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The Emergence of Sub-Syllabic Representations

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Abstract

In a variety of experimental paradigms speakers do not treat all subsyllabic sequences equally. In languages like English, participants tend to group vowels and codas together to the exclusion of onsets (i.e., /bet/ = /b-/et/). Three possible accounts of these patterns are examined. A hierarchical account attributes these results to the presence of categorical sub-syllabic divisions (e.g., onset /b/ vs. rime /et/). In contrast, a non-hierarchical account attributes these findings to the strength with which particular consonants and vowels co-occur (e.g., the relative frequency of /be/ vs. /et/). A third emergentist alternative is articulated, where speakers' knowledge is sensitive not just to the frequency with which particular segments co-occur but also to the general patterns of association within a language. These accounts are contrasted by examining sub-syllabic patterns in two languages: Korean and English. A statistical study shows distinctions in the general patterns of sub-syllabic associations in Korean and English. Consistent with the emergentist perspective, results of short-term memory experiments reveal that Korean and English speakers are sensitive not only to these general patterns but also to the strength with which particular segment sequences are associated. The implications of these results for theories of sub-syllabic patterns in languages are discussed.

Keywords: sub-syllabic constituents; short-term memory tests; phonotactic probability

The Emergence of Sub-Syllabic Representations

Researchers in the field of phonology generally agree that there are certain linguistically significant patterns that involve segment sequences occurring inside the syllable. For example, within the syllables of several Indo-European languages there are differences in phonological restrictions governing onset-vowel vs. vowel-coda sequences (e.g., Dutch: Martensen, Maris, & Dijkstra, 2000; English: Kessler & Treiman, 1997; French: Perruchet & Peereeman, 2004). For instance, Kessler and Treiman's (1997) statistical analyses of English monomorphemic monosyllables show that many phonologically legal combinations of vowel and coda never occur (e.g., /ib/), or occur less than expected by chance (e.g., /æɪ/), while there are relatively few restrictions on the combinations of onset and vowel. As reviewed below, behavioral results indicate that these patterns of associations exert an influence in many domains of language processing.

Despite the general agreement among researchers on the existence and significance of these sub-syllabic patterns, the exact mechanism that accounts for them remains an active issue of debate (Gupta & Dell, 1999; Pierrehumbert & Nair, 1995; Treiman & Kessler, 1995; Yip, 2003). One approach (referred to as the hierarchical model in this paper) utilizes concepts from generative phonological theory. Under this theory, syllables are hierarchically organized with certain primitive sub-syllabic constituents (Venneman, 1988). The observed distributional and behavioral patterns are a function of these sub-syllabic units. For example, in English the pattern of association /b-/e/ is more likely than the pattern of association /be-/t/ because the consonant /b/ forms a unit referred to as onset, while the vowel /e/ goes together with the final consonant /t/ to form a higher-

order grouping known as rime.

An alternative to this is a non-hierarchical approach. It utilizes no suprasegmental units inside the syllable to account for these patterns. Rather, it attributes these effects to statistical patterns of co-occurrence between individual segments (i.e., phonotactic probability; Frisch, Broe, & Pierrehumbert, 2004; Frisch, Large, & Pisoni, 2000; Jusczyk, Luce, & Charles-Luce, 1994; Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997). Thus, the finding that in /bet/ the /et/ is more strongly associated than /be/ is because the former has a higher phonotactic probability (i.e., .0049 vs. .0032, following the procedure of Vitevitch & Luce, 2004).

This work contrasts these perspectives with an integrative alternative. This approach views language processing as being sensitive not only to the probabilistic relationships between particular adjacent segments within syllables, but also to the general patterns that exist over all syllables in the language. Under this emergent perspective, sub-syllabic units (such as rime) are an emergent property that reflects “mass action of the stored vocabulary” (Dell, Juliano, & Govindjee, 1993, p. 158). Thus, under this view, units like onset and rime exist not as some sort of linguistic primitives but as a product of the general way consonants and vowels combine in English words.

To argue for this perspective, we first report results from a statistical study of the lexicons of both Korean and English. This analysis allows us to characterize the strength of association for both particular CV and of VC sequences as well as the general patterns of inter-segmental subsyllabic dependencies within each language. We then report two short-term memory (STM) experiments with native Korean and English speakers. The results reveal that speakers are sensitive not only to the relationship between

particular consonants and vowels but also to the general pattern of such dependencies that exists across the entire language. We conclude with a discussion of the implication of these results for the representation and processing of intrasyllabic phonological structure.

Subsyllabic patterns

The patterns of associations between segments within the syllable exert an influence on language processing in a wide variety of behavioral tasks. For example, in Treiman's (1983) language game study, English speakers were asked to transform monosyllabic nonwords (e.g., /skef/ into either /sæz kef/ or /skæz ef/). Consistent with the general sub-syllabic patterns of English, the latter response (treating the vowel and the coda as a chunk) was the preferred one. Similar findings have been found in short-term memory (STM) tests (Brady, Shankweiler, & Mann, 1983; Treiman & Danis, 1988; Treiman, Straub, & Lavery, 1994). Treiman and Danis (1988), for example, utilized a recall task with consonant-vowel-consonant (CVC) nonword lists. Consistent with a preference for vowel-coda associations, English-speaking adults exhibited a significant recall advantage for vowel-coda pairs over other intrasyllabic sequences of phonemes. Naturally occurring speech errors in Germanic languages also show similar patterns (Berg, 1989, 1991; MacKay, 1972; Stemberger, 1983) such that errors involving an entire VC component of a CVC word were observed more frequently than other two-segment errors.

Recent work by Derwing and colleagues has found a rather different pattern of performance in the non-Indo-European language Korean. Yoon and Derwing (2001) asked participants to rate the similarity of two spoken stimuli. Korean speakers considered pairs of stimuli that share onset and vowel like /mot/ and /mop/ to be more similar than those

that share vowel and coda like /mot/ and /pot/. English speakers exhibited the opposite pattern, preferring stimuli that shared VC sequences (Yoon & Derwing, 1994). Similarly, Derwing, Yoon, and Cho (1993) found that when Korean speakers were asked to blend two CVC words to create a single new CVC word, they favored splitting words between the vowel and coda. For example, when asked to blend /pan/ and /sik/, responses like /pak/ (retaining an onset-vowel sequence as a group) outnumbered responses like /pik/ (where vowel-coda is retained as a group). These data suggest that in Korean the onset and vowel are more strongly associated with each other than vowel and coda, opposite to the pattern observed in Indo-European languages such as English.

Accounting for sub-syllabic patterns

As noted above, two contrasting theoretical positions have been articulated to account for these results. The hierarchical model attributes these data to the presence of sub-syllabic constituent structure. For example, the presence of a rime constituent provides a domain over which restrictions or constraints on segments can be easily stated. This is used to account for the greater distributional restrictions on combinations of vowels and codas relative to onsets and vowels in the lexicon of languages such as English (Blevins, 1996; Fudge, 1969, 1987; Selkirk, 1980). Similarly, the fact that English users performed significantly better while manipulating the vowel and coda sequence of an input word as a unit instead of the coda alone in language games (e.g., Treiman, 1983) is accounted for by English speakers' implicit awareness of rime units. Note that within such an approach, the cross-linguistic difference in behavioral patterns between Korean- and English-speaking individuals must be attributed to structural differences between languages. For example, to account for contrasting patterns of

similarity judgments across languages, Yoon & Derwing (2001) claim that while English is an onset-rime language, Korean is a body-coda language (where the body refers to a sub-syllabic unit that includes the prevocalic consonant(s) and the vowel of a syllable).

A potential issue in the interpretation of these experiments, however, is that they failed to control for the phonotactic probability of segment sequences of the target items used. Because of this, a non-hierarchical model can attribute the results of many experiments to asymmetries in phonotactic probabilities. For example, /ger/ is a stimulus in Experiment 1 of Treiman and Danis (1988)'s STM study. Without knowing the phonotactic probabilities governing the two-phoneme sequences /ge/ and /er/, it is not clear whether this finding reflects the influence of abstract syllabic constituents (i.e., onset-rime) or just the influence of the phonotactic probabilities (i.e., /er/ is phonotactically more probable than /ge/ in English). The latter is a strong possibility given that phonotactic probability influences serial recall of nonwords (e.g., Gathercole, Frankish, Pickering, & Peaker, 1999; Thorn & Frankish, 2005).

The non-hierarchical view receives further support from research suggesting that segment arrangements within the syllable are essentially probabilistic. This is unexpected under the hierarchical view, which predicts a categorical, well-defined boundary between sub-syllabic units (Yip, 2003). For example, in a language game study Pierrehumbert and Nair (1995) asked English speakers to add a VC sequence as an infix (e.g., /əl/) to nonwords such as /stʌb/ resulting in either /s-əl-tʌb/ or /st-əl-ʌb/. The onset-rime theory predicts that the latter type of infixation (where the infix occurs at the division between onset and rime constituents) would overwhelmingly dominate participant responses. Although Pierrehumbert and Nair (1995) found a preference for this response pattern,

they also found more responses that broke up the segments within the onset unit than previous studies (e.g., Treiman, 1983). This probabilistic pattern is easily understood within a non-hierarchical account. The probability of retaining the /st/ sequence relative to the /tʌ/ sequence simply mirrors the relative strength of the statistical association between the two segments (see also Gupta & Dell, 1999; Kessler & Treiman, 1997; Treiman, Kessler, Knewasser, Tincoff, & Bowman, 2000, for discussion of the connection between probabilistic phonotactic patterns and subsyllabic constituent structure).

An integrative alternative

An alternative to these two perspectives—attributing all effects to abstract linguistic structure vs. completely denying any such influence—is to view structures such as onset and rime not as linguistic primitives but as an emergent product of the general distributional properties of consonants and vowels in English words. This perspective is congruent with that articulated in Dell, Juliano, and Govindjee (1993) (see also Chen, Dell, & Chen, 2004; Christiansen, Allen, & Seidenberg, 1998; Gupta & Dell, 1999; Sevald & Dell, 1994). Dell et al. (1993) describe a connectionist network that produces sequences of featural representations corresponding to CVC syllable words. Crucially, the network was not provided with a priori knowledge of subsyllabic patterns (e.g., in English, the vowel is more strongly associated to the coda than to the onset). Following some initial training, Dell et al. examined the errors the network produced. They found significantly more errors that retained the VC sequence (e.g., ‘read’ → ‘lead’) occurred for networks that were trained on vocabularies that “conform to the statistics of English sound distribution” (Dell et al., 1993, p. 158)—that is, vocabularies where vowel-coda sequences were on average more strongly associated than onset-vowel sequences. This

suggests that sub-syllabic units in natural languages (such as rime) may be an emergent property that reflects “mass action of the stored vocabulary” (Dell et al., 1993, p. 158).

One notable advantage of this perspective over the previously articulated theories is that it can explain the source of cross-linguistic differences in sub-syllabic patterns rather than simply postulating different constituent structures. In accounting for the behavioral difference in syllable experiments with Korean vs. English speakers, the hierarchical approach simply postulates that Korean is a body-coda while English an onset-rime language. In contrast to this, the emergent view suggests that mechanisms encoding sub-syllabic patterns are essentially the same across the two languages. The emergence of different processing units (e.g., rime vs. body) reflects learners’ exposure to different general patterns of phoneme combinations across languages. More specifically, this view claims that onset-rime structure emerges in Indo-European languages such as English due to strong associations between vowels and codas. The emergence of a different sub-syllabic structure in Korean reflects the contrasting statistical patterns of the Korean lexicon. Along these lines, Yoon and Derwing speculated that “Korean speakers are exposed to many more distinct CV-type syllables than VC-types, a disparity that might lend credence to the notion of the ‘body’.” (2001, p. 230). However, this speculation has not been more systematically explored.

Current study

In order to examine this possibility, we first establish that the general statistical pattern does in fact differ across Korean and English. We report the results of a study of Korean and English phoneme distributions that quantifies and compares the relative cohesiveness of onset-vowel as opposed to vowel-coda sequences in CVC words of the

two languages. Two short-term memory (STM) experiments were then conducted to examine the role of these statistical dependencies in Korean- and English-speakers' representation of syllable structure. By manipulating the probability of the component segment sequences of CVC syllables these studies allow us to test the contrasting predictions of the three views of syllable structure.

More specifically, first, the hierarchical model predicts that STM errors would more likely preserve a sequence of phonemes inside a sub-syllabic unit than a sequence of phonemes not belonging to the same sub-syllabic unit. This means that VCs will be remembered significantly better than CVs in English STM tests, while the reverse pattern should be observed from Korean STM tests. Critically, under the hierarchical view, the manipulation of phonotactic probabilities of component segment sequences should not affect the recall error pattern.

In contrast, the non-hierarchical model predicts that phoneme sequences preserved in STM errors will correspond to some objective measures of association. For both English and Korean speakers, this predicts that high probability CVs will be recalled better than the low probability VCs; this pattern will be reversed for low probability CVs and high probability VCs.

Finally, the emergent model predicts sensitivity both to the probability of particular sequences as well as more general patterns in the language. Since it does not adopt a priori sub-syllabic units such as rime, one can expect that speakers would be more likely to remember high probability sequences of phonemes that cross traditional constituents (e.g., CV in English and VC in Korean). This prediction distinguishes the emergent model from the hierarchical model. In addition, the emergent model predicts an

effect of the general statistical characteristics of a speaker's lexicon (e.g., English speakers may generally remember VCs better than CVs, and Korean speakers would generally remember CVs better than VCs). In particular, such a pattern may be found when the CV and VC component sequences of a syllable do not contrast in terms of phonotactic probability. This prediction distinguishes the emergent model from the non-hierarchical model.

Statistical Analyses of the Korean and English Lexicons

Phonemic dependencies at the sub-syllabic level of Korean syllables

In assessing the association of consonants and vowels in Korean, the current study concentrated on single-syllable CVC words. Focusing on monosyllabic words allow us to control for the contextual influences that might alter in one way or the other the onset and especially the coda consonant counts. This is especially so given that many coda consonants undergo a regressive assimilation to the onset of the following syllable in Korean (e.g., /tʃin/ 'true' + /li/ 'theory' → /tʃilli/ 'truth', Han, 1994). In addition, compared to other possible syllable types (namely, CV or VC or simple V) the set of CVC type words was the largest set in the database that was used in this study accounting for 69% of the single-syllable words. Kim (2007) reported a similar result using a different corpus of Korean monosyllabic words from the current one (in Kim's study 69.44% of the monosyllabic words were of the CVC syllable type). Finally, Thorn and Frankish (2005) found significant correlations between biphone frequency counts within single-syllable English words and all English words regardless of length. The above considerations therefore suggest that the set of CVC words are fairly representative

of monosyllable words in both Korean and English and so are a good place to start for these languages.

In the current study, we utilized a database available from the National Institute of the Korean Language (www.korean.go.kr). For our analyses, we omitted proper nouns, particles (including various Korean case markers), and the so-called linking words (including conjunctions). This yielded a total of 939 single-syllable words for analysis. This set of words included words like /kyul/ ‘tangerine’ which contains a pre-nuclear glide /y/. These are considered CVC words under the assumption that the two glides, /w/ and /y/ form a single nucleus unit with the following vowel (following Kang, 2003; Kim & Kim, 1991; Park, 2001, but see Ahn, 1985; Lee, 1994 for a different view). Note that the database included CVC homophones. These were treated as separate items for the purpose of calculations in this study. Finally, type frequency was used to calculate all statistical measures of association.

Following Perruchet and Peerean (2004), we assessed the strength of association of elements within subsyllabic sequences through correlation coefficients. Specifically, we examined the degree to which the presence of a specific consonant in a given position correlated with the occurrence of a specific vowel in the same syllable (e.g., for the sequence /et/, to what extent did the presence of /e/ correlate with the presence of /t/?). Since our data are dichotomous (i.e., presence vs. absence of vowel or consonant), we replaced the standard form of Pearson’s r with that of r_ϕ . This statistic is comparable to that of Pearson’s r , providing a value between -1.0 and $+1.0$ that expresses the degree to which two (dichotomous) variables are associated (Kurtz & Mayo, 1979). Previous studies have validated this as a measure of intra-syllabic dependencies. Relative to more

common measures such as transitional probability, Perruchet and Peereman (2004) found it to be the best predictor of French speakers' wordlikeness judgments of CVC nonwords in French. Since we are concerned only with the strength of association (and not whether the correlation is positive or negative), the analyses below examine the absolute value of r_ϕ for CV and VC sequences.

Using this procedure, the absolute value of r_ϕ was computed for all 152 CV and 76 VC sequences attested in the constructed Korean CVC wordlist, containing a total of 939 single-syllable words. As shown in Table 1, the overall distribution of r_ϕ values was significantly different across Korean CV and VC sequences. The mean value for CV sequences is .050 (*SD*: .037), while the comparable number for VC sequences is .039 (*SD*: .028). To see whether this difference is statistically significant, we used a non-parametric test, which unlike the *t*-test does not require normality. According to this test, the difference in mean absolute r_ϕ values between CV and VC was significant (Mann-Whitney *U* test ($U = 6723$), $p < .05$). This is the pattern predicted by the emergent account; Korean CV sequences are on average more cohesive than VC sequences.

Phonemic dependencies at the sub-syllabic level of English syllables

Comparable r_ϕ values were also obtained for English. A total of 2521 monomorphemic¹ CVC forms were extracted from the CELEX English phonological word form database (Baayen, Piepenbrock, & Gulikers, 1995). As in the Korean study, English CVC homophones were included and treated as separate items in the constructed English word list. r_ϕ was computed for all 280 CV and 222 VC sequences attested in the word list. As shown in Table 1, the distributions of r_ϕ values within these two sequences were significantly different. Consistent with previous studies (Kessler & Treiman, 1997), the

results reveal greater statistical dependencies within VC than CV sequences. The mean absolute r_ϕ value for CV sequences is .022 (SD : .019), while the comparable number for VC sequences is .034 (SD : .026). This difference was statistically significant by a Mann-Whitney U test ($U = 21582$, $p < .0001$).

As pointed out by a reviewer, the size of the Korean lexicon was smaller than that of the English database (i.e., 2521 English CVC words vs. 939 Korean CVC words). In order to see if we find a similar contrasting result with corpora of similar size, we took the 940 most frequent English words from the CELEX, and re-calculated the r_ϕ values for English. The asymmetry between English CV and VC sequences still holds in this reduced set. The mean absolute r_ϕ value for CV sequences is .033 (SD : .028), while the comparable number for VC sequences is .052 (SD : .072). The difference was significant (Mann-Whitney U test ($U = 18956$), $p < .0005$).

Discussion

Consistent with previous work (Kessler & Treiman, 1997), the current study finds stronger constraints on VCs than on CVs in English. The novel result is that in Korean the opposite pattern holds; the association between onsets and vowels is generally stronger than the dependency between vowels and codas.

As discussed above, some researchers have posited hierarchical body-coda accounts of behavioral results from experiments with Korean speakers (e.g., Derwing, Yoon, & Cho, 1993). However, this analysis raises the possibility that a non-hierarchical approach can also account for these data; Korean speakers' behavior may be attributable to contrasting phonotactic probabilities of onset-vowel vs. vowel-coda sequences.

Alternatively, following the emergent perspective, it is possible that such performance

reflects not just sensitivity to phonotactic probability differences between particular sequences but also the general statistical patterns of their language.

To contrast these possibilities, we manipulated the phonotactic probability of onset-vowel and vowel-coda sequences in both Korean and English and examined error patterns in a STM task. The hierarchical model predicts that responses will be affected only by cross-linguistic syllable structure differences. For example, Korean speakers will remember CVs (constituting body) better than VCs, regardless of the relative r_ϕ value of the CV and that of the VC sequence in test CVC syllables. English speakers will show the complementary pattern, preferring VC sequences (constituting rime) to CV sequences. In contrast, the non-hierarchical model predicts that only phonotactic probability will influence performance. For both Korean and English speakers, recall errors will favor whichever sequence has a higher r_ϕ value.

Finally, the emergent model predicts that errors would show effects of both the sub-syllabic constituents and phonotactic probabilities of phoneme sequences. If the statistics of the test CVC syllables are such that the r_ϕ value of a CV and that of a VC differ from each other, then the phoneme sequence with a greater r_ϕ value will be favored. But we should also observe biases in errors that do not directly reflect the statistics of the test syllables. For example, since in the Korean lexicon the association between onsets and vowels is generally stronger than the dependency between vowels and codas, CVs would be generally remembered better than VCs if the CV and VC sequence of a test syllable do not significantly differ from each other in terms of their r_ϕ values.

Experiment 1

Method

Participants

Twenty-four (9 female, 15 male) native Korean speakers participated in the experiment. They were paid for their participation. They were international students from the Republic of Korea studying at Northwestern University. The mean duration of their stay in the United States was 4 years and 1 month (range: 1 month to 10 years). The vast majority of participants came to the U.S. at 20 years of age or older (two participants arrived at 10 and 12 years old, respectively). None reported any history of speech or hearing impairment.

Materials

The stimuli consisted of 40 lists of six CVC nonsense syllables each. There were three types of CVC nonwords, referred to as CV+vc, cv+VC, and cv+vc. Capitalization in these labels refers to sequences with relatively high r_ϕ values; lower case sequences have relatively low r_ϕ values (as determined by a median split of all such two-segment sequences in Korean). Note that we were unable to construct a CV+VC condition where both onset-vowel and vowel-coda sequences within a syllable have relatively high r_ϕ values. This is due to the structure of the Korean lexicon; the number of nonwords composed of such sequences was too few to provide a sufficient number of stimuli. A list of all the stimuli used in Experiment 1 is given in Appendix 1.

In the CV+vc syllables, the r_ϕ values of the onset-vowel sequences ($M = .107$) were significantly higher than the vowel-coda sequences ($M = .014$; paired $t(59) = 18.75$, $p < .0001$). For the cv+VC syllables, the onset-vowel sequences had significantly lower

r_ϕ values ($M = .009$) than the vowel-coda sequences ($M = 0.083$; paired $t(59) = -25.22$, $p < .0001$). The components of cv+vc were both drawn from the lower half of the CV and VC distributions. However, there were slightly imbalanced (cv mean $r_\phi = .009$; vc mean $r_\phi = .014$) leading to a significant difference² in r_ϕ values ($t(59) = -3.29$, $p < .002$). We therefore report results from the overall data as well an analysis where only a matched subset of the cv+vc stimuli ($N = 44$) are used (For this subset, mean r_ϕ for both cv and vc = $.009$; $t(43) = .6$, $p < .53$).

These CVC nonwords were distributed to 4 different sets of 10 lists. Examples of stimuli in the sets are given in Table 2. For example, list type A had three syllables of CV+vc (e.g., /hyak/) and three syllables of cv+VC (e.g., /tip/), and list type B had three syllables of CV+vc and three syllables of cv+vc, etc. The lists (except the list type D) were designed in such a way that two different types of test syllables occur in a given list. Repetition of the same consonants in a given list was avoided as much as possible. However, since there are only 7 consonants available in the coda position in Korean syllables, this was not always possible. In these cases, the consonant was evenly distributed in onset and coda. Each participant was randomly assigned to one of the 24 permutations of list orders.

Procedure

The 6 syllables of each list were prerecorded twice in different random orders. Following the procedure in Treiman and Danis (1988), participants were first familiarized to the syllables in the list. They heard each syllable one by one and immediately repeated it. Mispronunciations were corrected. Following familiarization, participants listened to the entire set of 6 syllables in a different random order. There were then

asked to orally recall the 6 syllables. A practice list similar to the test lists was given prior to the start of experimental trials.

Results

Participants' responses were recorded and transcribed by the first author. Another phonetically-trained Korean speaker transcribed 15% of the entire set of recordings. Agreement on phonetic assignment between the two judges was 91%. The discrepancies between the two judges were distributed fairly evenly across onsets (6.7%), vowels (10.6%), and codas (9.7%).

There were 5946 responses in total. Out of these, 3045 (51%) were correct responses. Out of the 2901 errors, 660 (23%) were “don't remember” responses. Out of the remaining errors, those that retained two phonemes of an original stimulus were analyzed. For example, /k^hip/ was one of the to-be-remembered stimuli in a particular list in the experiment. If a participant produced /k^him/, /tʃip/, or /k^hap/ at any position in his/her recall list, this error was counted as sharing two phonemes with the (to-be-remembered) test stimulus /k^hip/, namely CV, VC, C_C, respectively.

Errors involving onset-coda (C_C) retentions were excluded from the analyses below. Such errors constituted on average less than about 10% of total errors for each condition. Furthermore, the percentage of such errors did not differ across the three types of stimuli. The percentage of onset-coda retention errors was analyzed in a repeated-measures analysis of variance (ANOVA) with the stimulus types (CV+vc, cv+VC, cv+vc) as a within-participant factor. The main effect of stimulus type was not significant ($F(2,46) = .276, p = .75$).

Figure 1 therefore reports the percentage of errors involving two adjacent

segments that retained onset and vowel as a group pooled over the four list types (i.e., the proportion of CV retentions in Figure 1 is 1 minus the proportion of VC retentions). Inspection of the figure reveals different patterns of responses across the different types of syllables. When the two sub-syllabic sequences contrasted in strength of association, participants preferred to retain the intrasyllabic sequence with the stronger association. When onset-vowel was more strongly associated than vowel-coda (i.e., CV+vc stimuli), participants preferred to retain onset-vowel sequences ($M = 67\%$, 95% Confidence Interval = $\pm 4.5\%$); in contrast, participants preferred to retain the vowel-coda when it was more strongly associated (cv+VC stimuli) ($M = 43\%$, 95% CI = $\pm 5.0\%$). In contrast, when sequences did not differ in strength of association (cv+vc) participants preferred to retain the onset and vowel, consistent with the general Korean pattern ($M = 65\%$, 95% CI = $\pm 3.7\%$). Similar results were found when analyzing the subset of stimuli where the r_ϕ values within ‘cv+vc’ were matched ($M = 64\%$, 95% CI = $\pm 4.0\%$).

To assess if these preference patterns were significantly different across conditions, the percentage of onset-vowel retention errors was analyzed in a repeated measures ANOVA with stimulus type as a within-participant factor. The main effect of stimulus type was significant ($F(2,46) = 29.73$, $p < .001$). Specifically, when onset-vowel was more strongly associated than vowel-coda (i.e., CV+vc stimuli vs. cv+VC stimuli comparison), participants retained significantly more onset-vowel sequences (mean difference across the two conditions = 24.0%; 95% Confidence Interval of Difference = $\pm 7.6\%$). In addition, the cv+vc stimuli also showed significantly more onset-coda retention than cv+VC (mean difference = 21.0%; 95% CI = $\pm 6.0\%$). In contrast, there

was no significant difference between ‘CV+vc’ vs. ‘cv+vc’ (mean difference = 3.0%; 95% CI = +/- 6.0%).

Similar results were found when analyzing the subset of stimuli where the r_ϕ values within cv+vc were matched. Error on these stimuli still showed a significant preference for onset-vowel retention errors ($M = 64.0\%$; 95% CI = +/- 7.0%). In the ANOVA, the main effect of stimulus type again reached significance ($F(2,46) = 19.61$, $p < .0001$). As above, the cv+vc stimuli showed a significantly higher rate of onset-coda retentions than the cv+VC condition (mean difference = 21.0%; 95% CI = +/- 8.7%), but no significant difference from the CV+vc condition (mean difference = 3.0%; 95% CI = +/- 8.3%).

Before considering the implications of these findings, we consider several factors that may provide alternative accounts of the results reported above. One simple measure of unithood is the chunk frequency of different elements. For example, it is possible that in Korean CVs have a higher type frequency than VCs; this could account for the results without appealing to more complicated measures of statistical dependency such as r_ϕ . However, analysis of the 939 words in the Korean database shows that this is not the case (Mean CV type-frequency = 2.40 vs. Mean VC type-frequency = 6.19). Chunk frequency therefore predicts a general recall advantage for VC-units, opposite what we observe in the data.

Alternatively, these findings may not reflect the sublexical property of phonotactic probability but rather some correlated lexical factor—namely, lexical neighborhood density. Short-term memory for nonwords is influenced by both of these factors (Thorn & Frankish, 2005). We assume that this reflects the simultaneous

contribution of both sub-lexical and lexical processes to performance in short-term memory tasks. For example, Thorn and Frankish (2005) sketch an account in which reintegration processes operate at both of these levels, allowing for factors such as phonotactic probability as well as neighborhood density to influence short-term memory errors. Alternatively, rather than reflecting the influence of two independent processes these effects may reflect a single highly integrated system that is sensitive to both sub-lexical and lexical properties of stimuli (e.g., Martin & Gupta, 2004).

To determine if phonotactic probability (as indexed by r_ϕ) makes an independent contribution to performance in this experiment, we examined the lexical neighborhood properties of stimuli in the cv+VC and cv+vc conditions. Using our database of monomorphemic CVC words, we found the number of Korean words that shared either the CV or VC of each stimulus. We assumed the relative percentage of these lexical neighbors that shared the CV would index the degree to which neighborhood density favors CV retentions.

The error patterns of Korean speakers were assessed using a linear mixed logistic regression model. Predictors for the likelihood of a CV vs. VC error included the r_ϕ of the CV and VC sequence of each target, the percentage of CV neighbors (i.e., number of CV neighbors / (number of CV + number of VC neighbors)), as well as the interactions of these factors. Random intercept terms were included for participants ($SD = 2 * 10^{-5}$) and items ($SD = .61$). As the r_ϕ of the CV sequence increased, errors were more likely to be CV than VC ($\beta = 10.69$; $SE = 5.16$; $z = 2.06$, $p < .05$). The likelihood of CV errors was also positively associated with the percentage of CV neighbors ($\beta = 1.65$; $SE = 0.69$; $z = 2.36$, $p < .05$). The r_ϕ of the VC sequence had

no significant effect ($|z| < 1$). None of the interactions were significant ($|z|s < 1.8$). Thus, both lexical neighborhood density and r_ϕ of the CV sequence exerted independent influences on Korean speakers' error patterns.

Finally, it is possible that non-phonological factors could influence the results. Unlike the Roman alphabetic system, where letters are linearly positioned next to each other, the writing system of Korean allows the letters to be arranged left-to-right, top-to-bottom in a square structure. This means that the Korean orthography in principle allows the onset-vowel sequences to occur as a writing unit such that the vowel character occurs on the same plane as that representing the onset. In contrast, the coda character is written underneath the onset-vowel letter sequence. This convention involves more than half of the simple vowels and more than two-thirds of the diphthongs in Korean (Yoon, Bolger, Kwon, & Perfetti, 2002). The dominance of CV errors may be partially due to this orthographic feature of Korean. This is plausible given other findings suggesting effects of orthography in the representation and production of speech (Seidenberg & Tanenhaus, 1979; Ventura, Morais, Pattamadilok, & Kolinsky, 2004; Ziegler & Ferrand, 1998; Ziegler, Ferrand, & Montant, 2004; but see Roelofs, 2006). To examine if subsyllabic structure exerts an effect independent of orthography, we examined two subsets of responses from the cv+vc condition. One set was composed of syllables written CV-over-C, while the other set is written C-over-V-over-C (for each set, $N = 24$). The subsets were matched for their CV phonotactic contingencies (mean r_ϕ , CV-over-C = .008; mean r_ϕ , C-over-V-over-C = .009, $t(23) = .721$, $p = .48$). Analysis of each participants responses within these subsets fails to reveal any significant differences in the percentage of errors retaining CV (paired t -test: $t(23)$

= .69, $p < .55$; mean difference between CV-C vs. C-V-C = 2.6%; 95% CI = $\pm 7.4\%$).

This suggests that the recall advantage for CV sequences cannot be solely due to the fact that such sequences are orthographically privileged in Korean.

Discussion

Two major patterns were found in the responses of Korean participants. When onset-vowel and vowel-coda components contrasted in terms of phonotactic probabilities (as assessed by r_ϕ values), a recall advantage was found for the sequence with a higher phonotactic probability. When the probability of sequences of adjacent phonemes did not contrast (i.e., cv+vc stimuli), a recall advantage was found for onset-vowel sequences.

The facilitative effect of phonotactic probability is in line with previous results showing a recall advantage for CVC nonwords consisting of both high vs. low biphone frequency/probability CV and VC sequences (Gathercole et al., 1999; Nimmo & Roodenrys, 2002; Thorn & Frankish, 2005). Crucially, this study reveals that such an effect is found for phoneme sequences that cross the body unit posited in hierarchical theories of Korean syllable structure (e.g., Yoon & Derwing, 2001). These probabilistic effects are not predicted by hierarchical theories; they claim that sequences inside a particular linguistic unit are inherently more tightly bound in memory relative to sequences that cross such units.

However, it is also clear that the phonotactic probability of particular consonant-vowel sequences was not the only variable that determines STM performance. For the cv+vc stimuli—where the degree of association and CV and VC did not differ—there was a considerable dominance of CV over VC retentions. This suggests that Korean speakers are sensitive not only to phonotactic probabilities that govern particular

sequences of segments but also to the general statistical skew existing in the Korean lexicon. Since both component segment sequences of cv+vc stimuli were equally low in probability, the knowledge of the dependencies governing particular two-phoneme sequences might have been of little help to the Korean speakers' recall of the stimuli. Instead, speakers appear to rely on the general statistical characteristics of segment combinations in Korean which favor CV sequences.

To summarize, the two major patterns of recall response reported above support the emergent account of sub-syllabic patterns outlined above. Korean speakers can take advantage of the association of adjacent phoneme sequences outside of the units of traditional hierarchical structures. However, they are also sensitive to the general pattern of relatively stronger dependencies between onsets and vowels in Korean.

The emergent view predicts that similar forces will shape the responses of English speakers. Responses will be influenced not only by the phonotactic probabilities of particular sequences but by the general statistical characteristic of English. However, since in English VCs are favored, we expect that when onset-vowel and vowel-coda components do not contrast a recall advantage will be found for VC sequences. This possibility was tested in the second experiment.

Experiment 2

Method

Participants

Twenty native speakers of English from the Northwestern University community participated in the experiment (16 females; 4 males) as part of a course requirement. No

participants reported any history of speech or hearing impairment.

Materials

The stimuli for the English STM experiment consisted of 25 lists of six CVC nonsense syllables each. The 25 lists consisted of 5 different sets. These sets are referred to as list type A – E and examples of stimuli in the sets are given in Table 3. For example, list type A had three syllables of CV+vc (e.g., /kɔɪd/, /jɛtʃ/, /geɪs/) and three syllables of cv+VC (e.g., /θɪp/, /ðɑɪt/, /dʒuʒ/). All six syllables in list type D were of cv+vc type and all six syllables in list type E contained both high CV and high VC sequences. Type E was the only difference between conditions present in the Korean and English STM experiments; as noted above, there was an insufficient number of Korean nonwords composed of both a high r_ϕ CV and VC sequence (i.e., all syllables composed of high CV and VC were words). As in the Korean STM test, high vs. low r_ϕ values for CV and VC was determined via a median split. This yielded a total of 150 test stimuli (i.e., 5 list types x 5 lists per each type x 6 nonsense CVC syllables per each list). No phonemes were repeated within a list. A list of all the stimuli used in Experiment 2 is given in Appendix 2.

For CV+vc stimuli, the r_ϕ values for CV sequences were significantly higher ($M = .053$) than for vc ($M = .019$; $t(29) = 9.13$, $p < .0001$). The difference for cv+VC was significant as well (cv $M = .007$; VC $M = .066$; $t(29) = -16.80$, $p < .0001$). As with the Korean stimuli, although the cv+vc components were selected from the bottom half of r_ϕ values for each condition, the difference between them was significant (cv $M = .009$; vc $M = .016$; $t(59) = -6.54$, $p < .0001$). Similarly, for the CV+VC stimuli, the difference was marginally significant (CV $M = .054$; VC $M = .068$; $t(29) = -1.97$, p

< .07). We therefore also report results from a subset analysis where the components in both types of stimuli were matched (for the cv+vc subset ($N = 30$), cv $M = .012$; vc $M = .014$; $t(29) = 1.47$, $p < .15$; for the CV+VC subset ($N = 27$), CV $M = .056$; VC $M = .064$; $t(26) = 1.08$, $p < .29$).

Procedure

The procedure was identical to that described for the Korean STM test. The presentation of the five lists to the participants was randomized using a 5 x 5 balanced Latin-square design (5 different list types and sets of 5 participants). This ensured that each list type preceded and followed every other list type equally often.

Results

Participants' responses were analyzed by a phonetically-trained native speaker of English. Another independent transcriber (also a native speaker of English with experience in phonetic transcription) analyzed 30% of the entire responses. Inter-transcriber agreement was 94%.

The scoring method was identical to the one used for the Korean STM test. There were 2850 responses in total. Out of these responses, 1147 (40%) were correct responses. Out of the 1703 errors, 401 (23%) were "don't know" responses. Out of the remaining errors, 809 errors shared two phonemes with the original to-be-remembered syllables, and this set of two-phoneme retention errors is the focus of the analysis reported below.

Following the Korean analysis, the onset-vowel retention errors are reported as a percentage of all adjacent phoneme retentions, excluding the onset-coda errors. As in the Korean results, there were few such errors; on average about 12% of the total errors of

each condition. Secondly, a repeated-measures ANOVA revealed the percentage of onset-coda errors did not significantly differ across the conditions ($F(3,57) = .71, p < .55$).

Figure 2 reports the percentage of errors involving two adjacent phonemes that retained onset and vowel as a group from the four stimulus types pooled over the five list types (i.e., the proportion of CV retentions is 1 minus the proportion of VC retentions). Inspection of these results reveals differences in response patterns across the various stimuli. As in Korean, when the two sub-syllabic sequences contrasted in strength of association, participants retained the more strongly associated sequence. When onset-vowel sequences were more strongly associated than vowel-coda (CV+vc stimuli), participants preferred to retain onset-vowel sequences ($M = 59.9\%$; 95% CI = $\pm 6.2\%$); in contrast, participants preferred the vowel-coda when it was more strongly associated (cv+VC stimuli) ($M = 38.9\%$; 95% CI = $\pm 11.7\%$). When sequences did not differ in strength of association participants preferred to retain the vowel and coda, consistent with the general English subsyllabic pattern. This preference is particularly strong when subsyllabic sequences are relatively weakly associated (cv+vc stimuli) ($M = 40.7\%$; 95% CI = $\pm 5.3\%$); however, even for stimuli whose sequences are strongly associated (CV+VC), participants appear to be at least numerically biased towards retaining the vowel-coda sequence ($M = 45.2\%$; 95% CI = $\pm 9.0\%$).

To assess if these contrasting preference patterns were reliably different, a repeated-measures ANOVA was performed on the percentage of onset-vowel retention errors. This revealed a significant main effect of condition ($F(3,57) = 4.78, p < .005$). Specifically, this effect was driven by responses in the CV+vc condition. In this condition, participants made a significantly higher rate of onset-vowel responses than in

the other three conditions (CV+vc vs. cv+VC mean difference = 21.1%; 95% CI = +/- 14.2%; CV+vc vs. cv+vc mean difference = 19.3%, 95% CI = +/-9.8%; CV+vc vs. CV+VC mean difference = 14.7%, 95% CI = +/- 12.9%). Comparisons between the other conditions yielded no significant differences (cv+VC vs. cv+vc: mean difference = -1.8%, 95% CI = +/- 13.2%; cv+VC vs. CV+VC: mean difference = -6.3%, 95% CI = +/-12.9%; cv+vc vs. CV+VC: mean difference = -4.5%, 95% CI = +/- 8.6%).

Analysis of the matched subset revealed similar results. A repeated-measures ANOVA again showed a significant main effect of condition ($F(3,57) = 5.63, p < .002$). As before, this was driven by the CV+vc condition; responses in this condition were significantly different from the matched subsets (CV+vc vs. cv+vc: mean difference = 17.6%, 95% CI = +/- 7.1%; CV+vc vs. CV+VC: mean difference = 12.8%, 95% CI = +/- 10.3%) whereas the subsets did not differ from each other or the cv+VC condition (cv+VC vs. cv+vc: mean difference = -3.5%, 95% CI = +/- 10.8%; cv+VC vs. CV+VC: mean difference = -8.3%, 95% CI = +/- 12.4%; cv+vc vs. CV+VC: mean difference = -4.8%, 95% CI = +/- 8.1%).

Following Experiment 1, we consider whether other factors could account for the results of this study. Recall that simple chunk frequency could not account for the Korean results. Analysis of the English lexicon reveals a rather different pattern from Korean. The mean type frequency of CV sequences (7.02) is almost the same as that of VC sequences (7.08), leading to the incorrect prediction that participants should retain CV sequences as equally often as VC sequences.

Recall that analysis of the Korean data revealed that phonotactic probability contributed to recall independent of lexical neighborhood density. Similar analyses for

English revealed the same effect. Neighborhood density was calculated following the methods outlined for Korean. Error patterns of English speakers were assessed using a linear mixed logistic regression model. Predictors for the likelihood of a CV vs. VC error included the r_ϕ of the CV and VC sequence of each target, the percentage of CV neighbors (i.e., number of CV neighbors / (number of CV + number of VC neighbors)), as well as the interactions of these factors. Random intercept terms were included for participants ($SD = .13$) and items ($SD = .95$). As the r_ϕ of the CV sequence increased, errors were more likely to be CV than VC ($\beta = 48.29$; $SE = 24.30$; $z = 1.99$, $p < .05$). The likelihood of CV errors was also positively associated with the percentage of CV neighbors ($\beta = 3.20$; $SE = 1.18$; $z = 2.70$, $p < .05$). The r_ϕ of the VC sequence had no significant effect ($z < 1.5$). None of the interactions were significant ($|z|s < 1.3$).

Although neighborhood density did exert a significant influence on responses, consistent with previous studies (Thorn & Frankish, 2005) as well as existing models of short-term memory (Martin & Gupta, 2004), there was an independent effect of the r_ϕ of the CV sequence on English speaker's error patterns. This suggests that the results cannot be attributed solely to lexical factors.

Discussion

Similar to the Korean results, the English participants in the STM paradigm exhibited two major patterns of responses. When CV vs. VC sequences do not contrast in terms of the strength of their association, errors reflect the general pattern of English (preferring VCs). However, when sequences are of contrasting strength, two-phoneme retention errors are more likely to reflect the stronger association. Critically, for CV+vc stimuli, this entails that errors are less, not more, likely to retain sequences within the

rime unit posited by hierarchical theories of subsyllabic structure.

These findings provide additional support for the emergent account of subsyllabic structure. Unlike the hierarchical theory, the emergent view does not require a common constituent structure across all syllables within a language. This accounts for the sensitivity of English speakers to sub-syllabic dependencies that cross the traditional rime unit. Second, unlike the non-hierarchical model, the emergent view can also account for the effect of general patterns that hold across the English lexicon. It allows a mechanism by which speakers can be sensitive not just to the association of particular sequences of segments but also to those associations that are generally much stronger in their native language.

It should be noted that the preference for retaining VC sequences was numerically stronger for syllables composed of all low (cv+vc) compared to all high r_ϕ sequences (CV+VC). In fact, for the latter the 95% confidence interval for %CV retentions includes 50%; this suggests that in this condition participants exhibited no preference for either subsyllabic sequence. However, the response patterns are not reliably different across these stimulus types; detailed examination of possible differences between these conditions is left for future research.

General Discussion

These results suggest that cross-linguistically common principles guide speakers' encoding of subsyllabic patterns. Speakers are sensitive not only to the two-way dependency between particular segments in their language (e.g., for /bet/, /be/ vs. /et/) but also to the general dependencies that exist in their language (e.g., onset-vowel vs.

vowel-coda). A statistical analysis revealed that the components of Korean and English CVC words differ in terms of their general patterns of association. Onset-vowel sequences in Korean syllables are on average more strongly associated than vowel-coda sequences, whereas the English lexicon exhibits the opposite pattern. Results from STM experiments revealed that speakers were sensitive not only to these general statistical regularities but also to the phonotactic probability of particular sequences. These results are consistent with an emergent account of how speakers represent sub-syllabic patterns; this predicts effects of not just the frequency of individual phoneme sequences but also an influence of the general statistical patterns in the lexicon.

The current findings thus provide support for recent approaches to the emergence of phonological entities, such as those advocated in Bybee (2001) and Bybee and McClelland (2005). According to this view, speakers of a language are implicitly aware of both specific phonetic/phonological details and the more general patterns that are derived from these specifics within their language. Abstract phonological entities are seen not as linguistic primitives but as an effect of generalization from specifics. In the case of sub-syllabic units at hand, this amounts to saying that Korean and English speakers implicitly know the probabilities of individual sequences in their language and the emergence of sub-syllabic units is a result that reflects speakers' generalizations over these specific instances.

We assume that speakers make these generalizations in the course of developing internal representations and processes that allow them to successfully perform speech production and perception tasks. Specifically, we assume that sub-syllabic units emerge out of the combined pressures of rapidly and efficiently parsing incoming speech signals,

planning and executing articulatory gestures, as well supporting mappings between these two domains (e.g., Plaut & Kello, 1999). These emergent generalizations are therefore an integral part of both perception and production processes, and should influence on-line behavior in multiple domains. In this work we have examined one aspect of language processing—short-term memory—which combines a number of perceptual, production and memorial systems. However we would expect that these representations underlie performance in other tasks. For example, a prediction can be made about speech errors such that CV would move as a unit for syllables that contain relatively high probability onset-vowel sequences.

If linguistic units (including the sub-syllabic units discussed here) are developed on the basis of the statistical patterns and thus are not inherently fixed in a language but are rather variable emergent properties, then the same principle may apply to the development of linguistic structures in domains other than phonology. An example of this is found in morphology. Although the classical treatment of word formation posits linguistically primitive categorical units (i.e., morphemes), recent investigations found that speakers' cognitive representation of derivationally complex words reflect the statistical characteristics of the base and the affix (Hay, 2001). This indicates that morphological units are something that emerges in the course of learning to use language (Seidenberg & Gonnerman, 2000).

Extensions of the current study

The typology of sub-syllabic patterns. Under this emergent view cross-linguistic differences in the behavior of adult speakers do not reflect categorically different memory mechanisms, but rather reflects the acquisition of different vocabularies (with distinct

distributional patterns). The onset-rime pattern of English speakers therefore reflects not categorically distinct processing units, but the presence of a statistical skew within the English lexicon. The emergent account thus predicts the existence of a language positioned intermediate between Korean-like and English-like languages. In such a language—where the statistical regularities of sub-syllabic sequences show no strong preference for either onset-vowel or vowel-coda—the emergent account predicts that any sub-syllabic constituency structure may also be correspondingly weak. Further cross-linguistic research is in order to determine if such a pattern is found in human languages.

Sub-syllabic organization in multi-syllabic words. The current study has shown that the general statistical characteristics of Korean CVC forms contrasts with the corresponding English forms. One question is if this pattern will also be found in more complex forms. These include: bi-syllables with no consonant clusters; mono-syllables with complex clusters in either onset or coda positions; as well as across morpheme and/or word boundaries where resyllabification and other phonological processes (e.g., assimilation) may occur. This may be critical, as the distributional patterns found in the current study may rather reflect the patterns of vowels and consonants at word (not syllable) edges, since the CVC forms examined in this paper in calculating the statistical characteristics were all monosyllabic words. Previous English lexicon studies suggest that the associations observed in simple CVC forms may generalize to polysyllabic words (Berg, 1994, and to some extent Randolph, 1989). However, for Korean, not such evidence is available; future work with more extensive word lists is necessary.

The role of sub-segmental representations. Syllabification patterns are clearly

influenced by sub-segmental structure. For example, the property of sonority (roughly, the degree to which segments are associated with relatively open vocal tracts) has been claimed to exert a strong influence on subsyllabic phonotactic patterns cross-linguistically (e.g., Clements, 1990). A number of previous studies (Geudens & Sandra, 2003; Gupta & MacWhinney, 1997; Hartley & Houghton, 1996; Kessler & Treiman 1997; Moreton, Feng, & Smith, 2005; Treiman, 1984; Treiman & Danis, 1988) have suggested that this may also influence the cohesiveness of segment sequences in behavioral tasks. This paper did not manipulate this factor; it is possible that this also exerts an influence on subsyllabic constituent structure.

It should be noted that studies that have claimed to reveal an influence of sonority have not controlled for the strength of association of subsyllabic sequences. Asymmetries in this stimulus property may also contribute to the observed patterns. For example, Nimmo and Roodenrys (2002) hypothesized that the greater number of onset-vowel (i.e., ‘body’) retention found in their English STM tests might have been due to sonority. In their tests, there were relatively more stimuli consisting of Vowel+obstruent than stimuli consisting of Vowel+sonorant. As obstruents are relatively low in sonority, Nimmo and Roodenrys claimed that obstruents are less likely to act as a unit with the preceding vowel, thus yielding more onset-vowel retention errors. To examine if the strength of association of segment sequences could also account for the results, we compared the r_ϕ value of CVs and VCs for the 33 high-frequency C/i/C nonword stimuli of Nimmo and Roodenry (2002:656). In nearly 2/3 of the items (21/33), the r_ϕ value of the onset-vowel sequence was higher than that of its vowel-coda sequence. This skew suggests that the observed rate of onset-vowel errors may be in part due to the overall

higher dependency values for onset-vowel sequences—not exclusively an effect of sonority.

In order to further examine the potential effect of sonority in the error patterns found in the current study, we compared the distribution of sonorants (including liquids and nasals) and obstruents (stops, fricatives, and affricates) across onset and coda position for the cv+vc stimuli in English and Korean. This allowed us to test for two potential sources of sonority effects. First, Nimmo and Roodenrys (2002) would predict that CV is remembered only if the coda in VC is relatively low in sonority, i.e., the coda is an obstruent. So, for the Korean stimuli in particular, we asked whether the codas were generally low in sonority relative to onsets. This did not appear to be the case. Sonorants in fact appeared in coda as equally often as obstruents. This suggests that the greater number of onset-vowel retention found from cv+vc stimuli in the current Korean STM test cannot be solely due to the relatively low sonority of coda consonants. Sonority also appears to be unable to account for the pattern of English participant responses. In the case of the English cv+vc stimuli, the majority of coda consonants were obstruents (85%). A sonority-based account would therefore predict that a significant recall advantage for English onset-vowel sequences, opposite the pattern observed in our data. Finally, if the distribution in terms of sonority across onset and coda is not really different for Korean vs. English, then the different behavior of participants across the two languages cannot be due to sonority. Consistent with this, a comparison of sonority distribution across the Korean and English (unmatched) ‘cv+vc’ stimuli failed to reveal any substantial differences. Specifically, in both languages, the majority of onset consonants were obstruents (83% and 71%, Korean and English,

respectively). This suggests that the contrasting patterns of behavior of participants from different language backgrounds cannot be solely due to sonority.

The role of orthography. As reported above, at least as far as the test items used in this study are concerned, Korean speakers' error patterns did not significantly differ as a function of how the particular syllables were spelled. This is consistent with other research showing that speakers' sensitivity to the general body-coda pattern of Korean is not influenced by changes in orthographic presentation format (i.e., Korean vs. linear Romanized format; Yoon, et al., 2002). However, these results do not completely exclude any influence of orthography, especially given previous reports (e.g., Yoon & Derwing, 2001) suggesting an advantageous role of the quite regular Korean orthographic system for highly literate participants in recall tasks. More concretely, as mentioned above, the body unit is visually very salient in Korean orthography. For example, in writing /kam/, the vowel letter representing /a/ is written to the right side of the letter representing /k/. The letter representing /m/ is then added to the bottom of the block of letters representing /ka/. What makes this orthographic body unit even more salient is the total absence of any counterbalancing convention that ever presented vowel-coda sequences as juxtaposed (Yoon & Derwing, 2001; Yoon et al., 2002; Kim, 2007). In addition to this, in learning to read Korean Hangul most children are presented with a chart that lists CVs (but never VCs) as building blocks to combine with final consonants in creating CVC syllables (Cho, McBride-Chang, & Park, 2008). Thus it is quite possible that this orthographic convention might have played as strong a role in the effect seen in the current Korean experiment as the phonotactic probabilities. A further study of pre-literate Korean speakers (following STM

tests of pre-literature speakers of English; Brady et al., 1983; Gathercole, Willis, Baddeley, & Emslie, 1994) may be necessary to strengthen the claim that the results in this study reflect sensitivity to the general statistical patterns governing sequences of sounds in Korean.

Implications for phonological theory. Moraic theory (e.g., Hayes, 1989, 1995)—a prominent perspective on cross-linguistic prosodic structure—posits an autosegmental unit (the mora) that intervenes between the syllable node and segments occurring in nucleus or coda positions. Critically, onset consonants are assumed not to be associated with morae. Since the emergent perspective allows onset-vowel sequence to become more strongly associated than vowel-coda sequences, it predicts that not only codas but also onsets may be a relevant factor in explaining phonological processes attributed to moraic structure. For example, stress placement in “weight sensitive” languages has been attributed to the influence of moraic structure; moraic but not non-moraic segments contribute to syllable weight. Since, as noted above, onset consonants are not moraic, they are predicted not to influence stress placement. In contrast, since the emergent perspective allows for the acquisition of onset-vowel constituents, we might expect cases of onset-sensitive stress systems. Several analysts have reported the existence of such languages (see, Everett, 1988; Everett & Everett, 1984; Gordon, 2005, for relevant data and discussions). Further empirical and theoretical work is clearly needed to examine the more general consequences of emergent subsyllabic structure for phonological patterns.

Conclusions

A good deal of recent research claims that linguistic constituent structure (be it phonological, morphological or syntactic) emerges based on the statistical properties of language (e.g., Bybee, 1985, 1995; Gupta & Dell, 1999; Seidenberg & Gonnerman,

2000). This contrasts with more traditional theories of morphology and syntax that assume certain primitive discrete constituents. Consistent with this view, the current results favor a perspective where the statistical properties of segment combinations in the words of Korean and English play an important role in how the speakers organize sub-syllabic phonemes into units. Further work investigating the relation between the statistical properties of sounds and other phonological units will shed more light on these contrasting perspectives on the structure of phonological representations.

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Footnotes

1. Specifically, English lemmas with CELEX morphological status code “M” (monomorphemic) or “Z” (zero derivation/conversion).
2. Note, however, that this difference would skew errors against the general patterns of Korean (as vowel-coda sequences have higher r_ϕ values). This imbalance will therefore serve to skew the results against the emergent hypothesis.

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Table 1

Mean absolute value of r_ϕ for CV and VC sequences in Korean and English.

		N	Mean absolute r_ϕ (Std. Dev.)	Mean type frequency
Korean	CV	152	.050 (.037)	2.40
	VC	76	.039 (.028)	6.19
English	CV	280	.022 (.019)	7.02
	full-set VC	222	.034 (.034)	7.08
English	CV	257	.033 (.028)	3.38
	smaller-set VC	186	.052 (.072)	4.68

Table 2

Examples of Korean STM stimuli across the 4 types of lists.

List Type	CV+vc	cv+VC	cv+vc
A	hyak, naŋ, sen	t'ip, hul, p ^h et	n/a
B	nit, kwap, hwem	n/a	k ^h ən, map, tʃ'ol
C	n/a	hun, s'op, tʃ'it	k ^h ək, k'oŋ, næm
D	n/a	n/a	p'æŋ, k ^h ək, tʃ ^h em, t ^h ən, mɪp, tʃ'ol

Table 3

Examples of English STM stimuli across the 5 types of lists.

List Type	CV+vc	cv+VC	cv+vc	CV+VC
A	kɔɪd, jɛtʃ, gɛɪs	θɪp, ðaɪt, dʒuːz	n/a	n/a
B	dauð, mæb, zul	n/a	hɪk, ʃadʒ, pouθ	n/a
C	n/a	sɔɪn, ðaɪt, ʃab	wɪθ, mʌl, fɪtʃ	n/a
D	n/a	n/a	sədʒ,maʊtʃ,jouð, rɪn, təb, vɛl	n/a
E	n/a	n/a	n/a	rʌs,bʊd,tʃəθ, zouɪ,dʒæʃ,jauɪ

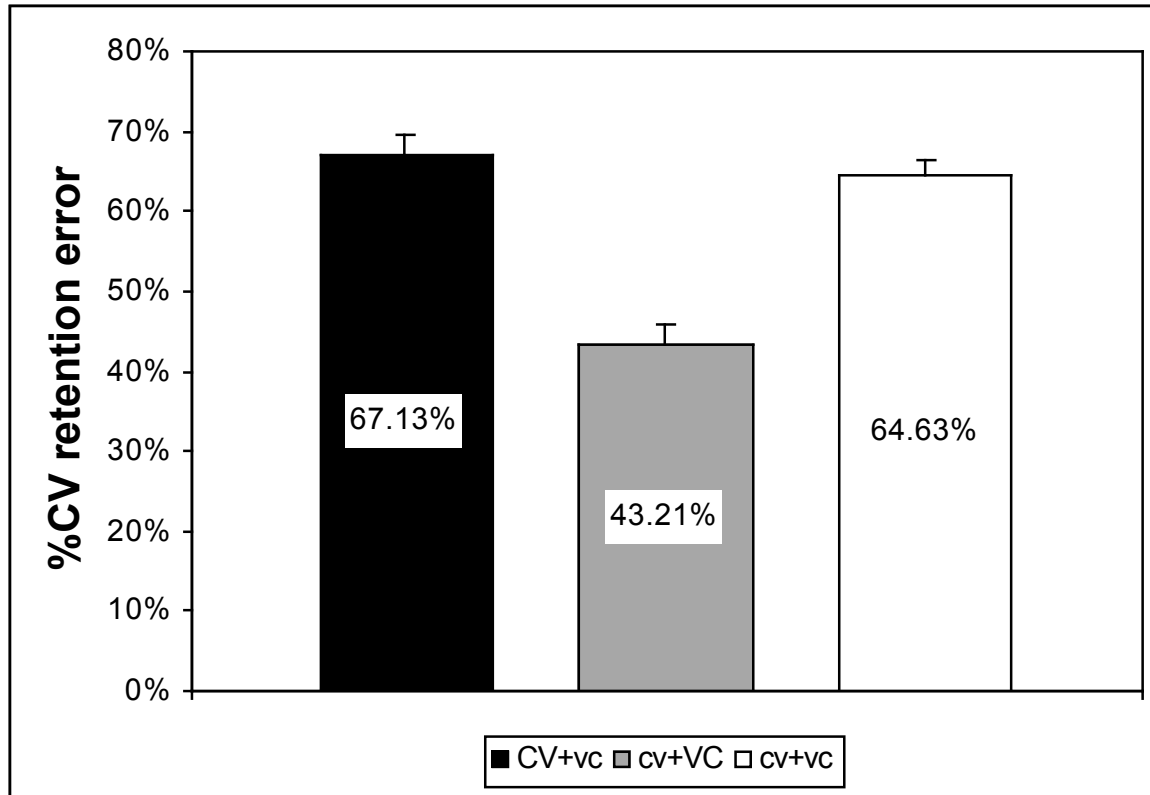


Figure 1. Mean %CV retention errors in Korean STM tests. Error bars show standard error of the mean.

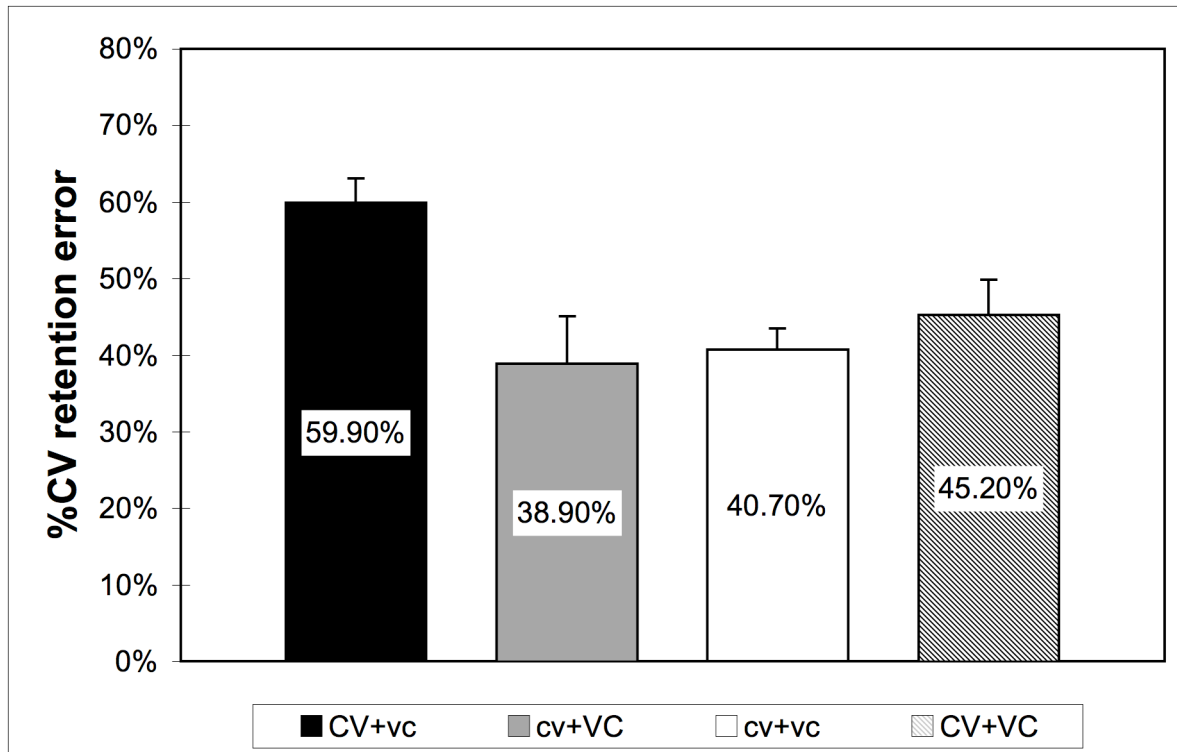


Figure 2. Mean %CV retention errors in English STM tests.

Appendix A Stimuli for Experiment 1.

CV+vc	kwal	t ^h om	k'wɛŋ	k ^h æk	tɛp	naŋ	hyul	k ^h wim	tʃin	sɛn
	kit	s'ət	nit	k ^h æŋ	t ^h ok	k ^h æm	k'ip	s'at	k'wap	tʃ ^h it
	t ^h ot	t'ap	t'an	tʃik	tʃ ^h in	tʃ ^h ək	tʃip	myək	hwɛm	t ^h on
	k'wɛm	mwək	sit	tʃit	s'ak	tʃəŋ	k'wɛt	k'wat	kwap	s'ap
	hyak	k'yam	k'wɛl	hyat	k'yap	ryal	k'wɛp	rik	kwak	ryaŋ
	p ^h uŋ	hyun	rit	p'yap	syon	tʃ ^h əp	syom	hwɛp	ryam	syok
cv+VC	k ^h ip	hwəl	mɛt	t'ip	p ^h ɛt	miŋ	tʃ'ip	p'uk	tʃ ^h wəl	hul
	tʃ'əm	hɛt	kip	tʃɛt	hun	tʃ'op	t ^h ul	tʃ'uk	kwəl	k ^h un
	tʃ'iŋ	s'op	nul	tʃwəp	tʃɛp	s'im	tʃ'it	p'um	tʃɛm	p'ut
	hip	hwəl	k'im	t'iŋ	s'up	s'ul	s'un	tʃ'iŋ	p'un	tʃ'il
	tʃ ^h ɛt	ryən	k ^h ik	nwəl	rim	syɛn	t'yɛn	tʃyɛn	t'yop	syɛŋ
	tʃ ^h yop	tʃyɛŋ	s'yɛn	p'yɛn	p'yəŋ	syum	k ^h ul	t'un	riŋ	syup
cv+vc	hæp	map	k ^h am	t'yun	tʃ ^h yul	p'it	tʃ'an	p'ət	k ^h ən	pot
	sip	hyal	s'yan	p'ol	t ^h yam	myat	səp	kyol	t ^h ɛp	k ^h yun
	p ^h æp	kap	tyam	syul	nit	k ^h an	sət	p ^h ən	pot	mip
	k ^h ək	næm	roŋ	hæn	tʃ'it	tyap	k ^h ən	hæŋ	rip	tʃ ^h ɛm
	tʃ'ol	t ^h ən	tʃ'ot	huŋ	syən	k'oŋ	t ^h ət	syun	t ^h ɛm	s'yap
	rok	t ^h əp	hæk	rin	t ^h ən	næp	kit	tʃɛm	p'æŋ	syat

Appendix B

Stimuli for Experiment 2.

CV+vc	kəɪd	jetʃ	geɪs	daʊð	ju:p	dʒætʃ	zɪʃ	liθ	waim	θæn
	θəŋ	zɪʃ	wəb	zul	naθ	θəb	rus	veɪm	mæb	ðætʃ
	jeɪg	reɪð	gæk	rouk	kɔɪs	matʃ	ðes	meɪð	sɪʃ	tʃɪb
cv+VC	θɪp	ðart	dʒuɜ	gum	wəŋ	tɔm	kaus	ʃab	joʊp	wak
	fɪp	bus	hið	səg	maʊt	fɔɪz	ʃəg	kaut	sɔm	rel
	dʒəŋ	mɪv	seɪɜ	naʊθ	ʃaʊl	vaɪð	kæŋ	muz	həʃ	maʃ
cv+vc	θɪl	guð	tɪb	dʒuθ	næk	hut	naʊz	daθ	gʊtʃ	hɪk
	ʃadʒ	pouθ	sʌdʒ	maʊtʃ	joʊð	ʃʊtʃ	mouθ	hæb	fɔɪd	mul
	fɪtʃ	rədʒ	kʊl	ðouk	rɪz	bʊp	tʃeɪg	nəʃ	joʊd	dʒaɪm
	tʃən	said	kaʊdʒ	dʒaθ	fɪm	tɔɪs	mɪz	ʃaʊð	seɪg	tʃadʒ
	nik	fəs	naɪb	fɔɪd	tʃeɪm	guθ	ʃʊp	res	θɪd	ʃadʒ
	dɪt	netʃ	bəs	təb	ʃeɪd	hɪf	detʃ	rɪn	wɪθ	vel
CV+VC	kɔɪz	jed	geɪɜ	wəɪv	tʃið	θəf	jaʃ	θɪg	ðæp	vɔɪm
	wətʃ	zut	pʊk	taɪð	veɪdʒ	naŋ	gaʊθ	juɜ	fʊʃ	ðet
	sɪv	kouz	mæŋ	daʊθ	rus	bʊd	tʃəθ	zoul	dʒæʃ	jaʊt