”). The letter ㅇ provides another situation in which the pronunciation changes with an coda–onset transposition because it is pronounced /ŋ/ when used as a coda, but is silent when used as an onset. So while the baseword 농민 is pronounced “nongmin”, the C–O item derived from it, 놈인, is pronounced “nomin”. Perhaps the weakness of TL effects in Korean arises from the alteration in phonology that takes place along with the graphemic transposition. That is, it may be the case that a TL nonword needs to phonemically match its baseword if a confusion is going to occur between them. There is, however, strong evidence against such a possibility.

Although Frankish and Turner (2007) have claimed that TL effects are influenced by phonological factors, Perea and Carreiras (2008) failed to find any phonologically based modulation of effects when TL nonwords were used to prime their basewords. That is, even when the prime changed phonemically as a result of transposition (e.g., the *c* of

[5] The letter ㄱ changes shape slightly when placed in the onset position, as seen in this example.

radical changing from /k/ to /s/ in *racidal*), lexical decision responses to the baseword were still facilitated. Consistent with such a finding is the fact that seven of the English C–O items used in Experiment 1 had different phonemes to their baseword (e.g., the *s* in *wisdom* changes from /z/ to /s/ in *widsom*), yet responses to these items still showed considerable TL interference relative to their controls (a mean difference of 43 ms on RTs and 23% on error rates). Furthermore, in Experiment 2, ten of the O–O and ten of the C–C Hangul items maintained all the phonemes of their baseword, but still failed to show a TL effect (659 ms vs 656 ms and 1.88% vs 1.86% for O–O items versus their control; 669 ms vs 683 ms and 3.17% vs 4.94% for C–C items versus their controls). It is evident, therefore, that phonological factors cannot account for the lack of a TL effect in Korean.

Most of the Korean basewords were compound words, with each syllable being a morpheme. This, then, is another factor that differs between the English and Korean stimuli because the majority of the English basewords were monomorphemic, and it may be the case that compound words do not show TL effects. Arguing against this, however, are the previous findings of strong TL effects across morpheme boundaries (e.g., Christianson et al., 2005; Perea & Carreiras, 2006a) as well as the fact that a post-hoc examination of the English items gives no indication at all that TL effects were carried by the noncompounds: The effect sizes for the RT and error rates of just the items with compound basewords were comparable to those reported in Table 1, if not larger (54 ms and 8.2% for the eight O–O items[6], 45 ms and 5.1% for the five C–C items, and 102 ms and 31.1% for the six C–O items). Therefore, the differing nature of the basewords is unlikely to account for the difference between the Hangul and English results.

Having dismissed possible methodological, perceptual, and phonological explanations for the contrast between the Hangul and English findings, we can now turn to an explanation in terms of the processing of letter information at the early stages of lexical processing. Hangul is possibly the only existing orthographic system for which the position of the onset and coda of every syllable can be identified on a purely physical basis. If recognition of a word involves a stage where letters are assigned to an onset or coda slot (see e.g., Fig. 1), such an assignment should be easily achieved in Hangul. As a result, there is little confusion about the appropriate slot that a letter should fill. In contrast, a linear script such as English only provides a physical demarcation of the beginning and final letter, but even these cannot be reliably identified as an onset and coda respectively, given that they need not actually be a consonant at all.

In fact, identification of onset position is more reliable in Hangul than the identification of coda position because every syllable must have an onset (even if it is the silent letter ㅇ), while a coda is optional. For instance, in the syllable 수 (“soo”), the vowel (ㅜ) fills in the space where the coda would be if there were one. Thus, assignment of a letter to the coda slot requires that it be identified as a consonant rather than a vowel, a discrimination task that is not difficult, but is complicated by the fact that there are just about as many Hangul letters corresponding to vowels as to consonants. The greater cognitive load when filling a coda slot than an onset slot might therefore lead to a greater inattention in assigning a coda to its appropriate slot. Indeed, there was not even a hint of an effect for O–O swap items in Hangul, but the participant analyses of response times and error rates were significant for C–C items, with a trend on response times for C–O items.

It should be noted that previous research in Korean (e.g., Yi, 1995, 1998) has suggested that the onset and vowel form a processing unit separate from the coda, giving an antibody + coda structure. It might therefore be argued that the apparently greater confusion in the position of a coda than an onset arose out of having a separate representation of the coda from the rest of the syllable. The problem with this explanation, however, is that there was no greater confusion observed in the position of an onset than a coda in English despite the internal structure of English grouping the vowel more closely with the coda than the onset, giving the onset + body structure depicted in Fig. 1 (e.g., Andrews & Scarratt, 1998; Bowey, 1990; Kay & Marcel, 1981; Taraban & McClelland, 1987; Treiman & Chafetz, 1987; Treiman & Zukowski, 1988; Treiman et al., 1995). In other words, the demonstrated difference in the internal structure of Korean and English syllables is not reflected in differential patterns of TL confusion between two onsets relative to two codas. Therefore, it appears that the locus of any TL effects is earlier than a stage where the specific grouping of the onset, vowel, and coda might be important.

Despite the possible slowing of responses when a coda is involved in Hangul, there is nevertheless a dramatic contrast with English (and presumably, other linear scripts) in relation to errors made when internal letters are transposed. When the coda of the first syllable of a Hangul word is transposed with the onset of its second syllable, the resultant nonword is easy to discriminate from the baseword, which is not the case in English, even when there is a physical gap between the syllables. If the English lexical processing system is similar to that depicted in Fig. 1, ambiguity in the assignment of a consonant to its onset or coda slot might lead to the inappropriate activation of a lexical representation when the letter-string is a nonword, hence generating an erroneous “word” classification. There will only be ambiguity, however, when there are no physical cues as to the subsyllabic function of the consonant. The physical cues available in Hangul therefore prevent ambiguity in assignment of the consonants to their slots.

It seems that ambiguity is also prevented in Hangul when consonants are assigned to the same type of subsyllabic slot in different syllables. This is particularly seen in the absence of any TL interference when onsets are exchanged between syllables. Such a finding implies a separation of the representations of subsyllabic structure for each syllable. That is, the onset of the first syllable is readily assigned to the onset slot for the first syllable with no attempt to assign it to the onset slot of the second syllable. Presumably syllable representations are processed quite separately in Korean. This appears to be different to the way in which syllables are processed when they are not physically separated in the script. Although, syllables do appear to be important processing units in linear scripts such as English (e.g., Taft, 1979; Taft & Forster, 1976) and Spanish (e.g., Carreiras, Álvarez, & de-Vega, 1993; Perea & Carreiras, 1998), research by

[6] Some of the words that were categorized as compounds included bound morphemes. For example, although the *bon* of *bonfire* is meaningless, it was considered a morpheme because a *bonfire* is a type of *fire*.

Perea and Carreiras (2006b) in Spanish suggests that TL effects arise at a stage that is insensitive to syllabic status, though sensitive to consonant/vowel status. The precise way in which syllables might be represented both in Korean and other languages warrants further exploration, especially within a framework such as that illustrated in Fig. 1.

In the experiments using English materials, the greater confusion arising from the transposition of adjacent letters (the C–O Swap condition) than from the transposition of nonadjacent letters (the O–O and C–C Swap conditions) makes it clear that the distance between transposed letters has an impact on TL effects in a linear script. However, the existence of TL effects even when the distance between the transposed letters extends beyond two letter positions is hard to explain within the parameters of current models of letter position: Neither the open-bigram nor spatial coding models predict a TL effect for either the O–O or C–C conditions and, although the overlap model could potentially handle the C–C effect if coding were sufficiently imprecise, a TL effect for the O–O conditions is hard to reconcile.

It is suggested that the results might be better handled by the account of letter position processing that incorporates the functional role of letters (i.e., onset, nucleus, and coda) during the assignment process, such as that depicted in Fig. 1. Here, TL effects arise from an imprecision in assigning letters to their appropriate slot. Precision in assignment is greatest when there is little if any ambiguity about the identity of the appropriate slot, and this is the case in English for initial onset and final coda positions. Nevertheless, confusion with the baseword was observed for the O–O and C–C Swap conditions in English despite them involving a disruption to the initial and final letter respectively, and this suggests that there is at least some ambiguity even in assignment of letters at the extremities of a letter-string.

Conclusions

What the present research provides is support for the idea that the function of a letter plays a role in the processing of its position in the word. It does this in two ways. First, the confusion that arises from the transposition of letters is much diminished in a script in which functional information is defined by structural cues, namely, the Hangul script of Korean. In such a situation, ambiguity in the assignment of a letter to its functional slot is reduced, if not eliminated. Second, it is shown in English that inter-syllabic transposition of the onsets of a word and, especially, inter-syllabic transposition of codas creates a nonword that is confusable with that word. Such a finding is incompatible with the current models of letter position processing, but can be explained in terms of confusion between slots that serve the same function in different syllables.

Fig. 1 presents a possible framework for explaining how information about onsets and codas might be incorporated into a model of word recognition. However, there are likely to be other possibilities as well, perhaps integrating useful features of the other accounts of letter processing. For example, insights in relation to overlapping distributions of activation across slots (e.g., Gómez et al., 2008) might be applicable to slots that are defined in terms of function rather than position, though how this might be specifically instantiated remains an open question.

Acknowledgments

The research reported in this paper was supported by the Special Research Grant of Sogang University awarded to the first author, and a grant from the Australian Research Council to the second author. We are grateful to Hong Mo Kang and Goran Lazendic who helped carry out the experiments.

Appendix A

A.1. Experiment 1 stimuli

TL nonwords paired with their controls.

O–O: pagmie, pagnie; fonbire, fonlire; wobceb, wobgeb; tockcail, tockvail; romcade, romtade; bupcoard, bupwoard; wardhare, wardmare; wayjalk, waypalk; nidkey, nidley; ladpock, ladtock; bainrow, baincow; nemrant, nemlant; hilsouette, hilmouette; padtole, padfole; nechtique, nechsique; kodva, kodca

C–C: nankip, nankid; shralnep, shralnet; scrakboop, scrakbood; wasrul, wasrud; hundbas, hundbal; nugmet, nugmel; dilmas, dilman; burlet, burlen; wimwag, wimway; hogdot, hogdoy; hoomlud, hoomlut; willfand, willfant; casvan, casvat; sachwind, sachwink; coybow, coybog; kipnad, kipnas

C–O: widsom, widrom; domga, domka; tobmoy, tobnoy; porftolio, porfkolio; ruwnay, ruwmay; pymgy, pymty; feebdack, feeblack; fimgent, fimcent; steafdast, steafhast; cidner, cidler; sebtack, sebwack; gynmast, gynvast; semron, semdon; parnter, parnker; semgent, semrent; chuntey, chungey;;

A.2. Experiment 2 stimuli

TL nonwords paired with their controls.

O-O: 묵긴, 묵빈; 낙젼, 낙견; 션항, 션랑; 숭짐, 숭님; 록딥, 록밉; 밤눅, 밤룩; 몽족, 몽녹;

랑격, 랑멱; 긴셩, 긴녕; 몽닌, 몽딘; 올접, 올멉; 준망, 준방; 팍줌, 팍룸; 굴먼, 굴번

C-C: 군믹, 군밉; 잔녁, 잔녕; 형산, 형삭; 줌싱, 줌신; 돕릭, 돕링; 낙붐, 낙분; 족몽, 족몬;

각령, 각련; 싱견, 싱결; 논밍, 논밉; 좁얼, 좁억; 뭉잔, 뭉잘; 잠푹, 잠푼; 문걸, 문겁

C-O: 굼긴, 굼딘; 잔견, 잔련; 혓낭, 혓망; 즛임, 즛딤; 돌깁, 돌닙; 납묵, 납눅; 좀옥, 좀곡;

갈역, 갈녁; 식녕, 식명; 놈인, 놈린; 종렵, 종겁; 뭍낭, 뭍랑; 잔굼, 잔둠; 묵련, 묵넌

References

Andrews, S. (1996). Lexical retrieval and selection processes: Effects of transposed-letter confusability. *Journal of Memory and Language, 35*, 775–800.

Andrews, S., & Scarratt, D. R. (1998). Rule and analogy mechanisms in reading nonwords: Hough Dou peapel rede gnew wirds? *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1052–1086.

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1995). *The CELEX lexical database. Release 2 (CD-ROM)*. Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania.

Berent, I., Bouissa, R., & Tuller, B. (2001). The effect of shared structure and content on reading nonwords: Evidence for a CV skeleton. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 1042–1057.

Bowey, J. A. (1990). Orthographic onsets and rimes are functional units of reading. *Memory & Cognition, 18*, 419–427.

Carreiras, M., Álavarez, C., & de-Vega, M. (1993). Syllable frequency and visual word recognition in Spanish. *Journal of Memory and Language, 32*, 766–780.

Chambers, S. M. (1979). Letter and order information in lexical access. *Journal of Verbal Learning and Verbal Behavior, 18*, 225–241.

Christianson, K., Johnson, R. L., & Rayner, K. (2005). Letter transpositions within and across morphemes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 1327–1339.

Davis, C. J. (2005). N-Watch: A program for deriving neighborhood size and other psycholinguistic statistics. *Behavior Research Methods, 37*, 65–70.

Davis, C. J. (2006a). Orthographic input coding: A review of behavioural evidence and current models. In S. M. Andrews (Ed.), *From inkmarks to ideas: Current issues in lexical processing* (pp. 180–206). Hove, UK: Psychology Press.

Davis, C. J. (2006b) MatchCalculator software. <http://www.pc.rhul.ac.uk/staff/c.davis/Utilities/MatchCalc/index.htm>.

Davis, C. J., & Bowers, J. S. (2004). What do letter migration errors reveal about letter position coding in visual word recognition? *Journal of Experimental Psychology: Human Perception and Performance, 30*, 923–941.

Davis, C. J., & Bowers, J. S. (2006). Contrasting five different theories of letter position coding: Evidence from orthographic similarity effects. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 535–557.

Forster, K. I., & Forster, J. C. (2002). DMDX display software. <http://www.u.arizona.edu/~kforster/dmdx/dmdx.htm>.

Forster, K. I., & Taft, M. (1994). Bodies, antibodies, and neighborhood density effects in masked form priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 844–863.

Frankish, C., & Turner, E. (2007). SIHGT and SUNOD: The role of orthography and phonology in the perception of transposed letter anagrams. *Journal of Memory and Language, 56*, 189–211.

Gómez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review, 115*, 577–601.

Grainger, J., & van Heuven, W. J. B. (2003). Modeling letter position coding in printed word perception. In P. Bonin (Ed.), *Mental lexicon: "Some words to talk about words"* (pp. 1–23). New York: Nova Science.

Grainger, J., & Whitney, C. (2004). Does the huamn mnid raed wrods as a wlohe? *Trends in Cognitive Sciences, 8*, 58–59.

Guerrera, C., & Forster, K. I. (2007). Masked form priming with extreme transposition. *Language and Cognitive Processes, 23*, 117–142.

Kay, J., & Marcel, A. J. (1981). One process, not two, in reading aloud: Lexical analogies do the work of nonlexical rules. *Quarterly Journal of Experimental Psychology, 33A*, 397–414.

Kim, J., Taft, M., & Davis, C. (2004). Orthographic and phonological links in the lexicon: When lexical and sublexical information conflict. *Reading and Writing, 17*, 187–218.

Korean Word Database (2001). *21th century Seiong project corpus*. The National Institute of the Korean Language, Seoul, Korea.

O'Connor, R. E., & Forster, K. I. (1981). Criterion bias and search sequence bias in word recognition. *Memory & Cognition, 9*, 78–92.

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighborhood frequency in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 134–144.

Perea, M., & Carreiras, M. (2006a). Do transposed-letter effects occur across lexeme boundaries? *Psychonomic Bulletin & Review, 13*, 418–422.

Perea, M., & Carreiras, M. (2006b). Do transposed-letter similarity effects occur at a syllable level? *Experimental Psychology, 53*, 308–315.

Perea, M., & Carreiras, M. (2008). Do orthotactics and phonology constrain the transposed-letter effect? *Language and Cognitive Processes, 23*, 69–92.

Perea, M., & Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with non-adjacent letter positions. *Journal of Memory and Language, 51*, 231–246.

Perea, M., Rosa, E., & Gómez, C. (2005). The frequency effect for pseudowords in the lexical decision task. *Perception & Psychophysics, 67*, 301–314.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56–115.

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

Simpson, G., & Kang, H. (2004). Syllable processing in alphabetic Korean. *Reading and Writing, 17*, 137–151.

Taft, M. (1979). Lexical access via an orthographic code: The basic orthographic syllabic structure (BOSS). *Journal of Verbal Learning and Verbal Behavior, 18*, 21–39.

Taft, M. (1991). *Reading and the mental lexicon*. Hove, UK: Erlbaum.

Taft, M. (1992). The body of the BOSS: Subsyllabic units in the lexical processing of polysyllabic words. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1004–1014.

Taft, M. (2003). Morphological representation as a correlation between form and meaning. In E. Assink & D. Sandra (Eds.), *Reading complex words*. Amsterdam: Kluwer.

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior, 15*, 607–620.

Taraban, R., & McClelland, J. L. (1987). Conspiracy effects in word pronunciation. *Journal of Memory and Language, 26*, 608–631.

Treiman, R., & Chafetz, J. (1987). Are there onset- and rime-like units in printed words. In M. Coltheart (Ed.), *Attention and performance* (Vol. XII). London: Lawrence Erlbaum Associates Limited.

Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, E. D. (1995). The special role of rimes in the description, use, and acquisition of English orthography. *Journal of Experimental Psychology: General, 124*, 107–136.

Treiman, R., & Zukowski, A. (1988). Units in reading and spelling. *Journal of Memory and Language, 27*, 466–477.

Velan, H., & Frost, R. (2007). Cambridge University versus Hebrew University: Impact of letter transposition on reading English and Hebrew. *Psychonomic Bulletin & Review, 14*, 913–918.

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8*, 221–243.

Whitney, C. (2008). Comparison of the SERIOL and SOLAR theories of letter-position encoding. *Brain & Language, 107*, 170–178.

Whitney, C., & Cornelissen, P. (2008). SERIOL reading. *Language and Cognitive Processes, 23*, 143–164.

Yi, K. (1995). The internal structure of Kulja and its relation to syllable in Korean. *Korean Journal of Experimental Psychology, 7*, 57–69.

Yi, K. (1998). The internal structure of Korean syllables: Rhyme or body? *Korean Journal of Experimental Psychology, 10*, 67–83.