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Sub-syllabic Constituency in Korean and English

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ABSTRACT

Sub-syllabic Constituency in Korean and English

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Behavioral results from syllable experiments with Korean speakers indicate that, given a C_1VC_2 syllable, users of this language show a strong tendency to group C_1 and V into a unit, excluding C_2. This is in contrast to the results from comparable investigations with speakers of many other languages, including English, suggesting the opposite pattern, i.e., V and C_2 seem to form a unit, excluding C_1. This typologically unusual way of breaking up the syllable by Korean users has been usually interpreted as a direct function of two a priori sub-syllabic constituents, 'body-coda', for Korean syllables (e.g., Yoon & Derwing, 2001), as opposed to 'onset-rime' for English syllables.

This dissertation aims to show that this cross-linguistic difference is not due to differences in constituent structure per se, but rather reflects speakers' sensitivity to the distributional statistics of their language at the sub-syllabic level. Specifically, I will show that the primary reason why Korean users generally prefer C_1V to VC_2 groupings is that they are implicitly aware that the two-way dependencies between segments are, on average, greater for C_1V than VC_2 sequences in the vocabulary of Korean. In order to demonstrate this, I first report

results from a statistical study of Korean and English C_1VC_2 words, measuring specifically the strength of association for each of the C_1V and of VC_2 sequences in the languages. It will be shown that various measures converge, indicating that C_1V is indeed generally more strongly associated with each other than VC_2 in Korean, while the opposite statistical pattern is true for English. Second, I report results from two psycholinguistic experiments -- serial recall and wordlikeness judgments of Korean and English C_1VC_2 nonwords -- further demonstrating that Korean- and English-users' knowledge of the statistical characteristic of their native languages play a key role in their task performances.

I conclude that the current findings are in support of an 'emergent model' of sub-syllabic constituency (along the line of Dell and Govindjee, 1993; Chen, Dell, and Chen, 2004) as a viable alternative to the traditional models of syllable structure of natural languages.

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CHAPTER 1

Introduction

1.1. Internal Structure of the Syllable

There is little doubt that the syllable is an essential prosodic constituent in properly describing various phonological phenomena found in natural languages. For example, the syllable is a unit that is necessary in delineating the domain within which a variety of co-occurrence restrictions within a language hold. For example, in English /a/ can occur before /r/ at the end of a syllable but /æ/ cannot (Kessler and Treiman, 1997). It is also the case that the syllable has long been an indispensable unit to phonologists when they need to specify the environments within which the phonological rules or constraints of a language apply, such as the stress placement rule in English (Hayes, 1995). The above examples, together with many other reasons, form the basis of arguments in support of advancing the syllable as an independent constituent in phonology.

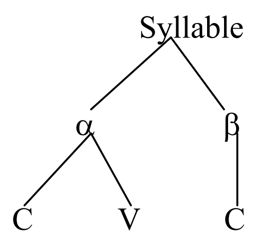
While the syllable is quite widely acknowledged as an essential prosodic unit in phonology, certain aspects of the syllable still remain as an issue of active discussion among phonologists as well as psycholinguists. The core issue that is the major focus of the investigation of this dissertation is the question of the precise way in which the internal structure of the syllable should be characterized. More precisely, how much structure do we need to posit within the syllable of a language and what are the factors that are responsible for a certain syllable internal structure of the language.

A review of previous studies indicates two major contrasting approaches to this question (see Chapter 2 for a detailed review of previous literature on this). One (more traditional) approach proposes a hierarchical structure of the syllable with certain linguistically primitive sub-syllabic constituents. Another approach assumes no such explicit constituents inside the syllable and attributes effects of apparent sub-syllabic units to language users' sensitivity to the characteristic of segment co-occurrence pattern present in the lexicon of their native language. In the following, I briefly discuss the major characteristics of these two models of syllable internal structure.

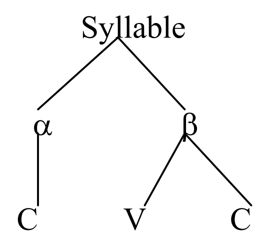
Under the more traditional view of syllable structure, the syllable internal structure of natural languages is represented with tree diagrams, similar to those trees found in syntactic theories. More specifically, this approach hypothesizes that the internal structure of syllables is such that the size of units that are posited below the syllable is bigger than just the syllable terminal segments themselves. Two particular examples that this view of syllable structure proposes are schematized in (1.a-1.b), which differ from each other in the kind of syllable-intermediate units that are posited.

(1) Structural Representation of the Syllable

(1.a) CV-Cluster Hypothesis



(1.b) VC-Cluster Hypothesis



Thus, the defining characteristic of this approach is that the subsyllabic units larger than the syllable terminal segments are explicitly represented in the syllable. Those syllable-intermediary units are taken to be primitive (i.e., they are built-in characters of languages) and languages may differ from each other in which of the two options they take.

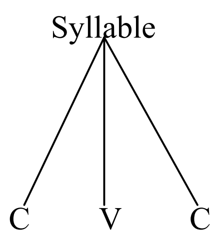
Two things stand out from these particular representations of syllable internal structure. First is that positing the intermediate units between the syllable and the syllable terminal segments obviously entails that the segments would always be indirectly linked to the syllable (via the sub-syllabic units). In this sense, this model of syllable structure is hierarchical in its nature.

Second, and more important, is that under this view, the syllable does not just consist of linear strings of segments, that is, a segment within a syllable is not equally preceded and followed by its neighboring sounds. Rather, some two-phoneme sequences are intrinsically more closely associated with each other than other two-phoneme sequences. For example, for a language for which the VC-cluster hypothesis is held to be the case (i.e., 1.b), the nucleus vowel should be inherently more strongly associated with the coda that it is with the onset.

Assuming that the representations shown in (1.a-1.b) are a part of language users' phonological grammar, one testable predication that follows is that language users' behavioral patterns (with regard to their chunking phonemes that appear within a syllable) will be a direct function of these sub-syllabic units. Thus, when given a sound sequence of 'a consonant (C_1) – a vowel – a consonant (C_2)' like /bʌs/, speakers of VC-cluster type language would predominantly prefer /b.ʌs/ (C_1//VC_2) to /bʌ.s/ (C_1V//C_2) partitioning. This is so, since the VC_2 sound strings are contained within the same syllable internal unit (i.e., they are immediate daughters of the same constituent) and accordingly it is predominantly the VC_2 strings that will show up as a chunk, not the C_1V strings which belong to two different sub-syllabic constituents. Importantly, this kind of pattern involving subjects' partitioning of CVC words is expected to be quite categorical, exhibiting little variance among speakers and among CVC words of the same language.

In contrast to this, another view of syllable structure in the literature, however, proposes that syllables simply consist of linear strings of segments with no sub-syllabic units. Under the approach, the syllable structure is envisioned as basically flat, as the one shown in (2). Breaking down segments within a syllable into some predetermined linguistic chunks is denied.

(2) Non-structural Representation of the Syllable



Positing no sub-syllabic units, for one thing, implies that no one syllable terminal segment is inherently more closely related to any other, i.e., the nucleus is no more closely related to either the prevocalic or postvocalic consonant(s). Related to this is a prediction that language users' behavioral patterns with regard to their syllabification of terminal segments in principle will show no strong signs of unit effects. For example, when given a sound sequence of 'a consonant (C_1) – a vowel – a consonant (C_2)' like /bʌs/, language users' partitioning of the segment strings into either /b.ʌs/ (C_1//VC_2) or into /bʌ.s/ (C_1V//C_2) is equally likely.

Second, since the model assumes no explicit structures inside the syllable, if one observes behavioral patterns that appear to reflect certain structures, then they should be a consequence of some other factors. One of the critical factors, suggested by this non-hierarchical approach, is the relative frequencies of segment sequences in the words of a language. More specifically, the basic claim is that segment sequences differ in the frequency with which they occur together in the vocabulary of a language and that users of the language are implicitly aware of that. Unit effects apparent in language users' behavioral patterns with regard to their syllabification of segments are claimed to reflect speakers' knowledge of such statistical patterns. For example, partitioning of a C_1VC_2 syllable into $C_1//VC_2$ is more likely to occur than $C_1V//C_2$, if the VC_2 sequence occurs with each other in the vocabulary of English more frequently than the C_1V sequence. The reverse partitioning pattern is likely if the C_1V occurs more frequently than the VC_2. Under this non-hierarchical model of syllable structure, then, what determines certain unit effect is not the sub-syllabic units per se, but language users' knowledge of the relative frequencies with which phoneme sequences occur in the vocabulary of their native language.

Summarizing, we see that the two theories differ mainly in terms of their answer to the following question. When we observe a consistent pattern in a language that shows that a sequence of segments within a syllable seems partitioned into different units, what is responsible for that effect? One approach hypothesizes that the syllable structure of natural languages is hierarchical with certain primitive sub-syllabic units and the unit effect is a function of these linguistically primitive sub-syllabic constituents. On the other hand, another approach hypothesizes that segment sequences may differ in how commonly they occur in the vocabulary of a language and language users have access to this probabilistic phonotactic information, which may produce some grouping effect. In a broader sense, one may say then that the two approaches differ from each other in the kind of knowledge that they emphasize regarding language users' representation of syllable structure: speakers' more abstract knowledge of certain sub-syllabic structures vs. their knowledge of the frequency with which sequences of phonological segments occur in words in the language.

1.2. Overview of the Dissertation

The ultimate goal of this dissertation is to contribute to the area of syllable structure research by producing new data that will test the descriptive and explanatory power of the two existing theories of syllable structure introduced above. In the current dissertation, I focus on investigating Korean and English syllable structure in a hope that the results obtained from the two languages will permit us further insights into our understanding of the nature of syllable structure of natural languages in general. I have chosen these two particular languages on the basis of my own literature review that suggests that the two may be different in an interesting way, primary in the kinds of sub-syllabic units that have been posited in the literature.

Chapter 2 builds the foundation for this dissertation by providing a detailed description of the two major contrasting views of the syllable structure, along with an introduction of a syllable structure model that this dissertation will ultimately argue for. The description will be accompanied by a review of empirical results from previous studies that have been used in support of the theories.

Chapter 3 examines the distribution of phonemes and phoneme sequences in Korean and English CVC single-syllable words. The major focus of the chapter is on quantifying the relative cohesiveness of onset-vowel as opposed to vowel-coda sequences in the CVC words of the languages. The results of the statistical study will be discussed in the light of the particular sub-syllabic structures that have been presented for Korean and English, that is how the previously proposed syllable structures of the two languages can be related to the general statistical characteristics of the lexicon of Korean and English.

Chapter 4 describes results from psycholinguistic experiments employing (verbal) short-term memory tests. This experimental technique basically measures the accuracy of subjects' recall for previously heard or unheard items (i.e., nonwords). This experimental method is adopted in the current thesis in order to examine the extent to which the accuracy of the recall of CVC nonwords in Korean and English varies as a function of the two variables of interest in this thesis, i.e., certain pre-determined sub-syllabic units in vs. phonotactic frequencies governing segment sequences in Korean and English. The results are discussed in the light of the predictions that the models of syllable structure introduced in Chapter 2 make, and will be interpreted in support of a more general model of syllable structure (that will be termed as an emergent model) than the two existing models.

Chapter 5 describes results from another psycholinguistic experiments employing wordlikeness judgment tasks in which subjects were asked to rate the extent to which CVC nonsense syllables were typical of the actual words in a language. The major goal of the experiment was to produce additional data that support the findings in Chapter 4, specifically by examining the characteristic of Korean- and English-speakers' sensitivity to the statistical dependencies between phonemes at the sub-syllabic level. The findings will also be shown to support the emergent model as an alternative to the traditional models of syllable structure.

Finally, Chapter 6 concludes the dissertation by pulling together the results of the statistical studies and the psycholinguistic experiments. Further implications for the internal structure of syllable structure in natural languages are discussed. Finally, limitations of the current dissertation and suggestions for further work are given.

CHAPTER 2

Background

2.1. Contrasting theories of syllable structure

The purpose of the current chapter is to provide a more extensive description of the two major contrasting views of the syllable structure introduced above, along with an introduction of a syllable structure model that this dissertation will ultimately argue for. The description will be accompanied by a detailed review of empirical results from previous studies that have been used in support of the theories.

We saw above that the debate in the area of syllable structure research centers on the status of the intra-syllabic structure of natural languages. Two currently competing theories are: (i) structural models: syllable structure as basically a hierarchical structure with some linguistically primitive constituents vs. (ii) non-structural models: syllable structure as simple linear strings of segments (emphasizing, instead, the role of differential phonotactic probabilities among segment sequences). I begin this chapter with a description of some specific configurations of syllable internal structure that the hierarchical models of syllable structure propose.

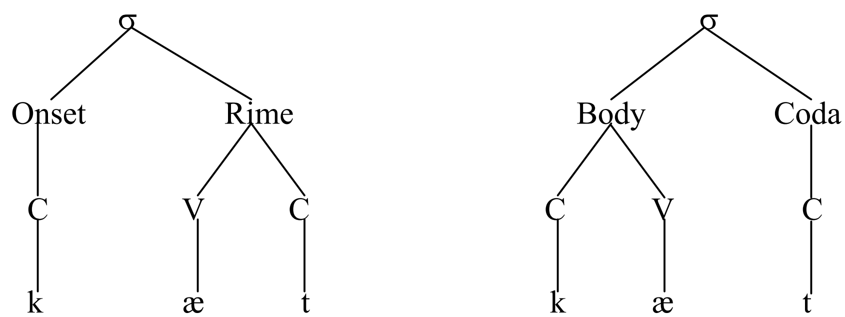
2.1.1. Models that are essentially structural: Onset/Rime and Moraic theories

(A) 'Onset-Rime' theory of syllable structure

One of the models that posit sub-syllabic units is Onset-Rime theory. This theory is probably the most popular theory of syllable structure of natural languages, especially of English. A significant number of researchers (e.g., Treiman & Kessler, 1995; Treiman & Kessler, 1997; Treiman, Fowler, Gross, Berch, and Weatherston, 1995; Treiman, Kessler, Knewasser, Tincoff, and Bowman, 2000; De Cara & Goswami, 2002) have argued in favor of this theory.

Fundamental to this theory is the claim that the relation between the syllable's vowel (nucleus) and following consonants (coda) is special in that they are the immediate daughters of a distinct constituent called the rime. The initial consonant or consonant cluster is, however, outside this constituent and forms on its own another distinct constituent, called the onset. These two sub-syllabic constituents are straddled between the syllable terminal phonemes and the syllable node. This particular model is also often said to be right-branching: it is the rime that branches into nucleus and coda, as shown in (3.a). No researchers that I am aware of advocate an English syllable structure like the one schematized in (3.b) where the onset and the syllable's vowel are grouped into a constituent that excludes the final consonant(s).

(3) (a) right-branching (b) left-branching



As was mentioned in the previous chapter, an important prediction that this model makes is that since nucleus and coda are daughters of a constituent (i.e. rime) that is local to them but onset and nucleus are not, the attraction between nucleus and coda should be inherently much stronger than the attraction between nucleus and onset in the grammar of English. Thus, in experiments that are designed to tap English-speaking subjects' implicit knowledge of the syllable structure of English, the subjects' behavioral pattern will be such that they would not only tend to form certain inter-syllabic groups using the segments and but also that any phenomena that treat the vowel and the coda as a group should far outnumber any phenomena that treat the vowel and the onset as a group.[1]

(B) 'Body-Coda' theory of Syllable structure

In contrast to English-type languages, which are commonly considered to have a syllable-internal structure of onset vs. rime, an alternative syllable-internal structure of

[1] A version of Government Phonology (GP: Kaye & Lowenstamm, 1981) can be called a variant of the onset-rime theory. GP also has an Onset-Rime distinction, although it does not acknowledge the syllable constituent.

'onset+nucleus' (often referred to as "Body") vs. coda (see, 1.b above) has been proposed for languages including Korean (Yoon & Derwing, 2001) and Japanese (Yoshiba, 1981; Katada, 1990). Derwing and his colleagues used a variety of experimental techniques in order to support the body-coda model for Korean syllables. In a blending experiment, Derwing et al. (1993), for example, have shown that blends of the type 'body + coda' significantly outnumber those of the type 'onset + rime' in Korean. Similar results were obtained by the method of 'sound similarity judgment' used in Yoon and Derwing (2001). In the experiment, Korean subjects were asked to rate how similar a pair of spoken stimuli is. The pattern in the data was that Korean speakers considered pairs of stimuli that share the body like /<u>mo</u>t/ and /<u>mo</u>p/ more similar than those that share the rime /m<u>ot</u>/ and /p<u>ot</u>/, contrary to what happens in English speakers (Yoon and Derwing 1994). Note that the same kind of prediction that the onset-rime theory has also applies under body-coda configuration of syllable structure, except that it is the two-phoneme sequences within the body (onset+nucleus) unit that are expected to be more strongly associated than the segments with the rime (nucleus+coda).[2]

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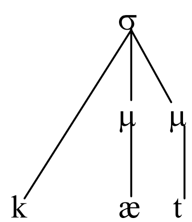
[2] A recent interesting proposal similar to the body-coda model regarding the Korean syllable comes from the Government Phonology (GP) community. As far as I know, two studies including Rhee (2002) and Goad & Kang (2003) stand out. They put forward a somewhat radical proposal that Korean (and in fact every language) is not a CVC language but a CV language, contra most, if not all, Korean phonologists. Their major concern focuses on whether or not Korean has branching rimes. Their claim is that Korean does not have branching rimes, rather it is a CV language with the final C being an onset of the following syllable whose head is empty. This claim is primarily due to its theory-internal condition that a single consonant cannot occur in the coda. Interestingly, here the most fundamental unit is the CV part of CVC, reminiscent of Derwing's finding that Korean speakers are constantly drawn to CV sequences, not VC sequences of CVC syllables in every experiment that he performed in order to tap

(C) Moraic (weight-unit) representation of syllable structure

As schematized in (4), under the mora-based theory of syllable structure (Hyman, 1985; Hayes, 1989), segments may either (i) be dominated directly by the syllable node, in which case they do not count for stress or bear tone, or (ii) be dominated by the mora, in which case they may count for stress and may bear tone.

(4) Moraic model



The moraic theory is in a sense flatter than the particular version of the onset-rime theory above, which has the (additional) labeled nodes under the rime. However, the moraic theory is similar to the onset-rime and the body-coda theories in that, as in the two theories, the syllable under the moraic theory is also exhaustively divided into two groups (although different kind): one that does not bear morae, another that does bear morae. Since the mora intervenes between a segment and its syllable node, it is reasonable to say that this model is also structural. In this sense, one may say that there is no essential difference between these two structural models, other than the units posited and the complexity of the hierarchy.

In sum, the above variants of the structural models of syllable structure essentially make

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the Korean speakers' representation of the syllable.

a similar prediction that subjects' behavioral pattern regarding the treatment of the terminal segments would be categorical; subjects would form certain groups using the segments and the grouping pattern that treats the sequences of segments within a particular sub-syllabic constituent would far outnumber the grouping pattern that treats the sequence of segments that have a constituent boundary that separates them.

It should be noted here that the representation of the syllable schematized in (4) is not the only option available in the moraic analysis of syllables. For example, some theorists (e.g., Broselow, 1995) propose that the onset is a dependent of the vowel's mora, not a dependent of the syllable node itself (as is the case for the initial segment /k/ in (4)). That is, the initial onset and vowel string is linked as a mora unit and the final consonant forms another independent mora. In addition, some (e.g., Cohn, 2003) have proposed that in the case of syllables whose rimes consist of a long vowel and a consonant, the (last) consonant is a dependent of the syllable node (not a mora) creating a division within the rime.

These two particular variants of moraic theory are in principle similar to the "standard" moraic analysis of syllables in that the former is also essentially structural as the latter is: any phenomena that treat the segments that belong to the same mora are expected to far outnumber any phenomena that treat the segments that do not belong to the same mora. The two variants differ from the standard moraic model only in the question of which particular syllable terminal segments are grouped into the same mora. For example, unlike the standard model, under the view of syllables that the first mora subsumes not only the vowel but also the initial consonant, the latter is claimed to form a unit together with the vowel, which thus suggests a sort of "body" grouping (onset + vowel vs. coda) identical to the representation schematized in (3.b) above. Likewise, while the standard moraic model predicts a consistent rime grouping of the last consonant inside a trimoraic rime (i.e., a long vowel + a final consonant), the variant model described above predicts that any phenomena that treat the long vowel as a group excluding the final consonant would outnumber any phenomena that treat the long vowel and the final consonant together as a group.

2.1.2. Models that are not structural: Probabilistic phonotactics-based models

In contrast to the hierarchical models of syllable structure, researchers such as Clements & Keyser (1983), Davis (1989), and Sevald and Dell (1994) argued for a syllable structure where the syllable node directly dominates each segment, with no sub-syllabic units like Onset-Rime. For them, a CVC syllable consists of strings of three segments such that the vowel is equally preceded and followed by the onset and the coda, respectively. Therefore, the nucleus is in principle no more closely related to either the prevocalic or postvocalic consonant(s), contrary to the hierarchical models of syllable structure that posit some predetermined sequential arrangement of phoneme sequences.

Non-structural models of syllable structure, however, do acknowledge the fact that in a given language it is often the case that the nucleus vowel in a syllable seems to be more closely related to either the prevocalic or postvocalic consonant(s). Rather than ascribing this to a consequence of certain sub-syllabic structural units per se, the non-structural models relate it basically to the frequency in which two phonemes appear together in the vocabulary of a language. The relative frequencies of segments and sequences of segments are called phonotactic probability in the literature (Jusczyk, Luce and Charles-Luce, 1994; Frisch, Broe, and Pierrehumbert, 1995; Vitevitch et al, 1997; Frisch, Large, and Pisoni, 2000).

The basic claim of this model is that speakers implicitly know the phonotactic probabilities governing phoneme sequences in their language, and this knowledge is reflected in their behavioral patterns regarding the syllabification. For example, if given a C_1VC_2 syllable where the initial consonant and vowel sequence (C_1V) has a higher phonotactic probability than the vowel and the final consonant (VC_2), then subjects may show a behavioral pattern that is consistent with the former being treated as if they formed a group. On the other hand, if given a

C_1VC_2 syllable where the initial consonant and vowel sequence has a lower phonotactic probability than the vowel and the final consonant, then subjects may treat the latter as a group. It is also a possibility that C_1VC_2 syllables consisting of C_1V and VC_2 which do not differ in terms of phonotactic probability from may not show any strong grouping effect. This suggests a possibility that subjects' representation of syllable structure can even be word-specific, which may vary with the probability pattern of two-phoneme sequences in a given word. In sum, thus under this non-structural models the way in which syllable terminal segments is grouped is a function of some objective measures of phonotactic probabilities associated with phoneme sequences attested in the words of a language.

2.1.3. Models that incorporate the characteristics of both structural and non-structural models

It is logically possible that the two approaches described above are not really incompatible with each other but in fact may be complementary to each other. This is based on my own observation that there are findings in previous studies of syllable structure that are difficult to explain based on only either of the two contrasting theories above.

On the one hand, the structural models have difficulty in explaining the finding that there is some evidence that the boundary between the supposed constituents is not always clear-cut but more or less probabilistic (Yip 2003), casting doubt on the reality of well-defined units like onset/rime. In Experiment 1 of Pierrehumbert & Nair's (1995) word-game study, for example, although the responses that split the test stimuli between the onset and the rime were relatively greater, there were also responses whose insertion point was not in the boundary between the onset and the rime. For example, although /stʌb/ was more likely to split between /t/ and the nucleus vowel /ʌ/, there were split of /s/ and /t/ much more than previously reported. This may be an indication that the arrangement of phonemes within a syllable is such that certain pairs of segments are simply more strongly connected than others. Thus, the surface groupings of phonemes, as reflected in syllable experiments, could be not all-or-nothing as the constituents-based models predict. Rather they may be essentially probabilistic. The strongest version of structural theory of syllable structure that takes clear-cut sub-syllabic constituents seriously cannot capture this probabilistic nature of associations between segments within syllables.

On the other hand, regarding the non-structural models, recall that these models do not recognize units like onset/coda and rather that subject's partitioning of a simple CVC syllable into some particular preferred groupings is a function of differential phonotactic probabilities among sequences of phonemes. But, as we will see in the following section, the results of many experiments, conducted according to different experimental methods, all seem to point to effects of certain 'structures/templates' inside the syllable that are not easily explained by the non-structural models alone.

A natural reaction to these findings is that both models have merits in describing the syllables and accordingly that a more adequate model of syllable internal structure of natural languages indeed must be general enough so that it can account for the effects of both certain structures as well as phonotactic probabilities on the observed behavioral data from syllable experiments. One possible idea would simply say that the structural units and the phonotactic probabilities may be independent entities in the grammar and are simply interacting with each other. Another possibility, which the current thesis will ultimately argue for, is the idea that the unit effects are an emergent property that has its origin in the statistical regularities governing the combinations of consonants and vowels in the words of a language. I discuss this latter hypothesis in some detail in the following subsection.

2.2. Review of arguments for structural or non-structural models of syllable structure

In this section, I provide a more detailed review of the general syllabification patterns that English speakers were claimed to show in previous studies. This section will help us to better understand the arguments that have been advanced in support of the models of syllable structure introduced above, providing us with a further insight into the nature of the issue surrounding the syllable internal structure of natural languages.

2.2.1. Arguments for a structural representation of English syllables

A number of experimental investigations into how English speakers syllabify CVC monosyllabic words have shown that English speakers parse simple (spoken) CVC strings generally into C//VC partitions (e.g., Treiman et al., 1982; Treiman, 1983; Fowler et al., 1993), where the major boundary lies between the onset and the vowel of the syllable. For researchers who hold the structural view of English syllable structure, this quite persistent finding, gathered from experiments using diverse experimental techniques, indicates that speakers of English have knowledge of two sub-syllabic constituents (onset and rime), and that they are sensitive to the boundary that separates the constituents.

A considerable body of work has been accumulated in support of this particular structure of English syllable. A review of literature that is in line with this position indicates two major sources of argumentations: one is primarily linguistic and the other is psycholinguistic in its nature. The former is usually based on the relative number of absolute phonotactic constraints as a function of sub-syllabic constituents within syllable. The latter has to do with processes that appear to manipulate these sub-syllabic units in language games or speech errors (both naturally occurring or experimentally induced).

Linguistic arguments in favor of the existence of the sub-syllabic constituents have been drawn usually from the observed difference in the phonotactic restrictions governing phonemes within the syllable. In English this has been done by comparing the number of constraints against combining certain vowels with certain codas with the number of constraints against combining certain vowels with certain onsets. For example, Fudge (1969; 1987) and Selkirk (1980), who investigated the frequency of absolute co-occurrence restrictions within English syllables, found that there were relatively more VC combinations that are missing from the theoretically possible VC combinations than CV combinations from the possible CV combinations. The usual explanation offered for this asymmetry in terms of the number of possible but unattested CV vs. VC sequences in English was that the vowel and final consonant are daughters of the same local constituent. That is, everything else being equal, the combination of two phonemes within a syllable should be more constrained if the two segments belong to the same linguistic unit than two segments that do not. If certain combinations are more restricted than others, we should see less number of instantiations of the restricted combinations in the language.

In addition to the investigations into the absolute constraints within the syllable in

English, in a quantitative survey of English probabilistic phonotactics, Kessler and Treiman (1997) examined the associations between onset, vowel, and coda in English. Their overall conclusion is that there are statistically significant associations between vowel and coda in English such that certain phonologically legal combinations of vowel and coda in English occurred less frequently than expected by chance given the frequency of vowel and coda. They did not find statistically significant associations between onset and vowel. Kessler and Treiman (1997) argue that this close statistical dependency between vowel and coda is a function of a constituent that is local to the vowel and coda, the rime. The general syllabification tendency by English speakers is then a by-product of subjects' sensitivity to the major boundary between the two independent constituents within syllable.

Psycholinguistic evidence in support of C//VC partition by English speakers is fairly abundant. Treiman & Kessler (1995) provides an extensive review of evidence gathered from language games specifically. A variety of experimental techniques have been used. Bertinetto (1996:49) summarizes them as follows: (a) adding, subtracting, or substituting speech materials, (b) switching syllables from one position in the (pseudo-)word to another, (c) blending (pseudo-)words according to one's preferences, or according to a predefined template, (d) inserting syllable breaks into (psedo-)words. The general finding from these various tasks is that when adult English subjects are taught alternative strategies (during experiments that used these various experimental methods), they perform significantly better while manipulating the vowel and coda sequence instead of the coda alone.

Consistent with this, it has been shown that frequently occurring VC biphones in English have a special role in the behavior of children (Bryant et al., 1990; Jared, 2002; Goswami, 1986; Treiman, 1994; Treiman et al., 1995; Wise et al., 1990). For instance, Treiman et al. (2000) report that second and fourth grade children judge nonsense CVC syllables as more word-like when the rime includes highly contingent vowels and coda. In addition, this particular aspect of children's knowledge gets refined as they get older, up to the age of adolescence (Treiman, 1985; Derwing et al., 1989).

Speech error patterns, another form of psycholinguistic evidence, are also in general congruent with C//VC partition by English speakers. Berg (1989; 1991), for example, note that speech error corpora show that errors involving the traditional Onset/Rime partition are far more common than any other logically possible errors. The patterns found in the above cited experiments were usually interpreted as evidence in support of the onset and rime structure in English.

2.2.2. Arguments for a non-structural representation of English syllables

As opposed to the researchers who posit hierarchical representation of the English syllable, those who do not posit such structure interpret the findings summarized above quite differently.

First, regarding the more traditional argument that there are more absolute restrictions involving VCs than those involving CVs in English, which thus supports the rime constituent in the language, Pierrehumbert & Nair (1995) questioned the validity of such purported evidence. According to them, the problem involves what Kessler & Treiman (1997) call "false zeroes" and "false positives". Pierrehumbert and Nair pointed out that observing a certain absolute constraint does not necessarily mean that there is a principled constraint against a certain sequence of segments. It is possible that some phonemes in English are so uncommon that some possible combinations involving them are not observed, precisely because they do not have a reasonable chance to occur together. An example of this may be the nonexistence of /ʊθ/ (Fudge, 1987:365), both of which are relatively uncommon. Thus, the mere fact that there is less number of VC combinations relative to the theoretically possible number of VC combinations does not in itself justify the rime structure in English syllable.

Secondly, there is a debate concerning the source of the finding that some legal combinations of vowel and coda in English occur less often than expected by chance. As mentioned above, as far as the hierarchical models of English syllable structure is concerned, this finding is the direct consequence of the rime. That is, combinations of phonemes within the same sub-syllabic constituent should be relatively more restricted than combinations of phonemes across two separate constituents, which is responsible for the skew in the observed frequency of attested VC combinations, relative to CV combinations in English.

Although researchers who hold the non-structural view of English also acknowledge this statistical imbalance in the English lexicon, they, however, look for the source of this finding from a mechanism other than the linguistic structure of syllable per se. Sevald & Dell (1994) and Gupta & Dell (1997), in particular, proposed that the mechanism might ultimately have to do with the more general way in which speakers store and retrieve the sounds of words. Specifically, it may have to do with the fact that in general it is better to have more shared material at the ends rather than at the beginnings of words in terms of efficient production/retrieval. That is so, because if there were more similarity in the beginning, that will be costly in terms of word production/retrieval. Then, the observation that in English syllables, VC combinations are in general more restricted (or more strongly associated with each other) than CV combinations may be a reflection of precisely there being more shared material at the ends than at the beginnings of syllable. If this is the case, then an account of grouping of segments (particularly the one that involves vowels and codas in English) does not necessarily require an existence of a primitive unit like the rime. The pattern of segment co-occurrence in English may be understood in light of the general way in which speech production system is set up.

In sum, the important claim of the non-structural view of syllable structure is that syllable terminal segments are not grouped according to some pre-determined syllable-internal templates. This, however, is not to deny that a nucleus vowel is often related more closely to either the prevocalic or postvocalic consonant(s). Under the non-structural models, this basically has to do with the differential degree of relative frequencies with which sequences of phonemes occur in the words of a language. That is, the pattern of the grouping of segments within a syllable more or less coincides with some objective measures of phonotactic probabilities governing sequences of segments such that a sequence of phonemes in a syllable with a higher co-occurrence frequency is more likely to be grouped into a unit than a sequence of phonemes in the same syllable with a relatively lower co-occurrence frequency.

2.2.3. An alternative model: Emergent Structures

As suggested above, it may be that the claims from both models are not really conflicting ones but may be complementary to each other, which thus calls for an alternative model that is general enough to suit the views of both of the syllable structure models. Based on the discussion so far, it is apparent that such a model would view the relation between adjacent segments in the syllable to be essentially probabilistic but nonetheless should also be able to express the effects of certain sub-syllabic units on language users' syllabification without actually explicitly invoking such constituents.

One particular model of syllable structure that is coherent with this requirement is described in Dell, Juliano, and Govindjee (1993) (see Christiansen, Allen, and Seidenberg, 1998; Chen, Dell, and Chen, 2004 for ideas that are in line with Dell et al. (1993)). I will refer to this model as emergent model hereafter and provide an introduction of the model in the following paragraphs.

Dell et al.'s (1993) major goal was to design a language production model that learns to produce English CVC syllable words, more specifically a connectionist model that learns to map from a set of input units to a set of output units mediated by a procedure that corrects any errors that might occur during the mapping. The most important characteristic of their model was that it was designed to learn to speak English CVC words without "knowing in advance" that English CVC syllables consist of onset plus rime (or in other words, without pre-specifying that vowels and codas together form a unit in English). Instead, the model assumed that the phoneme arrangements in the CVC words are purely sequential and it attempted to learn to speak English words by just learning the statistical regularities present in the combinations of consonants and vowels in the CVC vocabularies. One specific question that Dell et al. asked with regard to this goal was to see if the errors that the model may incur during its learning phase could produce what they call 'syllabic constituent effect'. By this, they meant those naturally occurring speech errors that were usually attributed to the action of rime, i.e., errors that seem to have slipped VC of CVC words, e.g., 'read' realized as 'lead'. Dell et al.'s idea was that if their model is indeed capable of learning to speak English words in the absence of any previous knowledge about the onset-rime structure in English syllables, then the errors that their model may incur should be in accord with the usual pattern of actual English speech-error data. That is, VC speech-errors should on average outnumber CV errors (MacKay, 1972; Stemberger, 1983).

Dell et al. found that the error pattern that the model exhibited varied, crucially, depending on the kind of vocabularies that the model was trained on. Concretely, they found that (i) VC slips were no more likely than CV slips for the model that was trained on what they call "infrequent" vocabularies, but that (ii) significantly more VC slips than CV slips were produced for the model that was trained on "frequent" vocabularies. Their frequent and infrequent (training) vocabularies were comprised of 50 CVC English words each and differed from each other in that the frequent words “conform to the statistics of English sound distribution better than the infrequent vocabulary” (Dell et al., 1993:158). By “the statistics of English sound distribution”, they meant their own assessment of the general statistical characteristic of English vocabulary, specifically, the relation between vowel-coda sequences in English are on average more restricted than the relation between onset-vowel sequences.

So the importance of the model in Dell et al.’s work, as it especially relates to the current thesis, is that it was able to generate/simulate *structural effects* (i.e., more VC than CV errors that was usually attributed to the consequence of the rime) without actually positing *explicit structures*. The only information that it made use of in deriving the rime effects was the way in which consonants and vowels were combined in the “frequent” English vocabularies, specifically vowel-coda sequences in these training words were in general much stronger in terms of their cohesiveness than onset-vowel sequences. Importantly for the current thesis, this error pattern in Dell et al’s production model then implies that the structural effects researchers have usually observed in behavioral data with English speakers may in fact also be an emergent property that reflects “mass action of the stored vocabulary” (Dell et al., 1993:158) in English speakers’ mental lexicon, thus the name of emergent model. More specifically, English-speaking subjects tend to show the behavioral pattern that is in consistent with structural units (onset/rime), not because of existence of explicit units *per se*, but because they have acquired the knowledge that there are relatively stronger dependencies between vowels and codas in English vocabularies in general, as a part of their vocabulary learning. This knowledge then becomes a part of the speaker's phonological grammar, to the extent that they influence linguistic behaviors like the spontaneous speech errors as well as other behavioral patterns observed in Section 2.2.1. In sum, I argue that the emergent model is more general than the other two models in that the former does not posit any inherent closeness of the nucleus vowel and the coda but at the same time it can explain the apparent rime effect using the characteristic "structure" of the English *vocabulary*, not the structure of the English syllables per se.

The emergent model construed in this way makes explicit and verifiable predictions. Among them, two stand out. First, note that the model is heavily influenced by words on which they are trained. This particular property of the model leaves it a possibility that speakers of languages other than English may show behavioral patterns that are consistent with sub-syllabic constituents other than the English rime. For example, if the sub-syllabic dependencies involving the onset and the vowel sequences in the words of a language in question are in general stronger than the dependencies governing the nucleus vowel and the coda, speakers of the language might show sensitivity to a unit including the onset and the vowel sequences, unlike the pattern that we often observe from English speakers.

Second, since the emergent model encodes no explicit structures within the syllable, English-speaking subjects' sensitivity to sequential probabilities does not have to be limited to those characteristics that are true of the rime. That is, the fact that there are in general statistically stronger correlations between vowels and codas in English does not preclude the possibility that English speakers might show some evidence that they are sensitive to phonemic contingency concerning other phoneme sequences than the vowel and coda. If a C_1VC_2 word consists of component sequences where C_1V sequence has a higher contingency than VC_2, then we might expect to find English speakers' sensitivity to the former sequence similar to their general sensitivity to the latter sequence. I will show that the findings from the two psycholinguistic experiments reported in Chapter 4 and 5 indeed are indeed fully consistent with the predictions this emergent model makes but are only partially consistent with the predictions either the structural or non-structural models make.

2.3 Summary

The above review of the arguments for structural and non-structural models of syllable structure suggests that both of the contrasting models have their own merits. The major issue is the question of the exact sources from which certain grouping effects arise.

The structural models suggest that the effects are the direct consequence of the substructure of the syllable. Since English syllables consist of explicit units, onset and rime, C//VC partitioning is predominant and there are greater probabilistic constraints on VC. The status of rime as a prosodic unit does not depend on other factors such as frequency of phoneme co-occurrence. The non-structural models, however, suggest that the statistical imbalances/probabilistic phonotactic constraints in English are not consequences of primitive onset/rime units, but that the former is the input to it, reflecting more general speech production/perception mechanism, which is realized in English vocabulary where words sharing the vowel and the coda are much more frequent than words sharing the onset and vowel.

As I mentioned above, a closer look at the findings of previous studies reveals that the defining characteristics of the two contrasting models ('structure' on the one hand and 'probabilistic phonotactics' on the other hand) may be not mutually exclusive but rather be complementary. For example, although the results from the blending tasks in Treiman et al. (2000) are in general consistent with accounts based on structure, but the English blending strategies reported in the work also do refer to co-occurrence patterns of segments in English. The subjects' preference for the C//VC partitions was much more evident when the input forms have high-frequency rimes as opposed to low-frequency rimes, in which case (quite interestingly) the C//VC partition was actually quite lower. One may reasonably argue on the basis of this that a satisfactory account of the subjects' behavioral patterns in syllable experiments may require a model that is general enough to accommodate both the structure and the frequency effects, such as the emergent model. A major aim of the current work is thus to gather experimental data to evaluate these three contrasting views of syllable structure.

CHAPTER 3

A Study of Distribution of Phonemes in Korean and English CVC Syllables

This chapter examines the distribution of phonemes in Korean and English CVC single-syllable words (i.e., words consisting of a syllable with one onset, one vowel, and one coda). The results contain information about the frequency of individual segments and sequences of segments (namely, onset + vowel and vowel + coda sequences) in CVC words in the two languages. The motivation of this study stems from the major question of the current dissertation: namely, how the sub-syllabic structures ('body-coda' for Korean, 'onset-rime' for English) can be related to the general statistical characteristics of the lexicon of Korean and English.

As far as I know, this particular aspect of Korean syllables has not been documented to a reasonable extent in past work on Korean syllables. The distribution of phonemes in English syllables, however, has been studied extensively before (e.g., Kessler and Treiman 1997). So, rather than simply presenting my own calculations of phoneme distribution in English syllables, I will compare the relevant numbers obtained from the current study with the comparable numbers available from the previous English studies, especially with the comparable numbers from Kessler and Treiman (1997). I will conclude this chapter by comparing the results from the two languages with a discussion of its implications for the different kinds of dominant sub-syllabic units previously proposed for the two languages.

3.1. Distribution of Phonemes in Korean CVC syllables

The statistical study of Korean phoneme distributions described here was performed with two goals in mind. The first goal (pursued in Study 1) was to establish the basic patterns of distribution of consonants and vowels in single-syllable words in Korean. A specific question that Study 1 asked was whether Korean consonants are evenly distributed over the onset and the coda position, or whether they occur either in onset or in coda more or less often than expected by chance. The second goal (pursued in Study 2) was to quantify the relative cohesiveness of Onset-Vowel as opposed to Vowel-Coda sequences in Korean CVC words. This was done in order to find out whether the number of cohesive two-phoneme sequences differs as a function of the dominant sub-syllabic units proposed in the traditional literature on the Korean syllable structure (e.g., Yoon and Derwing 2001).

3.1.1. A brief note on Korean phonemes and syllables

Before presenting the design of Study 1, I here provide an inventory of consonants and vowels in Korean. A brief introduction to the basic requirements for Korean syllables in general is also provided here.

An inventory of vowels and consonants in Korean (in the phonetic transcription adopted for the current study) is given in the footnote below.[3] Note that I assume that the two glides, *w* and *y*, are part of the nucleus vowel, together which constitutes one unit (following Kang, 2003; Park, 2001; Kim and Kim, 1991, but also see Lee (1994) and Ahn (1985) for an alternative hypothesis that view the glides as a part of the onset). This is a reason why I assume that there

[3]

Vowels		Consonants	
phonetic alphabet	description	phonetic alphabet	description
a		k	g (in voiced environment)
e		t	d (in voiced environment)
i		p	b (in voiced environment)
o		tʃ	voiceless palatal affricate
ɨ (= u)	rounded central high vowel	s	
æ		h	
ɛ		r	coronal flap
oy	rounded back mid vowel	l	IPA light l
uy	unrounded high back vowel	m	
wa	glide ‘w’+ a	n	
we	glide ‘w’+ e (i.e., rounded 'e')	kk (= k’)	tense 'k'
wu	rounded high back vowel (IPA, /u/)	tt (= t’)	tense 't'
wi	glide ‘w’ + i (i.e., rounded 'i')	pp (= p’)	tense 'p'
wæ	glide ‘w’ + æ (i.e., rounded 'æ')	cc (= c’)	tense 'tʃ'
wɛ	glide ‘w’ + ɛ (i.e., rounded 'ɛ')	ss (= s’)	tense 's'
ya	glide ‘y’ + a	K (= k^h)	heavily aspirated 'k'
ye	glide ‘y’ + e	T (= t^h)	heavily aspirated 't'
yo	glide ‘y’ + o	P (= p^h)	heavily aspirated 'p'
yu	glide ‘y’ + u	$tʃ^h$ (= c^h)	heavily aspirated 'tʃ'
yæ	glide ‘y’ + æ	ŋ (= G)	
yɛ	glide ‘y’ + ɛ		

are no complex onsets in Korean. The phoneme inventory shows that there are 20 consonants and 21 vowels in Korean. Korean is known for its three-way contrast of obstruent series. The geminates/fortis consonants ("kk", "pp", "tt", "cc", "ss") are phonemic units: they contrast with plain slightly aspirated stops ("k", "p", etc) in onset positions. Heavily aspirated ‘K’, ‘T’, and ‘P’ are phonemes as well and they contrast with the fortis and plain slightly aspirated stops. The flap ‘r’ is an allophone of /l/. The realization of the former is fully predictable and it appears in an intervocalic position only.

A Korean syllable consists of one or no onset consonant, one vowel, and one or no coda consonant. Thus, a legitimate Korean syllable minimally consists of one vowel, with onsets and codas being optional. Unlike English, no complex onsets (onsets with two or more consonants) and no complex codas are attested in the surface. Combinations of 20 onsets, 21 vowels, and 20 codas can thus mathematically generate 8400 different CVC syllable types. However, not all combinations of the consonants and vowels are possible. This is in part due to the absolute restrictions governing lateral /l/ and velar nasal /ŋ/, both of which are never allowed in the onset position, and in part due to the absolute coda neutralization in Korean phonology, the result of which is that only the seven consonants /k,t,p,l,n,m,ŋ/ can surface in the coda positions. The remaining 13 consonants are never allowed in the coda position. Thus, theoretically, 2646 (18 onsets x 21 vowels x 7 codas) different combinations of CVC syllable types are possible. In the next section, I report how many of these syllables were attested as real CVC-syllable words in a corpus that was used in the current study.

3.2. Study 1: Distribution of Korean consonants in the onset and the coda

3.2.1. Constructing a list of CVC single-syllable words in Korean

In order to assess the distribution and association of consonants and vowels in Korean, the current study decided to count only the phonemes and biphone sequences (i.e., CV- and -VC) that appear in CVC single-syllable Korean words. Restricting the counts to single-syllable words only obviously has limitations compared to a more complete measure of frequency of occurrence that is based on all words in Korean. Despite the limitations, CVC words are a reasonably good starting place for investigating the statistical nature of Korean phonemes and phoneme sequences in general.

First of all, 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, given that many coda consonants undergo a regressive assimilation to the onset of the following syllable in two-syllable words in Korean. Another reason to decide to count phonemes in CVC words only was that the set of CVC type words was the largest set, compared to other possible syllable types of words (namely, words consisting of 'CV' or 'VC', or simple 'V') found in the database that was used in the current work (see below for more information about the database). The set of CVC type words accounted for about 60% of the entire single-syllable words (i.e., including 'CVC', 'CV', 'VC', and 'V' words) in the database.

Another reason was that previous literature has established that the set of 'a consonant-a vowel-a consonant' words is a subset of words that fairly well represents the entire single-syllable words in a given language. Thorn and Frankish (2005), for example, demonstrated this for English. They compared biphone frequency counts based only on single-syllable English words with the counts based on all words in English. Their study found that the correlation between the two counts was significant.

In constructing a list of CVC single-syllable words in Korean, the current study used a database available from the Korean Academy in Korea (http://www.korean.go.kr).[4] The database contains four different lexical 'fields': (i) Proper nouns, (ii) Particles (including various Korean case markers), (iii) the so-called Linking words, and (iv) Words. The last 'Words' field contains Korean content words. A list of CVC words constructed in this dissertation was developed based on these content words, omitting the other three word types.

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[4] The database file name is 'freqdata.zip'.

I should note here that not all of the CVC words found in the 'Words' field of the database, however, were included in the final constructed list of CVC words because of the following reason. Some of the Korean content words in the database can 'stand' on their own (and thus are usually listed as separate entities in Korean dictionaries), while other content words can only be used in conjunction with other content words or inflectional/derivational endings. Due to this, the words that are not used in usual Korean texts on their own were not listed as separate lists in the Words field of the Korean Academy database. Consequently, these words were not added to the constructed list of C_1VC_2 words. One last note is that Korean has lots of homophones. For example, /pæk/ is ambiguous between 'the color white' and 'the number hundred'. These homophones were treated as separate items in the Korean Academy database and thus the current study treats each of the homophones as separate items for the purpose of computations reported below. Thus, for example, consonant /p/ in /pæk/ contributed two toward the counts of /p/ in the onset position and the onset-vowel sequence /pæ/ contributed two toward the counts of 'CV-' sequences.

3.2.2. The counts

The constructed Korean CVC word list had a total of 939 single-syllable words. We observed

Table 3.1. Frequency of Vowels and Consonants in Korean CVC words

Vowel	Example	gloss	Frequency	Cons.	Example	gloss	Frequency
a	kan	‘liver’	208	k	kaŋ	‘river’	318
e	kem	‘sword’	144	t	tol	‘stone’	123
i	kil	‘road’	85	p	pal	‘leg’	136
o	mok	‘neck’	153	tʃ	tʃan	‘cup’	95
ɨ	hɨk	‘soil’	57	s	sam	‘three’	113
æ	sæk	‘color’	52	h	hyeŋ	‘brother’	64
ɛ	sɛm	‘calculation’	8	r	ran	‘plant’	10
oy	hoyk	‘line’	3	l	kkwul	‘honey’	147
uy	n/a		0	m	mal	‘horse’	185
ya	hyaŋ	‘scent’	7	n	nal	‘day’	235
ye	myen	‘cotton’	67	ŋ	nɨŋ	‘tomb’	181
yo	syol	‘shawl’	3	kk	kkɨt	‘end’	23
yu	kyul	‘tangerine’	5	tt	ttek	‘rice cake’	21
yæ	n/a		0	pp	ppyam	‘cheek’	14
yɛ	n/a		0	cc	ccok	‘page’	21
wa	hwaŋ	‘yellow’	18	ss	ssal	‘rice’	13
we	kwen	‘classifier’	4	K(k^h)	Kal	‘knife’	23
wu	kwuk	‘soup’	117	T(t^h)	Toŋ	‘container’	40
wi	swin	‘fifty’	6	P(p^h)	Pal	‘arm’	58
wæ	kkwæk	‘interjection’	1	$tʃ^h$	$tʃ^h$wum	‘dance’	58
wɛ	n/a		0				

above that, theoretically, 2646 (18 onsets x 21 vowels x 7 codas) different combinations of CVC syllable types are possible in Korean. Thus, many of possible CVC combinations are not real CVC words. Table 3.1 shows that in the 939 words how often each vowel and each consonant occurs. Some vowels (such as /uy/, /yæ/, etc) were not attested in the CVC word list at all. The vowel and consonant counts reflect type-frequency, unweighted by token frequency.

As mentioned above, a specific question that Study 1 asked was whether the frequencies of consonants in Korean are affected by syllable position, namely onset and coda. For this purpose, I tested for each consonant type the degree to which their observed frequency fits the frequency we expect from chance. If the syllable position has no effect, then the two frequencies will match perfectly (i.e., they will occur in both positions equally). I computed the expected frequencies under the null hypothesis that consonants would be evenly distributed between onset and coda. Because all words in the constructed list had exactly one onset and one coda consonant, this means that each consonant should occur half the time in an onset and half the time in a coda. For each consonant type, separate two-cell goodness-of-fit tests with Pearson's χ^2 were performed, with the computed expected frequencies for each consonant type. Since the total number of times each consonant occurred in the list varied from one consonant to another quite a lot, the coefficient of association (ϕ) for the contingency tables was also computed for each consonant type, as an indication of the strength of the association between the syllable slots and the consonant in question.

3.2.3. Consonant Distribution by Onset and Coda

Table 3.2 shows the number of times each consonant occurs in onset and coda. The table contains information about two types of consonants in Korean: (i) consonants that are restricted

Table 3.2. Distribution of Korean Consonants within Onset and Coda

Phone	Onset	Coda	$\chi 2$	ϕ	Onset vs.
tʃ	95	0	95*	1.000	Onset
cc	21	0	21*	1.000	Onset
s	113	0	113*	1.000	Onset
ss	13	0	13*	1.000	Onset
h	64	0	64*	1.000	Onset
r	10	0	10*	1.000	Onset
l	0	147	147*	1.000	Coda
ŋ	0	181	181*	1.000	Coda
kk	23	0	23*	1.000	Onset
tt	21	0	21*	1.000	Onset
pp	14	0	14*	1.000	Onset
K	23	0	23*	1.000	Onset
T	40	0	40*	1.000	Onset
P	58	0	58*	1.000	Onset
$tʃ^h$	58	0	58*	1.000	Onset
n	51	184	75*	.859	Coda
m	73	112	8*	.237	Coda
k	125	193	14*	.213	Coda
p	84	52	7*	.211	Onset
t	53	70	2	.138	Coda

Note: Statistics examine the difference between the frequency of each consonant in the onset and its frequency in the coda. (* $p < .05$, 1 *df*)

to certain position, that is, consonants that occur either only in onset or only in coda, and (ii) consonants that are not restricted to certain position, that is consonants that occur in both syllable positions. The whole table is arranged by the strength of association between consonant type and syllable position, as assessed by phi (ϕ). The phi coefficient of association for the consonants that occur only in one position is, of course, 1.

From the table, we first observe that onset is the position that is generally preferred by majority of Korean consonants. There are only six consonant types (including /l/ and /ŋ/ that only occur in coda) out of 20 consonants that prefer coda position. Secondly, we notice from the table that among the five consonants that are not restricted to either onset or coda, all of them except /t/ appeared in either onset or coda more often than one would expect on the basis of random assignment of the consonants. That is, they are not distributed equally over the onset and the coda. Specifically, /p/ prefers the onset position, while /n, m, k/ prefer the coda position.

3.3. Study 2: Phonemic dependencies at the sub-syllabic level of Korean syllables

In this section, I report various measures of association that were made between onset and vowel sequences and between vowel and coda sequences in Korean. This was done in order to determine whether Korean Onset-Vowel (CV) and Vowel-Coda (VC) units display any differences in terms of cohesiveness of their component phonemes. More specifically, Study 2 was performed to investigate whether or not Onset-Vowel sequences in Korean on average have a tighter association than Vowel-Coda sequences.

One way of getting a rough estimation of relative cohesiveness of 'CV-' and '-VC' units in Korean is to divide the number of existing CVs (or VCs) by the number of theoretically possible CV (or VC) units, assuming that there are no co-occurrence constraints that hold for the sequences. In other words, the question we can ask regarding the relative cohesiveness of two phoneme sequences is that relative to the number of permissible groupings computed as the mere product of the number of different onsets and different vowels (for CV units) or different vowels and different codas (for VC units), what is the proportion of actually existing CV combinations and what is the proportion of actually existing VC combinations? Here the existing combinations correspond to the number of actual CV or VC combinations found with the Korean database. If the constraints governing the combination of onset with vowel in Korean are relatively stronger than the those governing the combination of vowel with coda, and thus the components of CV units are in general more cohesive than the components of VC units, then the proportion of existing CV units (relative to the possible CV units) should be smaller than the proportion of existing VC units (relative to the possible VC units). Conversely, if the phonotactic constraints governing vowel and coda combinations are stronger than those governing onset and vowel, then the reverse phonotactic patterns should be observed.

It was shown above that there are 18 different types of onset consonants and 21 different types of vowels in Korean. So, mathematically, we can expect 378 different types of onset and vowel combinations in the surface. In the database adopted for the current study, there were 152 distinct actually attested 'CV-' sequences. Thus, the proportion of existing CVs relative to theoretically possible CVs is about 40% (i.e., 152/378). For VC sequences, there were 76 actually existing sequences out of 147 theoretically possible combinations. Thus, the relevant proportion for VC sequences is about 52% (i.e., 76/147). Hence, the indication is that permissible Onset-Vowel sequences in Korean are in percentage more constrained than the permissible Vowel-Coda sequences, and thus the components of Onset-Vowel sequences may be on average more cohesive than the components of Vowel-Coda sequences in Korean.

The method used above is an estimation of percentage of the units realized in the language relative to all mathematically possible combinations of segments. I did another computation similar to the one above, but at this time by using only the segments within CVC words that were actually found in the corpus. The basic idea behind this calculation was that if there were no dependencies between Onset-Vowel or between Vowel-Coda, then the probability of a particular sequence is the probability of the actually attested consonant (in either onset or in coda) in the corpus multiplied by the probability of the actually attested vowel.

The numbers we get from this calculation are the expected frequencies for Onset-Vowel and Vowel-Coda sequences. We can then compare these expected frequencies with the actual observed frequencies of CVs and VCs, as an estimation of the co-occurrence restrictions that govern the sequences in question (following the idea presented in Pierrehumbert, 1994). If there are no strong phonotactic constraints that go against a combination of a certain pair of segments (either C+V or V+C), then the expected frequency and the observed frequency of the two phoneme sequences should be about the same.

For this, I first obtained the observed frequencies for each CV and VC sequences and then, based on these numbers, I computed the expected frequencies for them. For example, for onset-vowel pair /ka/ in Korean, the observed frequency count was 19. Given that /k/ occurred 125 in onset and /a/ occurred 208 in the CVC word list, we would expect them to occur together about 28 times (given there being a total of 939 CVC words in the word list). With the expected and observed frequencies in hand, I then computed the size of the deviation of the two frequencies for each of the onset and vowel, as well as for each of the vowel and coda pair, using the following equation in (5). The difference between the observed frequencies and the expected frequencies were squared to get the absolute number of the deviations.

(5) Deviation of the expected frequencies from the actual observed frequencies

$$\frac{(Observed - Expected)^2}{Expected}$$

For each of the CV and VC sequences that had an expected frequency of 5 or more[5], I counted the total number of CV and VC sequences whose deviation value was at least 1 or more.

[5] This number reflects the minimum threshold for a 1x2 or 2x2 table, i.e., the expected frequencies in each cell must be at least 5.

As mentioned above, I did this under the hypothesis that if a particular consonant does not prefer a particular vowel (i.e., the two are not closely related), then the expected frequency and the observed frequency will be about the same, which means that the deviation score will be close to zero. There were a total of 72 CV sequences that had expected frequencies 5 or more. There were a total of 50 VC sequences that had expected frequencies 5 or more. Among the 72 testable CV sequences, about 65% (47/72) of them had a value of at least 1 or more deviations, with the mean value of the deviation being 3.02. Among the 50 testable VC sequences, about 46% (23/50) of them had a value of at least 1 or more deviations, with the mean value of deviation being 1.64. The result thus indicates that, on average, the combination of onset-vowel was more constrained than the combination of vowel and coda. This result indicates that the component phonemes of CV sequences in Korean may be more strongly associated with each other than the component phonemes of VC sequences.

Deviations of 1 or more do not necessarily indicate that an association between two phonemes is statistically significant. In order to address this issue, chi-square tests were carried out for each of the 72 testable CV sequences and the 50 testable VC sequences. For this, 2x2 tables were constructed for each of the CV sequences, one dimension being the number of words that had the consonant in question as onset vs. every other consonant in Korean as onset, and the

Table 3.3. Pairs of Phonemes that Occur at Frequencies Significantly Different from Chance, $p < .0005$

CV units		VC units	
occurs more than expected	occurs less than expected	occurs more than expected	occurs less than expected
mye, t^ho, $tʃ^h$e, tʃe	(sye)	yen	uŋ
7%		4%	

Note: Table lists CV and VC units that occur more or less frequently than expected by chance ($p < .0005$). The percentage value, 7% and 4%, in the last row indicates that 7% and 4% of the testable CV and VC units respectively occurred at frequencies significantly different from chance. The pair in the parenthesis never occurred in the corpus.

other dimension being the number of words that had the vowel in question vs. every other vowel in Korean. The same kind of 2x2 tables were constructed for each of the VC sequences as well. Table 3.3 reports the result, listing the CV and VC pairs that occur significantly more or less often than expected.

In order to correct for multiple comparisons, the critical significance level p was adjusted from .05 to .0005 using the Bonferroni correction. This particular p value was obtained by dividing the usual critical p value (.05) by the total number of comparisons (122 = 72CV + 50 VC), i.e., .05/122 is approximately .0005. The table shows that if we pick the chi-square that (in sample statistics with 1 degree of freedom) would correspond to a significance level of $p < .0005$, then there were 5 CV pairs that exceeded this value, as compared to 2 VC pairs. That is, 7% (5/72) of the testable CV pairs exceeded the chi-square value, while 4% (2/50) of testable VC pairs exceeded the value. In sum, here we found that CV phoneme sequences, compared to VC sequences, occurred together in proportion more or less frequently than predicted by chance given the frequency of each individual phoneme in the Korean CVC word list. Although the numerical difference between the percentage of the statistically significant CV pairs and that of the statistically significant VC pairs seems quite small, an analysis based on chi-square values of all CV and VC pairs indicated that the onsets and vowels in Korean are indeed on average associated with each other more strongly than the vowels and codas. Specifically, the mean value of the chi-squares of all testable 72 CV sequences was 3.807, while the comparable value for all testable 50 VC sequences was 2.106. To summarize, we see that the analyses based on both the significance tests and the means of all chi-square values converge, indicating that the component segments of CV sequences in Korean may be more constrained in forming a unit than the component segments of VC sequences.

Finally, here I report another measure of association between two phonemes, called "Rho" values. I will give a more detailed discussion of this particular measure of association in the next chapter. The Rho basically measures the two-way dependency between two segments, say s_1 and s_2 such that the value quantifies both the degree to which s_1 is dependent on s_2 and the degree to which s_2 is dependent s_1. The Rho value specifically gives us the strength of the

Table 3.4. Mean Rho values for CV and VC sequences in Korean

	N	Minimum	Maximum	Mean	Std. Dev.
CV Rho Values	152	-.090	.191	**.023**	.058
VC Rho Values	76	-.103	.119	**.006**	.047
CV Abs.* Rho Values	152	.003	.191	**.050**	.037
VC Abs.* Rho Values	76	.001	.119	**.039**	.028
Ten most freq. CV	10	-.070	.170	**.048**	.083
Ten most freq. VC	10	-.050	.060	**.024**	.034

* Absolute Rho Values

association (not just testing the significance of association, which is the case in the case of chi-square tests of significance). The Rho values vary between -1 in the case of inverse interdependencies and +1 when contingency is maximal. The Rho value was computed for all 152 CV and 76 VC sequences attested in the wordlist. When the association values were averaged over the whole CVs and VCs, a difference between the two types of sequences was observed, as shown in Table 3.4.

It basically shows that CV sequences were on average more cohesive than VC sequences. The first and second row of the table show that the mean value of the Rho values for CV sequences was .023, while the comparable number for VC sequences was .006. The two mean values are quite small, reflecting the fact that there were many inverse (i.e., negative Rho value) interdependencies. Thus, the mean values of the absolute Rho values for CV and VC sequences were calculated (the third and fourth row of the table), which also indicated a greater mean Rho value for the former than for the latter. Finally, the mean values of the Rho values for the ten most frequent (in terms of raw type frequency) CV and VC sequences are provided in the last two rows of the table as well. The values also indicate that the correlation existing between onset and vowel is on average greater than the correlation existing between vowel and coda.

3.4. Distribution of Phonemes in English CVC syllables

Here, I report findings from a study of the distribution of phonemes found in English single-syllable words. The statistical characteristics of phoneme distribution in English syllables have been studied to a considerable extent in the past. Kessler and Treiman (1997) is one such example whose major finding is that in English the correlations existing between vowels and the final consonants are much greater than the correlations existing between onsets and vowels. It will be shown that the results from the current study also support this quite consistent finding reported in the previous literature, forming a sharp contrast to the pattern that we have just observed from the Korean biphone sequences above.

3.4.1. Constructing an English wordlist

In investigating the distribution of phonemes in English syllables, the current study analyzed phonemes and biphone sequences that appear within English CVC single-syllable words (namely, words consisting of one syllable with an onset, a vowel, and a coda). Single syllable words that have consonant clusters as their margins were excluded for the purpose of the current study. The relevant CVC words were obtained from the CELEX database (Baayen, Piepenbrock, and Gulikers, 1995). Specifically, the CVC words adopted for the purpose of this study were all of the English lemmas in CELEX that were monosyllabic CVCs, whose morphological status was either "M" (monomorphemic) or "Z" (zero derivation/conversion). Conversion lemmas are those like the verb "bank" which "come from" a word of another grammatical class (e.g., the noun bank). Some CVC word entries listed in the CELEX database ended with the 3rd person present singular marker, /s/ and /z/, or with the past marker /t/ and /d/. Some other words had the plural markers, /s/ and /z/, for example, 'boys'. These words were excluded from further consideration. This choice was made in order to make a CVC wordlist that contains only the words that are not decomposable in terms of meaning (which was an important criterion that was adopted for the Kessler and Treiman's CVC word list). Also excluded words were the entries in the CELEX database that end with a syllabic nasals/approximants or the so-called linking 'r's. As in the Korean study, English CVC homophones were included and treated as separate items in the constructed English word list. So, for example, consonant /b/ in 'bait' and 'bate' contributed two toward the counts of /b/ in the onset position and the onset-vowel sequence /be^{j}/ contributed two toward the counts of 'CV-' sequences.

3.4.2. English counts

The constructed English CVC word list had a total of 2521 words (34.7% of the set of all single syllable words in the English database). The comparable wordlist reported in Kessler and Treiman (1997) had a total of 2001 CVC words. The word list in the current study has more words probably because the selection criterion for CVC words adopted in Kessler and Treiman's study was stricter than the one adopted in the current study. For example, Kessler and Treiman excluded from their final CVC wordlist words such as *this* and *that*, because they were concerned that *th* portion of the words may be a some sort of demonstrative morpheme and thus the words are morphologically complex words. The current study did include this kind of words. The fact that Kessler and Treiman used a different lexical database (i.e., the unabridged Random House Dictionary) from the one used in the current study might also have contributed to the difference in the total number of CVC words in the two studies. For example, words containing /ɪə/, /eə/, and /ʊə/ are treated in the CELEX as separate items from words containing /ɪ/, /e/, and /ʊ/, reflecting the RP (Received Pronunciation) usage of the database. Although the current wordlist had more words than Kessler & Treiman's list, it will be shown below that the relative frequency of the phonemes in the two lists is quite comparable.

Table 3.5 shows that in the 2521 CVC words, how often each vowel and consonant occurs. In the table, the vowel and consonant counts of the current study are paired with their comparable counts provided in Kessler and Treiman. The percentage in parenthetical next to the frequency counts indicates the proportion of the respective phoneme relative to the entire consonant or vowel counts. The phoneme counts in both the current and the Kessler and Treimian's study reflect type-frequency, unweighted by their token frequency. Since the word list in the current study had about 500 more CVC words than in Kessler and Treiman, the absolute phoneme counts in the current list are in general bigger numerically. However, as we can see, the percentage of the respective phoneme is similar across the two lists. There are no comparable scores for the vowels /ɪə/, /eə/, and /ʊə/ in Kessler and Treiman. This is because these vowels were lumped together to /ɪ/, /e/, and /ʊ/, respectively in their work.

Table 3.5. Frequency of vowels and consonants in CVC words in English

Vowel	Example	Frequency		Cons.	Example	Frequency	
		current study 2521 words	K&T 1997 2001 words			current study	K&T 1997
ɑː	barn	142 (6%)	30 (1%)	b	be	281 (6%)	216 (5%)
æ	pat	241 (10%)	198 (10%)	tʃ	chip	171 (3%)	115 (3%)
ɒ	pot	205 (8%)	128 (6%)	d	do	315 (6%)	268 (7%)
ɑɪ	buy	170 (7%)	136 (7%)	ð	then	31 (1%)	15 (0%)
ɑʊ	brow	60 (2%)	44 (2%)	f	fee	223 (5%)	160 (4%)
eɪ	bay	238 (9%)	183 (9%)	g	go	183 (4%)	155 (4%)
ɛ	pet	159 (6%)	159 (8%)	h	he	155 (3%)	105 (3%)
ɚ	burn	149 (6%)	115 (6%)	j	you	38 (1%)	30 (1%)
i	bean	203 (8%)	210 (10%)	dʒ	jay	129 (3%)	115 (3%)
ɪ	pit	244 (10%)	207 (10%)	k	key	412 (8%)	324 (8%)
əʊ	no	165 (7%)	146 (7%)	l	low	444 (9%)	365 (9%)
ɔː	born	0 (0%)	110 (5%)	m	me	309 (6%)	243 (6%)
ɔɪ	boy	33 (1%)	25 (1%)	n	no	353 (7%)	306 (8%)
u	boon	121 (5%)	117 (6%)	ŋ	sing	54 (1%)	46 (1%)
ʊ	put	45 (2%)	38 (2%)	p	pie	359 (7%)	240 (6%)
ʌ	putt	240 (10%)	155 (8%)	r	roll	195 (4%)	287 (7%)
ɪə	ear	52 (2%)	n/a	s	see	273 (6%)	242 (6%)
eə	air	46 (2%)	n/a	ʃ	shoes	141 (3%)	109 (3%)
ʊə	tour	8 (1%)	n/a	t	tea	426 (9%)	323 (8%)
				θ	think	57 (1%)	56 (1%)
				v	van	104 (2%)	99 (2%)
				w	win	170 (3%)	82 (2%)
				z	zoo	93 (2%)	71 (2%)
				ʒ	azure	4 (0%)	6 (0%)
total		2521 (100%)	2001 (100%)	total		4920 (100%)	3978 (100%)

3.4.3. English Consonant Distribution by Onset and Coda

With the consonant counts, I calculated the probability of occurrence of the consonants in onset and coda position to see whether the occurrence of the consonants is affected by the position. For this purpose, I used the same method used for calculating the likelihood of Korean consonants by position. That is, I tested for each consonant type the degree to which their observed frequency fits the frequency we expect from chance. The expected frequencies were obtained under the null hypothesis that consonants would be evenly distributed between onset and coda. Because all words in the constructed English list also had exactly one onset and one coda consonant, this means that each consonant should occur half the time in an onset and half the time in a coda.

Table 3.6 shows the result of the computation. It first shows the number of times each consonant occurs in onset and coda. Then it shows the chi square statistics for each consonant type. The starred χ^2 statistics indicate the consonants that occur in either the onset or the coda more often than one would expect. The whole table is arranged by the strength of association between consonant type and syllable position, as assessed by phi (ϕ). The last column compares the chi square statistics obtained from the current study with the ones reported in Kessler and Treiman (1997).

TABLE 3.6. Distribution of English Consonants within Onset and Coda

Phone	Onset	Coda	χ2	ϕ	Sig. in K & T
h	155	0	155.00*	1.000	yes
j	38	0	38.00*	1.000	yes
ŋ	0	54	54.00*	1.000	yes
r	195	0	195.00*	1.000	yes
w	170	0	170.00*	1.000	yes
ʒ	0	4	__	1.000	n/a
z	15	78	42.68*	.677	yes
b	211	70	70.75*	.502	yes
n	105	248	57.93*	.405	yes
v	33	71	13.88*	.365	no
t	137	289	54.23*	.357	yes
k	164	248	17.13*	.204	yes
θ	23	34	2.12	.193	yes
f	132	91	7.54*	.184	no
l	184	260	13.01*	.171	yes
ʃ	80	61	2.56	.135	yes
d	142	173	3.05	.098	no
ð	14	17	0.29	.097	yes
s	148	125	1.94	.084	no
dʒ	69	60	0.63	.070	yes
m	147	162	0.73	.049	no
p	186	173	0.47	.036	no
tʃ	83	88	0.15	.029	no
g	91	92	0.01	.005	no

Note: Statistics examine the difference between the frequency of each consonant in the onset and its frequency in the coda.

* $p < .05$, 1 *df*

From the number of the stared χ^2 statistics obtained both from the current study and those from Kessler and Treiman, we see that most of the English consonants occur in either onset or coda position more often than one would expect them on the basis of random assignments of the consonants to the syllable position. Among the consonants that are not restricted to either onset or coda, /b/ and /f/ prefer onset, while /z/, /n/, /v/, /t/, /k/ prefer coda. It is interesting that bilabial /p/ in Korean also tends to go to onset, and /n/ and /k/ in Korean also prefer coda (Korean does not have /f/, /z/, /v/).

3.4.4. Segmental dependencies at the sub-syllabic level of English syllables

Here I report various measures of association that were made between onset and vowel sequences and between vowel and coda sequences in English. The same methods that were used for measuring the cohesiveness of Korean Onset-Vowel and Vowel-Coda sequences were adopted.

First, I asked relative to the number of permissible groupings computed as the mere product of the number of different onsets and different vowels (for CV units) or different vowels and different codas (for VC units), what is the proportion of actually existing CV combinations and what is the proportion of actually existing VC combinations? English CV combinations can theoretically generate 368 CV sequences (i.e., 23 possible initial x 16 possible vowel), while

English VC combinations can possibly generate 336 VC sequences (16 vowel x 21 possible coda). The actually existing combinations of CV found with the English wordlist in the current study were 280 and the actually existing combinations of VC were 222. So, as expected, the proportion of existing VC combinations (66%) was smaller than the proportion of existing CV combinations (76%), suggesting that permissible Vowel-Coda sequences in English are on average more constrained than the permissible Onset-Coda sequences.

Another calculation of the likelihood of two phoneme sequences was made by using only the segments within CVC words that are actually found in the constructed English wordlist. Expected frequencies of all the attested two phoneme sequences were computed by multiplying the probability of the actually attested consonant (in either onset or in coda) with the probability of the actually attested vowel. I then computed the size of the deviation of the expected frequencies for each of the consonant and vowel pair from their observed frequencies, using the equation given in (5). More specifically, for each of the CV and VC sequences that had an expected frequency of 5 or more, I counted the total number of CV and VC sequences whose deviation value was at least 1 or more.

There were a total of 203 CV sequences that had expected frequencies 5 or more. There were a total of 154 VC sequences that had expected frequencies 5 or more. Among the 203 testable CV sequences, about 41% (84/203) of them had a value of at least 1 or more deviations, with the mean value of the deviation being 1.86. Among the 154 testable VC sequences, about 67% (103/154) of them had a value of at least 1 or more deviations, with the mean value of deviation being 5.00. The result thus indicates that, on average, the combination of vowel-coda was more constrained than the combination of onset and vowel. This result indicates that the component phonemes of VC sequences in English may be more strongly associated with each other than the component phonemes of CV sequences.

In order to test for the significance of these deviations, chi-square tests were carried out for each of the 203 testable CV sequences and the 154 testable VC sequences. As in the Korean case above, the critical significance level *p* was adjusted from .05 to .0001 (i.e., .05/357), in order to correct for multiple comparisons. Table 3.7 reports the result, listing the CV and VC pairs that occur significantly more or less often than expected. The table shows that if we pick the chi-square that (in sample statistics with 1 degree of freedom) would correspond to a significance level of $p < .0001$, then there were 5 CV pairs that exceeded this value, as compared to 19 VC pairs. That is, 2.5% (5/203) of the testable CV pairs exceeded the chi-square value, while 12.3% (19/154) of testable VC pairs exceeded the value. In sum, in English VC phoneme sequences, compared to CV sequences, occurred together more or less frequently than predicted

Table 3.7. Pairs of English Phonemes that Occur at Frequencies Significantly Different from Chance, $p < .0001$

CV units		VC units	
occurs more than expected	occurs less than expected	occurs more than expected	occurs less than expected
daʊ, jɛ, kɔɪ, vɔɪ	rɚ	eɪl, eɪz, ɑɪt, ɚθ, ɔɪl, əʊl, æŋ, æʃ, æg, ɪŋ, ɒb, ɒŋ, ɒʃ, ʊʃ, ʊk, uʒ, ʌf, ʌg	æl
2.5%		12.3%	

Note: Table lists CV and VC units that occur more or less frequently than expected by chance ($p < .0001$). The pairs are arranged in descending order by the phi values that indicate the strength of the association between the component segments. The percentage value, 2.5% and 12.3%, in the last row indicates that 2.5% and 12.3% of the testable CV and VC units respectively occurred at frequencies significantly different from chance.

by chance given the frequency of each individual phoneme. An analysis based on chi-square values of all CV and VC pairs also indicated that the vowels and codas in English are indeed on average associated with each other more strongly than the onsets and vowels. Specifically, the mean value of the chi-squares of all testable 203 CV sequences was 2.126, while the comparable value for all testable 154 VC sequences was 4.113.

Finally, the Rho was computed for all 280 CV and 222 VC sequences attested in the wordlist, in order to assess the strength of the association. Recall that the Rho values vary between -1 in the case of inverse interdependencies and +1 when contingency is maximal.

Table 3.8. Mean Rho values of English two phoneme sequences

	N	Minimum	Maximum	Mean	Std. Dev.
CV Rho Values	280	-.07	.17	**.005**	.028
VC Rho Values	222	-.10	.12	**.013**	.041
CV Abs. Rho Values	280	.0002	.17	**.021**	.018
VC Abs. Rho Values	222	.0005	.12	**.040**	.056
Ten most freq. CV	10	.01	.07	**.039**	.017
Ten most freq. VC	10	.01	.09	**.056**	.024

The Rho was computed for all 280 CV and 222 VC sequences attested in the wordlist. When the association values were averaged over the whole CVs and VCs, a difference between the two types of sequences was observed, as shown in Table 3.8. It basically shows that VC sequences were on average more cohesive than CV sequences. Likewise, the mean values of the absolute Rho values for CV and VC sequences (the third and fourth row in the table) also indicated a greater mean Rho value for the former than for the latter. Finally, the mean values for the ten most frequent (in terms of raw type frequency) CV and VC sequences are provided in the table as well. The values also indicate that the correlation existing between onset and vowel is on average greater than the correlation existing between vowel and coda.

3.5 Comparison between Korean and English

The purpose of this chapter was to identify the overall characteristics of phoneme distributions in Korean and English, specifically the degree of tightness between two-phoneme sequences within CVC syllables of the languages. The results indicate that CVC words of each language have a characteristic distribution of phoneme combinations that differs from each other.

As is summarized in the following table (Table 3.9), at least by the measures of association performed in this study, for Korean the correlations between onsets and vowels are in general stronger than those between vowels and codas: (1) in percentage there are less number of actually existing CVs relative to the theoretically possible combinations of CVs than the number of actually existing VCs relative to the theoretically possible combinations of VCs, (2) in percentage, there are more CVs that occur significantly more or less than expected by chance than VCs, (3) on average CVs are more strongly dependent upon each other than VCs. The results from the English study, on the other hand, showed the opposite pattern, where VCs are more strongly associated with each other, consistent with reports from previous studies.

The fact that there are strong probabilistic constraints on the VC combinations in English has been reported before and my own calculations are also consistent with it. More interesting is the fact that in Korean the phonemic dependency between onsets and vowels is

Table 3.9. Comparison of cohesiveness between Korean and English two-phoneme sequences within CVC words in the two languages

	Korean		English	
	CV	VC	CV	**VC**
% of actually existing units relative to theoretically possible combinations	**40%**	52%	76%	**66%**
% of units with deviation 1 or more	**65%**	46%	68%	**80%**
% of units occurring more or less than by chance ($p < .005$)	**7.0%**	4.0%	2.5%	**12.3%**
mean rho values	**.023**	.006	.005	**.013**

stronger than the dependency between vowels and codas, which deserves some further comments.

First, as mentioned earlier in this thesis, some researchers have argued that Korean might have a syllable-internal structure of 'Body (Onset + Vowel) + Coda' division (Derwing et al. 1993, Wiebe & Derwing 1994, Yoon & Derwing 1994, 2001). Derwing et al. (1993), for example, argued for this, based on their finding that Korean subjects showed a strong preference of the type Body + Coda blending over the type Onset + Rime in blending preference tasks. On the basis of this, one possible interpretation of the finding in the current chapter is to say that it is a direct consequence of and thus in support of this particular hierarchical representation of Korean syllable-internal structure, namely Body-Coda syllable-internal division. The argument is that two phoneme sequences that belong to the same constituent should vary less (or are more strongly related with each other) than two phoneme sequences that do not belong to the same constituent.

Secondly, if this characteristic of Korean lexicon is a true consequence of the internal organization of the syllable as such, then Korean (and other languages that have similar characteristic as Korean) may be taken as evidence providing additional support for the legitimacy of the hierarchal models of syllable structure in general. Some researchers have expressed concern that the apparent primacy of vowel-coda sequences in many languages as evidence supporting the hierarchical structures of the syllable would not be so compelling if all languages are like English (e.g., as is apparent in claims like the universality of the rime in Fudge (1987) and Kaye (1989)), since if this is the case then "[the] result might depend on some hidden experimental artifact, rather than being a true reflexion of the internal organization of the syllable as such" (Bertinetto (1996:51)). Similarly, Yoon & Derwing (2001) argued that the hierarchical models would be more plausible only if they are falsifiable in the sense that we do find a language that has an opposite structure from English. Researchers like these might use the current finding presented in this chapter (coupled with previous behavioral findings) to argue that Korean does provide such a contrastive cross-linguistic data.

However, seen from a different perspective, the very skew in terms of two-phoneme cohesiveness existing between CVs and VCs in the Korean lexicon can also pose a problem for the traditional interpretation of the empirical results provided by researchers such as Derwing and his colleagues. For example, the strong preference of CV//C over C//VC division that Derwing's Korean subjects showed with respect to blending of two words in fact may reflect the subjects' sensitivity precisely to the finding reported in this chapter: the association between onsets and vowels in Korean is in general stronger than the association between vowels and codas in the words in Korean. Their subjects might have liked to use relatively strongly associated two-phoneme sequences as a group in blending, and the two-phoneme sequences are more than likely to be onset and vowel sequences in Korean.

As such, I would argue that the statistical characteristic of Korean presented in this chapter is basically ambiguous with regard to the nature of the internal representation of Korean syllables: it is not necessarily indicative of certain syllable-internal units like body and coda per se. In order to distinguish the contrasting theories, we need to design experiments that directly control for the relevant variables, namely sub-syllabic structures and the relative cohesiveness of two-phoneme sequences. In such experiments, the hierarchical approach of Korean syllable structure expects to find subjects' behavioral pattern that coincides with, for example, the body-coda structure (as Derwing and his colleagues would suggest), irrespective of the relative strength of association between two phonemes within syllables. If subjects rather have access to, broadly speaking, phonotactic information in their phonological knowledge and if that information plays an important role in subject's partitioning of syllable terminal segments, we would expect to find evidence of this knowledge reflected in behavioral data: the pattern of syllabification should more or less coincide with some objective measures of phonotactic probabilities governing sequences of segments. Testing these predictions is the major focus of the experiments reported in the subsequent two chapters.

CHAPTER 4

Short-term memory Tests: The relative contribution of sub-syllabic units and phonotactic probabilities to STM errors

4.1. Short-term memory tests

The experiments reported in this chapter used short-term memory (STM) tests. A good number of previous studies used this experimental technique in investigating syllable structure. Those include Drewnowski & Murdock (1980), Brady, Shankweiler, & Mann (1983), Brady, Mann, Schmidt (1985), Treiman & Danis (1988), Treiman, Straub, & Lavery (1994), and Treiman and Kessler (1995). They basically looked at STM errors produced by subjects to see whether certain sequences of phonemes are more likely to stay together in the errors as a group than other logically possible groups of segments. For example, suppose that the to-be-remembered stimulus is a 'C_1VC_2' syllable like /din/. In a typical STM test, subjects are asked to remember a list of stimuli including this particular stimulus. If a subject inadvertently makes an error in recalling the to-be-remembered word and the error retains two phonemes from the original stimulus (i.e., the subjects correctly remembered only two segments of the CVC stimulus), the specific question asked in this type of experiment is whether the two phonemes that were remembered as a group will be more likely /di_/ (often referred to as C_1V retention error), or /_in/ (VC_2 retention error), or /d_n/(C_1C_2 retention error).

As Treiman et al. (1994) pointed out, the majority of experimental evidence gathered in previous syllable structure research is from tasks that were performed in a conscious and deliberate manner, focusing on tapping into subjects' metalinguistic judgments or manipulation of speech material. One of the tasks in Treiman's (1983) study, for example, was a substitution task where English subjects were *explicitly* taught alternative strategies and were asked to perform transformations on nonwords using the two strategies that subjects were instructed to use. The task was transforming a nonword, for example, /rov/ either into /**r**eg s**ov**/ or into /**ro**g se**v**/. The former transformation supposedly involves the Onset-Rime division while the latter involves the Body-Coda division of the input. Treiman examined which of the two strategies lead to a better performance, the overall result being that subjects performed significantly better using the strategy using the traditional rime (i.e., vowel + coda) instead of the coda alone (which thus involves body-coda division).

Pierrehumbert and Nair (1995) is an extension of this language game paradigm, although in their experiment subjects were required to produce a single noncompound word as an output, with a '-VC' sequence being added as an infix, such as "boy" + əl → /bəloy/. They examined the site of infixation that their subjects preferred, the result of which lead them to propose a model of syllable structure flatter than the traditionally popular hierarchical models of English syllables.

The experimental technique of short-term memory tests was adopted in this thesis based on the belief that it can provide additional data on the existing syllable structure research, mostly based on these explicit tasks that ask subjects perform certain tasks in a conscious manner. I believe that more empirical results from tasks that are less likely to be affected by deliberate strategies are needed in developing a more empirically adequate model of syllable structure, precisely because the nature of the tasks involved seems to affect experiment outcomes regarding syllable structure. Geudens and Sandra's (2003) study is a case in point where they found that Dutch-speaking pre-reading children between six and seven show no evidence of onset and rime units in their 'explicit' phonological awareness, a finding that is somewhat unexpected given the usual claim about Dutch syllable structure based on data collected from methods involving conscious judgments. An example of experimental tasks that does not require subjects' explicit manipulations of certain strategies is precisely the short-term memory tests adopted here. Like spontaneous speech errors, errors in short-term memory for speech are less likely to be affected by deliberate strategies on the subjects' side. That is, subjects, in producing short-term memory errors, cannot consciously control whether to make one type of error or another.

Short-term memory tasks requiring the immediate repetition or recall of a series of single-spoken words and nonwords have been used to a considerable extent in psycholinguistic research (e.g., Gathercole et al. 1999, Gupta & MacWhinney 1997, Majerus & Van der Linden 2003, Majerus et al. 2004, Roodenrys & Hinton 2002, Thorn & Frankish 2005, Vitevitch et al 1997). A particular advantage of using STM tests over other experimental techniques in investigating syllable structure is that the previous psycholinguistic studies have established that phonotactic probabilities of segment sequences, one of the critical variables that this dissertation examines regarding syllable structure, is a critical factor that affects subjects' performances with regard to their repetition or recall of previously (un)heard items.

Vitevitch et al. (1997), for example, found that phonotactic probabilities exert a significant influence on STM from tasks requiring the immediate repetition of single spoken nonwords. They found that nonwords stimuli that consist of high probability segment sequences were repeated by English-speaking adult subjects more accurately than low probability nonwords. In addition, Gathercole et al. (1999) found that English-speaking 7 and 8 year olds also showed superior recall accuracy for high over low probability nonwords. These findings indicate that phonotactic probability indeed is knowledge that adult as well as young language users have access to in recalling nonwords. This established role of phonotactic probability governing segment sequences in STM tasks will allow us to better interpret the results from our own STM tests reported below, weighting the relative contribution of sub-syllabic units vs. phonotactic probabilities to the representation of syllable structure.

The current thesis extends the previous work using the STM technique in investigating syllable structure in two important ways. First, most previous work that used STM tests as an experimental technique especially for examining the syllable structure did not control for the phonotactic probability of segment sequences of the target items used. For example, /ger/ is a stimulus in Experiment 1 of Treiman & Danis (1988) study that used the STM technique. Without knowing the phonotactic probabilities governing the two-phoneme sequences /ge/ and /er/ (more generally the overall characteristic of the probabilities of 'CV-' and '-VC' sequences in their stimuli), it is not clear whether their finding that their subjects on average remembered /er/ better than /ge/ reflects the English syllable structure per se (i.e., onset-rime) or their subjects' sensitivity to the possibility that /er/ is phonotactically more probable than /ge/ in English (or, '-VC' sequences are in general more probable than 'CV-' in their English stimuli). In the STM tests reported in the current dissertation, the probability of segment sequences was strictly controlled to allow a better interpretation of the results than previous studies.

Second, even in those experiments where the bi-phone frequency/probability was controlled, the target CVC stimuli were typically made up of exclusively two types; high probability CVC nonwords with both high probability ‘CV-’ and high probability ‘-VC’ vs. low probability CVC nonwords with both low probability ‘CV-’ and low probability ‘-VC’ (e.g., Gathercole et al., 1999; Thorn and Frankish, 2005). The current experiments used an inventory of stimuli richer than this. Specifically, not only there were CVC words with ‘High CV- + High -VC’ and ‘Low cv- + Low -vc’ pattern but also there were CVC words with ‘High CV- + Low -vc’ and ‘Low cv- + High -VC’ pattern. That is, there were syllables that were designed to have an ‘intermediate’ probability. This set of items (with contrasted CV and VC sequences) was prepared so that the recall protocols can be scored not only at the whole-item level (high probability CVC stimuli vs. low probability CVC stimuli) but also at the two-phoneme sequences level below the syllable unit, permitting us a direct assessment of the extent to which the accuracy of the recall items is constrained by the phonotactic probabilities (or the relative cohesiveness) of two-phoneme sequences, which is one of the core interests of this dissertation.

4.2. Korean Short-term Memory Tests

4.2.1. Measures of Association of ‘CV-’ and ‘-VC’ sequences in Korean

In order to construct stimuli for the Korean STM test that manipulates the phonotactic probability of CV and VC sequences, I obviously needed to estimate the phonotactic probabilities of every two-phoneme sequence attested in Korean CVC words; namely, I needed to know how high/low a particular CV- sequence is located in a scale of CV-cohesiveness, and how high/low a particular -VC sequence is positioned in a scale of -VC cohesiveness. Although I talked about phonotactic probability of speech segments above as a key variable that characterizes the non-hierarchical representation of syllable structure, I was not clear about how to determine whether one sequence is more phonotactically probable than another.

One simple way of estimating the phonotactic probability of a sequence would be simply to count the co-occurrence frequency of the sequence in question, i.e., how often a particular sequence appears in the CVC word list. If a sequence appears more often than another sequence (that is if a sequence is attested in more words than other sequence), then the former combination would be probably more phonotactically probable than the latter. This is, however, obviously quite limited as an indicator of the strength of relationship between two phonemes. For example, there is this issue of "false positives", mentioned earlier in this thesis. Relatively frequently-occurring sequences do not necessarily mean that the combinations are phonotactically more probable than other existing sequences. It is possible that some phonemes in a language are (relatively) quite common that the combinations involving them are simply observed quite often, precisely because they have relatively much more chances to occur together. Thus, relative frequencies of certain sequences are not in direct proportion to their phonotactic probabilities.

Another traditionally popular measure of association (other than the simple co-occurrence frequency) is the transitional probability. Given a pair of sequence of segments, say C_1V and C_2V, this measure estimates the relative cohesiveness of the two sequences by comparing the probability that C_1 is followed by the vowel with the probability that C_2 is followed by the same vowel. If the transitional probability of C_1V is higher than that of C_2V, then the component phonemes of C_1V can be taken to be more strongly associated with each other than those of C_2V.

Recently, however, there has been an active discussion of the kind of measure of association that may best estimate the relative cohesiveness of sound sequences in natural languages, casting some doubt on the validity of some traditionally popular metrics as the main measure of association of speech segments. For example, although the transitional probability has been used quite extensively in quantifying an association (e.g., Saffran, Newport & Aslin 1996), recent findings suggest that this metric seems to provide only part of the relevant information. Perruchet and Peereman (2004) is an example that demonstrated this. In the study, they examined a total of five statistical measures of associations (including the transitional probability) that may be potentially useful in measuring statistical regularities embedded in linguistic utterances. They found that the transitional probability measure was in fact a poor indicator of association compared to other measures of association.

Recognizing this, in the current dissertation, I estimated the relative cohesiveness of 'CV-' and '-VC' sequences in Korean using a more variety of measures, specifically a total of seven statistical measures of associations including the five measures reported in Perruchet and Peereman's study plus two additional measures. A detailed description of the computation of the seven measures of association will be provided below. Eventually, I have chosen among them one particular measure of association, called Rho values, in estimating the relative strength of tightness between C_1 and V, and between V and C_2 found in the compiled list of 939 Korean C_1VC_2 words. The internal contingency of two-phoneme sequences included in the test stimuli in the following Korean STM tests was assessed precisely by these Rho values: if the Rho value of a particular sequence is higher than another sequence, then the former were considered to be more contingent upon each other (or put differently more phonotactically probable) than the latter.

As an illustrative purpose, let us consider two successive phonemes within a syllable, /t/ and /i/. To explore the seven measures of associations between these two phonemes, let us

Table 4.1. A contingency matrix (adopted from Perruchet & Peereman 2004:100)

		/i/	
		+	–
/t/	+	a	b
	–	c	d

Note: In the following formulae, 'e' refers the sum of 'a' through 'd'.

consider a 2 x 2 contingency matrix, shown in Table 4.1, where the letter 'a' stands for the number of /t/ and /i/ phoneme co-occurrences, 'b' for the number of co-occurrences of /t/ followed by a vowel different from /i/, 'c' for the number of occurrences of /i/ preceded by a consonant different from /t/, and 'd' for the number of two phoneme sequences comprising neither /t/ nor /i/. Finally, let us call 'e' the sum of 'a', 'b', 'c', and 'd'.

The first index of relationship measured between a consonant and a vowel in Korean is the conditional or transitional probability (TP), mentioned above. For example, given a sound sequence of 'ti', TP (or P(i/t)), is the probability that consonant 't' is followed by vowel 'i' (or equivalently, the probability of 'i' given 't'), and can be computed as (6).

(6) $$TP = \frac{a}{a+b}$$ (Perruchet & Peereman 2004: 100)

The second index of association is called Delta P (or ΔP), shown in (7). This gives us the difference in TP relative to the forward conditional probability of /i/ given /t/. That is, this metric asks whether or not the probability of ‘i’ is larger in the presence of a particular onset segment, i.e., ‘t’. So, this measure indicates how well ‘i’ can be predicted specifically from ‘t’, and accordingly more constrained that the usual forward transitional probability measure. The higher Delta P of /ti/ is, the more likely that ‘i’ appears after ‘t’ and not after other consonants.

(7) $\Delta P = \frac{a}{a+b} - \frac{c}{c+d}$ (Perruchet & Peereman 2004: 100)

The third and fourth index of association are related to the “backward” relation between ‘t’ and ‘i’. These are given in (8-9) below. TP’ (read as TP prime), for example, tells us the probability that ‘i’ is *preceded* by ‘t’, unlike the forward TP that computes the probability that ‘t’ is *followed* by ‘i’. In this sense, basically, the two can be thought of as measuring the degree to which ‘t’ is the only predictor of ‘i’ in a ‘C(onsonant)+i’ sequence.

(8) $TP' = \frac{a}{a+c}$ (Perruchet & Peereman 2004: 101)

(9) $\Delta P' = \frac{a}{a+c} - \frac{b}{b+d}$ (Perruchet & Peereman 2004: 101)

The most important index of association for the purpose of the STM tests reported in the current dissertation is the measure that quantifies the ‘two-way’ dependency between ‘t’ and ‘i’, which I call Rho values. As mentioned above, eventually, this index was adopted in constructing the test stimuli. This index was adopted in part because it was found in Perruchet and Peereman’s (2004) study that the tightness of the association between the consonants and the vowels in their study mostly depended on both forward and backward relationships. Specifically, in their study, this particular measure of association was the best predictor of English speaking children and adult judgment of word-likeliness. Compared to other measures of associations (especially to the forward transitional probability used in many previous studies), the higher Rho values a VC sequence in English has, the more likely that a word that contains the sequence was rated as a better English-sounding word by both children and adults. The Rho values are expressed as:

(10) $$r_{\varphi} = \frac{ad - bc}{\sqrt{(a+b)\times(c+d)\times(a+c)\times(b+d)}}$$ (Perruchet & Peereman 2004: 101)

A point that is noteworthy here is that Perruchet & Peereman showed that (10) is formally equivalent to the equation given in (11). An importance of the equivalent between (10) and (11) is that Rho values "can also be expressed as the geometric mean of forward and backward ΔP" (Perruchet & Peereman 2004: 101), meaning that the Rho metric is a more comprehensive measure of association than, in particular, the TP metric alone. That is, as shown in (11), the Rho metric is a more sophisticated measure of association between two events to the extent that it clearly includes the equations given in (6) through (9).

(11) $$\gamma_{\varphi} = \sqrt{\left(\frac{a}{a+b} - \frac{c}{c+d}\right)\left(\frac{a}{a+c} - \frac{b}{b+d}\right)}$$ (Perruchet & Peereman 2004: 101)

Two additional indexes of association were calculated, including 'Mutual Information' (MI) and 'Chi-square' (from Manning & Schütze 1999). Mutual Information basically tells us, given /ti/, how much the amount of information we have about 't' increases if we are told that 'i' occurs in next position, or equivalently how much the certainty that /i/ occurs next in a sequence increases if we are told that /t/ is the current segment. MI can be computed as (12). This metric is similar to the Rho in that the two both measure bi-directional associations. One difference between the two measures is that MI is a good measure of *independence* that works relatively better with high-frequency stimuli (Manning & Schütze 1999:182), while the Rho is basically a measure of inter-*dependence*.

(12) $$\mathrm{MI} = -LOG_2 \frac{(\frac{a}{e})}{(\frac{a+b}{e}) \times (\frac{a+c}{e})}$$ (Manning & Schütze 1999:178)

The chi-square test is usually applied to 2-by-2 table and basically compares the observed frequencies in the table with the frequencies expected for independence. Basically, if the difference between observed and expected frequencies is large, then we can reject the null hypothesis of independence. The computation of chi-square is given in (13).

(13) $$\chi^2 = \frac{e \times (a \times d - b \times c)^2}{(a+b) \times (a+c) \times (b+d) \times (c+d)}$$ (Manning & Schütze 1999:169)

In preparation for calculating these seven measures of association for each of the 152 CV- and 76 -VC biphone sequences in Korean, the following steps were taken. As an example, let me use /ta/ sequence, which was one of the 155 CV sequences in Korean.

For that sequence, first, I obtained the number of C_1VC_2 mono-syllabic words that have /t/ and /a/ as its onset and vowel, respectively. This corresponds to symbol ‘a’ in Table 4.1. There were 19 such words, and this number reflects the co-occurrence frequency of /ta/.[6] Second, I obtained the number of CVC words that have /t/ as its onset, followed by a vowel that is not /a/, i.e., ‘t~a’. This corresponds to symbol ‘b’ in the above equations and there were 34 such words. Third, I obtained the number of CVC mono-syllabic words that have /a/ as its vowel, preceded by consonants that is not /t/, i.e., ‘~ta’ (symbol ‘c’). There were 189 such words. Fourth, I obtained the number of CVC mono-syllabic words that neither have /t/ nor /a/ as its onset and vowel, respectively, i.e., ‘~t~a’ (symbol ‘d’). There were 697 such words. Finally, I calculated the sum of these four numbers (symbol ‘e’), which was 939.

I repeated this procedure for each of the 152 ‘CV-’ and 76 ‘-VC’ sequences in Korean. With the values corresponding to symbols ‘a’ through ‘e’ in Table 4.1 above for all sequences in question, I computed the seven values of associations for each of the CV- and -VC sequences.

To take /ta/ again as a specific example, the equation in (6) returned 0.358 as TP value of /ta/ sequence in Korean (i.e., a/(a+b)= 19/(19+34) = 0.358). So, the probability that /t/ is followed by /a/ (out of all possible vowels in Korean in that context) is about 36%. This TP value

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[6] Recall that we said earlier that there are only seven consonants available as coda in Korean. One may wonder than how we get 19 of ‘taX’ words, where ‘X’ is a final consonant. This has to do with our decision to count homophones as separate entities. Two items that denote different entities, while are pronounced the same in the surface, contributed two counts to the count of the sequence in question.

of /ta/ appears to be a quite high one and it was indeed the highest one among the TP values obtained computed over all ‘t’ + ‘V’ sequences in Korean. The equation in (10) returned 0.08 as Rho value of /ta/. Although this number looks very small, it was higher than the median Rho value computed across the Rho values obtained from the ten most frequently occurring CVs (in terms of type-frequency) in Korean. This relatively high Rho value of /ta/ (along with its relatively high TP value) indicates that these two phonemes is relatively quite strongly dependent upon each other compared to other /t + vowel/ sequences in Korean. In the remaining parts of the current dissertation, when I say a CV sequence has a high phonotactic probability, I mean that the particular CV sequence’s Rho value is higher than the median Rho values computed across the whole population of CV sequences. Likewise, a VC sequence is considered to have a high phonotactic probability if that sequence’s Rho value exceeds the median Rho values computed across the whole population of VC sequences.

The statistics from /ta/ sequence suggest that there may be a correlation amongst the different measures of association. This appears to be the case at least for the relatively frequently occurring two-phoneme sequences in Korean, as shown in Table 4.2. It shows that the ten most frequent CV items were overall not only frequent occurring, but also had higher TPs (the traditionally popular metric) and Rho values (the metric adopted in this thesis) than the median

Table 4.2. TP and Rho values of the ten most frequent Korean 'CV-' and '-VC' sequences (in terms of type-frequency)

C	V	Type-Freq.	TP	Rho	V	C	Type-Freq.	TP	Rho
tʃ	ə	32	0.337	0.171	a	ŋ	45	0.216	0.035
s	ə	27	0.239	0.088	a	n	42	0.202	0.010
m	a	22	0.301	0.056	o	ŋ	36	0.235	0.050
s	a	21	0.186	-0.032	o	k	36	0.235	0.040
k	o	21	0.168	0.005	a	k	34	0.163	-0.050
tʃʰ	ə	20	0.345	0.136	e	k	33	0.229	0.032
k	a	19	0.152	-0.066	u	k	31	0.265	0.062
t	a	19	0.358	0.081	e	n	30	0.208	0.015
s	i	19	0.168	0.100	u	n	30	0.256	0.060
n	a	18	0.353	0.076	a	m	28	0.135	0.021
Median of 10 most freq. CV			0.261	0.062	Median of 10 most freq. VC			0.215	0.028
Median of entire CV			0.118	0.023	Median of entire VC			0.171	0.007

TP and Rho values pooled over the entire population of CVs in Korean. The same pattern was true for the Korean VC sequences (Appendix 1 reports the values of the seven measures of associations for every CV and VC sequence attested in the CVC words found with the Korean database adopted for the current dissertation).[7]

Table 4.3 shows the values of the remaining five measures of association for the ten most frequent CV and VC sequences. It also shows that for all measures the frequently-occurring CV and VC sequences had higher values than the values computed across the entire population.

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[7] Note that some sequences have negative Rho values, which indicate that the component segments are inversely related.

Table 4.3. ΔP, TP′, ΔP′, MI and Chi-square values of the ten most frequent Korean 'CV-' and '-VC' sequences (in terms of type-frequency)

C	V	ΔP	TP′	ΔP′	MI	Chi	V	C	ΔP	TP′	ΔP′	MI	Chi
tʃ	ə	.204	.222	.143	7.173	27.4	a	ŋ	.033	.259	.037	7.449	1.10
s	ə	.097	.188	.079	7.175	7.24	a	n	.010	.237	.011	7.474	.094
m	a	.087	.106	.036	7.704	2.92	o	ŋ	.053	.207	.048	7.448	2.31
s	a	-.041	.101	-.025	7.707	.947	o	k	.042	.198	.037	7.513	1.43
k	o	.006	.137	.005	7.265	.027	a	k	-.047	.187	-.052	7.516	2.24
$tʃ^h$	ə	.204	.139	.091	7.173	17.4	e	k	.035	.181	.029	7.513	.909
k	a	-.080	.091	-.054	7.709	4.04	u	k	-.009	.219	-.011	7.199	.087
t	a	-.080	.091	-.054	7.709	4.04	e	n	.075	.170	.052	7.512	3.54
s	i	.145	.091	.045	7.703	6.11	u	n	.016	.169	.014	7.474	.208
n	a	.088	.224	.113	6.417	9.40	a	m	.071	.169	.051	7.472	3.28
Median of 10 most freq. CV							Median of 10 most freq. VC						
		.087	.122	.040	7.484	5.06			.034	.192	.033	7.474	1.26
Median of entire CV							Median of entire VC						
		.012	.076	.013	6.443	1.60			.016	.097	.013	6.128	1.23

Finally, the statistics involving /ta/ sequences indicate that there may be a considerable inter-correlations among the statistics measured here. In order to see this, the inter-correlations between the seven different measures of associations were computed across the whole population of 152 CV and 76 VC sequences in Korean. The result is reported in Table 4.4. The upper panel in each row is for CV sequences (in bold case), and the lower panel in each row is for VC sequences.

Table 4.4. Inter-correlations among the seven measures of association computed across the whole population of 152 CV and 76 VC

		Freq.	TP	ΔP	TP′	ΔP′	Rho	MI	Chi
Freq.	**CV**	**1**							
	VC	1							
TP	**CV**	**.614**	**1**						
	VC	.142	1						
ΔP	**CV**	**.332**	**.703**	**1**					
	VC	-.060	.841	1					
TP′	**CV**	**.047**	**-.197**	**.213**	**1**				
	VC	.852	-.089	-.071	1				
ΔP′	**CV**	**-.084**	**-.139**	**.296**	**.959**	**1**			
	VC	.311	.516	.600	.398	1			
Rho	**CV**	**.224**	**.368**	**.831**	**.620**	**.705**	**1**		
	VC	.212	.698	.831	.254	.927	1		
MI	**CV**	**.463**	**.555**	**-.098**	**-.696**	**-.714**	**-.453**	**1**	
	VC	.390	.418	-.134	-.012	-.018	-.082	1	
Chi	**CV**	**.258**	**.278**	**.535**	**.572**	**.611**	**.726**	**-.268**	**1**
	VC	.016	.170	.167	.003	.126	.154	.007	1

First, in the case of ‘CV-’ sequences (the upper panel in each row), the higher (positive) correlations are between ΔP′ and TP′ (.959) on the one hand, Rho and ΔP (.831), on the other hand. The strong correlation between ΔP′ and TP′ is not surprising since both measure a similar relation between C and V; the strength of C as the sole predictor of V in a given CV sequence. The strong correlation between Rho and ΔP (interestingly, 0.831 in both CV and VC sequences) is more noteworthy. Given that many previous studies (including Shanks 1995) regarded ΔP as *the* normative measure of contingency, the fact that ΔP and Rho are correlated allows us to reduce the risk of relying on one particular metric (i.e., Rho) in assessing the contingency between two phonemes in the current thesis. By contrast, the lower correlations are between co-occurrence frequency and TP', which is only 0.047. Interestingly, the correlation between these two statistics in the case of 'VC' sequences is quite high (.852).

Overall, unlike other inter-correlations, the correlations between Rho values and the other main measures are always positive in both CV and VC sequences. This may have to do with the fact that, as Perruchet & Peereman 2004 mentioned, Rho is a metric that is most sophisticated among the major measures of associations and especially with the fact that, as discussed earlier, the four measures of association including TP, ΔP, TP′, and ΔP′ are embedded into the equation in (11) that expresses Rho value. I argue that this is another piece of evidence that supports the decision in the current thesis to choose Rho as the measure of association that assesses the relative cohesiveness between two phonemes in Korean.

4.2.2 Experimental Design

Experimental conditions. The stimuli for this experiment consisted of 40 lists of six CVC nonsense syllables each. There were 4 conditions (Condition A – D) in the experiment and each condition contained 10 lists of six CVC nonwords. A sample list that belongs to Condition A is

Table 4.5. A sample of stimuli used in a list in Condition A of Korean STM test

Cond. A **High CV**	C	V	c	**CV**+vc	Rho of ‘CV’		Cond. A **High VC**	c	V	C	cv+**VC**	Rho of ‘VC’
1	k	wa	l	kwal	0.13		4	k^h	i	p	k^hip	0.12
2	t^h	o	m	t^hom	0.11		5	s	ye	n	syen	0.11
3	kk	oy	ŋ	kkoyŋ	0.11		6	m	ɛ	t	mɛt	0.11

given in Table 4.5 (see Appendix 2 for the Korean stimuli used in the test). The stimuli in each condition were prepared according to different criteria specified as follows. I begin with a description of the stimuli in Condition A.

There were two subgroups of stimuli in Condition A. One subgroup consisted of CVC syllables in which the Rho values of ‘CV-’ sequences were relatively high.[8] Let us call the stimuli that belong to this group ‘High CV’ syllables. Stimuli #1, #2, and #3 in Table 4.5 belonged to this. Another subgroup consisted of syllables in which the Rho values of ‘-VC’ sequences were high. Call this group ‘High VC’. Stimuli #4, #5, and #6 in Table 4.5 belonged to this. Each list of six CVC syllables in Condition A thus contained 3 ‘High CV’ syllables and 3 ‘High VC’ syllables.

Consider the Rho values for the ‘V to C’ transitions in the High CV stimuli, and Rho

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[8] As mentioned above, to get a high Rho CV sequence, I did a median split of the entire Rho values of the 152 CVs. A CV has a High Rho if its Rho value is higher than the median. If its Rho is lower than the median, it has a Low Rho CV group. The same method was applied to the VC sequences in Korean.

values for the 'C to V' transitions in the High VC stimuli. In each High CV syllable stimulus, the transition from the vowel to coda had a low Rho value. Likewise, in each High VC syllable stimulus, the transition from the onset to the vowel had a low Rho value. So, for example, stimulus #1 'kwal' consisted of a CV sequence (i.e., /kwa/) that had a high Rho value and a VC sequence (i.e., /wal/) that had a low Rho value. Refer to stimulus #1-#3 as '**CV** + vc' type (upper-letter CV refers to a high Rho CV, lower-letter vc a low Rho vc). Stimulus #4 'khip', on the other hand, consisted of a VC sequence (i.e., /ip/) that had a high Rho value and a CV sequence (i.e., /khi/) that had a low Rho value. Refer to stimulus #4-#6 as 'cv + **VC**' type (lower-letter cv refers to a low Rho cv, upper-letter VC a high Rho VC). I made an effort to make the CV sequences in '**CV**+vc' group and the VC sequences in 'cv+**VC**' group have similar (relatively high) Rho values. Likewise, the vowel and coda sequences in '**CV**+vc' group and the onset to vowel sequences in 'cv+**VC**' group were designed in such a way that the two share similar (relatively low) Rho values.

It was sometimes impossible not to repeat a phoneme within a list, as was the case in the list shown in Table 4.5. In the list, /m/ was repeated in item # 2 and in item #6. This was in part due to the fact that there were only 6 final consonants available in Korean. Avoiding the repetition of an identical sound in two stimuli in a given list was also difficult due to the fact that out of the 6 final consonants, /ŋ/ is not eligible for an onset. But whenever possible, I tried to avoid the repetition of the same consonants in a given list. In case this was impossible, I distributed the consonant to onset and coda evenly, so that a particular repeating consonant appears once in onset and once in coda. One practice list similar to Table 4.5 was constructed. Each list of six CVC syllables in Condition B contained 3 '**CV**+vc' type syllables and another set of 3 syllables whose CV and VC component sequences were both low in terms of the Rho values (which I will refer to as 'cv+vc' type stimulus). Thus, in this condition, there were no stimuli that had a high Rho VC sequence. In contrast to this, each list of Condition C contained 3 'cv+**VC**' and 3 'cv+vc' type stimuli, namely there were no stimuli that had a high Rho CV sequence. Finally, in each list of Condition D, all 6 syllables consisted of 'cv+vc' type stimulus, i.e, all transitions in this condition were low in terms of Rho values. The mean values of the CV and VC sequences used for the test stimuli in each condition with their standard deviations are summarized in table 4.6.

I note here that it is important to establish at this point that the onset-vowel and vowel-coda sequences in Condition D are equally "low", as this equality will be shown to be critical in interpreting the result. For this, the Mann-Whiney U test was performed, testing the null hypothesis that there are no differences between the low rho values of onset-vowel and the low

Table 4.6. Mean Rho values (with SD) as a function of Stimuli Type

Cond.	Stimuli	Rho value	Rho Values of Two-phoneme sequence CV *M*	CV *SD*	VC *M*	VC *SD*
A	**CV**+vc vs. cv+**VC**	High	0.089	0.024	0.087	0.024
		Low	0.009	0.002	0.011	0.004
B	**CV**+vc vs. cv+vc	High	0.125	0.036	n/a	
		Low	0.008	0.002	0.015	0.013
C	cv+vc vs. cv+**VC**	High	n/a		0.080	0.021
		Low	0.008	0.004	0.011	0.003
D	all cv+vc	High	n/a		n/a	
		Low	0.009	0.004	0.013	0.008

rho values of vowel-coda sequences in the condition.[9] The mean rank for onset-vowel was 26.30 and the mean rank for vowel-coda was 34.70, suggesting that the two groups are equal in terms of the rho values. Indeed, the difference was not significant (U = 324.00; p = .062 (two-tailed)).[10] A Sign-test was additionally performed comparing the rho value of the onset-vowel with the vowel-coda component in every cv+vc stimulus in Condition D. The Sign-test evaluates the null hypothesis that given a random pair of measurements of two variables, say x and y, they are equally likely to be larger than the other. The test also produced no significant difference (Z score = -0.73, ns). Based on this, I take it that the "low" Rho values in Condition D were equal.[11]

[9] This test was done instead of the t-test, since the t-test showed that both populations did not have equal variances, an assumption that should be met for t-tests.

[10] Note that although the difference in means between the CVs and VCs in Condition D was statistically not significant, there was a numeric difference, which was actually the opposite of the general pattern in Korean (i.e., on average greater Rho values for CV than VC sequences in Korean CVC vocabulary).

[11] The onset-vowel and vowel-coda sequences in the 'cv+vc' stimuli in Condition B and C were "equally" low as well. The mean rank for CVs and VCs of the 'cv+vc' stimuli in Condition B was 26.86 and 34.13, respectively (U =

Note that unlike the stimuli in Condition D, the stimuli in Condition A-C were made with the intention that the "high" and "low" CV (or the "high" and "low" VC) sequences *differ* from each other in terms of the Rho values. This was checked and indeed it was the case. So, for example, in Condition A, the mean of Rho values of "high" CV sequences was .089, whereas the mean of Rho values of "low" CV sequences in the same condition was .009. This difference was significant by the Mann-Whiney U test.[12]

The rationale behind designing the stimuli in A-C to be contrasting in terms of Rho values was of course to see whether STM errors that subjects may make are affected by the relative cohesiveness of two-phoneme sequences. So, for example, if a subject makes an error that retains two phonemes out of to-be-remembered '**CV**+vc' type stimuli, the expectation is that the error would be more likely to retain as a group the onset and vowel than the vowel and coda sequence, since the former sequence is higher in terms of Rho value that the latter. This is of course based on the hypothesis that the subject is sensitive to the relative cohesiveness of the sequences and it affects which sequences of phonemes are retained in STM errors.

341, p = 0.1). The mean rank for CVs and VCs of the 'cv+vc' stimuli in Condition C was 26.68 and 34.31, respectively (U = 335, p = 0.08).

[12] The mean rank for "high" and "low" **CV**s was 45.5 and 15.5, respectively. This difference was significant ($U = 0$, $p < .001$ (two-tailed). Likewise, the difference in the mean of the Rho values between "high" vs. "low" **VC** sequences in condition A was also significant (the mean rank for "high" and "low" VCs was 46.3 and 13.1, respectively with $U = 0$, $p < .001$ (two-tailed)). In Condition **B**, only **CV** sequences were contrasted. The mean rank for "high" and "low" CVs in that condition was 45.3 and 15.5, respectively. This difference also was statistically significant ($U = 0$, $p < .001$ (two-tailed)). Finally, in Condition **C**, only **VC** sequences were contrasted. The mean rank for "high" and "low" VCs was 45.5 and 15.5, respectively. This difference was statistically significant as well (U = 0, p < .001 (two-tailed)).

Participants. Thirty subjects (12 female, 18 male) participated in the experiment. They were paid for their participation. Most of them were international students from the Republic of Korea studying at Northwestern University. The mean duration of their stay in the US was 4 years and 1 month. It ranged from 1 month to 10 years. There were two subjects who came to the U.S. when they were relatively younger (10 and 12 years old, respectively) than other participants. Except the two subjects, all came to the U.S. not earlier than at their age of 20. No one reported speech or hearing impairment at the time of the experiment.

In each experiment, I ran the subjects individually in a quiet room. I made 24 different orders of presenting the four conditions, in order to counterbalance the order of presenting the 4 conditions (i.e., 24 possible permutations of presenting the 4 conditions to the subjects). The initial plan was to run each order with two subjects, which would have required a total of 48 subjects. I failed to recruit them all, so in this thesis I analyze the results from the first 24 subjects only (meaning that the results from the remaining 6 subjects are not reported).

Procedure. I prerecorded the 6 syllables of each list, repeating them twice in different random orders. The syllables were spoken at a rate of about one per second. There were two trials. In the first trial, subjects simply repeated each syllable one by one immediately after they have heard it. I corrected subjects if I thought that they mispronounced the intended syllable. In the second trial, subjects listened to the same 6 syllables, though in a different random order, in one stretch. After the sixth syllable, I asked the subjects to repeat the 6 syllables that they just heard in the order given and as many syllables as they can. Subjects were told to guess if they could not recall a syllable. A practice list was given first, followed by 10 lists that belong to one of the 4 conditions. There were 5-10 minutes of break between each condition. In an earlier phase of this Korean STM experiment, subjects were asked to come in to two sessions. The subjects (n = 4) in that phase finished 2 conditions one day and they returned for the remaining two conditions. Later, it became apparent to me that subjects can finish the tasks in one session without tiring themselves too much. So, I asked the subjects in that later phase of the experiment (n = 26) to come in to just one session. These subjects thus finished the 4 conditions in one session. For them, it took about an hour to finish all conditions. There were frequent rests in-between the conditions for the subjects who finished the experiment in one day. Subjects' responses were recorded, and were analyzed later by me. Another Korean-speaking phonetically-trained transcriber transcribed 15% of the entire recordings obtained. Agreement on phonetic assignment between me and the other judge was obtained for approximately 91 % of the recordings that were transcribed by the both transcribers. The discrepancies between the two

Table 4.7. Predictions regarding two-phoneme retention errors in Korean STM tests

Models of syllable structure		supposing that the to-be-remembered items have the form of C_1VC_2
Hierarchical models	Predictions	STM errors would more likely preserve as units a sequence of phonemes occurring together *inside a sub-syllabic unit* than a sequence of phonemes not belonging to the same sub-syllabic unit. Specifically, in Korean STM tests, *C_1V* will always be remembered better as a group (according to the 'Body-Coda' model) than VC_2 -- the manipulation of relative dependencies of two-phoneme sequences *should not matter*
Probabilistic Phonotactics-based models	Predictions	STM errors would more likely preserve as units a sequence of phonemes that *has a high Rho value* than a sequence of phonemes that has a low Rho value. The groups of phonemes that are remembered more or less would correspond to some *objective measures* of associations of phonemes C_1V will be remembered better as a group (if Rho of C_1V > Rho of VC_2) VC_2 as a group (if Rho of VC_2 > Rho of C_1V) C_1V and VC_2 are equally likely (if Rho of C_1V ≈Rho of VC_2)
Emergent Model	Predictions	Errors would show effects of *both* the sub-syllabic units and phonotactic probabilities of phoneme sequences. If Rho of C_1V ≈ Rho of VC_2, then, C_1V will be remembered better than VC_2, on the basis of the results from the Korean statistical study reported in Chapter 3. If Rho of C_1V ≠ Rho of VC_2, then C_1V as a group (if Rho of C_1V > Rho of VC_2) VC_2 as a group (if Rho of VC_2 > Rho of C_1V)

judges were distributed fairly evenly across onsets (6.7%), vowels (10.6%), and codas (9.7%).[13]

Predictions. The predictions of the contrasting theories of Korean syllable structure regarding the STM errors are specified in table 4.7 to facilitate the discussion of the STM results.

[13] A significant portion of the disagreements between the two judges stemmed from whether an onset stop was a voiceless 'slightly' aspirated or a voiceless 'unaspirated' stop (e.g, /tʃ^{h}it/ vs. /tʃit/). Another quite frequent disagreement involved /i/ vs. /ɨ/ distinction (the latter is high (central) rounded vowel).

4.2.3. Results

Tallying the errors. There were 5946 responses in total. Out of these responses, 3045 (51%) were correct responses. An item was considered to be a correct response as long as it was accurately reported. Although I asked the subjects to recall the items in the order given in a particular list, as long as the subjects reported the items correctly, those responses were considered to be correct, regardless of the order in which the original items appeared in the response phase. Out of the 2901 errors, 660 (23%) were "don't know" responses. Two-phoneme retention errors out of the remaining errors were analyzed. When I say that there was a two-phoneme retention error, it means the following. For example, /k^hip/ was one of the to-be-remembered stimuli in a particular list in the experiment. As an illustrative purpose, if a subject produced /**k^hi**m/, /c**ip**/, or /**k^h**a**p**/ at any position in his or her recall list, this error was counted as sharing two phonemes with the (to-be-remembered) test stimulus /k^hip/, namely C_1V, VC_2, C_1C_2, respectively. Since in that particular list it was only the word /k^hip/ (but no other remaining five words in the list) that had /k^hi-/ sequence, the error /k^him/, for example, must be an erroneous combination of the phoneme sequence of /k^hi-/ of the original item /k^hip/ and a segment /m/ of some other words. Having defined the meaning of two-phoneme retention errors in this way, I will use expressions like the following interchangeably in this dissertation: (i) "there were more two-phoneme retention errors involving /C_1V/ than other two-phoneme errors, (ii) "the sequence /C_1V/ was retained as a unit more often than other sequences", and (iii) "the /C_1V/ sequence was remembered better than other sequences".

One of the critical variables that the Korean STM tests aimed to examine was the role of phonotactic probability of phoneme sequences in subjects' retentions of certain groups of phonemes. For this, each of the two-phoneme retention errors was coded in terms of their Rho value in the original stimuli with which the error is associated. For example, if a subject produced an error /**k^hi**m/ from the to-be-remembered stimulus /k^hip/, this was coded as a 'High' Rho C_1V retention error, since the Rho value of the sequence /k^hi-/ in /k^hip/ was high. If a subject instead produced /c**ip**/, then this constitutes an error originating form a 'Low' Rho VC_2, since the sequence /-ip/ in /cip/ had a low Rho value. Below I report the errors not only in terms of C_1V, VC_2, or C_1C_2, but also in terms of the Rho value of the original biphone sequences with which the errors associated.

Findings. Figure 4.1 reports the percentage of two-phoneme errors that retained 'onset and vowel' as a group from the three types of to-be-remembered stimuli (i.e., '**CV**+vc', 'cv+**VC**', or 'cv+vc'), pooled over the four conditions. At this point, I need to make it clear that the % onset-vowel retention errors represented in Fig. 4.1 are based on % onset-vowel errors relative to

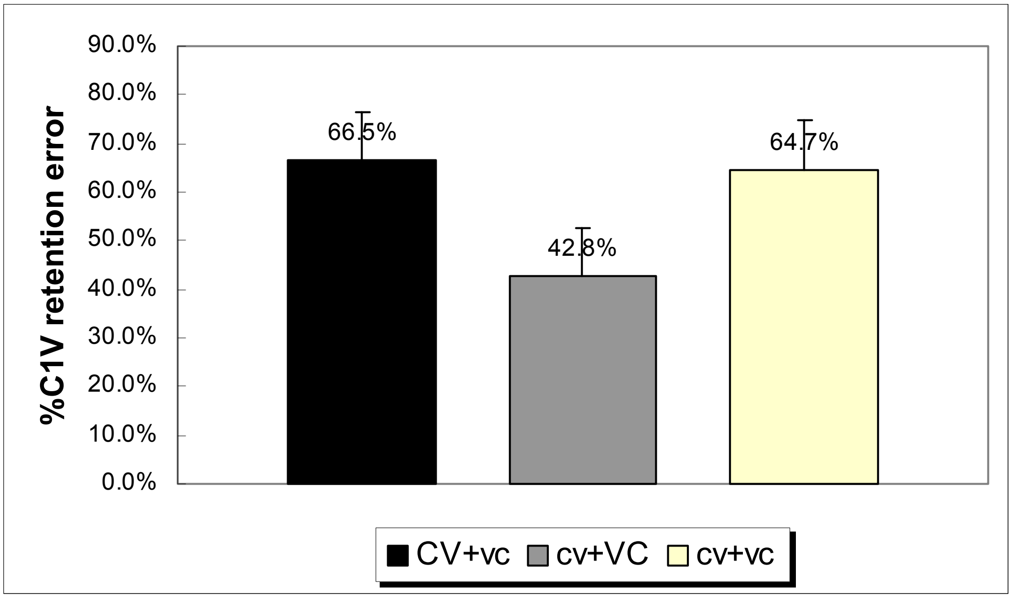

Figure 4.1. %C_1V retention errors in Korean STM tests (as a function of the to-be-remembered stimuli type).The %C_1V errors reflect the percentage of onset-vowel retention errors relative to the sum of C_1V and VC_2 retention errors

the sum of the 'onset-vowel' and 'vowel-coda' errors only, excluding the 'onset-coda' errors. That is, my analysis reported below is focusing on the errors that involve *immediately adjacent* segments within the syllable. This strategy was taken for the following reasons. First of all, there were few onset-coda retention errors across the three conditions (i.e., "**CV**+vc', 'cv+**VC**', or 'cv+vc'); the errors constituted on average less than about 10% of total errors for each condition. Secondly, the percent onset-coda errors did not differ across the conditions. For this, the % onset-coda retention error was analyzed in an analysis of variance with the stimuli types (**CV**+vc, cv+**VC**, cv+vc) as a within-subject factor. The main effect of stimuli type was not significant ($F(2,46) = .276$, $p = .75$). Post-hoc comparisons found no significant difference between any pair of the conditions (all $p = 1$). Finally, unlike the onset-vowel and vowel-coda sequences, the inter-phoneme dependencies between onset and coda sequences used in the stimuli were not controlled. Thus, it was not quite feasible to make a reasonable interpretation of the onset-coda retention errors.

This being said, a visual inspection of Fig. 4.1 suggests that the onset-vowel sequence does not seem to have been retained equally across the three types of to-be-recalled stimuli. Particularly, in the case of 'cv+**VC**' to-be-remembered stimuli (the middle bar in the figure), it is apparent that proportionally less C_1V was retained as a group, compared to the percentage of C_1V from 'CV+vc' and 'cv+vc' stimuli. In order to examine whether the proportion of the onset-vowel sequence retained differed significantly as a function of the different types of to-be-remembered stimuli, the % onset-vowel retention error was analyzed in an analysis of variance with the stimuli types (**CV**+vc, cv+**VC**, cv+vc) as a within-subject factor. The sphericity assumption was met. The main effect of stimuli type was significant ($F(2,46) = 13.032$, $p < .001$). Post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. The difference between '**CV**+vc', 'cv+**VC**' was significant ($p < .05$). The difference between 'cv+**VC**' and 'cv+vc' was also significant ($p < .05$). The difference between '**CV**+vc' and 'cv+vc' was not significant ($p = 1.00$).

Table 4.8. Chi-square table for C_1V and VC_2 retention errors in Korean STM

two-phoneme errors	retention	**<u>CV</u>**+vc	cv+**<u>VC</u>**	cv+vc	Total
C_1V	Count	238	179	192	609
	Expected	211.8	226.5	170.7	609
	%	39.0%	29.3%	31.5%	100%
VC_2	Count	123	207	99	429
	Expected	149.2	159.5	120.3	429
	%	28.6%	48.2%	23.0%	100%
	Count	361	386	291	1038
Total	Expected	361	386	291	1038
	%	34.7%	37.1%	28.0%	100%

Thus, the results suggest that the pattern of onset-vowel retention was indeed different between '**<u>CV</u>**+vc' and 'cv+vc' stimuli on the one hand and 'cv+**<u>VC</u>**' on the other.[14]

In order to further test if the types of two-phoneme segments retained were different depending on the types of to-be-remembered stimuli, I examined the C_1V and VC_2 retention error totals for '**<u>CV</u>**+vc', 'cv+**<u>VC</u>**', and 'cv+vc' stimuli in a chi-square statistic.[15] The actual counts and the expected counts are reported in Table 4.8 with the result of $\chi 2 = 67.011$, $df = 2$, $p < 0.001$, providing additional evidence that the units that were retained most often were different as a function of the stimuli types.

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[14] A non-parametric test, i.e., the sign test, was also performed for each of the three types of stimuli, specifically comparing the number of C_1V with VC_2 retention errors across the subjects. C_1V retentions significantly outnumbered VC_2 retentions for '**<u>CV</u>**+vc' and 'cv+vc' type stimuli (Z score for 'CV+vc' = 2.27, $p < 0.05$, one-tailed, and Z score for 'cv+vc' = 4.16, $p < 0.05$, one-tailed). In contrast, VC_2 retentions significantly outnumbered C_1V retentions for 'cv+**<u>VC</u>**' type stimuli (Z score for 'cv+VC' = 3.02, $p < 0.05$, one-tailed).

[15] As shown in the chi-square table, the chi-square also was performed on error totals excluding the C_1C_2 retention errors. Again this particular type of errors was excluded primarily because % C_1C_2 retention errors were not significantly different across the three types of stimuli.

4.2.4 Discussion

The major question asked in this study was which groups of phonemes of the to-be-remembered stimuli would be retained most often (or equivalently, would be remembered better by the subjects). The gathered data suggest the following patterns.

First, the data suggest that overall when an error retained two phonemes of a to-be-remembered stimulus, it involved the onset and vowel sequence more often than the vowel-coda or the onset-coda sequence. For this, compare the sum of the errors in C_1V row with the sum of the errors in VC_2 row in Table 4.8 above. That is, when the number of errors from the different types of stimuli are collapsed, we observe that the subjects overall remembered onset-vowel sequences better than vowel-coda sequences. This is consistent with Derwing's hierarchical model of Korean syllable structure (see Table 4.7). It posits that onsets and vowels in Korean form an independent constituent (body) and this combines with a coda to form a syllable. Component phonemes of a sub-syllabic unit, according to the model, are expected to stay together more often than a sequence of phonemes that are not immediate daughters of the same unit. This sub-syllabic structure, presumably stored as a piece of phonological knowledge in the long-term memory, may have played an important role in the recall for previously unheard verbal items. That is, for the Korean participants, their knowledge of certain linguistic structure within the syllable might have enhanced their performance regarding recalling certain sequence of segments, namely onset and vowel. This model, however, cannot account for the full range of the data obtained. Particularly, it is at odds with the current finding that C_1V retentions prevailed for '**CV**+vc' and 'cv+vc' type stimuli only. In the case of 'cv+**VC**' type stimuli, VC_2 retention errors outnumbered C_1V retentions. If grouping of segments within a syllable is determined solely by the local constituent that the segments belong to, the error pattern from the 'cv+**VC**' type stimuli is expected to be similar to the error pattern from the other two types of stimuli. This prediction, however, was not borne out.

The finding from the lists of 'cv+**VC**' words is important for two reasons. First, it shows that the apparent unit of segments that "stayed together" or "were remembered better" in the surface most often was not determined solely by the serial position of the segments in the syllable. If it were only onset and vowel sequence that were retained most often, then the finding might be ambiguous between whether it points to a linguistic unit (i.e., body) or whether to the fact that the two phonemes in question are merely the first two segments of the syllable. One might as well argue that the subjects remembered simply the first two sounds of the syllable better. This possibility, however, should be ruled out based on the finding from the 'cv+**VC**' type stimuli.

Second, the finding from 'cv+**VC**' stimuli agrees with the results from previous studies of English that have shown that phonotactic probabilities of components of nonwords do influence serial recall of nonwords (e.g., Gathercole et al. 1999, and Thorn & Frankish 2005). Specifically, superior recall accuracy was reported for nonwords composed of phoneme pairs (i.e., CV and VC) that occur frequently than for those composed of infrequently occurring biphone pairs. In the context of syllable structure research pursued here, the findings from the current study further show that the relative cohesiveness of particular phoneme combinations (as assessed by Rho) not only plays a role in the accurate recall of whole words, but also of units smaller than the words. Namely, the retention of specific sequences of two-phoneme varied as a function of the strength of sub-syllabic dependencies in question: when such dependencies were strong for the sequence of the onset and vowel, they tend to be retained, while when dependencies were strong for the sequence of the vowel and coda, it was retained as a group more often (i.e., compare the different error pattern from 'CV+vc' vs. 'cv+VC'). Unlike the traditionally popular 'body-coda' model of Korean syllable structure, the probabilistic-phonotactic based model does predict this finding (see Table 4.7). This model, however, as it stands, does not give us a satisfactory account of the pattern of two-phoneme retentions when 'CV-' and '-VC' sequences within a CVC syllable are matched for the contingency, namely the 'cv+vc' type stimuli in the current experiment. The model makes a prediction that in this type of stimuli, the number of C_1V and that of VC_2 retentions would be statistically random, while the actual finding indicates a considerable dominance of C_1V over VC_2 retentions.

Given this, one plausible interpretation of the findings from the Korean STM test is that the types of sequence of segments better remembered as a group in the test were influenced by both probabilistic contingencies and some sub-syllabic units. To the extent that STM errors reflect the internal structure of Korean syllables, the findings then suggest that an empirically adequate model of Korean syllable structure must be general enough to account for the relevance of both of the factors in Korean syllables. More specifically, the ideal model should be able to account for the following two empirical findings: (i) the role of inter-phoneme dependencies (a notion that is in principle sequential): When onset-vowel and vowel-coda sequences in the syllable were *contrasted* in terms of 'dependency' (as assessed by Rho values), whichever sequence that had a high dependency score was remembered better than the sequence that had a relatively low dependency score. It did not matter whether the highly dependent sequence was onset-vowel or vowel-coda sequences, (ii) the role of apparent units (a notion that is in principle non-sequential): When onset-vowel and vowel-coda sequences in the syllable *did not contrast* (in the Korean case, both low), onset-vowel sequences were on average remembered better than vowel-coda sequences.

I would argue that the emergent model can account for these findings and that as such it is a superior model over the other two models in describing Korean syllable structure. As described in Chapter 2, the emergent model is built upon the ideas presented especially in Dell et al., 1993 and Chen et al., 2004. An important merit of the model, as demonstrated in the two cited studies, is its ability to account for the effect that is usually ascribed to explicit constituents as well as to capture the fact that segment arrangements within the syllable are essentially probabilistic. Importantly, this can be done under the emergent model without actually positing explicit units such as the rime.

More specifically, first, the emergent model can account for the contrast in terms of the error type between '**CV**+vc' (i.e., more CV errors) and 'cv+**VC**' (i.e., more VC errors) stimuli with the following assumption. The assumption is that Korean speakers are aware of the *difference* in the degree of the two-way dependencies across the 'CV-' and '-VC' positions at the sub-syllabic level and this knowledge affects them in reconstructing the incomplete memory traces, created by the nonwords. For example, if /kap/, for example, is a to-be-remembered item, and the two-way dependency for /ka-/ is higher than the dependency for /-ap/, then /**ka**m/ is a potential error that is more likely to occur than /m**ap**/. That is, people would remember /ka-/ better than /-ap/ because of the higher dependency for the former and thus an error combining /ka-/ with something else would be more likely to occur. By the same token, if /ap/ has a higher dependency value than /ka/, then /m**ap**/ would be an error that subjects will more likely make than /**ka**m/. This assumption is a reasonable one in the sense that at least English speakers seem to be aware of the difference in frequency/phonotactic probability across the 'CV-' and '-VC' sequences within the syllable (see the results from English STM tests reported in e.g., Gathercole et al., 1999 and Thorn & Frankish, 2005).

Second, the emergent model can also account for a greater number of C_1V recall errors than VC_2 errors from 'cv+vc' stimuli with the following assumption. The assumption is that Korean speakers are also aware of the *general* statistical characteristic of words in Korean and this knowledge helps them reconstruct the original to-be-remembered stimuli whose onset-vowel and vowel-coda sequences are not contrasted in terms of dependency. As an illustration of this point, let us assume that a to-be-remembered word /kap/ is a type of /cv+vc/, that is the dependency of the onset-vowel and that of vowel-coda are both low. It is not unreasonable to think that subjects' reconstruction of this particular type of stimuli might have involved even poorer memory traces than the other two types of stimuli, simply because both of the components of the stimuli were relatively unfamiliar to the subjects. Thus, under this circumstance, the knowledge of the dependencies governing *individual* two-phoneme sequences would be of little help. However, if Korean users know (as a result of their vocabulary learning) that the contingencies involving onset-vowel sequences are stronger in general than those involving vowel-coda sequences, then an error like /**ka**m/ that retains the onset-vowel sequence of the original stimulus is one that is more likely to occur than an error like /m**ap**/ that retains the vowel-coda. That is, Korean speakers remember onset-vowel sequences better than vowel-coda sequences because in Korean the onset consonants that precede a specific vowel vary to a much lesser extent than the coda consonants that follow the same vowel.

This is to say that Korean-speaking subjects tend to show the behavioral pattern that is consistent with structural units (body-coda), not because of existence of explicit units per se, but because they have acquired the knowledge that there are relatively stronger dependencies between onsets and vowels in Korean vocabularies in general. This knowledge becomes a part of the speakers' phonological grammar, to the extent that they influence certain linguistic behaviors (in the current case, remembering sequences of segments in 'cv+vc' stimuli where the sequence probabilities are equated). The emergent model described above (along the line of Dell et al., 1993 and Chen et al., 2004) was shown to exhibit this type of unit effect (essentially reflecting the statistical property of the vocabulary that they are trained on) without positing explicit constituents, so the current Korean STM findings are a piece of evidence that provides a support in favor of the model over the other alternatives.

One advantage of adopting the emergent model would be that, under this model, Korean syllable structure is not so "atypical" in terms of syllable structure of natural languages (considering that the internal structure of syllables in many languages have been suggested to be "right-branching"). Korean has the syllable "structure" it has because it reflects the general statistical characteristic of the words precisely in the Korean lexicon, not due to some radical differences in structures per se between Korean and other languages. Another advantage of adopting the emergent model is that it allows us to account for the emerging of salient units at the sub-syllabic level in Korean without excluding the possibility of any other conceivable aggregations of phoneme sequences within a syllable, namely VC_2 as a potential unit in Korean. I discuss this point in detail when I discuss the results from the English STM tests in the next section.[16]

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[16] Another plausible hypothesis in accounting for the Korean STM data is simply to posit that the structural units and frequency/phonotactic probabilities are distinct entities in Korean users' grammar and that the error pattern from the 'cv+vc' type stimuli in particular reveals the interaction of the two factors. This hypothesis is plausible in that frequency has been shown to interact with other component of grammar. Plaut, Seidenberg, McClelland, and Patterson (1996), for example, have demonstrated that in word-reading tasks, high frequency words were named faster than low-frequency words, and words with greater spelling-sound consistency were named faster than words

4.3 English Short-term Memory Test

Here, I report results from STM tests with English-speaking subjects. It will be shown that, consistent with the Korean STM results, English users are also aware of both the difference in the two-way dependencies between 'CV-' and '-VC' sequences within a syllable and the overall phonotactic regularities that are specific to English.

4.3.1 Measures of Association of CV- and -VC sequences in English

The relative contingency of each of the 280 'CV' and 222 'VC' English sequences was estimated using the same seven measures of associations performed for the Korean CV and VC sequences. As was the case for the Korean STM test, eventually the internal contingency of two-phoneme sequences included in the test stimuli in the English STM test was assessed by the relative Rho value of each sequence. Thus, a high contingency English CV sequence indicates that that particular CV sequence's Rho value was higher than the median Rho values computed

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with less consistency. However, the effect of frequency was salient only when spelling-sound consistency was low. That is, the frequency effect diminished as consistency increased such that when spelling-sound consistency was high, increasing frequency yielded little improvement. Likewise, in the current study, one could argue that the inter-phoneme contingencies might have played a role only when the contingency factor was salient enough to make a difference, i.e., when CV and VC were contrasted for two-phoneme dependencies within a syllable. When the contingencies were not a factor, i.e., when they were matched for CV and VC, what appears to be a dominant sub-syllabic structure of Korean syllables, namely body, may have determined which sequence of two phonemes would most likely to be remembered. However, I argue that the emergent model is a better model in the sense that it is a much simpler model (see Plaut et al. for a similar argument in the case of reading): it does not have to posit structures as entities entirely separate from the statistical characteristic of the Korean lexicon. Structures are discovered as a consequence of vocabulary learning in the emergent model. This is much simpler than to say that the appropriate structure of the Korean syllable and the statistical characteristic of the Korean lexicon have to be learned separately.

Table 4.9. TP and Rho values of the ten most frequent English ‘CV-’ and ‘-VC’ sequences (in terms of type-frequency)

C	V	Type-Freq.	TP	Rho	V	C	Type-Freq.	TP	Rho
b	ʌ	190	0.150	0.058	e^j	d	161	0.151	0.006
w	ɪ	175	0.180	0.055	e^j	z	146	0.137	0.072
ɹ	e^j	165	0.144	0.054	aɪ	d	145	0.200	0.043
w	ɛ	136	0.140	0.059	ɛ	ɹ	143	0.461	0.380
k	ɒ	134	0.147	0.075	u	d	142	0.199	0.042
ɹ	ɪ	133	0.116	0.001	i	d	139	0.154	0.008
w	e^j	131	0.135	0.040	ɪ	t	132	0.133	0.024
l	ɪ	131	0.123	0.007	o	d	127	0.175	0.024
h	ʌ	122	0.128	0.030	ɛ	d	127	0.204	0.043
p	ɪ	121	0.173	0.041	e^j	n	124	0.116	0.053
Median of 10 most freq. CV			0.144	0.042	Median of 10 most freq. VC			0.193	0.069
Median of entire CV			0.058	0.018	Median of entire VC			0.051	0.032

across the whole population of 282 CV sequences. Likewise, a VC sequence was considered to have a high phonotactic probability if that sequence’s Rho value exceeded the median Rho values computed across the whole population of 222 VC sequences found with the CELEX database.

A survey of the computed statistics of the English CV and VC sequences raised a possibility of a substantial correlation amongst the different measures of association. This indeed appeared to be the case at least for the quite frequently occurring two-phoneme sequences in English. Table 4.9 shows that the ten most frequent CV and VC items were overall not only

Table 4.10. ΔP, TP′, ΔP′, MI and Chi-square values of the ten most frequent English ‘CV-’ and ‘-VC’ sequences (in terms of type-frequency)

C	V	ΔP	TP′	ΔP′	MI	Chi	V	C	ΔP	TP′	ΔP′	MI	Chi
b	ʌ	.041	.117	.036	7.911	3.76	e^j	d	-.035	.052	-.046	7.449	4.01
w	ɪ	.079	.119	.057	7.934	11.3	e^j	z	.063	.269	.180	6.291	28.3
ɹ	e^j	.042	.109	.035	7.899	3.75	aɪ	d	.020	.087	.020	7.441	1.03
w	ɛ	.046	.113	.049	7.318	5.66	ɛ	ɹ	.015	.100	.037	5.922	1.37
k	ɒ	.043	.098	.035	7.684	3.88	u	d	-.038	.023	-.027	7.451	2.57
ɹ	ɪ	.023	.094	.019	7.935	1.08	i	d	.043	.127	.049	7.439	5.28
w	e^j	.038	.092	.028	7.899	2.61	ɪ	t	-.033	.073	-.028	8.181	2.29
l	ɪ	-.057	.033	-.044	7.943	6.44	o	d	.010	.075	.010	7.441	.255
h	ʌ	.009	.067	.006	7.912	.124	ɛ	d	.054	.110	.050	7.439	6.68
p	ɪ	.000	.074	.000	7.936	.000	e^j	n	.048	.137	.047	7.958	5.63
Median of 10 most freq. CV							Median of 10 most freq. VC						
		.039	.096	.031	7.911	3.75			.017	.093	.028	7.441	3.29
Median of entire CV							Median of entire VC						
		.001	.050	.002	7.372	.694			.008	.069	.008	6.705	1.811

frequent occurring, but also had higher TPs and Rho values than the median TP and Rho values pooled over the entire population of CVs and VCs in English. Table 4.10 shows the values of the remaining five measures of association for the ten most frequent CV and VC sequences. It also shows that for all measures the frequently-occurring CV and VC sequences had higher values than the values computed across the entire population.

The inter-correlations between the seven different measures of associations (seen in Table 4.11 below), computed across the whole population of 282 CV and 222 VC sequences, suggested that the close association among the statistics are the general trend. It is particularly

Table 4.11. Intercorrelations among the seven measures of association computed across the whole population of 282 English CV and 222 VC

		Freq.	TP	ΔP	TP′	ΔP′	Rho	MI	Chi
Freq.	**CV**	**1**							
	VC	1							
TP	**CV**	**.515**	**1**						
	VC	.439	1						
ΔP	**CV**	**.258**	**.806**	**1**					
	VC	.309	.959	1					
TP′	**CV**	**.469**	**.055**	**.287**	**1**				
	VC	.465	.222	.319	1				
ΔP′	**CV**	**.242**	**.266**	**.526**	**.835**	**1**			
	VC	.390	.372	.470	.937	1			
Rho	**CV**	**.366**	**.607**	**.853**	**.618**	**.839**	**1**		
	VC	.514	.737	.805	.675	.799	1		
MI	**CV**	**.498**	**.542**	**-0.19**	**-.397**	**-.382**	**-.171**	**1**	
	VC	.493	.262	.006	-.412	-.397	-.118	1	
Chi	**CV**	**.091**	**.315**	**.436**	**.349**	**.462**	**.532**	**-.092**	**1**
	VC	.337	.656	.696	.403	.491	.811	-.018	1

interesting to see that the higher correlations exist between Rho and ΔP for both CV and VC (0.85 and 0.80, respectively), which was also the case for the Korean CVs and VCs. As claimed earlier, considering that ΔP has been regarded by many researchers as *the* normative measure of contingency, the close relation between ΔP and Rho allows us to reduce the risk of relying on one particular metric (i.e., Rho) in assessing the contingency between two phonemes in the current thesis.[17] Appendix 3 reports the values of the seven measures of associations for every CV and

[17] This of course also means that the potential effect of phonemic contingencies on STM tasks in English and Korea alike should not be exclusively ascribed to Rho values, a metric adopted for the current study. The search for which

VC sequence attested in the CVC words found with the English database adopted for the current dissertation.

4.3.2 Method

Material. The stimuli for the English STM experiment consisted of 25 lists of six CVC nonsense syllables each. There were 5 conditions (Condition A – E) in the experiment and each condition contained 5 lists of six CVC nonwords (5 conditions x 5 lists each condition x 6 nonwords each list = total of 150 test stimuli). Condition A had three syllables of '**CV**+vc' and three syllables of 'cv+**VC**' stimuli in each of the five lists. Each list of Condition B had three syllables of '**CV**+vc' and three syllables of 'cv+vc'. Each list of Condition C had three syllables of 'cv+**VC**' and three syllables of 'cv+vc'. Condition D and E had six syllables of 'cv+vc' and '**CV**+**VC**' in each list, respectively. '**CV**+**VC**' stimuli refer to syllables where both onset-vowel and vowel-coda sequences had a high Rho value. Condition E was the only difference between the conditions present in Korean and in English STM tests. I was not able to make this condition for the Korean tests since there were not enough high Rho CV and VC sequences in Korean, the combinations of which resulted in nonsense Korean words. Examples of the stimuli in each condition are presented in Table 4.12 (The full list can be found in Appendix 4). Due to the

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measure of these statistics is the best predictor of performance of the subjects requires a separate research effort.

Table 4.12. Examples of English STM stimuli across the five conditions

	<u>CV</u>+vc	cv+**<u>VC</u>**	cv+vc	**<u>CV</u>**+**<u>VC</u>**
Cond. A	kɔɪd,jɛtʃ,geɪs	θip,ðaɪt,dʒuʒ	n/a	n/a
Cond. B	daʊð,mæb,zul	n/a	hik,ʃadʒ,poʊθ	n/a
Cond. C	n/a	sɔɪn,ðaɪt,ʃab	wiθ,mul,fɪtʃ	n/a
Cond. D	n/a	n/a	sʌdʒ,maʊtʃ,joʊd, rɪn,tɚb,vɛl	n/a
Cond. E	n/a	n/a	n/a	rus,bʊd,tʃɚθ, zoʊl,dʒæʃ,jaʊt

Note: Each condition had 5 lists and each list had 6 syllables.

limitation of available coda consonants, a phoneme was sometimes repeated in a list in the Korean STM tests. But no phoneme was repeated within a list in the English STM tests. Also, no two-phoneme sequence was repeated in a given condition. I tried to make the high and low Rho CV and VC sequences in the different conditions as comparable as possible. The mean values of the CV and VC sequences used for the test stimuli in each condition with their standard deviations are summarized in Table 4.13 below.

As was the case in Korean STM tests, it is important to establish at this point that the onset-vowel and vowel-coda sequences in Condition D are equally "low", and the onset-vowel and vowel-coda sequences in Condition E are equally "high", as this equality is important in interpreting the result to be obtained. For this, the Mann-Whiney U test was performed, testing

Table 4.13 Mean Rho values as a function of Probability Type (by conditions)

			Rho Values of Two-phoneme sequence			
			CV		VC	
Cond.	Stimuli	Rho type	*M*	*SD*	*M*	*SD*
A	**CV**+vc vs. cv+**VC**	High	0.052	0.018	0.061	0.017
		Low	0.009	0.007	0.021	0.011
B	**CV**+vc vs. cv+vc	High	0.053	0.018	n/a	
		Low	0.010	0.006	0.017	0.009
C	cv+vc vs. cv+**VC**	High	n/a		0.068	0.021
		Low	0.007	0.004	0.017	0.009
D	all cv+vc	High	n/a		n/a	
		Low	0.003	0.002	0.011	0.006
E	all **CV**+**VC**	High	0.056	0.015	0.063	0.012
		Low	n/a		n/a	

the null hypothesis that there are no differences between the CV and VC components of the stimuli in Condition D and E. First, for the ‘cv+vc’ stimuli in Condition D, the mean rank for onset-vowel was 25.8 and the mean rank for vowel-coda was 33.4, suggesting that the two groups may be equal in terms of the Rho values. Indeed, the difference was not significant (U = 309; p = 0.08(two-tailed)). Second, for the ‘CV+VC’ stimuli in Condition E, the mean rank for onset-vowel was 28.5 and the mean rank for vowel-coda was 32.4. This difference was not significant either (U = 392; p = 0.39(two-tailed)). Based on this, I take it that the “low” and “high” Rho values in Condition D and E, respectively, were nearly equal.[18]

[18] Condition B and C also had ‘cv+vc’ stimuli. The mean rank for onset-vowel and vowel-coda sequences of the ‘cv+vc’ stimuli in Condition B was 11.85 and 17.14, respectively. This difference was not significant (U = 61, p = 0.09 (two-tailed)). The mean rank for onset-vowel and vowel-coda sequences of the ‘cv+vc’ stimuli in Condition C was 12.5 and 18.5, respectively. This difference was not significant either (U = 67.5, p = 0.06 (two-tailed).

In contrast to Condition D and E, the stimuli in Condition A-C were made so that the "high" and "low" CV (or the "high and low" VC) sequences *differ* from each other in terms of the Rho values. So, for example, in Condition A, the mean of Rho values of "high" CV sequences was .052, whereas the mean of Rho values of "low" CV sequences in the same condition was .009. This difference was statistically significant by the Mann-Whiney U test.[19]

Participants. Twenty-one undergraduate students from the Northwestern University community participated in the experiment (4 males; 17 females) in compliance with a course requirement. One participant's data was not analyzed since she reported that her first language is Spanish and learning English as a foreign language. All other participants reported that they were native speakers of English. All participants reported no history of hearing impairment.

Procedure. Procedure was identical to the Korean STM tests. Complete counterbalancing of the five conditions would have required 120 different orders (and thus at least 120 subjects). In order to minimize any carryover effects while maintaining the practicality of the experiment, I had to settle for incomplete counterbalancing, using a 5 x 5 balanced Latin-square design (5 conditions and sets of 5 subjects). The goal of the design was to make sure that

[19] The mean rank for "high" and "low" CVs was 23 and 8, respectively. This difference was statistically significant ($U = 0$, $p < .001$). Likewise, the difference in the mean of the Rho values between "high" vs. "low" VC sequences in condition A was also significant ($U = 0$, $p < .001$). In Condition B and C, only CV or VC sequences, respectively, were contrasted. The difference in mean rank for "high" and "low" CVs (for Condition B) as well as for "high" and "low" VCs (for Condition C) was both statistically significant (both, $U = 0$, $p < .001$).

Table 4.14 The English STM tests design

		Square 1 Order of Condition				
		A	B	C	D	E
	1	1	2	5	3	4
	2	2	3	1	4	5
Subject	3	3	4	2	5	1
Number	4	4	5	3	1	2
	5	5	1	4	2	3
		Square 2 Order of Condition				
		A	B	C	D	E
	6	4	3	5	2	1
	7	5	4	1	3	2
Subject	8	1	5	2	4	3
Number	9	2	1	3	5	4
	10	3	2	4	1	5

each condition precedes and follows every other condition equally often. In a balanced Latin-square design, if the number of conditions in an experiment is odd, as in the current experiment, then two squares are needed to have every condition following every other condition an equal number of times. The second square is simply a reversal of the sequences of the first square. The first five subjects of the current experiment were assigned to the first square and the second five subjects were assigned to the second. This was repeated with additional ten subjects. See Table 4.14 for the design used in the current experiment (adopted from Elmes, Kantowitz, and Roediger, 1995:236).

Subjects' responses were recorded into a microcassette recorder, and were analyzed later by a phonetically trained native speaker of English. Another independent transcriber (who is also a native speaker of English) transcribed 30% of the entire recordings obtained. The original recording sheet was provided to the two transcribers to aid phonetic transcription. Agreement on phonetic assignment between the two judges was obtained for approximately 94 % of the recordings that were transcribed by the both transcribers. The discrepancies between the two judges were distributed fairly evenly across onsets (8%), vowels (3%), and codas (5%). A significant portion of the disagreements between the two judges stemmed from whether a particular sound (usually in the coda position) that they heard was voiced or voiceless (e.g, /guθ/ vs. /guð/). Another quite often disagreements involved /θ/ vs. /f/, /ð/ vs. /v/, and /tʃ/ vs. /ʃ/ distinctions.

4.3.3 Results

The scoring method was identical to the Korean STM study above. There were 2850 responses in total. Out of these responses, 1147 (40%) were correct responses. Out of the 1302 errors, 401 (14%) 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.

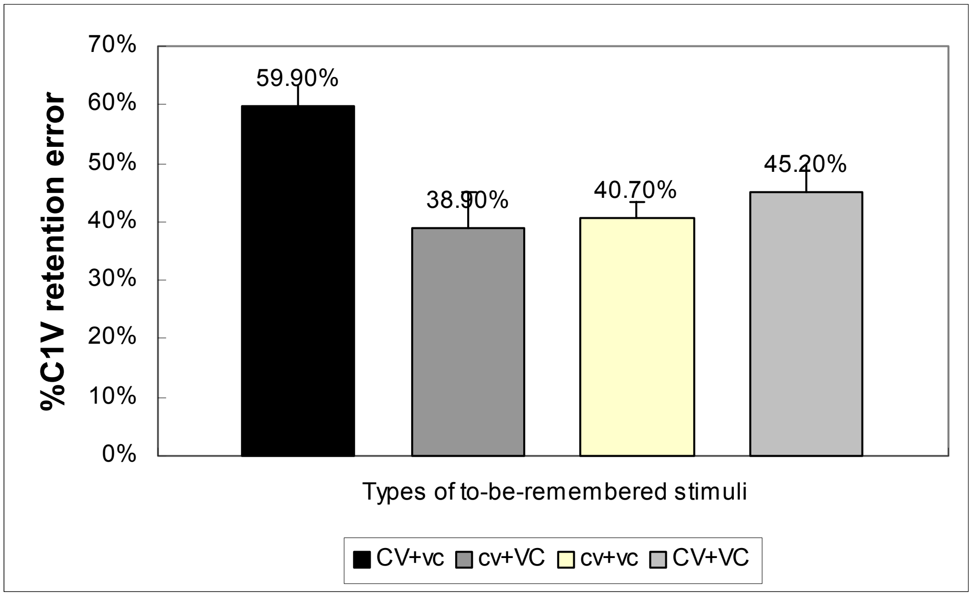

Figure 4.2. % C_1V retention errors in English STM tests (as a function of the to-be-remembered stimuli type). The % C_1V errors reflect the percentage of onset-vowel retention errors relative to the sum of C_1V and VC_2 retention errors only

Findings. Figure 4.2 reports the percentage of two-phoneme errors that retained 'onset and vowel' as a group from the four types of to-be-remembered stimuli ('**CV**+vc', 'cv+**VC**', 'cv+vc', '**CV**+**VC**'), pooled over the five conditions. In order to be consistent with the analysis done for the Korean STM results, the % onset-vowel retention errors represented in Fig. 4.2 are based on % onset-vowel errors relative to the sum of onset-vowel and vowel-coda errors only, excluding the onset-coda errors. Similar to the onset-coda errors in the Korean STM tests, first of all, there were few onset-coda errors across the four conditions (i.e., "**CV**+vc', 'cv+**VC**', 'cv+vc', or '**CV**+**VC**'), on average about 12% of the total errors of each condition. Secondly, the percent onset-coda errors did not differ across the conditions. For this, the % onset-coda retention error was analyzed in a 2x2 repeated-measures analysis of variance using the factors of C_1V contingency (high vs. low) and VC_2 contingency (high vs. low). Neither the main effect of C_1V contingency and that of VC_2 contingency on % onset-coda errors was significant ($F(1,19) = 1.069$, $p > .1$, and $F(1,19) = .0018$, $p > .5$). Nor was there an interaction ($F(1,19) = .486$, $p > .4$). Thus, the following analysis only focuses on % onset-vowel retention error based on the sum of CV and VC retention errors only.

A visual inspection of the figure suggests that the onset-vowel sequence does not seem to have been retained equally across the three types of to-be-recalled stimuli. Particularly, in the case of '**CV**+vc' to-be-remembered stimuli (the left-most bar in the figure), it is apparent that proportionally more C_1V was retained as a group, compared to the percentage of C_1V from 'cv+**VC**', 'cv+vc', and 'CV+VC' stimuli. In order to examine whether the proportion of the onset-vowel retention errors was different depending on the to-be-remembered stimuli, the % onset-vowel retention error was analyzed in a 2x2 repeated-measures analysis of variance using the factors of C_1V contingency (high vs. low) and VC_2 contingency (high vs. low). The analysis revealed a significant effect of the contingency of onset-vowel sequences ($F(1,19) = 12.717$, $p < 0.005$) on the % onset-vowel retention error. More onset-vowel retention errors occurred from stimuli with a high contingency onset-vowel sequence than from stimuli with a low contingency onset-vowel sequence. The effect of the contingency of Vowel-Coda sequences (on the % onset-vowel retentions) was not significant ($F(1,19) = 2.968$, $p > 0.1$). There was no significant interaction between the contingency of Onset-Vowel and that of Vowel-Coda sequences ($F(1,19) = 1.948$, *ns*.). Post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. A significant difference in % onset-vowel retention was found between the High CV group stimuli (i.e., **CV**+vc and **CV**+VC) and Low CV group stimuli (i.e., *cv*+VC and '*cv*+vc') ($p < .05$). In contrast, the difference in % onset-vowel retention between High VC group stimuli (i.e., 'cv+VC' and 'CV+VC') and Low VC group stimuli (i.e., 'CV+vc' and 'cv+vc') was not significant ($p > .1$).

The above analysis thus suggests that the types of two-phoneme segments retained most often were different, crucially, depending on the types of to-be-remembered stimuli. In order to further examine this, I examined the C_1V and VC_2 retention error totals (again excluding C_1C_2 retention errors) for '**CV**+vc', 'cv+**VC**', 'cv+vc', and '**CV**+**VC**' in a chi-square statistic. The actual counts and the expected counts are reported in Table 4.15, with the result of $\chi^2 = 20.234$, $df = 3$, $p < .001$, providing additional evidence that the units that were retained most often were different as a function of the stimuli types.

Table 4.15 Chi-square table for C_1V and VC_2 retention errors in English STM

		<u>CV</u>+vc	cv+**<u>VC</u>**	cv+vc	**<u>CV</u>**+**<u>VC</u>**	Total
C_1V	Count	118	59	75	80	332
	Expected	93.8	75.4	82.2	80.3	332
	%	36%	18%	23%	24%	100%
VC_2	Count	76	97	95	86	354
	Expected	100.1	80.5	87.7	85.6	354
	%	21%	27%	27%	24%	100%
	Count	194	156	170	166	686
Total	Expected	194	156	170	166	686
	%	28%	23%	25%	24%	100%

Lastly, I examined the type of the two-phoneme sequence that was retained most often for each of the four types of to-be-remembered stimuli separately. For the stimuli type of '**<u>CV</u>**+vc', retention of C_1V (55%) sequences significantly outnumbered retention of VC_2 (36%) and C_1C_2 (9%) sequences. However, the pattern was different for the stimuli types 'cv+**<u>VC</u>**' and 'cv+vc'. In these two types of stimuli, VC_2 retentions significantly outnumbered retentions of C_1V and C_1C_2 sequences.[20] In the case of 'cv+**<u>VC</u>**', retention of VC_2 was 54%, which was significantly more than the retention of C_1V (33%) or C_1C_2 (14%). In the case of 'cv+vc', retention of VC_2 was 48%, which was significantly more than the retention of C_1V (38%) or C_1C_2 (14%). Interestingly, the number of C_1V (42%) and VC_2 (46%) retention errors did not

[20] Sign-tests were performed for each of the three types of stimuli, specifically comparing the number of C_1V with VC_2 retention errors across the subjects. C_1V retentions significantly outnumbered VC_2 retentions for 'CV + vc' type stimuli (Z score for 'CV + vc' = 2.77, p = 0.003, one-tailed). In contrast, VC_2 retentions significantly outnumbered C_1V retentions for 'cv + VC' and 'cv + vc' type stimuli (Z score for 'cv + VC' = 2.214, p = 0.013, one-tailed, and Z score for 'cv + vc' = 1.686, p = 0.046).

differ significantly from each other in the case of '**CV**+**VC**' stimuli by a Sign-test (Z score = 0.512, p = 0.304 (one-tailed)).

4.3.4 Discussion

Overall, the results indicate that when phonemic contingencies are contrasted at the sub-syllabic level, the inter-phoneme contingencies exert a significant influence on the types of two-phoneme retention errors. With a to-be-remembered CVC syllable, when the contingency was higher for the vowel and the final consonant, these two tended to be retained. In contrast, when the contingency was higher for the initial consonant and the vowel, they were retained as a group significantly more often than the vowel and the final consonant sequence. This pattern is certainly inconsistent with the view that English CVC syllables are coded in terms of onset and rime units (e.g., Treiman & Danis 1988). The model that posits explicit sub-syllabic structures predicts that the vowel and final consonant (i.e., the traditional rime) should always less likely separate into their components phonemes in STM tests, regardless of the differences in the strength of cohesiveness governing CV and VC at the intra-syllabic level. The finding from '**CV**+vc' type stimuli, however, clearly shows that the traditional rime was not always retained most often. The result from '**CV**+vc' stimuli also excludes the possibility that the English CVC stimuli simply broke into two regions, the boundary of which is the transition between the first consonant and the vowel. If this were the case, then we should have observed preponderance of VC_2 errors regardless of the stimuli types, which was not in fact the case.

The strongest version of probabilistic model of English syllable internal structure also cannot account for the full range of the obtained data either, particularly the finding from 'cv+vc' type stimuli. It predicts that the number of C_1V and VC_2 retentions should not significantly differ. VC_2 retentions, however, did outnumber C_1V retentions in this type of stimuli. As was suggested for the Korean 'cv+vc' type stimuli, the recall advantage obtained for VC_2 sequences from the 'cv+vc' to-be-remembered words may have to do with English speakers' sensitivity to the fact that there are strong probabilistic constraints on the VC combinations in the vowel and coda sequences. Implicit knowledge of these phonotactic regularities in English could have facilitated reconstruction of the original VC sequence, especially in the context where the original to-be-remembered syllables only provide a very unfamiliar sequence of sounds, namely 'cv+vc'. In the case of '**<u>CV</u>**+**<u>VC</u>**', the benefit of this knowledge of the skew present in English VC sequences may have been minimal, since the stimuli consisted of CV and VC sequences which were equally quite familiar. Overall, the current findings from English STM test indicate contributions of two factors to the recall of English CVC nonwords: (i) English speakers' knowledge of the difference in the two-way contingencies between onset-vowel and vowel-coda sequences within a syllable and (ii) English speakers' more global knowledge of stronger probabilistic constraints on the VC combinations in general than on the CV combinations in English.

One thing that is relatively clear from the discussion so far is that a view of syllable structure that assumes a rigid template of syllables coded in terms of onset and rime only is least capable of accounting the relevant findings, and accordingly is the least plausible model of English syllable structure. To the extent that the recombination errors from STM tests reveal the internal structure of English syllables, an alternative to the onset-rime model, while still maintaining a hierarchical structure of English syllables, might be to say that English syllables exhibit a sort of variable geometry, namely, onset-rime as well as body-coda, with a strong preference for the former when the effects of other factors (such as the phonotactic probabilities) are not at play.

I would argue, however, that a less radical and more plausible interpretation of the findings than this would be to view English syllables as a prosodic unit with no predetermined internal structure, while acknowledging the special role of the generally higher contingencies for vowel-coda sequences in this language. That is to say that, similar to the current proposal for the body in Korean, the 'rime' unit, apparent in the data from 'cv+vc' type stimuli, may not exist as primitives of syllable organization, but are instead the result of the stronger contingency of vowel and coda combinations in general. That is like Korean learners, English users also acquire this knowledge, as a part of their vocabulary learning, and it becomes a part of their phonological grammar, to the extent that they guide certain linguistic behaviors like the elicited speech errors reported here. If this is the case, then the English STM results are also in favor of the emergent model of syllable structure, which hypothesizes that certain salient sub-syllabic clustering of syllable terminal segments is the result of speakers' sensitivity to the two-way dependencies that are in general much stronger in their native language.

One advantage of adopting this model, as was mentioned for the Korean case above, is that it allows us to account for the emergence of certain dominant units at the sub-syllabic level in a given language without excluding the possibility of any other conceivable aggregations of phoneme sequences within a syllable, namely VC_2 as a unit in Korean and C_1V as a unit in English. More generally, this model allows us to account for the difference between the two languages at the sub-syllabic level in a way that does not complicate the process of acquiring the syllable structure of any one language. The hierarchical models of syllable structure, especially the ones that are based on parameterized UG approach to language acquisition, have relied on the difference in branching within syllable in order to account for the difference between two languages like Korean and English (see Yoon & Derwing, 2001 for a relevant discussion). The assumption has been that languages should initially allow multiple branching options within the syllable in order to accommodate the variability found in natural languages, and what language-learning children do is to sort out the appropriate subset of branching structures that are suitable for the language that they are learning. The model that the current thesis puts forward, however, does not require such a separate learning process tailored specifically for the domain of learning the syllable structure. Under the emergent model, acquiring syllable structure is a consequence of vocabulary learning for both language speakers and the difference lies only in terms of the two-phoneme sequences to which they fine-tune themselves, as their vocabulary learning continues.

4.4 Summary of Korean and English STM study results

Previous contrastive studies of the internal structure of Korean vs. English syllables usually came to a conclusion that the two languages have syllable internal structures that are incompatible with each other. The current findings, however, suggest that descriptions of CVC syllables of the two languages may not necessarily require such two distinct structures at the sub-syllabic level. In some sense, one may even say, on the basis of the current findings, that the two languages are

Table 4.16 Chi-square table for two-phoneme retention errors from '**<u>CV</u>**+vc' stimuli in Korean and English STM tests

Language		CV errors	VC errors	Total
	Count	274	133	407
Korean	Expected	265.5	141.5%	407
	%	67.3%	32.7%	100%
	Count	118	76	194
English	Expected	126.5	67.5	194
	%	60.8%	39.2%	100%
	Count	392	209	601
Total	Expected	392	209	601
	%	65.2%	34.8%	100%

more similar than different in terms of syllable structure, contrary to what has been claimed before. This seems quite plausible especially given the findings from '**<u>CV</u>**+vc' and 'cv+**<u>VC</u>**' type stimuli in both languages. This claim can be made more explicit, for example, by examining the kinds of two phoneme retention errors from the two types of stimuli (i.e., '**<u>CV</u>**+vc' and 'cv+**<u>VC</u>**') in the two languages in a chi-square test. First, for '**<u>CV</u>**+vc' to-be-remembered stimuli, the actual counts and the expected counts are reported in Table 4.16. The result (χ^2 = 1.138, *df* = 1, p = .286) was not significant, lending support to the conclusion that the sequence of segments that retained most often in 'CV+vc' syllables was not different in the two languages.

Likewise, the actual counts and the expected counts for 'cv+**<u>VC</u>**' to-be-remembered stimuli are reported in Table 4.17 with the result being χ^2 = 1.138, *df* = 1, p = .286, again providing a piece of evidence to conclude that the unit of segments retained from this type of

Table 4.17 Chi-square table for two-phoneme retention errors from 'cv+**VC**' stimuli in Korean and English STM tests

Language		CV errors	VC errors	Total
	Count	201	270	471
Korean	Expected	195.3	275.7	471
	%	42.7%	57.3%	100%
	Count	59	97	156
English	Expected	64.7	91.3	156
	%	37.8%	62.2%	100%
	Count	260	367	627
Total	Expected	260	367	627
	%	41.5%	58.5%	100%

stimuli was not different in the two languages either.

The units of most often retained segments, however, were different in the two languages for stimuli whose C_1V and VC_2 components were not contrasted ($\chi^2 = 21.018$, $df = 1$, $p < .001$), i.e., both low cv + low vc stimuli, as shown Table 4.18. As noted above, data like this would require two distinct syllable types (left-branching for Korean and right-branching for English) under the hierarchical model. Under the model that this dissertation proposes, however, even the existence of a difference like this can be understood in terms of the effect of a process that is common in the two languages, namely, speakers' gradual acquisition of the fact that the correlations existing between certain segments may be 'special' in their language and the salient syllable subcomponents emerge as a consequence of this. As also noted above, one additional advantage of this particular interpretation of the result reported in Table 4.18 is to allow for the

Table 4.18 Chi-square table for two-phoneme retention errors from 'low cv + low vc' stimuli in Korean and English STM tests

Language		CV errors	VC errors	Total
	Count	245	132	377
Korean	Expected	220.5	156.4	377
	%	64.9%	35.0%	100%
	Count	75	95	170
English	Expected	99.4	70.5	170
	%	44.1%	55.8%	100%
	Count	320	227	547
Total	Expected	320	227	547
	%	58.5%	41.4%	100%

possibility that speakers of Korean and English can learn sub-syllabic dependencies other than the 'special' correlations in their own language. The findings from '**CV**+vc' and 'cv+**VC**' type stimuli from both languages are a piece of evidence that supports this. I further examine the consequence of adopting an emergent model of syllable-internal structure in the next chapter using the experimental technique of wordlikeness judgments.

CHAPTER 5

Wordlikeness Judgments of English and Korean CVC Nonwords

5.1. Introduction

An important finding of Chapter 4 is that Korean and English speakers are sensitive to the statistical dependencies between phonemes at the sub-syllabic level. Specifically, to the extent that two-phoneme retention errors reflect speaker's sensitivity to the dependencies of two-phoneme sequences, the STM data, first, indicate that both Korean and English speakers are sensitive to what one may call the 'statistical skew' existing in their native language. This was apparent from the finding that given a 'cv+vc' stimulus (where the dependencies of the segment sequences are relatively low), the speakers of both languages better remembered the sequence of segments that have on average higher inter-phoneme dependencies in the lexicon of their native language. Secondly, the STM data also indicate that both Korean and English speakers are sensitive to what one may call 'cross-position' differences in dependencies. That is, given a CVC syllable, both Korean and English subjects seem to know that which of the two pairs of adjacent segments (i.e., either CV or VC) is higher in terms of the inter-phoneme dependency. This was apparent from the finding that the speakers of both languages remembered onset-vowel sequences better than vowel-coda sequences from '**<u>CV</u>**+vc' stimuli and that they also remembered vowel-coda sequences better than onset-coda sequences from 'cv+**VC**' stimuli.

If speakers of both languages know the general statistical characteristic as well as the cross-position differences in dependencies within the syllable, then it is also possible that the speakers know what one may call 'within-position' differences in dependencies. That is, it is possible that the speakers of both languages may know that the two-way contingency involving a certain onset-vowel sequence is stronger than the one involving another particular onset-vowel sequence, as well as that the two-way contingency involving a certain vowel-coda sequence is stronger than the one involving another particular vowel-coda sequence. That is, the speakers not only know the contrast between '**CV** vs. vc' and cv vs. **VC** (as the STM study demonstrates) but also the contrast between '**CV** vs. cv' (and likewise the contrast between '**VC** vs. vc').

Thus, the major goal of the study reported in the current chapter is to examine the effects of not just the 'primary' components (rime in English and body in Korean) but also the other parts of the syllable in the languages, using an additional experimental technique, called wordlikeness judgment tasks. Two particular questions that were asked with the tasks are the following. First, I asked whether speakers of English are aware that certain sequences of vowel-coda are more contingent other than other sequences of vowel-coda. An affirmative answer to the question would indicate that speakers of English have developed a sensitivity to the distributional patterns involving the segments inside the particularly salient sub-syllabic unit of English syllables. Second, I asked whether speakers of English are also aware that certain sequences of onset-vowel are more contingent upon each other than other particular sequences of onset-vowel. An affirmative answer to this question would indicate that speakers of English have developed similar sensitivity in the case of sub-syllabic dependencies other than the 'primary/salient' component of the syllable, i.e., the rime. Positive answers to these two questions would then lend an additional support to the emergent model developed based on the findings from the STM tests, which predicts English speakers' sensitivity to the different degrees of two-way dependencies of two-phoneme sequences inside the syllable even if the sequences are not the ones occurring inside the rime unit. The same questions were also asked for Korean.

5.2. Experimental Design

5.2.1. Wordlikeness experiment

Previous studies have shown that nonwords vary in terms of the likelihood of their being an actual word of a language. This subjective judgment of the typicality of certain sound sequences as actual words in a listener's native language is referred to as wordlikeness. Previous studies such as Bailey and Hahn (2001) showed that these judgments correlate with two factors: (i) the degree of similarity of the nonword to real words (referred to as 'neighborhood density effect'), and (ii) the frequency with which components of the nonword occur in real words (referred to as 'phonotactic probability effect').

First regarding (i), phonological neighborhood is often defined as a set of words that differ from a given target word by one phoneme substitution, addition, or deletion (Charles-Luce & Luce, 1990, Landauer & Streeter, 1973, Luce, 1986, Luce & Pisoni 1998). According to this metric, the neighborhood density of, for example, [hæt] is 32, as shown in (14), which is adopted from De Cara & Goswami (2002). Researchers such as Greenberg & Jenkins (1964) and Ohala & Ohala (1986) showed that the greater the neighborhood density of a nonce form, the greater its wordlikeness.

(14)	vat,that,tat,rat,pat,matt,mat,gnat,gat,fat,chat,cat,bat,at	[X**æt**]
	hut,hurt,hot,hoot,hit,height,heat,heart,hate,hart,	[**h**X**t**]
	have,hatch,hash,hap,hang,ham,hag,hack	[**hæ**X]

Second, regarding (ii) which is the focus of the investigation in the current study, Coleman & Pierrehumbert (1997) calculated the expected frequency of, for example, [tip] by determining the frequency of [t] and the frequency of [ip], and multiplying them together (i.e., P(tip) = P(t) x P(ip)). They asked subjects to judge whether each word could or could not be a possible English word. The results showed that subjects' judgments correlated with the frequency of the phonological constituents that make up the nonce forms. Building on Coleman and

Pierrehumbert (1997), Frisch, Large, and Pisoni (2000) used a corpus of nonwords with more variety of length and with a wider range of probabilities. Their data also confirmed Coleman and Pierrehumbert's results, reporting that wordlikeness judgments were higher for nonwords containing high-probability constituents.

More directly relevant to the current thesis are wordlikeness studies such as Treiman et al. (2000) and Perruchet & Peereman (2004). They specifically looked at the relative contribution of more frequently occurring vowel-coda sequences *vs.* less frequently occurring vowel-coda sequences to the subjective judgment of goodness of English nonwords. Treiman et al. (2000) presented adults and children subjects with pairs of nonsense syllables differing by their vowel-coda frequency. For example, /r**up**/ and /n**ɚk**/ had vowel-coda sequences that occur more frequently in English than /r**uk**/ and /n**ɚp**/. They asked subjects to rate the stimuli on a scale of wordlikeness from 1 ("doesn't sound at all like an English word) to 7 ("sounds very much like an English word). They found a reliable difference between the stimuli with more frequently occurring vowel-coda sequences and the stimuli with less frequently occurring ones, suggesting English speaking subjects' sensitivity to the frequency difference concerning vowel-coda sequences. Perruchet & Peereman (2004), inspired by Treiman et al. (2000), tested French speaking children and adults, using pairs of nonsense French syllables differing by 'vowel-coda' frequency, as assessed by two-way dependencies between the segments. Perruchet & Peereman (2004) showed that the judgment of French speaking children and adults as to the wordlikeness of CVC nonsense syllables are influenced by the degree of association between the vowel and coda segments.

These studies provide an answer to one of the two questions that this chapter explores, namely whether speakers of English, in particular, have developed a sensitivity to the difference in phonotactic probabilities governing the vowel and coda sequences. In the current chapter, I undertake a replication of these studies for English. I also explore whether the same pattern holds true for Korean, that is whether the judgment of Korean speaking subjects as to the wordlikeness of CVC nonsense syllables are influenced by the degree of association between the onset and coda. This will be an independent contribution of the current study in wordlikeness literature. A prediction based on English and French is that Korean nonce words containing a highly-contingent onset-vowel sequence would be rated as a better sounding Korean word than nonce words containing a low probability onset-vowel sequence.

A second independent contribution of the current study comes from the second major question that this chapter asks, namely whether speakers of English and Korean have developed a similar sensitivity in the case of sub-syllabic dependencies for segment sequences other than vowel-coda for English and onset-vowel for Korean. If they have developed such sensitivity, then English-speaking subjects would judge nonce words containing a highly-contingent onset-vowel sequence to be better sounding English words than those containing a low probability onset-vowel sequence. Likewise, wordlikeness ratings would be higher for Korean nonwords containing a high-probability vowel-coda sequence than a low-probability vowel-coda sequence.

5.3. English Wordlikeness Experiment

5.3.1. Method

Participants. Thirty-six undergraduate students (27 female, 9 male) earning experimental credit for their introductory linguistics courses participated. The results from one male (Russian L1) and three female (2 Mandarin Chinese L1 and 1 Korean L1) speakers were excluded from the further analysis. All others reported that they were native speakers of English with little or no L2 background, and that they had no previous history of speech or hearing impairments.

Stimuli. Each subject judged the goodness of a total of 48 CVC nonwords as a possible English word. The 48 words reflect 24 pairs of CVC syllables that differ from each other by only one phoneme (2 CVC syllables in each pair x 24 pairs = 48 words). The two

Table 5.1. A sample of English wordlikeness test stimuli

Rime Varying				**Body** Varying			
Set A		Set B		Set C		Set D	
H+**H** vs. H+**L**		L+**H** vs. L+**L**		**H**+H vs. **L**+H		**H**+L vs. **L**+L	
vɚ**tʃ**	vɚ**k**	fɪ**p**	fɪ**tʃ**	**s**if	**h**if	**θ**ʌk	**n**ʌk

Note: Each set consisted of six pairs of two contrasted CVC syllables.

members of each pair were designed to contrast in a way that is explained below (see Appendix 5 for the English wordlikeness test stimuli). As an illustrative purpose, four such pairs of the test stimuli (representing the four different sets of stimuli in the experiment) are given in Table 5.1.

Note that Set A and B are referred to as 'rime varying' and that Set C and D are referred to as 'body varying'. Each of the rime varying pairs consisted of two CVC nonwords that were identical to each other except the final consonant. This was done in order to contrast the two syllables in each pair in terms of the strength of the two-way dependency of 'vowel-coda' (VC) sequence, as assessed by Rho. So, for example in Table 5.1, /vɚ**tʃ**/ had a high Rho VC sequence, while /vɚ**k**/ had a low Rho VC sequence.[21] Note also that the rime-varying pairs were further divided into two subsets as a function of the relative strength of the onset-vowel (CV) dependency. For example, the Rho of CV sequence in /vɚtʃ/ vs. /vɚk/ pair in Set A was set high (i.e., /vɚ/ had a high Rho value), while the Rho of CV sequence in /fɪp/ and /fɪtʃ/ pair in Set B

[21] As was in the STM test stimuli, a high Rho two-phoneme sequence refers to a sequence whose Rho was higher than the median Rho computed across either all CV or VC sequences in English. A low Rho two-phoneme sequence had a Rho value lower than the appropriate median.

was set low (i.e, /fɪ/ had a low Rho value). Previous studies examining the role of the frequency of rime constituent in English wordlikeness judgments (such as Treiman et al., 2000) were not clear about how the frequency of the sub-syllabic constituent other than the rime was controlled in their test stimuli. In order to interpret the results better, the current study specifically controlled this potentially confounding factor.

Likewise, the body-varying pairs (Set C and D) consisted of two CVC nonwords that were contrasted for the strength of the two-way dependency of onset-vowel sequence. So, for example, /**si**f/ had a high Rho CV sequence, while /**hi**f/ had a low Rho CV sequence. The body-varying pairs were also further divided into two (i.e., Set C and D) as a function of the relative strength of the vowel-coda dependency (the Rho of vowel-coda in Set C was set high, while the Rho of vowel-coda in Set D was set low).

Each of the four sets contained six pairs of CVC nonwords (4 sets x 6 pairs in each set = 24 pairs of CVC nonwords = a total of 48 words). The means and SDs of Rho values for the CV and VC sequences in each set are given in Table 5.2. For example, the mean of Rho values of vowel-coda sequences in 'H+**H**' in Set A was 0.0792. The mean of Rho values of vowel-coda sequences in 'H+**L**' in the same set was 0.0089. This difference was statistically significant by one-tailed t-test ($t(5) = 6.382$, $p < 0.01$). The differences of the remaining contrasted sequences

Table 5.2. Means and SDs of stimuli used in English wordlikeness experiment

	4 sets of pairs		Onset-Vowel		Vowel-Coda	
			Mean	SD	Mean	SD
Rime Varying	A	H+**H**	0.0491	0.0136	0.0792	0.0268
		H+**L**	same as above		0.0089	0.0065
	B	L+**H**	0.0057	0.0053	0.0760	0.0311
		L+**L**	same as above		0.0200	0.0121
Body Varying	C	**H**+H	0.0660	0.0538	0.0615	0.0189
		L+H	0.0034	0.0022	same as above	
	D	**H**+L	0.0547	0.0166	0.0138	0.0112
		L+L	0.0094	0.0066	same as above	

in Set B, C, and D were also significant, i.e., Set B: $t(5) = 4.801$, $p < 0.01$, Set C: $t(5) = 2.897$, $p = 0.02$, Set D: $t(5) = 5.619$, $p < 0.01$ (all one-tailed).

Regarding the order in which the stimuli were presented to the subjects, the following considerations were taken into account. First, the two members of a particular contrasting pair in a given set did not immediately precede or follow each other. Thus, the /vɚtʃ/ and /vɚk/ syllables in Set A, for example, never appeared immediately adjacent to each other. In addition to this, as can be seen in Table 5.1 and 5.2, stimuli that are similar in terms of the Rho values of their components occurred across the different sets, e.g., H+H in Set A and H+H in Set C. I further restricted the order of the presentation of the stimuli such that such comparable syllables did not occur next to each other. The order of the presentation of the stimuli constrained by these two factors yielded a total of 16 orders. Each order had two subjects assigned to it (i.e., 16 orders x 2 subjects each = total of 32 subjects).

A (phonetically trained) female native speaker of English produced a spoken version of the 48 nonwords. The talker read the nonwords transcribed in IPA. The digitally recorded nonwords were edited later using the Praat speech software in order to make the 16 orders of presentation. The recording occurred in a sound-attenuated booth, using a Marantz tape recorder and a Condenser microphone.

Magnitude estimation of linguistic acceptability technique. Previous wordlikeness experiments usually asked subjects to rate the nonwords for their wordlikeness on a 7-point scale, 1 being 'highly unlikely as an actual word', 7 being 'highly likely as an actual word', and the intermediate numbers being 'medium likely/unlikely as an actual word'. The rating method used in the current experiment did not use this 7-point scale of wellformedness. Instead, the method used was 'magnitude estimation' as proposed by Lodge (1981) and extended to linguistic stimuli by Bard, Robertson, and Sorace (1996). This method has been used in various linguistics studies, and is discussed at length in Bard et al. (1996) and Cowart (1997), so I sketch it only briefly here. In a magnitude estimation experiment, subjects are presented with an initial stimulus (referred to as a modulus) and are asked to express grammaticality judgments about the wellformedness of the modulus by a numerical number. In the experiment reported here, following the standard protocol of magnitude estimation, subjects were asked to judge the goodness of a modulus CVC nonword as an actual English word by providing a number of their own choice, like 20. The subjects were then presented with the rest of the test stimuli and were asked to assign a number to each of the following stimuli *in proportion* to the modulus. For example, if the stimulus immediately following the modulus sounded twice as good as an actual English word as the modulus, the stimulus (immediately following the modulus) gets a score of 40, or if the stimulus sounded half as good as an actual English word as the modulus, then the stimulus gets a score of 10. Unlike the traditional 7-point scale, these characteristics of the magnitude estimation basically allows us to observe more finely differentiated grammaticality judgments by asking subjects (i) to state how many times better or worse a stimulus A is than a stimulus B, (ii) to provide such judgments with a scale that is open-ended and has no minimum division, and (iii) to provide purely comparative judgments relative to their own previous judgments during the experiment. When the limitation imposed by such scale as the 7-point scale is removed in this way, the results obtained may provide potentially more linguistically important differentiations, which otherwise can be undetected.

Procedure. I went over with the participants the instructions that detailed the concept of magnitude estimation (see Appendix 6 for the instructions used). Participants were told that their task was to judge how good or bad each nonword as a potential English word by assigning a number to it. It was emphasized that they can use any range of positive numbers that they like including, if necessary, fractions or decimals, and that they should not restrict their responses to an academic grading scale. It was also emphasized that they should evaluate each of their judgments in proportion to the reference word. They were encouraged not to spend too long thinking about their judgment.

The stimuli were played by computer over a speaker in a quiet room. Participants indicated their responses using pen on a response sheet. The test stimuli were preceded by a practice set of stimuli to familiarize the participants with applying the magnitude estimation to wordlikeness judgment.

5.3.2. Results

Following the standard practice of magnitude estimation, as it is applied in evaluating linguistic judgments, I first normalized the data by dividing each numerical judgment by the modulus value that the subject had assigned to the modulus nonword stimulus. For example, if a subject gave 10 to the modulus, the normalized value of the modulus is 1 (i.e., 10/10). If a subject gave 20 to the second stimulus, the normalized value of the second item is 2 (= 20/10). This operation

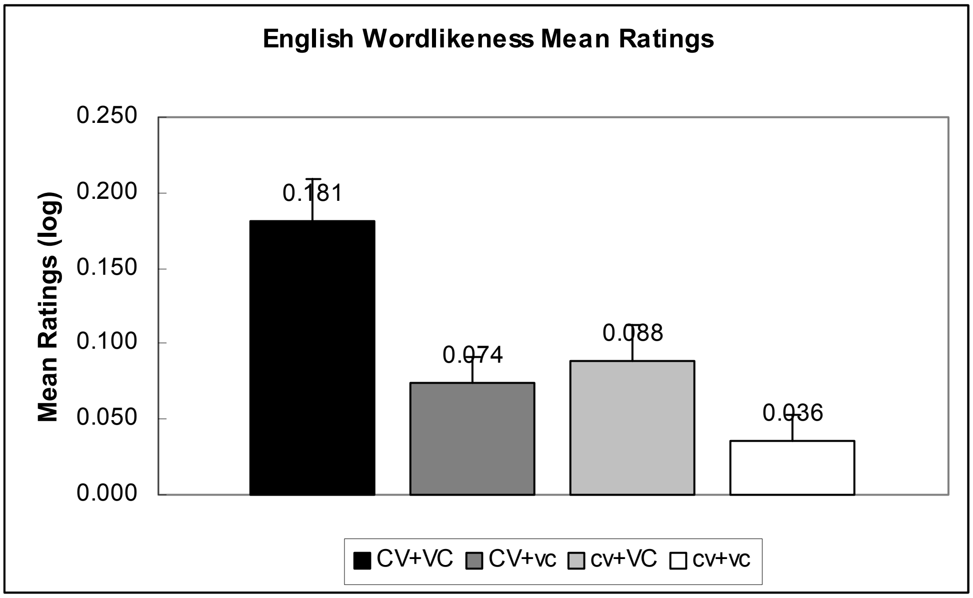

Figure 5.1 Mean subjective ratings (in log): English wordlikeness test.

creates a common scale for all subjects. Then the data were transformed by taking the logarithm with base 10. Thus, the transformed value of the modulus is now $\log_{10}(1) = 0.00$ and the transformed value of the second stimulus is now $\log_{10}(2) = 0.30$. This transformation ensures that the judgments are normally distributed and is standard practice for magnitude estimation data (Bard et al., 1996; Lodge, 1981). All analyses were conducted on the normalized, log-transformed judgments.

Figure 5.1 displays the means ratings of wordlikeness (in $\log_{10}$) for the four types of stimuli (**H**+**H**, **H**+L, L+**H**, and L+L). Recall that each of these four types of stimuli appeared in two different sets. For example, the '**H**+**H**' type appeared in '**H**+**H** vs. **H**+L' contrast (in Set A 'rime varying') and also appeared in '**H**+**H** vs. L+**H**' contrast (in Set C 'body varying'). The mean rating of **<u>H</u>**+**<u>H</u>** in Figure 5.1 reflects the average of the mean ratings of the two. The same principle applies to the rest three types of stimuli.

The mean ratings were analyzed in a 2 x 2 repeated-measures analysis of variance using the factors of C_1V contingency (high vs. low) and VC_2 contingency (high vs. low). The analysis revealed a significant main effect of the contingency of vowel-coda sequences, i.e., the effect of the rime contingency ($F(1,31) = 6.956$, $p = .01$) on the mean ratings. Importantly, the main effect of the onset-vowel contingency was also significant ($F(1,31) = 4.884$, $p < .05$). In addition, there was a significant interaction between the contingency of vowel-coda and that of onset-vowel sequences ($F(1,31) = 4.816$, $p < .05$). Post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. A significant difference in average ratings was found between the High CV group stimuli (i.e., **H**+L and **H**+L) and the Low CV group stimuli (i.e., *L*+H and '*L*+L') ($p < .05$). Another comparison that was significant was involving the High VC group stimuli (i.e., 'L+**H**' and 'H+**H**') on the one group and the Low VC group stimuli (i.e., 'H+*L*' and 'L+*L*') on the other ($p < .05$).

The data reveal three things with regard to English listeners' sensitivity to the 'within-position' differences in dependencies: (i) First, as consistent with previous studies (e.g., Treiman et al., 2000), English users are aware that a particular vowel-coda sequence is "better" than another particular vowel-coda sequence. This is reflected in a higher mean rating for the stimuli with high Rho VC sequences than for the stimuli with low Rho VC sequences. (ii) Second, English listeners are also (equally well) aware that a particular onset-vowel sequence in English is "better" than another particular onset-vowel sequence. This is reflected in a higher mean rating for the stimuli with high Rho CV sequences than for the stimuli with low Rho CV sequences. This, thus, seems to suggest that English listeners' sensitivity to the contingencies between adjacent phonemes within CVC syllables is not restricted to the particular unit of English syllables, that is, to the sequences occurring inside the unit that is special in English (i.e., vowel-coda). Rather the finding suggests that the statistical sensitivity can extend to sequences of segments that are not statistically special in the lexicon of English. (iii) Finally, as is apparent from the interaction, the effect of the contingency on wordlikeness ratings seems to be cumulative, i.e., the effect of rime contingency on the rating gets much bigger when the contingency of the onset-vowel sequence within the same syllable is also high. For this compare the mean rating for the 'H+H' nonwords with that for the 'L+H' nonwords in which case only the contingency of the rime is high.

The findings reported in (i-iii) are based on the pooled data across the participants only. In the following I report how the differences in wordlikeness rating fared when they were

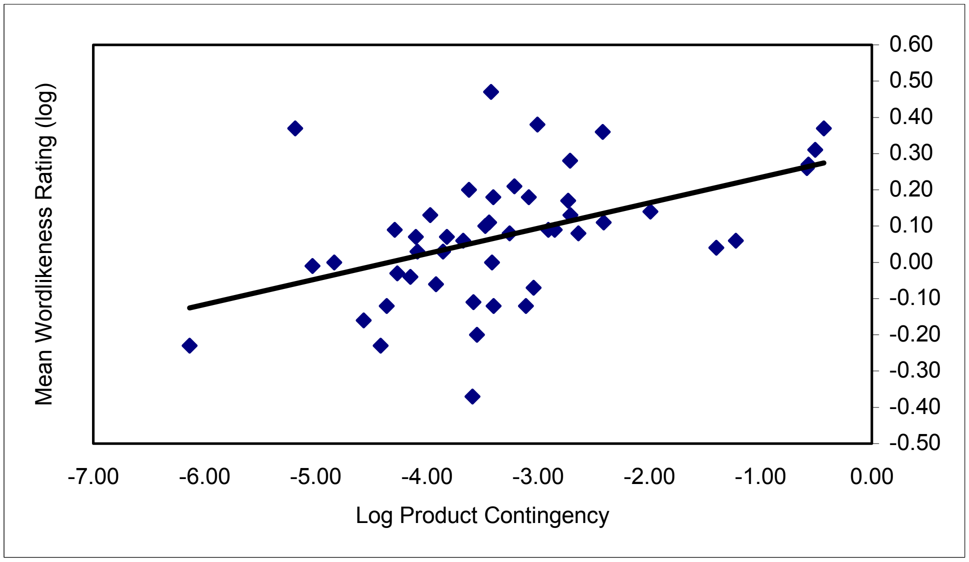

Figure 5.2 Mean subjective ratings for each nonword in English wordlikeness experiment as a function of the log product of onset-vowel and vowel-coda contingencies for the nonword (R Sq Linear = 0.232)

computed across the items. For this, I computed the log product contingency of every test stimulus used in the experiment. This was done by multiplying the contingencies of the syllable's two subcomponents, i.e., 'Rho of C_1V-' x 'Rho of -VC_2' (adopting the strategy in Coleman & Pierrehumbert 1997, Frisch, Large, and Pisoni 2000), and then transforming them by taking the logarithm with base 10.

Figure 5.2 displays mean ratings for every stimulus used in the experiment, as a function of log product contingency. The figure shows that the average ratings are reasonably well predicted by the product contingency (Pearson Correlation = 0.481, $p < .01$ (two-tailed)). That is, the general pattern is that, as the product contingency of a syllable gets bigger, the wordlikeness rating of the syllable also gets higher.[22]

5.3.3. Discussion

The major goal of this experiment was to further examine whether the sensitivity of English speakers to the 'cross-position' differences in contingencies (i.e., the contrast between '**CV** vs. vc' or 'cv vs. **VC**') that was demonstrated in the STM tests could be extended to the 'within-position' differences in contingencies (i.e., the contrast between 'CV vs. cv', or 'VC vs. vc'), using a different experimental task, namely the wordlikeness judgments.

For this, first, I asked whether English subjects are sensitive to the contingency of sequences of segments occurring inside the rime. The results indicated that they are. The subjects tended to judge /v**ɚtʃ**/ as more wordlike than /v**ɚk**/, for example, in line with the fact that /ɚtʃ/ is more contingent upon each other than /ɚk/. Second, I asked whether English subjects are also sensitive to the contingency of a sequence of syllable terminal segments outside the rime. The result shows that they are. The subjects tended to judge /**si**f/ as more wordlike than /**hi**f/, for example, in line with the fact that /si/ is more contingent upon each other than /hi/. In fact, it is apparent that the English subjects in the current study judged the '**H**+L' nonwords as possible English words as equally likely as the 'L+**H**' nonwords. They did not prefer the latter to the

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[22] As is apparent in Fig. 5.2, there were several outliers that scored an exceptionally high or low rating. The ones with an exceptionally high rating include /liθ/, /tætʃ/, and /nʌk/, which might have been heard as actual words, i.e., 'lease', 'attach', and 'knock', respectively. The one that scored an exceptionally low rating was /fɔɪz/ for which I don't have a good explanation.

former.

Regarding this latter finding, I should note that the current experiment is not the only one that found English subjects' sensitivity to the more frequent (contingent) vs. less frequent (contingent) onset-vowel sequences. For example, in their regression analyses of Experiment 1 in Treiman et al. (2000)'s study, they also found that English-speaking adult's wordlikeness ratings were influenced by the frequency of the *onset-vowel* as well as by the frequency of the vowel-coda. They simply could not make a strong claim about the role of the potential unit including onset and vowel because they did not directly manipulate the frequency of the onset-vowel sequence in their experiment. The present finding provides additional evidence for this.[23]

To summarize, the major finding of the current experiment is that English speakers are sensitive to within-position differences in dependencies in the sense that they know that a particular onset-vowel (or vowel-coda) sequence is more strongly associated with each other than another particular onset-vowel (or vowel-coda) sequence. As such, the current findings provide an additional support for the superiority of the emergent model of syllable internal structure over other alternative models of syllable structure, especially over the onset-rime model of English syllable structure. Particularly, under the emergent model, the special dependency

[23] In section 5.5., I will provide a further discussion about the current finding that our English subjects only showed 'general' sensitivity to wordlikeness, and did not prefer nonwords with a high-contingency rime to those with a high-contingency body.

pattern that involves vowels and codas in English is not considered as reflecting some kind of rigid sub-syllabic structural templates, excluding the possibility of any other conceivable grouping of segments with the syllable. That is, under the emergent model, though certain salient sub-syllabic dependencies can exist in a lexicon (e.g., the dependency existing for vowel and coda in English), the mere presence of such dependencies does not preclude the possibility that speakers of the language can learn sub-syllabic dependencies other than the salient pattern of segment co-occurrences. That English users in the current experiment showed sensitivity to the differences in dependencies involving onsets-vowels demonstrates that this is indeed the case.

Finally, the current findings provide an additional support for previous studies, which have demonstrated the graded aspect of wordlikeness judgments, and especially that judgments of nonwords are a function of (product) phonotactic frequencies of their components (Coleman & Pierrehumbert (1997), Frisch et al. (2000)). This can be seen by looking at Figure 5.2. This finding is certainly not consistent with the orthodox phonological theory that maintains that the relative contingency of a certain phoneme sequence should not bear on how wellformed the word that contains the sequence is. But the present finding is fully consistent with recent alternative views of phonology such as the stochastic phonological grammar in Coleman & Pierrehumbert (1997), showing the importance of probabilistic phonotactics in processing nonwords.

5.4. Korean Wordlikeness

5.4.1. Method

Participants. 10 native-speakers of Korean (7 female, 3 male), studying at Northwestern University, participated. They were paid for their participation. The mean duration of their stay in the U.S. was 2 years and 10 months. It ranged from 1 month to 5 years. There was one subject who was born in the U.S. but lived in Korea before she came back to the U.S. at the age of 10. Others came to the U.S. not earlier than at their age of 20. No one reported speech or hearing impairments at the time of the experiment.

Stimuli. As in the English wordlikeness experiment, each subject judged the goodness of a total of 48 CVC nonwords as a possible Korean word. The 48 nonce forms reflect 24 pairs of CVC syllables that differ from each other by only one phoneme. Specifically, 12 pairs of the stimuli were 'rime-varying' and another 12 pairs of the stimuli were 'body-varying', example of which are given in Table 5.3 (see Appendix 7 for the Korean wordlikeness test stimuli). As was the case in the English experiment, syllables of each pair in 'rime-varying' set contrasted in terms of vowel-coda contingency, while syllable of each pair in 'body-varying' set contrasted in terms of onset-vowel contingency. Note, however, that unlike the English wordlikeness experiment, 'H+**H**' vs. 'H+**L** and '**H**+H' vs. '**L**+H' comparisons are not present here in the

Table 5.3 A sample of Korean wordlikeness test stimuli

Rime Varying (12 pairs)		**Body** Varying (12 pairs)	
L+**H**	L+**L**	**H**+L	**L**+L
s'**ɨŋ**	s'**ɨt**	**mwu**p	**p'wu**p

Table 5.4 Mean and SD of stimuli used in Korean wordlikeness experiment

		Onset-Vowel		Vowel-Coda	
		Mean	SD	Mean	SD
Rime Varying	L+**H**	0.037	0.039	0.069	0.020
	L+**L**	same as above		0.012	0.029
Body Varying	**H**+L	0.096	0.051	0.003	0.044
	L+L	0.002	0.033	same as above	

Korean wordlikeness experiment. This is due to lack of sufficient number of 'H+H' syllables that are nonwords in Korean.[24]

The means and SDs of Rho values for the CV and VC sequences in each set are given in Table 5.4. The difference in means between the two contrasted VC sequences in the 'rime-varying' set was statistically significant by one-tailed t-test ($t(11) = 7.374$, $p < .001$). The differences in means between the two contrasted CV sequences in the 'body-varying' set was also significant as well ($t(11) = 8.190$, $p < .001$).

Two different orders of presenting the forty-eight CVC test stimuli were prepared. Each of the orders was made with the following considerations. First, the two members of a particular

24 As was in the STM test stimuli, a high Rho two-phoneme sequence refers to a sequence whose Rho was higher than the median Rho computed across either all CV or VC sequences in Korean. A low Rho two-phoneme sequence had a Rho value lower than the appropriate median.

contrasting pair did not immediately precede or follow each other. Thus, the /s'**ɨŋ**/ and /s'**ɨt**/ pair in the rime-varying set, for example, never appeared immediately adjacent to each other. Second, 'L+L' syllables never appeared immediately adjacent to each other. The subjects were assigned to either of the two orders. The two orders had same number of subjects assigned to it. I produced a spoken version of the 48 nonwords. The recording and editing method were same as the English experiment.

Procedure. The Korean wordlikeness experiment also used the magnitude estimation technique in soliciting the subjects' subjective judgments of the goodness of the nonwords as a possible Korean word. Procedure was identical to the English wordlikeness experiment.

5.4.2 Results and Discussion

As was in the English wordlikeness experiment, all analyses reported below are conducted on the normalized, log-transformed judgments. Figure 5.3 displays the means ratings of wordlikeness for the two sets of stimuli. Recall from Table 5.4 that the 'L+L' type appeared in the 'rime varying' set as well as in the 'body varying' set. The mean rating of 'L+L' in Figure 5.3 reflects the average of the mean ratings of the two.

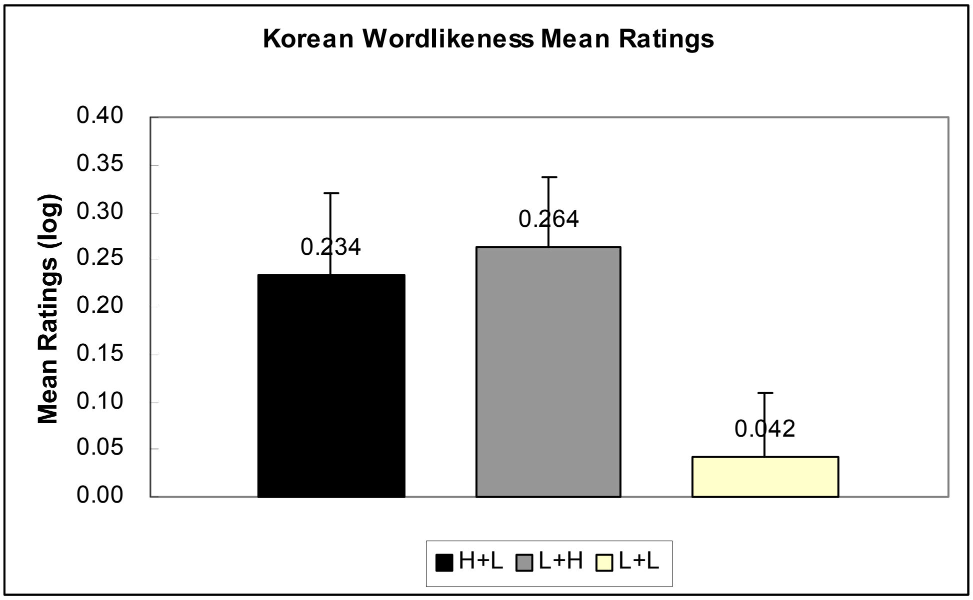

Figure 5.3 Mean Subjective ratings (in log): Korean wordlikeness test

The mean ratings were analyzed in an analysis of variance with the stimuli types (H+L, L+H, L+L) as a within-subject factor. The sphericity assumption was met. The main effect of stimuli type was significant ($F(2,18) = 17.434$, $p < .001$). Post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. The difference between ‘H+L’ and ‘L+L’ was significant ($p < .01$). The difference between ‘L+H’ and L+L’ was also significant ($p < .001$). The difference between ‘H+L’ and ‘L+H’ was not significant ($p > .1$).

The results suggest that, as consistent with the English wordlikeness results, Korean listeners are also sensitive to the different degrees of the ‘within-position’ differences in contingencies. Specifically, the Korean listeners are aware that a particular onset-vowel sequence is better than another particular onset-vowel sequence, which is reflected in a higher mean rating for nonwords with a high-contingency onset-vowel sequence than for nonwords with a low-contingency onset-vowel sequence. In addition, Korean listeners are aware that a particular vowel-coda sequence is better than another particular vowel-coda sequence, seen by a higher average rating for nonwords with a high-contingency vowel-coda sequence than for nonwords with a low-contingency vowel-coda sequence. This latter finding thus additionally indicates that, consistent with the result from the English wordlikeness test reported above, Korean listeners are also sensitive to the contingency of a sequence of segments outside the statistically salient unit within Korean syllables, namely the rime.

In addition to the average ratings computed across the subjects, the mean ratings were also examined across the items. Figure 5.4 (below) shows the result, displaying the mean ratings of every stimulus in the Korean wordlikeness test, as a function of log product contingency. Unlike the finding from the English wordlikeness experiment, there was no strong correlation between the mean rating and the log product contingency ($r = .264$, p = .07). In order to examine the possibility that the items in the 'body varying' set and those in the 'rime varying' set might have behaved differently, the mean ratings of the contrasted syllables in each pair of stimuli in the two sets were examined separately.

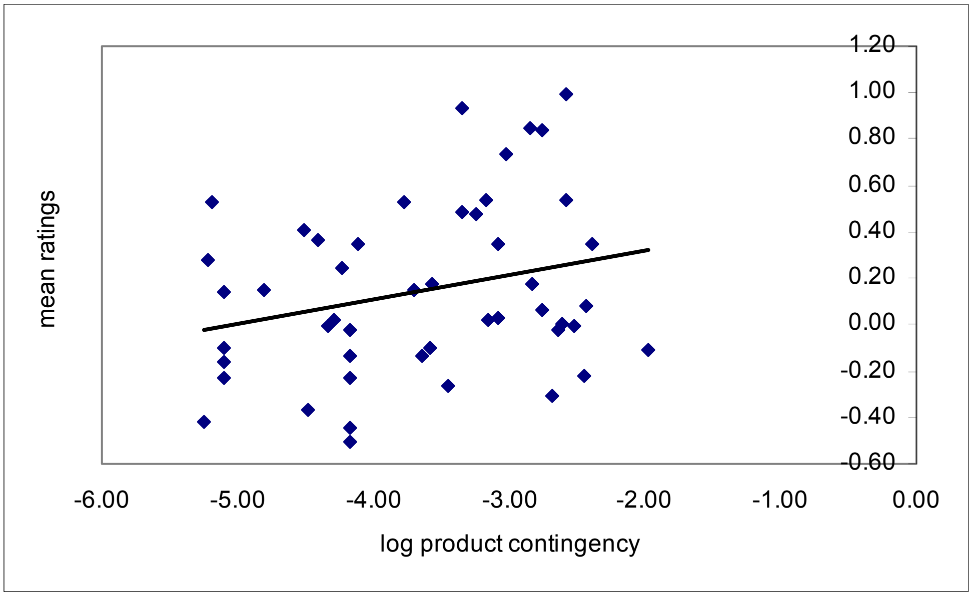

Figure 5.4 Mean subjective ratings for each nonword in Korean wordlikeness experiment as a function of the log product of onset-vowel and vowel-coda contingencies for the nonword

First, the difference in mean rating between the two contrasted members of each pair in the 'body' varying set was examined in a *t*-test, the result of which was very close to the .05 significance level (t(11) = 1.724, p = 0.056, one-tailed). This indicates that a '**H**+L' item was in general judged as a better-sounding Korean word than its '**L**+L' counterpart, although the pattern was not as strong as the one based on the data computed across the subjects. In contrast to this, the difference in mean rating between the two contrasted members in the 'rime' varying set was not statistically significant assessed by a one-tailed *t*-test (t(11) = 1.137, p > 0.1). This indicates that when the two contrasted members in the rime-varying set are examined separately, a 'L+**H**' item was not always judged better as a possible Korean word than its 'L+**L**' counterpart. This is not consistent with the finding based on the pooled data across subjects. Thus, considering the mean wordlikeness ratings computed across the subjects and items together, for Korean, it is apparent that manipulation of the contingency of the vowel-coda (rime) sequence can produce a similar difference in judged wordlikeness to manipulation of the contingency of the onset-vowel (body) sequence, but the effect of the former variable looks much less reliable than that of the latter one.

To summarize, the Korean wordlikeness test results suggest that (i), as consistent with the English wordlikeness results, Korean users are sensitive to the correlation between segments inside the primary sub-syllabic unit in their language (i.e., body) and that (ii) Korean users are also sensitive to the statistical pattern involving two-phoneme sequences occurring within the 'non-primary' unit, although this appears to be not as strong as we observed from English users. This latter point needs to be examined further with more Korean subjects (given that there were only 10 participants for the study) and more items.

5.5. Summary of wordlikeness experiments

First of all, the results reported in this chapter add additional evidence to the literature that suggests that the objective measure of correlations between a consonant and a vowel inside the primary sub-syllabic unit in a given language play an important role in nonword processing (e.g., Treiman et al., 2000). A natural interpretation of this finding is that native speakers of a language are aware (most likely through vocabulary learning) that certain two-phoneme sequences appearing inside the unit in question (e.g., rime and body in English and Korean respectively) are more likely in their language than other particular two-phoneme sequences inside the same unit.

Secondly, the results indicate an effect of the correlations of two-phoneme sequences occurring inside the 'non-primary' sub-syllabic units (body for English and rime for Korean) on nonword processing. This means that the knowledge that there is a generally salient statistical characteristic of English and Korean CVC syllables (the greater correlations existing between vowels and codas for English and the reverse for Korean) does not hinder the speakers from learning the correlations other than those primary units. An implication of this finding is that learning the correlations between adjacent segments inside the syllable is not necessarily restricted to some particular segment sequences. Instead, the learning may in fact involve any two adjacent phonemes within the syllable.

These two results taken together lend a further support to the suggested interpretations of the STM results in the previous chapter. The major assumption behind the suggested account of the STM data was that Korean and English speakers implicitly know the correlations existing between adjacent segments in their native language and it influences the two-phoneme retention error pattern. The wordlikeness results indicate that this assumption is indeed a reasonable one. The results are also in an indirect support of the emergent model of syllable structure in which sub-syllabic structures emerge from the learning of the general statistical characteristics of individual words in a language. If, for example, onset/rime structures are the only possible structures explicitly represented in English syllables and the greater correlations between vowels and codas are a direct function of these structures, then our English subjects' sensitivity to the different degrees of correlations between onsets and vowels is somewhat hard to explain. If sub-syllabic units can be thought of as some kind of localized blocks in strings of segments appearing inside the syllable where the correlations between adjacent segments are computed, the onset/rime model would predict English speakers' sensitivity to correlations between segments inside the rime only. Or, at least, their sensitivity to correlations between segments outside the rime should be much weaker than their sensitivity to those between segments inside the rime. The data available from at least the English experiment in this study indicate that the prediction is not entirely borne out.

Under the emergent model where such rigid sub-syllabic frames are denied and surface structural effects are rather viewed an emerging property of the general statistical characteristic of segment sequences in words in a language, the sensitivity to the correlations between segments inside the primary unit as well as to the correlations between segments outside the unit is not so surprising. In fact, language users are expected to learn regularities governing sequences of phonemes even those that are not so 'special' in their native language. We observed that at least for English this seemed to be the case: English subjects quite consistently judged nonwords containing a high-contingency CV sequence more wordlike than nonwords containing a low-contingency CV sequence.

Lastly, I need to provide some discussion about the current finding that both English and Korean speakers only showed 'general' sensitivity to wordlikeness. That is, the magnitude of the influence of the degree of association between two phonemes on the wordlikeness of CVC nonwords did not significantly differ whether the high-contingency phoneme sequences were the ones that are composing the "primary" units (e.g., rime for English) or the ones that are composing the "non-primary" units (e.g., rime for Korean). In other words, our English listeners, for example, judged 'L+**H**' (high rime) nonwords no better than '**H**+L' (high body) nonwords, although they did judge the two to be significantly better than 'L+L' nonwords. One may say that this finding is somewhat unexpected, given (i) the contingency involving VCs is 'special' in

English and (ii) English speakers are aware of this, to the extent that this knowledge affects their behavioral performance such as remembering the 'L+L' stimuli in the current STM tests. The same question arises for the Korean subjects' judgments of the goodness of Korean '**H**+L' vs. 'L+**H**' nonwords as actual Korean words. One may, reasonably, expect that Korean speakers would judge the former more wordlike than the latter. The Korean wordlikeness data, however, indicate that they apparently did not.

One speculation I offer for this finding is that the level of control I made in constructing the test stimuli in both English and Korean wordlikeness experiments created a situation where the degree of association between phonemes in the "high" rimes was virtually the same as the degree of association between phonemes in the "high" bodies. That is, in both English and Korean test stimuli, the high CV sequences in the '**H**+L' nonwords and the high VC sequences in the 'L+**H**' nonwords had practically the same degree of cohesion. This is probably why we did not observe the expected difference in mean ratings between the two types of nonwords.

In contrast to this, the results reported in the lexicon study in Chapter 3 raise the possibility that in the actual vocabulary of, for example, English, it is likely that phonemes comprising high rimes are generally "higher" in terms of cohesiveness than phonemes

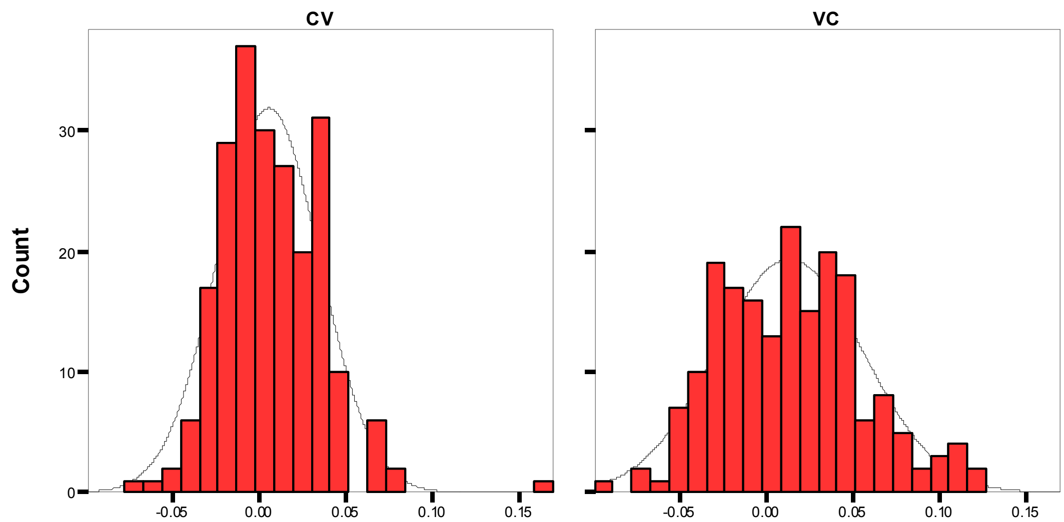

Figure 5.5 Histogram for English CV and VC Rho Values

comprising high bodies. Figure 5.5 shows that this in fact might be the case. The figure displays the histograms for the Rho values (x-axis) of the CVs and VCs found with the current English database. It shows that the VC Rho values indeed form a relatively wider distribution than the CV Rho values, and particularly that there are more VCs than CVs that exceed a certain threshold that may divide "high" vs. "low" Rho sequences in English (i.e., approximately around 0.04, which is the average of the averages of the CV and VC Rho values). If my construction of the English nonwords had followed this statistical trend, then we might have seen a relatively greater contribution of the rime contingencies to the wordlikeness than that of the body.

Following the same logic, I expect that Korean subjects will show not only the general

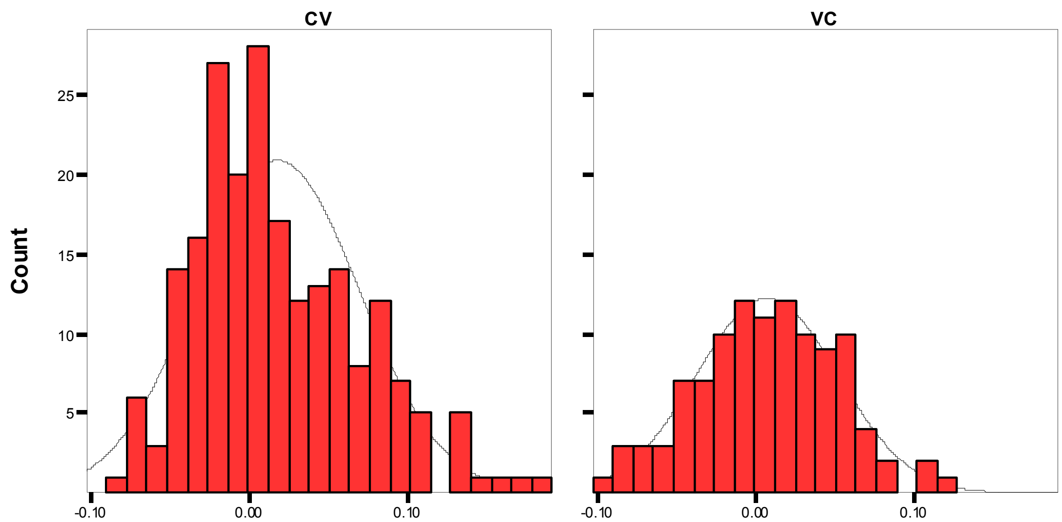

Figure 5.6 Histogram for Korean CV and VC Rho Values

sensitivity to wordlikeness but also prefer ‘high’ body to ‘high’ rime CVC nonwords if the construction of wordlikeness stimuli (i.e., “H+L” vs. “L+H”) followed the general statistical pattern in Korean, that is, phonemes comprising high bodies are generally “higher” in terms of cohesiveness than phonemes comprising high rimes, as can be inferred from Figure 5.6.

One problem for this kind of explanation for why English and Korean speakers only showed general sensitivity to wordlikeness, however, is its inconsistency with the data from the STM tasks. The degree of association between CV sequences and VC sequences in the STM ‘cv+vc’ stimuli was also explicitly controlled but we still observed that both language speakers in general remembered the statistically ‘special’ sequences in their own language (CVs and VCs for

Korean and English, respectively) significantly better. One response to this is that even though CV vs. VC contrast in both ('cv+vc' stimuli of) STM tasks and ('**H**+L' vs. 'L+**H**' stimuli of) wordlikeness tests were not systematically different, there is still a difference between the stimuli in the two tasks. Specifically, CV vs. VC in the STM tasks were set 'equally' *low*, while they were set equally *high* in '**H**+L' vs. 'L+**H**' wordlikeness stimuli. A conjecture based on this is that the lack of the effect of the salient probabilistic pattern in a language in wordlikeness judgments of '**H**+L' vs. 'L+**H**' stimuli may (somehow) have to do with the fact that both sequences were equally familiar. In contrast to this, the effect of the salient statistical pattern in a language in remembering 'cv+vc' stimuli may have emerged in part because both sequences were equally unfamiliar. It is, however, possible that the primary reason for no significant difference in wordlikeness between '**H**+L' vs. 'L+**H**' stimuli may lie somewhere else. One possibility has to do with the nature of the wordlikeness task itself. Recall that in the current study, due to the way the stimuli was presented, our participants did not directly compare the wordlikeness of a 'L+**H**' item with that of a 'L+L' item (i.e., an item identical to the former except the coda). Likewise, they rated the wordlikeness of a '**H**+L' item independently from that of its 'L+L' counterpart (i.e., an item identical to the former except the onset). This may have contributed to the finding that for example our English listeners did not particularly prefer 'L+**H**' to '**H**+L' items as potential words in English. As long as the nonwords contain a familiar consonant and vowel sequence (be that an onset-vowel or a vowel-coda sequence), the nonwords are a reasonably good candidate as a potential English word. Most of the previous studies that found the effect of rime frequency on wordlikeness judgments from English speakers, however, used the experimental condition such that subjects were asked to directly compare a high frequency rime CVC with a low frequency rime CVC word which was identical to the former except the final consonant (e.g., Treiman et al., 2000). Given this, it is possible that we may see English-speaking subjects' preference of 'L+**H**' to '**H**+L' items if we present the two items as a pair to the subjects and ask them to compare the wordlikeness of the two items directly.

To conclude this chapter, as many previous studies have suggested, the current experiment shows that language users do pick up certain statistical regularities in the vocabulary of their language. An independent contribution of the current work is that the regularities that language users pick up can be more specific than most previous studies seem to suggest. That is, the regularities that language users are sensitive to involve not only the contrast that exists between segment sequences across the position (e.g., more frequent/probable onset-vowel versus less frequent/probable vowel-coda), but also the contrast that exists between segment sequences within the position (e.g., more frequent/probable onset-vowel vs. less frequent/probable onset-vowel), even if the position involves non-primary units in a language, which is a finding that is consistent with the emergent view of the sub-syllabic constituency. This is a finding that is more consistent with the emergent model of syllable structure than it is with especially the structural models.

CHAPTER 6

Conclusion

6.1. Summary of predictions and findings

The central question of the current dissertation was that given the observation that, in many languages, a sequence of segments within a syllable seems partitioned into different units, precisely what kind of mechanism is responsible for this unit effect? A review of the literature indicated three possible mechanisms and they were evaluated in the current thesis by case-studying how phoneme sequences within the Korean and English syllables go together in the lexicon of the two languages and in two psycholinguistic experiments.

The three mechanisms make different predictions regarding the pattern of grouping of syllable terminal segments. The structural approach predicts that the pattern of grouping should coincide with language-specific sub-syllabic constituents. The probabilistic-phonotactics approach predicts that the pattern of grouping should coincide more or less with some objective measure of phonotactic probabilities governing individual sequences of segments found in a language. The hybrid model predicts the role of both structures and phonotactic probabilities in the grouping of segments inside the syllable.

Before testing the predictions of the theories in two psycholinguistic experiments, I examined the statistical characteristics of the distribution of phonemes in Korean and English. The investigation into the English lexicon, confirming previous studies, revealed that the two-way dependency between a nucleus vowel and its following consonant in English syllables is on average stronger than the dependency existing between a vowel and its preceding consonant. Importantly, the statistical study of the Korean lexicon revealed the opposite pattern. That is, converging evidence from several different measures of associations between a consonant and a vowel at the sub-syllabic level suggested that onset-vowel sequences in Korean syllables are on average more dependent upon each other than vowel-coda sequences. This sharp contrast between English and Korean in terms of the distribution of phonemes raised the possibility that the virtually opposite behavioral results obtained from previous English and Korean syllable experiments might in fact reflect the difference in the statistical characteristic of the lexicon between the two languages, not the difference in the structural properties per se.

Building on this observation, the relative contribution of the two factors, namely, structures and probabilistic dependencies between segments, to subjects' behavioral pattern in their grouping of segments inside the syllable were examined in STM tests. The examination of the recombination errors in the tests revealed that (i) contra what the structural models predict, the sequence of segments within 'rime' and 'body' in English and Korean respectively were not always the better-remembered string of segments, and that (ii) contra what the probabilistic-phonotactic models predict, the sequence of segments that were remembered better did not always coincide with the objective measure of phonotactic probabilities of the sequences. The results from both English and Korean STM studies rather suggested that the grouping of segments within both English and Korean syllables seems to reflect an effect of the following speakers' knowledge: (i) that the 'CV-' and '-VC' components of a CVC syllable may differ in terms of the degree of two-way dependency, and (ii) that either the 'CV-' or the '-VC' component of CVC syllables in their native language may have a particularly strong two-way dependency. The STM results from both languages were interpreted as a combined effect of these two types of implicit knowledge and were advanced in support of a particular hybrid model, namely the superiority of the emergent model over the other two models in describing English and Korean syllable structure. The primary conclusion of the STM tests was that language users are not somehow endowed with but basically 'discover' certain sub-syllabic units as a part of their acquisition of these kinds of statistical patterns in their native language.

The finding from the STM tests that English and Korean speakers are sensitive to the statistical dependencies at the sub-syllabic level was further investigated in another psycholinguistic experiment where subjects judged the phonological wellformedness of nonsense forms. The results from the wordlikeness tests were in general consistent with the findings from the STM tests – in particular, both English and Korean users showed evidence that they implicitly know that a particular sequence of segments is more frequent/probable than another particular sequence of segments not only for those segments that occur inside the primary unit (rime and body for English and Korean respectively) but also for those segments that occur in the non-primary unit. These findings from the wordlikeness tests were interpreted as providing a further support for the superiority of the emergent model in describing speakers' representation of syllable structure.

To summarize, an important picture that emerges from the current investigation into the kinds of linguistic properties that are represented in the Korean and English syllables is that the syllable structure of natural languages might be better described by what one may call the *nonstructural* properties of the syllable, in particular, by the statistical properties of consonants and vowel combinations in the syllables of a language.

6.2. General Discussion

One important finding of the current dissertation is that when inter-phoneme contingencies of the CV and VC component of a CVC syllable are controlled, the sub-syllabic boundary that is available for manipulations in a syllable experiment is not always the one that the traditional onset-rime and body-coda view of English and Korean syllables would have predicted. This finding that the sub-syllabic constituents seem to vary in part as a function of the phonotactic probabilities of the segment sequences was critical in refuting the syllable models that explicitly posit certain pre-defined templates for the construction of the syllable.

A closer examination of previous studies of at least English syllables reveals that the current finding is actually not such an unexpected one, that is, the onset-vowel component of a CVC syllable in English, in particular, appears as a sub-syllabic unit much more often than what one would usually expect. For example, Duncan et al. (1997) report that when English-speaking school children in their study were asked to say the bits of syllabless which sound the same, on average, body portion of the syllables (e.g., /mæ/ in <u>ma</u>t-<u>ma</u>n pairs) was better identified than rime portion of the syllables (e.g., /oʊt/ in b<u>oat</u>-g<u>oat</u>) (also see Johnston, Anderson, & Holligan, 1996 for a similar finding that shows an advantage of breaking up the rime in experiments involving English-speaking children). The fact that Seymour and Duncan (1999) and Goswami & East (2000) replicated Duncan et al. (1997) suggests that this kind of finding is not due to some artifacts hidden in some specific experiments. Similar findings have been reported with adult subjects as well. Nimmo & Roodenrys (2002), for example, found that when English-speaking adult subjects heard four one-syllable English nonwords and were asked to repeat the nonwords back, a greater number of responses retained the CV component of the syllables than any other phoneme pair. Similar findings have also been reported with languages other than English. Geudens & Sandra (2003) report that Dutch-speaking pre-readers and beginning readers find it easier to break up a rime than segment an onset-vowel sequence in a CVC syllable.

An idea that has often been proposed to deal with this apparent discrepancy between the studies that reported the supremacy of onset-rime division in languages like English and the studies that reported no such clear division (or the division that is in fact consistent with the body-coda structure of English syllables) is to take "perceptual-phonetic factors in the interpretation of different cohesion patterns" (Geudens & Sandra 2003:173). This position is different from the one that the current dissertation puts forward, namely, the (not-so-typical) CV//C division might reflect the higher dependency of the onset-vowel sequence relative to that of the vowel-coda sequence. Thus, I need to discuss these "perceptual-phonetic factors" in some detail here.

The basic idea behind this 'phonetic' approach is that the different degree of articulatory overlapping of obstruents, nasals, or liquids with the nucleus vowel influences the cohesiveness of segment sequences and accordingly the outcomes of syllable experiments such as STM (see also Gupta & MacWhinney 1997, Hartley & Houghton 1996, Treiman 1984, Treiman & Danis 1988, Kessler & Treiman 1997 for similar claims). This possibility has been discussed particularly in the context of the differential degree of overlapping between postvocalic consonants and their preceding vowel in English. Specifically, in English postvocalic nasals/obstruents are said to have a lesser degree of coarticulation with the preceding vowel than postvocalic liquids (or put differently, the degree of vowel-likeness of liquids in syllable-final position is higher than nasals/obstruents). According to this position, then, the English syllable experiments that have found a division of CV//C not C//VC might have had disproportionally greater numbers of 'CV+nasal/obstruent' stimuli than 'CV+liquid stimuli'. For example, Nimmo & Roodenrys (2002) suspect that the greater number of onset-vowel (i.e., 'body') retention that they have found in their English STM tests might have been an artifact of the nature of their stimuli, i.e., only 10% of their stimuli were 'CV+liquid' type (they also cite Treiman (1984) that found that greater retention of VC where the postvocalic C is liquids than where the postvocalic C is nasals or obstruents).

I feel that it would be too strong to attribute the emergence of onset-vowel unit in some of the previous English syllable experiments only to the effect of coarticulations, especially in light of the findings that the current thesis has produced. Since Nimmo & Roodenrys (2002) is a study that specifically discusses coarticulations as the potentially causal factor in greater number of onset-vowel retention errors than expected in their experiment, I examined the 80 high-frequency CVC nonword stimuli that appear in Appendix A in Nimmo & Roodenrys (2002:656). Indeed, only 4 of the stimuli had /l/ as their final consonant. Compare this to 27 items that ended with nasals and 49 items that had obstruents as their final consonant. One factor that they did not take into account, however, is precisely the role of inter-phoneme contingency that I argue plays a crucial role in groupings of segments inside the syllable. That is, it is possible that in their CVC stimuli, the contingencies of onset-vowel sequences might have been on average much higher than those of vowel-coda sequences. In order to examine this possibility, I compared the Rho value of CV with that of VC in each of the Nimmo & Roodenrys' 80 CVC stimuli (the Rho values of the sequences are of course according to the computations provided in this thesis). First, it turned out that almost half of the 80 stimuli (i.e., 33/80) had /ɪ/ as their nucleus vowel, and in about 2/3 of the 33 items (i.e., 21/33), the Rho score of the onset-vowel sequence was higher than that of its vowel-coda counterpart. The second most-frequent nucleus vowel of the stimuli was /ʌ/ (11 out of 80). In this case also the Rho score of onset-vowel was on average higher than that of vowel-coda sequence. On the basis of this, it is possible that a greater number of onset-vowel retention errors reported in Nimmo & Roodenrys (2002) (possibly as well as the analogous findings in the relevant previous studies) may be in part due to the overall higher dependency values for onset-vowel than for vowel-coda sequences in the stimuli used, not exclusively due to the coarticulation factor.

In spite of this, I also feel that it would be fair to say that the degree of coarticulation (particularly the one that involves the nucleus vowels and the postvocalic consonants) seems to exert some influence on the way in which the syllable terminal segments are grouped. The question is how? One speculation of how to account for the apparent effect of the co-articulation factor while maintaining the importance of inter-phoneme contingency on grouping of segments is the following (adopting the idea presented in Peereman et al., 2004). The idea is that English obstruent-vowel-obstruent syllables show a greater variation between C//VC and CV//C than liquid-vowel-liquid syllables because learning inter-phoneme contingency is generally easier when the two involved sounds are easily isolated, or equivalently *less coarticulated*. This amounts to saying that the magnitude of the effect of inter-phoneme contingency on segment grouping would be greater on obstruent-vowel-obstruent sequences than on liquid-vowel-liquid sequences. That is, given a CVC syllable, English speakers may be able to learn and thus tell the difference in the degree of two-phoneme dependency better if the involved pair of two-phoneme sequences is obstruent-vowel and vowel-obstruent contrast (e.g., ta- vs. -ap) than liquid-vowel and vowel-liquid contrast (e.g., ra- vs. -al), simply because the former set of contrast is easier to be isolated than the latter. This is probably a part of reason why we observe a greater variation between C//VC and CV//C when the consonants involved are especially obstruents than liquids. If this speculation is a reasonable one, then coarticulations can still be said to play a role in English speakers' grouping segments to the extent in which a lesser degree of articulatory overlapping of a two-phoneme sequence helps the listener segment sound sequences better and thus to learn the relative dependencies of the segment sequences with a greater ease. This kind of conception of the relation between articulatory overlapping of two segments and relative ease of learning the dependency of the two segments may bear some relevance on the question of why English and Korean have different statistical properties in the first place: that is, why there are in general higher dependencies for vowel-coda sequences in English than in Korean. A possibility given the discussion above is that the articulatory overlapping between vowels and codas in English and those in Korean syllables might systematically differ – specifically, the degree of coarticulation between vowels and codas in English is in general greater than in Korean.

Although the difference in the pattern of coarticulation between vowels and codas in the two languages may be a factor that is responsible for the differences between the statistical characteristics of the Korean and English lexicon, it may not be the only possibility. Indeed, there is a controversy in the literature regarding the source of the cross-linguistic difference in the degree of associations between vowels and consonants in the lexicon of languages. Some researchers speculate that, in line with the coarticulation explanation suggested above, the difference may have its origin in the difference in physical facts of articulation and acoustics (e.g., Cutler, 1982; Sevald and Dell, 1994). An alternative to this explanation is that the crucial cross-linguistic/typological variable is rather the presence in English-like languages versus absence in Korean-like languages of 'coda' consonant(s), which in turn gives rise to clusters across syllable boundaries as well as the general presence of clusters within syllables.[25] Stated another way, the different dependency patterns may be ultimately related to the difference in coda restrictions in the languages. In the phonology of languages like Korean, the number of phonologically legal consonants in the coda position is restricted (relative to the legal consonants in the onset position) and thus coda consonants are utilized in the words of the languages as frequently as they can be. A consequence of this is that Korean coda consonants are relatively unpredictable; they are informative and distinctive (compared to coda consonants in languages like English). This hypothesis makes some verifiable predictions. One is that if we ran psycholinguistic experiments (like the STM tests in the current thesis) on speakers of languages with very restricted codas (which thus have a similar dependency pattern as Korean), we would

[25] I thank Ann Bradlow for suggesting this possibility to me.

expect that all such languages show the same pattern as Korean, most notably the bias towards CV retention errors in the STM task. Related to this is an expectation that if we ran the same kind of experiments on speakers of a language like Hebrew or Arabic where we have triconsonantal roots that merge/conflate with vowels on a separate tier and the link between consonants (i.e., CCC dependencies) is relatively quite tight (compared to languages like English and Korean), then we would expect more CC retention than CV or VC retention errors on the STM task.

The claim in the current thesis that sub-syllabic units are emergent has some implications for phonological theory, particularly for moraic theory. As introduced earlier in this dissertation, the moraic representation of syllables posits mora units intermediate between the syllable node and the syllable terminal segments. Moraic syllables have been widely accepted in part because they are very adept in accounting for phonological phenomena like stress placement, constraints on word-internal coda consonants, and compensatory lengthening. For example, the fact that in many languages a loss of coda (but not a loss of onset) consonant brings about lengthening of the preceding vowel can be accounted for by (i) linking the coda to a mora unit and (ii) spreading the strayed mora of the coda consonant to the preceding vowel, effectively making it a vowel with two morae (i.e., a long vowel). Loss of an onset, however, does not result in a compensatory lengthening because onsets are inherently non-moraic, possibly universally (Hayes, 1989). One prediction that the current claim that sub-syllabic units are emergent makes is that not only codas but also onsets may be a relevant factor in explaining phonological processes that moraic theory is especially concerned with. This is even so, considering the fact that English users are sensitive to the nature of onsets to the extent that the latter affects their performance with regard to remembering especially 'CV+vc' stimuli in the STM tests. This is to say that contra the standard model of moraic theory that ignores the relevance of onsets in areas like syllable weight calculations, we might expect cases where the phonological nature of onsets is relevant and in certain contexts crucial in understanding phonological processes, especially those that moraic theory is good at explaining, like stress placement. Indeed, the fact that a proper description of stress patterns in some languages (e.g., Pirahã and to some extent English and Italian) requires onset-sensitive weight distinction (as well as rimal based ones) is consistent with this prediction (see Everett and Everett, 1984, D. Everett, 1988, Gordon, 2005 for relevant data and discussions).

Finally, here I discuss two issues that have to do with calculating and learning dependencies between vowels and consonants presented in this dissertation. One issue has to do with "scaling up"/generalization from CVC word to longer and more complex forms. Another issue has to do with the question of when and how people learn about the dependencies. Regarding the first issue, recall that in the current thesis, I focused on examining the distributional patterns for phonemes in CVC forms in Korean and English. The investigation revealed that in English, for example, as long as CVC words are concerned, vowel-coda associations are generally stronger than onset-vowel associations. A question that one can ask of this finding is whether this statistical pattern can be generalized to more complex forms, including 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 may occur. In order to answer this, it is necessary to examine word lists different from the ones used in the current study. A review of some previous studies, however, indicates that the general pattern of associations that is observed in simple CVC words may be generalized to longer/complex words, at least for polysyllabic words. With an English database that included polysyllabic words, Berg (1994), for example, found that VC associations are generally stronger than CV associations, the same pattern we observe with CVC monosylalbic wordlists. The result reported in Randolph (1989) that used English polysyllabic words is also generally consistent with this pattern as well: the strength of associations between vowels and consonants in his study were two to three times larger for vowel and codas than for vowels and onsets, although the result should be taken with caution that the difference in the degree of associations between vowel-coda and vowel-onset sequences in his study was only numerically evident but not statistically significant. This line of finding is important for the current thesis, considering especially the possibility that the distributional patterns for phonemes found in the current study may rather reflect the patterns for vowels and consonants at the 'word' edges, not for vowels and consonants at the 'syllable' level per se. In other words, since the CVC forms examined in the current work are necessarily words, one can say, for example, that in English vowels are associated more strongly with 'word'-final consonants, not with 'syllable'-final consonants. The previous findings mentioned just above suggest that the pattern of associations reported in the current dissertation cannot be solely word-based but can be indeed syllable-based, which can be scaled up to the pattern of consonants and vowels combinations occurring beyond monosyllables.

If, as claimed above, the general statistical pattern that holds in simple CVC forms also holds in longer words with more complex structure, we may expect that the effect of the statistical pattern would be extended to subjects' remembering two-phoneme sequences occurring inside longer/complex words as well. For example, when given an English bisyllabic nonword such as 'cvc.cvc' where all consonant-vowel sequences have low Rho values, the language users would remember vowel-coda sequences (not only the ones that occurs word finally but also the ones that occur word-medially) better than vowel-onset sequences.

Regarding other complex forms, it would be particularly interesting to examine the distributional patterns for phonemes in English mono-syllables with complex clusters in the onset position. One speculation that I offer for this type of syllables is that it may be that CC+V associations are in general stronger than V+C in CCVC syllables (unlike the general pattern in English), given that the inventory of CC-clusters that can occur before the vowel is obviously more restricted than the inventory of simple onset consonants that can occur in the same position. If this pattern turns out to be true, then we might expect that English users would remember CCVs better than VCs from CCVC nonwords. This potential finding would go against the prediction that the traditional structural model of English syllables would make – under the model the syllable structure of CCVC and simple CVC syllables are the same and thus English users would generally remember VCs better for both types of syllables. This potential finding, conversely, would corroborate the current claim that sub-syllabic units are not something that is primitive but is in part determined by the asymmetry in degree of dependency among phoneme sequences occurring inside the syllable, further supporting the underlying structures of syllables that I posit and their psychological reality.[26]

[26] A further issue of interest regarding $C_1C_2VC_3$ forms in English is the potential difference in dependency between C_1+V and C_2+V. Some phonological theories (e.g., Pierrehumbert and Nair, 1995) propose that the first member of the onset cluster is actually attached to the word-level, while the second member of the onset cluster is attached to

Now I discuss the second issue of how and when people learn the dependencies that this dissertation makes use of. I suggested earlier in this dissertation that the pattern governing two-phoneme sequences in the two languages may be acquired through 'vocabulary learning' (as in meaningful chunks of sounds). An alternative to this is that these patterns are learned (or at least partially learned) prior to the onset of word acquisition, i.e., simple statistical learning over sound sequences (without reference to 'words' per se). The latter possibility is indeed a plausible one, as suggested by some of the infant statistical learning literature in recent years. For example, Maye et al. (2001) have shown that 6- and 8-month-old infants are sensitive to the statistical distribution of phonetic variation in the speech signal in the input language. Considering the age range of the infants studied, it is safe to say that statistical learning can occur without infants' having a sizable lexicon, or in other words, some kind of distribution-sensitive mechanism is available at the very early stage of life and young infants may use it to figure out the distributional pattern. In addition to their sensitivity to the statistical variation in speech perception, infants have been also shown to show sensitivity to probable (not just legal/illegal) speech sound sequences in their input language (Jusczyk et al, 1994; Zamuner, 2001). These

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the syllable. In addition, since the first member is further apart in terms of distance from the nucleus vowel than the second member, it is likely that the C_1V dependency may be less strong than the C_2V dependency. This is all the more likely given the finding in Pierrehumbert (1993) for Arabic and in Berkley (1994) for English that the strength of phonotactic restrictions weakens as the distance of the two related items is increased. If this is the case, then the prediction that the claim in the current thesis makes is that C_2Vs would be remembered better than C_1Vs by English users when they are given $C_1C_2VC_3$ nonwords in the STM task. This is, of course, something that the traditional onset-rime model of English syllables does not predict, as both C_1 and C_2 are part of an (complex) onset.

studies taken together thus suggest that computing dependencies between (at least immediately adjacent) speech signals may be something that language learners can perform even before they realize that some chunks of sounds may constitute a meaningful unit in their input language.

At the same time, previous studies also indicate that language users' sensitivity to probabilistic patterns in the input continues to contribute to language learning well past infancy, suggesting that learning dependencies (between speech sounds) may also continue throughout the lifetime. In fact, I believe that the bulk of acquisition of dependencies may occur after language learners develop some form of phoneme awareness, that is, after they become aware that physical continuations in speech input can be represented via some abstract entities. This is based on two hypotheses: (i) computing dependencies requires that language learners can make a phonemic categorization of speech inputs and (ii) phonemes are developed mostly on the basis of word learning and thus phoneme awareness is preceded by word learning. Regarding the second point, studies on development of phoneme awareness have suggested that one logical source of phoneme awareness is vocabulary acquisition (e.g., Metsala and Walley, 1998). According to this view, early word representations are most likely holistic, representing only global phonological characteristics (e.g., Jusczyk, 1993; Walley and Flege, 1999). However, as the vocabulary learning continues, children's phonological representation of speech input becomes more fine-grained (i.e., phonemic/segmental) in order to efficiently store and distinguish the increasing number of (similar-sounding) words. If dependency learning is, as I hypothesize, mostly phoneme-based and vocabulary learning forms the basis of phonemic awareness, then it is plausible to say that most of the learning dependencies may occur in tandem with or as a result of vocabulary learning, favoring the idea that the dependencies are learned over some meaningful chunks of sounds. The finding that English-speaking children show better phonemic awareness for words that have more similar-sounding words than for words that have less similar-sounding words indirectly supports this hypothesis (Metsala & Walley, 1988; Goswami, 2002).

6.3. Further work

Here I discuss some future projects that need to be done in order to further support the claims that I have made in the current thesis.

Firstly, in Korean many underlyingly distinct syllable-final consonants undergo place/manner neutralizations in the coda position. For instance, /natʃ/ 'day', /nas/ 'scythe', and /nat^h/ 'face' are all pronounced the same in the surface as /nat/. The Korean bi-phone counts reported in Chapter 3 and the Rho values computed from the counts were based on the pronounced forms of the single syllable words in Korean. This means that the three words cited above, for example, contributed three counts to the /-at/ sequence, instead of contributing one count to /-atʃ/, /-as/, and /-at^h/ each separately. An obvious concern here is whether the experimental results reported in this thesis might have been affected by this particular way in which the Korean two-way dependencies were calculated (this issue does not arise for English which does not have coda neutralizations). In a sense, the issue here has to do with the more general question of the level in which the computation of statistical regularities in a language should be made (i.e., surface/output vs. underlying/input level). A new set of computations using the underlying forms and experiments that use the new numbers, and their comparison to the findings in the current work will clarify the issue here.

Secondly, a further study that involves pre-readers of Korean might be necessary to further strengthen the current claim that the emergence of the salient unit (body) in Korean is ultimately attributed to the language users' sensitivity to the general statistical patterns governing sequences of *sounds* in Korean. The need for testing pre-readers stems from the fact that the standard Korean orthography treats the onset-vowel sequences as a writing unit in many written words. That is, many CVC words are written in such a way that the vowel letter occurs in a dimension with the letter that represents the onset, but not with the letter that represents the coda.

Other CVC words are written in a more linear way, although the letters are put together in vertical arrays, unlike the English orthography where letters are put together in horizontal arrays. In order to ensure that the emergence of body unit in the Korean STM test reported in this thesis is not due to this potential effect of the Korean orthography, a future study needs to test Korean learning children who did not master the orthography at the time of the experiment. In this respect, the STM test employed in the current dissertation is a good venue for doing it, precisely because the technique does not assume the knowledge of orthography and has been successfully performed with pre-readers speaking other languages including English (e.g., Gathercole, Willis, Baddeley, and Emslie, 1994; Brady, Shankweiler, and Mann, 1983).

Lastly, a future study is needed to explore the implications of the current study on the typology of syllable internal constituency in natural languages in general. Specifically, the current thesis' proposal that the units inside the syllable are an emergent property of the lexicon of a language predicts a language that might be positioned in half way between Korean-like and English-like languages. That is, if the statistical regularities of segment sequences within the syllables of a language show no strong preference for either onset-vowel or vowel-coda sequences, then the status of the sub-syllabic constituency of that language may also be weak. Languages whose syllable structure has been said to be 'variable' or been claimed to exhibit 'overlapping sub-syllabic units' in the literature (e.g., Italian according to Bertinetto, 1996) would be a good starting point for this research effort.

To conclude, the overall significance of the current dissertation is that it produced new sets of empirical data that contribute to the area of the research of sub-syllabic constituency. As mentioned at the beginning of the dissertation, an important tradition of this research area has been focusing on exploring sub-syllabic constituents as linguistic entities separate from their phonemic *content*, that is, the segments that make up the syllable. In that tradition, the way in which segments are selected for syllabification in the output has usually been inherently constrained using certain language-specific well-delimited syllable templates. The data that the current thesis produced, however, suggest that exploring syllable structures of natural languages needs to take the content of the structures into consideration, the content being the segments that comprise the syllable, and more generally the statistical properties of segment distributions in the words of a language. At least for the research efforts involving Korean syllables, the current thesis may serve as an important point of departure. Finally, the findings in this dissertation are informative for our understanding of the linguistic constituents in other fields of linguistics. The classical approaches to the linguistic constituents (be they syntactic or morphological) can be broadly termed "discrete". The alternative approach to sub-syllabic constituents taken in the current dissertation leaves it as an open question whether these discrete morphological and syntactic constituents also can be better viewed as (at least in part) an emergent property of statistical properties inherent in the relevant domains of language.

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APPENDIX

1.

The Seven Measures of Association of Korean Onset-Vowel Sequences

Note on how to read the numbers in the table below: Take the phoneme sequence /ka/ for an example, in the following table, ‘a’ column = the number of /k/ and /a/ phoneme co-occurrences in the constructed list of CVC words, ‘b’ = the number of occurrences of /k/ followed by a vowel different from /a/, ‘c’ = the number of occurrences of /a/ preceded by a consonant different from /k/, ‘d’ = the number of occurrences of two phoneme sequences comprising neither /k/ nor /a/. Sequences of phonemes whose type frequency was zero in the constructed list in the current thesis are not reported in the table below. The letters inside parentheses next to some of the vowels are Korean characters, which are given for ease of reference.

C	V	a	b	c	d	TP	∆P	TP'	∆P'	Rho	MI	ChiSq
k	a	19	106	189	625	0.152	-0.080	0.091	-0.054	-0.066	7.709	4.040
t	a	19	34	189	697	0.358	0.145	0.091	0.045	0.081	7.703	6.1116
p	a	17	67	191	664	0.202	-0.021	0.082	-0.010	-0.014	7.706	0.195
c	a	17	78	191	653	0.179	-0.047	0.082	-0.025	-0.034	7.707	1.1104
s	a	21	92	187	639	0.186	-0.041	0.101	-0.025	-0.032	7.707	0.947
h	a	10	54	198	677	0.156	-0.070	0.048	-0.026	-0.043	7.709	1.696
r	a	1	9	207	722	0.100	-0.123	0.005	-0.008	-0.030	7.714	0.865
m	a	22	51	186	680	0.301	0.087	0.106	0.036	0.056	7.704	2.927
n	a	18	33	190	698	0.353	0.139	0.087	0.041	0.076	7.703	5.402
kk	a	2	21	206	710	0.087	-0.138	0.010	-0.019	-0.051	7.716	2.475
tt	a	8	13	200	718	0.381	0.163	0.038	0.021	0.058	7.703	3.166
pp	a	2	12	206	719	0.143	-0.080	0.010	-0.007	-0.023	7.710	0.509
cc	a	8	13	200	718	0.381	0.163	0.038	0.021	0.058	7.703	3.166
ss	a	7	6	201	725	0.538	0.321	0.034	0.025	0.090	7.702	7.679
kh	a	3	20	205	711	0.130	-0.093	0.014	-0.013	-0.035	7.711	1.134
th	a	11	27	197	704	0.289	0.071	0.053	0.016	0.034	7.704	1.060
ph	a	11	49	197	682	0.183	-0.041	0.053	-0.014	-0.024	7.707	0.541
ch	a	12	46	196	685	0.207	-0.016	0.058	-0.005	-0.009	7.706	0.076
k	e	11	114	133	681	0.088	-0.075	0.076	-0.067	-0.071	7.186	4.743
t	e	3	50	141	745	0.057	-0.103	0.021	-0.042	-0.066	7.195	4.049
p	e	11	73	133	722	0.131	-0.025	0.076	-0.015	-0.019	7.180	0.356

s	e(어)	27	86	117	709	0.239	0.097	0.188	0.079	0.088	7.175	7.246
h	e(어)	4	60	140	735	0.063	-0.098	0.028	-0.048	-0.068	7.193	4.366
r	e(어)	1	9	143	786	0.100	-0.054	0.007	-0.004	-0.015	7.184	0.221
m	e(어)	3	70	141	725	0.041	-0.122	0.021	-0.067	-0.090	7.205	7.682
n	e(어)	3	48	141	747	0.059	-0.100	0.021	-0.040	-0.063	7.194	3.7117
kk	e(어)	1	22	143	773	0.043	-0.113	0.007	-0.021	-0.048	7.203	2.192
tt	e(어)	2	19	142	776	0.095	-0.059	0.014	-0.010	-0.024	7.184	0.558
pp	e(어)	5	9	139	786	0.357	0.207	0.035	0.023	0.070	7.173	4.545
cc	e(어)	1	20	143	775	0.048	-0.108	0.007	-0.018	-0.044	7.200	1.849
ss	e(어)	1	12	143	783	0.077	-0.078	0.007	-0.008	-0.025	7.188	0.593
kh	e(어)	4	19	140	776	0.174	0.021	0.028	0.004	0.009	7.177	0.076
th	e(어)	8	30	136	765	0.211	0.060	0.056	0.018	0.033	7.176	0.996
ph	e(어)	7	53	137	742	0.117	-0.039	0.049	-0.018	-0.027	7.182	0.664
ch	e(어)	20	38	124	757	0.345	0.204	0.139	0.091	0.136	7.173	17.45
k	i	12	113	73	741	0.096	0.006	0.141	0.009	0.007	6.424	0.052
t	i	2	51	83	803	0.038	-0.056	0.024	-0.036	-0.045	6.448	1.901
p	i	6	78	79	776	0.071	-0.021	0.071	-0.021	-0.021	6.429	0.408
c	i	16	79	69	775	0.168	0.087	0.188	0.096	0.091	6.417	7.790
s	i	19	94	66	760	0.168	0.088	0.224	0.113	0.100	6.417	9.400
h	i	2	62	83	792	0.031	-0.064	0.024	-0.049	-0.056	6.456	2.930
r	i	3	7	82	847	0.300	0.212	0.035	0.027	0.076	6.413	5.387
m	i	3	70	82	784	0.041	-0.054	0.035	-0.047	-0.050	6.445	2.348
n	i	2	49	83	805	0.039	-0.054	0.024	-0.034	-0.043	6.447	1.724
kk	i	1	22	84	832	0.043	-0.048	0.012	-0.014	-0.026	6.443	0.633
tt	i	1	20	84	834	0.048	-0.044	0.012	-0.012	-0.023	6.440	0.480
cc	i	3	18	82	836	0.143	0.054	0.035	0.014	0.028	6.419	0.714
kh	i	1	22	84	832	0.043	-0.048	0.012	-0.014	-0.026	6.443	0.633
ph	i	5	55	80	799	0.083	-0.008	0.059	-0.006	-0.007	6.426	0.040
ch	i	9	49	76	805	0.155	0.069	0.106	0.049	0.058	6.418	3.138
k	o	21	104	132	682	0.168	0.006	0.137	0.005	0.005	7.265	0.027
t	o	15	38	138	748	0.283	0.127	0.098	0.050	0.080	7.261	5.938
p	o	13	71	140	715	0.155	-0.009	0.085	-0.005	-0.007	7.266	0.045
c	o	10	85	143	701	0.105	-0.064	0.065	-0.043	-0.052	7.270	2.577
s	o	16	97	137	689	0.142	-0.024	0.105	-0.019	-0.021	7.267	0.429
h	o	9	55	144	731	0.141	-0.024	0.059	-0.011	-0.016	7.267	0.250
r	o	2	8	151	778	0.200	0.037	0.013	0.003	0.010	7.264	0.101
m	o	10	63	143	723	0.137	-0.028	0.065	-0.015	-0.020	7.267	0.390
n	o	12	39	141	747	0.235	0.077	0.078	0.029	0.047	7.262	2.070
kk	o	5	18	148	768	0.217	0.056	0.033	0.010	0.023	7.263	0.512

tt	o	3	18	150	768	0.143	-0.021	0.020	-0.003	-0.008	7.267	0.063
cc	o	6	15	147	771	0.286	0.126	0.039	0.020	0.050	7.261	2.373
ss	o	1	12	152	774	0.077	-0.087	0.007	-0.009	-0.028	7.276	0.7151
kh	o	3	20	150	766	0.130	-0.033	0.020	-0.006	-0.014	7.268	0.182
th	o	14	24	139	762	0.368	0.214	0.092	0.061	0.114	7.260	12.25
ph	o	7	53	146	733	0.117	-0.049	0.046	-0.022	-0.033	7.269	1.006
ch	o	6	52	147	734	0.103	-0.063	0.039	-0.027	-0.041	7.271	1.604
k	u(으)	13	112	44	770	0.104	0.050	0.228	0.101	0.071	5.846	4.740
t	u(으)	6	47	51	835	0.113	0.056	0.105	0.052	0.054	5.845	2.715
c	u(으)	3	92	54	790	0.032	-0.032	0.053	-0.052	-0.041	5.879	1.572
s	u(으)	5	108	52	774	0.044	-0.019	0.088	-0.035	-0.025	5.866	0.610
h	u(으)	8	56	49	826	0.125	0.069	0.140	0.077	0.073	5.844	4.979
r	u(으)	1	9	56	873	0.100	0.040	0.018	0.007	0.017	5.847	0.273
n	u(으)	4	47	53	835	0.078	0.019	0.070	0.017	0.018	5.851	0.297
kk	u(으)	8	15	49	867	0.348	0.294	0.140	0.123	0.191	5.836	34.08
tt	u(으)	3	18	54	864	0.143	0.084	0.053	0.032	0.052	5.842	2.542
ss	u(으)	1	12	56	870	0.077	0.016	0.018	0.004	0.008	5.851	0.060
kh	u(으)	1	22	56	860	0.043	-0.018	0.018	-0.007	-0.011	5.866	0.122
th	u(으)	1	37	56	845	0.026	-0.036	0.018	-0.024	-0.030	5.889	0.821
ch	u(으)	3	55	54	827	0.052	-0.010	0.053	-0.010	-0.010	5.861	0.087
k	A(애)	4	121	48	766	0.032	-0.027	0.077	-0.059	-0.040	5.746	1.506
t	A(애)	4	49	48	838	0.075	0.021	0.077	0.022	0.021	5.719	0.433
p	A(애)	8	76	44	811	0.095	0.044	0.154	0.068	0.055	5.715	2.801
c	A(애)	2	93	50	794	0.021	-0.038	0.038	-0.066	-0.050	5.770	2.380
s	A(애)	5	108	47	779	0.044	-0.013	0.096	-0.026	-0.018	5.733	0.304
h	A(애)	5	59	47	828	0.078	0.024	0.096	0.030	0.027	5.718	0.679
m	A(애)	5	68	47	819	0.068	0.014	0.096	0.019	0.017	5.721	0.260
n	A(애)	3	48	49	839	0.059	0.004	0.058	0.004	0.004	5.725	0.012
tt	A(애)	2	19	50	868	0.095	0.041	0.038	0.017	0.026	5.715	0.652
pp	A(애)	1	13	51	874	0.071	0.016	0.019	0.005	0.009	5.720	0.069
cc	A(애)	1	20	51	867	0.048	-0.008	0.019	-0.003	-0.005	5.731	0.024
kh	A(애)	5	18	47	869	0.217	0.166	0.096	0.076	0.112	5.706	11.830
ph	A(애)	6	54	46	833	0.100	0.048	0.115	0.055	0.051	5.714	2.439
ch	A(애)	1	57	51	830	0.017	-0.041	0.019	-0.045	-0.043	5.785	1.718
p	E(에)	1	83	7	848	0.012	0.004	0.125	0.036	0.012	3.122	0.125
c	E(에)	1	94	7	837	0.011	0.002	0.125	0.024	0.007	3.138	0.050
s	E(에)	3	110	5	821	0.027	0.020	0.375	0.257	0.073	3.055	4.943
n	E(에)	1	50	7	881	0.020	0.012	0.125	0.071	0.029	3.075	0.784

th	E(에)	1	37	7	894	0.026	0.019	0.125	0.085	0.040	3.056	1.484
ch	E(에)	1	57	7	874	0.017	0.009	0.125	0.064	0.024	3.085	0.556
h	O(외)	2	62	1	874	0.031	0.030	0.667	0.600	0.134	1.632	16.97
kk	O(외)	1	22	2	914	0.043	0.041	0.333	0.310	0.113	1.618	12.01
s	ya(야)	1	112	6	820	0.009	0.002	0.143	0.023	0.006	2.970	0.033
h	ya(야)	2	62	5	870	0.031	0.026	0.286	0.219	0.075	2.854	5.255
r	ya(야)	1	9	6	923	0.100	0.094	0.143	0.133	0.112	2.821	11.699
kk	ya(야)	1	22	6	910	0.043	0.037	0.143	0.119	0.066	2.841	4.1351
pp	ya(야)	1	13	6	919	0.071	0.065	0.143	0.129	0.091	2.827	7.860
kh	ya(야)	1	22	6	910	0.043	0.037	0.143	0.119	0.066	2.841	4.1351
ch	ya(야)	0	58	7	874	0.000	-0.008	0.000	-0.062	-0.022	#NUM	0.464
k	ye(여)	16	109	51	763	0.128	0.065	0.239	0.114	0.086	6.077	6.983
p	ye(여)	12	72	55	800	0.143	0.079	0.179	0.097	0.087	6.075	7.1184
h	ye(여)	10	54	57	818	0.156	0.091	0.149	0.087	0.089	6.074	7.470
m	ye(여)	14	59	53	813	0.192	0.131	0.209	0.141	0.136	6.073	17.32
n	ye(여)	4	47	63	825	0.078	0.007	0.060	0.006	0.007	6.084	0.040
pp	ye(여)	2	12	65	860	0.143	0.073	0.030	0.016	0.034	6.075	1.096
ph	ye(여)	9	51	58	821	0.150	0.084	0.134	0.076	0.080	6.075	5.983
s	yo(요)	3	110	0	826	0.027	0.027	1.000	0.882	0.153	1.640	21.99
k	yu(유)	2	123	3	811	0.016	0.012	0.400	0.268	0.057	2.413	3.102
s	yu(유)	1	112	4	822	0.009	0.004	0.200	0.080	0.018	2.484	0.301
h	yu(유)	2	62	3	872	0.031	0.028	0.400	0.334	0.096	2.369	8.715
k	wa(와)	8	117	10	804	0.064	0.052	0.444	0.317	0.128	4.192	15.41
c	wa(와)	1	94	17	827	0.011	-0.010	0.056	-0.047	-0.021	4.308	0.419
h	wa(와)	4	60	14	861	0.063	0.047	0.222	0.157	0.085	4.193	6.858
kk	wa(와)	3	20	15	901	0.130	0.114	0.167	0.145	0.129	4.180	15.52
cc	wa(와)	1	20	17	901	0.048	0.029	0.056	0.034	0.031	4.200	0.924
kh	wa(와)	1	22	17	899	0.043	0.025	0.056	0.032	0.028	4.203	0.741
k	we(워)	1	124	3	811	0.008	0.004	0.250	0.117	0.023	2.179	0.475
h	we(워)	1	63	3	872	0.016	0.012	0.250	0.183	0.047	2.094	2.091
m	we(워)	2	71	2	864	0.027	0.025	0.500	0.424	0.103	2.054	9.989
k	wu(우)	18	107	99	715	0.144	0.022	0.154	0.024	0.023	6.879	0.497
t	wu(우)	4	49	113	773	0.075	-0.052	0.034	-0.025	-0.036	6.889	1.242

p	wu(우)	16	68	101	754	0.190	0.072	0.137	0.054	0.063	6.877	3.670
c	wu(우)	13	82	104	740	0.137	0.014	0.111	0.011	0.012	6.880	0.145
s	wu(우)	10	103	107	719	0.088	-0.041	0.085	-0.040	-0.040	6.886	1.535
h	wu(우)	2	62	115	760	0.031	-0.100	0.017	-0.058	-0.076	6.917	5.487
r	wu(우)	1	9	116	813	0.100	-0.025	0.009	-0.002	-0.008	6.884	0.056
m	wu(우)	14	59	103	763	0.192	0.073	0.120	0.048	0.059	6.877	3.2751
n	wu(우)	4	47	113	775	0.078	-0.049	0.034	-0.023	-0.034	6.888	1.053
tt	wu(우)	2	19	115	803	0.095	-0.030	0.017	-0.006	-0.013	6.885	0.169
pp	wu(우)	3	11	114	811	0.214	0.091	0.026	0.012	0.033	6.876	1.048
cc	wu(우)	1	20	116	802	0.048	-0.079	0.009	-0.016	-0.035	6.901	1.167
ss	wu(우)	3	10	114	812	0.231	0.108	0.026	0.013	0.038	6.875	1.362
kh	wu(우)	3	20	114	802	0.130	0.006	0.026	0.001	0.003	6.881	0.007
th	wu(우)	2	36	115	786	0.053	-0.075	0.017	-0.027	-0.045	6.898	1.880
ph	wu(우)	15	45	102	777	0.250	0.134	0.128	0.073	0.099	6.875	9.240
ch	wu(우)	6	52	111	770	0.103	-0.023	0.051	-0.012	-0.016	6.884	0.253
s	wi(위)	2	111	4	822	0.018	0.013	0.333	0.214	0.052	2.668	2.587
h	wi(위)	2	62	4	871	0.031	0.027	0.333	0.267	0.084	2.632	6.685
kh	wi(위)	1	22	5	911	0.043	0.038	0.167	0.143	0.074	2.618	5.108
th	wi(위)	1	37	5	896	0.026	0.021	0.167	0.127	0.051	2.641	2.476
h	wA왜)	1	63	1	874	0.016	0.014	0.500	0.433	0.079	1.094	5.885
kk	wA왜)	1	22	1	915	0.043	0.042	0.500	0.477	0.142	1.033	18.96

Measures of association of Korean Vowel-Coda Sequences

V	C	a	b	c	d	TP	ΔP	TP'	ΔP'	Rho	MI	ChiSq
a	ŋ	45	163	129	573	0.216	0.033	0.259	0.037	0.035	7.449	1.101698
A	ŋ	13	39	161	697	0.250	0.062	0.075	0.022	0.037	7.448	1.232644
e	ŋ	23	121	151	615	0.160	-0.037	0.132	-0.032	-0.035	7.451	1.096684
i	ŋ	7	78	167	658	0.082	-0.120	0.040	-0.066	-0.089	7.461	7.183988
o	ŋ	36	117	138	619	0.235	0.053	0.207	0.048	0.050	7.448	2.311430
u	ŋ	17	40	157	696	0.298	0.114	0.098	0.043	0.070	7.447	4.504943
wu	ŋ	10	107	164	629	0.085	-0.121	0.057	-0.088	-0.103	7.460	9.706837
ya	ŋ	1	6	173	730	0.143	-0.049	0.006	-0.002	-0.011	7.452	0.106642
ye	ŋ	20	47	154	689	0.299	0.116	0.115	0.051	0.077	7.447	5.384346
yu	ŋ	2	3	172	733	0.400	0.210	0.011	0.007	0.039	7.445	1.417238
a	k	34	174	148	554	0.163	-0.047	0.187	-0.052	-0.050	7.516	2.249821
A	k	15	37	167	691	0.288	0.094	0.082	0.032	0.054	7.512	2.697406
e	k	33	111	149	617	0.229	0.035	0.181	0.029	0.032	7.513	0.909554
E	k	1	7	181	721	0.125	-0.076	0.005	-0.004	-0.018	7.519	0.283744
i	k	11	74	171	654	0.129	-0.078	0.060	-0.041	-0.057	7.518	2.919786
o	k	36	117	146	611	0.235	0.042	0.198	0.037	0.040	7.513	1.431929
u	k	11	46	171	682	0.193	-0.007	0.060	-0.003	-0.005	7.514	0.018716
we	k	1	3	181	725	0.250	0.050	0.005	0.001	0.008	7.513	0.062775
wu	k	31	86	151	642	0.265	0.075	0.170	0.052	0.062	7.512	3.540703
ya	k	2	5	180	723	0.286	0.086	0.011	0.004	0.019	7.512	0.323920
ye	k	7	60	175	668	0.104	-0.103	0.038	-0.044	-0.067	7.521	4.124572
a	l	32	176	114	588	0.154	-0.009	0.219	-0.011	-0.010	7.199	0.087021
A	l	3	49	143	715	0.058	-0.109	0.021	-0.044	-0.069	7.215	4.322494
e	l	19	125	127	639	0.132	-0.034	0.130	-0.033	-0.034	7.200	1.031222
E	l	1	7	145	757	0.125	-0.036	0.007	-0.002	-0.009	7.201	0.075255
i	l	19	66	127	698	0.224	0.070	0.130	0.044	0.055	7.195	2.770524
o	l	27	126	119	638	0.176	0.019	0.185	0.020	0.020	7.197	0.350910
u	l	7	50	139	714	0.123	-0.040	0.048	-0.017	-0.027	7.201	0.639338
we	l	2	2	144	762	0.500	0.341	0.014	0.011	0.061	7.191	3.439093
wu	l	26	91	120	673	0.222	0.071	0.178	0.059	0.065	7.195	3.804730
ye	l	8	59	138	705	0.119	-0.044	0.055	-0.022	-0.032	7.201	0.904206
yo	l	1	2	145	762	0.333	0.173	0.007	0.004	0.027	7.193	0.667960
yu	l	1	4	145	760	0.200	0.040	0.007	0.002	0.008	7.196	0.058414
a	m	28	180	83	619	0.135	0.016	0.252	0.027	0.021	6.805	0.402062
A	m	9	43	102	756	0.173	0.054	0.081	0.027	0.038	6.802	1.344601
e	m	17	127	94	672	0.118	-0.005	0.153	-0.006	-0.005	6.806	0.024575
E	m	2	6	109	793	0.250	0.129	0.018	0.011	0.037	6.799	1.235113
i	m	15	70	96	729	0.176	0.060	0.135	0.048	0.053	6.802	2.599524

o	m	13	140	98	659	0.085	-0.044	0.117	-0.058	-0.051	6.811	2.352364
u	m	11	46	100	753	0.193	0.076	0.099	0.042	0.056	6.801	2.862537
wu	m	12	105	99	694	0.103	-0.022	0.108	-0.023	-0.023	6.808	0.472491
ya	m	1	6	110	793	0.143	0.021	0.009	0.001	0.006	6.804	0.028713
ye	m	3	64	108	735	0.045	-0.083	0.027	-0.053	-0.067	6.828	4.024923
a	n	42	166	135	567	0.202	0.010	0.237	0.011	0.010	7.474	0.094688
A	n	8	44	169	689	0.154	-0.043	0.045	-0.015	-0.025	7.476	0.581947
e	n	30	114	147	619	0.208	0.016	0.169	0.014	0.015	7.474	0.208780
i	n	14	71	163	662	0.165	-0.033	0.079	-0.018	-0.024	7.476	0.531414
o	n	22	131	155	602	0.144	-0.061	0.124	-0.054	-0.058	7.477	3.019320
u	n	4	53	173	680	0.070	-0.133	0.023	-0.050	-0.081	7.488	5.999637
we	n	1	3	176	730	0.250	0.056	0.006	0.002	0.009	7.472	0.078973
wu	n	30	87	147	646	0.256	0.071	0.169	0.051	0.060	7.472	3.284034
ya	n	2	5	175	728	0.286	0.092	0.011	0.004	0.020	7.472	0.374568
ye	n	23	44	154	689	0.343	0.161	0.130	0.070	0.106	7.471	10.21814
yu	n	1	4	176	729	0.200	0.006	0.006	0.000	0.001	7.474	0.000968
a	p	12	196	39	663	0.058	0.002	0.235	0.007	0.004	5.698	0.013848
A	p	3	49	48	810	0.058	0.002	0.059	0.002	0.002	5.698	0.002832
e	p	10	134	41	725	0.069	0.016	0.196	0.040	0.025	5.694	0.580678
E	p	1	7	50	852	0.125	0.070	0.020	0.011	0.028	5.683	0.725419
i	p	12	73	39	786	0.141	0.094	0.235	0.150	0.119	5.682	12.84448
o	p	6	147	45	712	0.039	-0.020	0.118	-0.053	-0.033	5.711	0.984544
u	p	4	53	47	806	0.070	0.015	0.078	0.017	0.016	5.693	0.229542
wu	p	1	116	50	743	0.009	-0.055	0.020	-0.115	-0.079	5.846	5.725387
ye	p	1	66	50	793	0.015	-0.044	0.020	-0.057	-0.050	5.773	2.311449
yo	p	1	2	50	857	0.333	0.278	0.020	0.017	0.069	5.676	4.374629
a	t	15	193	54	648	0.072	-0.005	0.217	-0.012	-0.008	6.129	0.052926
A	t	1	51	68	790	0.019	-0.060	0.014	-0.046	-0.053	6.187	2.520732
e	t	12	132	57	709	0.083	0.009	0.174	0.017	0.012	6.126	0.137656
E	t	3	5	66	836	0.375	0.302	0.043	0.038	0.106	6.111	10.30897
i	t	7	78	62	763	0.082	0.007	0.101	0.009	0.008	6.126	0.057030
o	t	13	140	56	701	0.085	0.011	0.188	0.022	0.016	6.125	0.219414
u	t	3	54	66	787	0.053	-0.025	0.043	-0.021	-0.023	6.137	0.466770
wu	t	7	110	62	731	0.060	-0.018	0.101	-0.029	-0.023	6.133	0.490192
ya	t	1	6	68	835	0.143	0.068	0.014	0.007	0.022	6.118	0.452341
ye	t	5	62	64	779	0.075	-0.001	0.072	-0.001	-0.001	6.128	0.001479
yo	t	1	2	68	839	0.333	0.258	0.014	0.012	0.056	6.112	2.848252
yu	t	1	4	68	837	0.200	0.125	0.014	0.010	0.035	6.115	1.106304

2.

Korean STM stimuli

CV high + VC low stimuli (**CV** + vc)	(list A) /kwal/, /tʰom/, /k’oyŋ/, /ryam/, /kʰæk/, /naŋ/, /hyak/, /rit/, /kʰwim/, /sɛn/, /kɨt/, /pwuk/, /p’ət/, /k’yam/, /kwak/, /k’oyl/, /ryal/, /kʰæm/, /hyat/, /rik/, /tʰot/, /tʃʰiŋ/, /t’ap/, /t’an/, /tʃʰin/ (list B) /syol/, /tʃʰək/, /k’ɨm/, /hyək/, /hoym/, /k’woyp/, /tʰon/, /k’oym/, /kʰæŋ/, /ryaŋ/, /sit/, /mwək/, /hyun/, /pʰuŋ/, /p’yat/, /s’ak/, /k’woyt/, /tʃəŋ/, /pʰyək/, /tʃʰəp/
CV low + VC high stimuli (cv + **VC**)	(list A) /syɛn/, /kʰip/, /mɛt/, /s’yən/, /t’ip/, /pʰɛt/, /t’yop/, /tʃyen/, /kɨŋ/, /tʃʰəl/, /p’uk/, /tʃ’ip/, /tʃʰop/, /syɛŋ/, /hwul/, /hɛt/, /t’yɛn/, /kip/, /tʃɛt/, /tʃ’yop/, /tʰul/, /hun/, /kʰun/, /k’əl/, /tʃ’uk/, /nul/, /tʃ’ɨŋ/, /s’yop/ (list C) /p’yɛn/, /s’ɨm/, /p’yəŋ/, /syul/, /tʃyem/, /tʃ’it/, /ryən/, /hip/, /k’im/, /hwəl/, /t’ɨŋ/, /tʃ’ip/, /rɨm/, /s’ul/, /s’un/, /tʃ’ip/, /tʃ’il/, /tʃ’ɛt /, /p’un/, /kʰul/, /rɨŋ/, /t’un/, /kʰɨk/, /nwəl/
CV low + VC low stimuli (cv + vc)	(list B) /hæp/, /tʰyat/, /t’yun/, /map/, /tʃʰyul/, /p’it/, /kʰok/, /tʃ’aŋ/, /p’ət/, /sɨp/, /pyot/, /s’ən/, /p’ol/, /kʰap/, /kyol/, /səp/, /myat/, /tʰɛp/, /kʰyun/, /pʰæŋ/, /syul/, /kʰan/, /k’it/, /tʃæŋ/, /mɨp/, /t’ot/ (list C) /kʰək/, /roŋ/, /næm/, /tʃ’it/, /tʰɛp/, /rok/, /hæŋ/, /kʰən/, /rɨp/, /tʃʰɛm/, /tʃ’ol/, /tʰət/, /syan/, /tʰɛp/, /k’oŋ/, /tʰət/, /syun/, /kʰət/, /tʰɛm/, /rɨm/, /tʰəp/, /hæk/, /tʰən/, /kit/, /tʃɛm/, /syat/, /p’æŋ/

3.

<u>The Seven Measures of Association of English Onset-Vowel Sequences</u>

(see Appendix 1 for an explanation of ‘a’, ‘b’, ‘c’ and ‘d’ in the table)

C	V	a	b	c	d	TP	DP	TP'	DP'	Rho	MI	Chisq
dʒ	eɪ	5	64	233	2220	0.072	-0.023	0.021	-0.007	-0.013	7.902	0.398319
b	eɪ	17	194	221	2090	0.081	-0.015	0.071	-0.014	-0.014	7.901	0.513162
tʃ	eɪ	6	77	232	2207	0.072	-0.023	0.025	-0.009	-0.014	7.902	0.489600
ʃ	eɪ	13	67	225	2217	0.163	0.070	0.055	0.025	0.042	7.898	4.487340
θ	eɪ	1	22	237	2262	0.043	-0.051	0.004	-0.005	-0.017	7.907	0.703413
d	eɪ	10	132	228	2152	0.070	-0.025	0.042	-0.016	-0.020	7.902	1.009662
f	eɪ	18	114	220	2170	0.136	0.044	0.076	0.026	0.034	7.898	2.874183
g	eɪ	18	73	220	2211	0.198	0.107	0.076	0.044	0.068	7.897	11.81772
h	eɪ	10	145	228	2139	0.065	-0.032	0.042	-0.021	-0.026	7.903	1.722200
k	eɪ	11	153	227	2131	0.067	-0.029	0.046	-0.021	-0.025	7.903	1.529228
l	eɪ	13	171	225	2113	0.071	-0.026	0.055	-0.020	-0.023	7.902	1.306377
m	eɪ	16	131	222	2153	0.109	0.015	0.067	0.010	0.012	7.899	0.382641
n	eɪ	7	98	231	2186	0.067	-0.029	0.029	-0.013	-0.020	7.903	0.983840
p	eɪ	13	173	225	2111	0.070	-0.026	0.055	-0.021	-0.024	7.902	1.407736
r	eɪ	26	169	212	2115	0.133	0.042	0.109	0.035	0.039	7.899	3.754245
s	eɪ	16	132	222	2152	0.108	0.015	0.067	0.009	0.012	7.900	0.347236
t	eɪ	9	128	229	2156	0.066	-0.030	0.038	-0.018	-0.024	7.903	1.393911
v	eɪ	7	26	231	2258	0.212	0.119	0.029	0.018	0.046	7.897	5.424820
w	eɪ	22	148	216	2136	0.129	0.038	0.092	0.028	0.032	7.899	2.619129
dʒ	ɑɪ	5	64	165	2288	0.072	0.005	0.029	0.002	0.003	7.417	0.028858
b	ɑɪ	7	204	163	2148	0.033	-0.037	0.041	-0.046	-0.041	7.426	4.292225
ð	ɑɪ	1	13	169	2339	0.071	0.004	0.006	0.000	0.001	7.417	0.003622
tʃ	ɑɪ	5	78	165	2274	0.060	-0.007	0.029	-0.004	-0.005	7.418	0.070105
ʃ	ɑɪ	3	77	167	2275	0.038	-0.031	0.018	-0.015	-0.022	7.424	1.175530
d	ɑɪ	9	133	161	2219	0.063	-0.004	0.053	-0.004	-0.004	7.418	0.038808
f	ɑɪ	11	121	159	2231	0.083	0.017	0.065	0.013	0.015	7.416	0.562039
g	ɑɪ	4	87	166	2265	0.044	-0.024	0.024	-0.013	-0.018	7.422	0.825885
h	ɑɪ	8	147	162	2205	0.052	-0.017	0.047	-0.015	-0.016	7.420	0.655333
k	ɑɪ	2	162	168	2190	0.012	-0.059	0.012	-0.057	-0.058	7.455	8.505723
l	ɑɪ	20	164	150	2188	0.109	0.045	0.118	0.048	0.046	7.414	5.382543
m	ɑɪ	9	138	161	2214	0.061	-0.007	0.053	-0.006	-0.006	7.418	0.094908
n	ɑɪ	9	96	161	2256	0.086	0.019	0.053	0.012	0.015	7.415	0.584141
p	ɑɪ	8	178	162	2174	0.043	-0.026	0.047	-0.029	-0.027	7.422	1.901204
r	ɑɪ	20	175	150	2177	0.103	0.038	0.118	0.043	0.041	7.414	4.155447
s	ɑɪ	14	134	156	2218	0.095	0.029	0.082	0.025	0.027	7.415	1.848746
t	ɑɪ	13	124	157	2228	0.095	0.029	0.076	0.024	0.026	7.415	1.740729
	ɑɪ											

w	ɑɪ	19	151	151	2201	0.112	0.048	0.112	0.048	0.048	7.414	5.705612
dʒ	ɚ	3	66	146	2307	0.043	-0.016	0.020	-0.008	-0.011	7.232	0.310637
b	ɚ	15	196	134	2177	0.071	0.013	0.101	0.018	0.015	7.227	0.597470
tʃ	ɚ	8	75	141	2298	0.096	0.039	0.054	0.022	0.029	7.225	2.148631
ʃ	ɚ	4	76	145	2297	0.050	-0.009	0.027	-0.005	-0.007	7.230	0.122539
θ	ɚ	3	20	146	2353	0.130	0.072	0.020	0.012	0.029	7.223	2.125973
d	ɚ	5	137	144	2236	0.035	-0.025	0.034	-0.024	-0.025	7.235	1.542143
f	ɚ	11	121	138	2252	0.083	0.026	0.074	0.023	0.024	7.225	1.473895
g	ɚ	2	89	147	2284	0.022	-0.038	0.013	-0.024	-0.030	7.244	2.337782
h	ɚ	9	146	140	2227	0.058	-0.001	0.060	-0.001	-0.001	7.228	0.003064
j	ɚ	1	37	148	2336	0.026	-0.033	0.007	-0.009	-0.017	7.240	0.745049
k	ɚ	13	151	136	2222	0.079	0.022	0.087	0.024	0.023	7.226	1.286016
l	ɚ	5	179	144	2194	0.027	-0.034	0.034	-0.042	-0.038	7.240	3.634747
m	ɚ	4	143	145	2230	0.027	-0.034	0.027	-0.033	-0.034	7.239	2.851987
n	ɚ	4	101	145	2272	0.038	-0.022	0.027	-0.016	-0.019	7.234	0.867912
p	ɚ	18	168	131	2205	0.097	0.041	0.121	0.050	0.045	7.224	5.132607
s	ɚ	14	134	135	2239	0.095	0.038	0.094	0.037	0.038	7.225	3.567332
t	ɚ	10	127	139	2246	0.073	0.015	0.067	0.014	0.014	7.226	0.504429
v	ɚ	4	29	145	2344	0.121	0.063	0.027	0.015	0.030	7.223	2.322048
w	ɚ	16	154	133	2219	0.094	0.038	0.107	0.042	0.040	7.225	4.025597
dʒ	ɔɪ	2	67	31	2422	0.029	0.016	0.061	0.034	0.023	5.063	1.388922
b	ɔɪ	4	207	29	2282	0.019	0.006	0.121	0.038	0.016	5.074	0.614927
tʃ	ɔɪ	2	81	31	2408	0.024	0.011	0.061	0.028	0.018	5.067	0.805857
f	ɔɪ	2	130	31	2359	0.015	0.002	0.061	0.008	0.004	5.081	0.046069
k	ɔɪ	8	156	25	2333	0.049	0.038	0.242	0.180	0.083	5.056	17.30719
l	ɔɪ	1	183	32	2306	0.005	-0.008	0.030	-0.043	-0.019	5.145	0.899498
m	ɔɪ	1	146	32	2343	0.007	-0.007	0.030	-0.028	-0.014	5.126	0.477050
n	ɔɪ	1	104	32	2385	0.010	-0.004	0.030	-0.011	-0.007	5.103	0.107588
p	ɔɪ	2	184	31	2305	0.011	-0.003	0.061	-0.013	-0.006	5.096	0.084577
s	ɔɪ	2	146	31	2343	0.014	0.000	0.061	0.002	0.001	5.086	0.002237
t	ɔɪ	2	135	31	2354	0.015	0.002	0.061	0.006	0.003	5.082	0.025704
v	ɔɪ	6	27	27	2462	0.182	0.171	0.182	0.171	0.171	5.047	73.72031
dʒ	o	2	67	163	2290	0.029	-0.037	0.012	-0.016	-0.025	7.385	1.540530
b	o	10	201	155	2156	0.047	-0.020	0.061	-0.025	-0.022	7.378	1.224359
ð	o	1	13	164	2344	0.071	0.006	0.006	0.001	0.002	7.374	0.008300
tʃ	o	2	81	163	2276	0.024	-0.043	0.012	-0.022	-0.031	7.389	2.397420
ʃ	o	2	78	163	2279	0.025	-0.042	0.012	-0.021	-0.030	7.388	2.208108
θ	o	1	22	164	2335	0.043	-0.022	0.006	-0.003	-0.009	7.379	0.182837
d	o	9	133	156	2224	0.063	-0.002	0.055	-0.002	-0.002	7.375	0.010281

f	o	7	125	158	2232	0.053	-0.013	0.042	-0.011	-0.012	7.377	0.349935
ɡ	o	5	86	160	2271	0.055	-0.011	0.030	-0.006	-0.008	7.376	0.169553
h	o	14	141	151	2216	0.090	0.027	0.085	0.025	0.026	7.372	1.674422
j	o	3	35	162	2322	0.079	0.014	0.018	0.003	0.007	7.373	0.115392
k	o	18	146	147	2211	0.110	0.047	0.109	0.047	0.047	7.371	5.637974
l	o	14	170	151	2187	0.076	0.012	0.085	0.013	0.012	7.373	0.369061
m	o	11	136	154	2221	0.075	0.010	0.067	0.009	0.009	7.373	0.225852
n	o	9	96	156	2261	0.086	0.021	0.055	0.014	0.017	7.372	0.737682
p	o	13	173	152	2184	0.070	0.005	0.079	0.005	0.005	7.374	0.065569
r	o	18	177	147	2180	0.092	0.029	0.109	0.034	0.031	7.372	2.498038
s	o	8	140	157	2217	0.054	-0.012	0.048	-0.011	-0.011	7.376	0.332437
t	o	11	126	154	2231	0.080	0.016	0.067	0.013	0.014	7.373	0.523735
v	o	4	29	161	2328	0.121	0.057	0.024	0.012	0.026	7.370	1.702002
w	o	1	169	164	2188	0.006	-0.064	0.006	-0.066	-0.065	7.460	10.56936
z	o	2	13	163	2344	0.133	0.068	0.012	0.007	0.021	7.370	1.138109

dʒ	ɑʊ	1	68	59	2394	0.014	-0.010	0.017	-0.011	-0.010	5.945	0.264068
b	ɑʊ	2	209	58	2253	0.009	-0.016	0.033	-0.052	-0.028	5.965	2.030847
ʃ	ɑʊ	2	78	58	2384	0.025	0.001	0.033	0.002	0.001	5.929	0.005203
d	ɑʊ	10	132	50	2330	0.070	0.049	0.167	0.113	0.075	5.914	14.08878
f	ɑʊ	5	127	55	2335	0.038	0.015	0.083	0.032	0.022	5.921	1.190363
ɡ	ɑʊ	5	86	55	2376	0.055	0.032	0.083	0.048	0.040	5.917	3.945404
h	ɑʊ	5	150	55	2312	0.032	0.009	0.083	0.022	0.014	5.924	0.509837
j	ɑʊ	2	36	58	2426	0.053	0.029	0.033	0.019	0.023	5.917	1.381804
k	ɑʊ	4	160	56	2302	0.024	0.001	0.067	0.002	0.001	5.930	0.002715
l	ɑʊ	4	180	56	2282	0.022	-0.002	0.067	-0.006	-0.004	5.932	0.035968
m	ɑʊ	4	143	56	2319	0.027	0.004	0.067	0.009	0.006	5.927	0.078625
n	ɑʊ	3	102	57	2360	0.029	0.005	0.050	0.009	0.007	5.926	0.107822
p	ɑʊ	4	182	56	2280	0.022	-0.002	0.067	-0.007	-0.004	5.933	0.045155
r	ɑʊ	3	192	57	2270	0.015	-0.009	0.050	-0.028	-0.016	5.943	0.643007
s	ɑʊ	3	145	57	2317	0.020	-0.004	0.050	-0.009	-0.006	5.934	0.083898
t	ɑʊ	3	134	57	2328	0.022	-0.002	0.050	-0.004	-0.003	5.932	0.022348

dʒ	ɪə	2	67	50	2403	0.029	0.009	0.038	0.011	0.010	5.719	0.245935
b	ɪə	4	207	48	2263	0.019	-0.002	0.077	-0.007	-0.004	5.730	0.031467
tʃ	ɪə	2	81	50	2389	0.024	0.004	0.038	0.006	0.005	5.723	0.051406
ʃ	ɪə	4	76	48	2394	0.050	0.030	0.077	0.046	0.037	5.711	3.532039
d	ɪə	4	138	48	2332	0.028	0.008	0.077	0.021	0.013	5.720	0.424808
f	ɪə	3	129	49	2341	0.023	0.002	0.058	0.005	0.003	5.725	0.030672
ɡ	ɪə	2	89	50	2381	0.022	0.001	0.038	0.002	0.002	5.726	0.008640
h	ɪə	2	153	50	2317	0.013	-0.008	0.038	-0.023	-0.014	5.744	0.486830

j	ɪə	2	36	50	2434	0.053	0.033	0.038	0.024	0.028	5.711	1.958034
k	ɪə	1	163	51	2307	0.006	-0.016	0.019	-0.047	-0.027	5.791	1.831588
l	ɪə	3	181	49	2289	0.016	-0.005	0.058	-0.016	-0.009	5.735	0.182940
m	ɪə	2	145	50	2325	0.014	-0.007	0.038	-0.020	-0.012	5.741	0.380198
n	ɪə	5	100	47	2370	0.048	0.028	0.096	0.056	0.040	5.712	3.955404
p	ɪə	4	182	48	2288	0.022	0.001	0.077	0.003	0.002	5.726	0.007820
r	ɪə	5	190	47	2280	0.026	0.005	0.096	0.019	0.010	5.722	0.264002
s	ɪə	2	146	50	2324	0.014	-0.008	0.038	-0.021	-0.012	5.742	0.393051
t	ɪə	2	135	50	2335	0.015	-0.006	0.038	-0.016	-0.010	5.739	0.259993
v	ɪə	1	32	51	2438	0.030	0.010	0.019	0.006	0.008	5.719	0.155301
w	ɪə	2	168	50	2302	0.012	-0.009	0.038	-0.030	-0.017	5.748	0.707637
b	ɛə	5	206	41	2270	0.024	0.006	0.109	0.025	0.012	5.547	0.382954
ð	ɛə	1	13	45	2463	0.071	0.053	0.022	0.016	0.030	5.531	2.224191
tʃ	ɛə	2	81	44	2395	0.024	0.006	0.043	0.011	0.008	5.547	0.164409
ʃ	ɛə	3	77	43	2399	0.038	0.020	0.065	0.034	0.026	5.538	1.711616
d	ɛə	2	140	44	2336	0.014	-0.004	0.043	-0.013	-0.008	5.563	0.145069
f	ɛə	5	127	41	2349	0.038	0.021	0.109	0.057	0.034	5.538	3.000230
h	ɛə	3	152	43	2324	0.019	0.001	0.065	0.004	0.002	5.552	0.011473
k	ɛə	3	161	43	2315	0.018	0.000	0.065	0.000	0.000	5.554	0.000027
l	ɛə	2	182	44	2294	0.011	-0.008	0.043	-0.030	-0.015	5.575	0.602041
m	ɛə	2	145	44	2331	0.014	-0.005	0.043	-0.015	-0.009	5.564	0.187198
n	ɛə	1	104	45	2372	0.010	-0.009	0.022	-0.020	-0.014	5.582	0.464774
p	ɛə	4	182	42	2294	0.022	0.004	0.087	0.013	0.007	5.549	0.119610
r	ɛə	1	194	45	2282	0.005	-0.014	0.022	-0.057	-0.028	5.630	2.028876
t	ɛə	3	134	43	2342	0.022	0.004	0.065	0.011	0.007	5.549	0.108273
w	ɛə	9	161	37	2315	0.053	0.037	0.196	0.131	0.070	5.534	12.25856
b	ʊə	2	209	6	2305	0.009	0.007	0.250	0.167	0.034	3.059	2.896351
d	ʊə	1	141	7	2373	0.007	0.004	0.125	0.069	0.017	3.078	0.712772
g	ʊə	1	90	7	2424	0.011	0.008	0.125	0.089	0.027	3.051	1.824350
l	ʊə	2	182	6	2332	0.011	0.008	0.250	0.178	0.038	3.051	3.719207
t	ʊə	2	135	6	2379	0.015	0.012	0.250	0.196	0.049	3.038	5.981845
dʒ	ɑr	2	67	140	2313	0.029	-0.028	0.014	-0.014	-0.020	7.169	0.996440
b	ɑr	18	193	124	2187	0.085	0.032	0.127	0.046	0.038	7.156	3.645477
tʃ	ɑr	12	71	130	2309	0.145	0.091	0.085	0.055	0.071	7.153	12.58635
ʃ	ɑr	5	75	137	2305	0.063	0.006	0.035	0.004	0.005	7.158	0.059684
d	ɑr	8	134	134	2246	0.056	0.000	0.056	0.000	0.000	7.159	0.000003
f	ɑr	7	125	135	2255	0.053	-0.003	0.049	-0.003	-0.003	7.160	0.028103
g	ɑr	5	86	137	2294	0.055	-0.001	0.035	-0.001	-0.001	7.160	0.003283

h	ɑr	15	140	127	2240	0.097	0.043	0.106	0.047	0.045	7.155	5.090527
j	ɑr	3	35	139	2345	0.079	0.023	0.021	0.006	0.012	7.156	0.372275
k	ɑr	14	150	128	2230	0.085	0.031	0.099	0.036	0.033	7.156	2.788053
l	ɑr	11	173	131	2207	0.060	0.004	0.077	0.005	0.004	7.159	0.045188
m	ɑr	13	134	129	2246	0.088	0.034	0.092	0.035	0.035	7.156	3.032970
n	ɑr	3	102	139	2278	0.029	-0.029	0.021	-0.022	-0.025	7.169	1.585912
p	ɑr	16	170	126	2210	0.086	0.032	0.113	0.041	0.036	7.156	3.337486
s	ɑr	2	146	140	2234	0.014	-0.045	0.014	-0.047	-0.046	7.191	5.418211
t	ɑr	5	132	137	2248	0.036	-0.021	0.035	-0.020	-0.021	7.165	1.069771
v	ɑr	1	32	141	2348	0.030	-0.026	0.007	-0.006	-0.013	7.168	0.425456
z	ɑr	2	13	140	2367	0.133	0.077	0.014	0.009	0.026	7.153	1.685051
dʒ	æ	10	59	231	2222	0.145	0.051	0.041	0.016	0.028	7.916	2.000523
b	æ	20	191	221	2090	0.095	-0.001	0.083	-0.001	-0.001	7.918	0.001589
ð	æ	5	9	236	2272	0.357	0.263	0.021	0.017	0.066	7.914	11.14589
tʃ	æ	4	79	237	2202	0.048	-0.049	0.017	-0.018	-0.030	7.924	2.227913
ʃ	æ	7	73	234	2208	0.088	-0.008	0.029	-0.003	-0.005	7.919	0.062088
θ	æ	2	21	239	2260	0.087	-0.009	0.008	-0.001	-0.003	7.919	0.019875
d	æ	11	131	230	2150	0.077	-0.019	0.046	-0.012	-0.015	7.920	0.570016
f	æ	11	121	230	2160	0.083	-0.013	0.046	-0.007	-0.010	7.919	0.240890
g	æ	15	76	226	2205	0.165	0.072	0.062	0.029	0.046	7.916	5.242229
h	æ	15	140	226	2141	0.097	0.001	0.062	0.001	0.001	7.918	0.002821
j	æ	6	32	235	2249	0.158	0.063	0.025	0.011	0.026	7.916	1.734594
k	æ	18	146	223	2135	0.110	0.015	0.075	0.011	0.013	7.918	0.409060
l	æ	17	167	224	2114	0.092	-0.003	0.071	-0.003	-0.003	7.918	0.023044
m	æ	19	128	222	2153	0.129	0.036	0.079	0.023	0.029	7.917	2.050294
n	æ	9	96	232	2185	0.086	-0.010	0.037	-0.005	-0.007	7.919	0.122862
p	æ	15	171	226	2110	0.081	-0.016	0.062	-0.013	-0.014	7.919	0.516792
r	æ	18	177	223	2104	0.092	-0.004	0.075	-0.003	-0.003	7.919	0.025850
s	æ	11	137	230	2144	0.074	-0.023	0.046	-0.014	-0.018	7.920	0.820292
t	æ	15	122	226	2159	0.109	0.015	0.062	0.009	0.011	7.918	0.325256
v	æ	2	31	239	2250	0.061	-0.035	0.008	-0.005	-0.014	7.922	0.472662
w	æ	10	160	231	2121	0.059	-0.039	0.041	-0.029	-0.034	7.922	2.846280
z	æ	1	14	240	2267	0.067	-0.029	0.004	-0.002	-0.008	7.921	0.145746
dʒ	ɪ	11	58	233	2220	0.159	0.064	0.045	0.020	0.036	7.934	3.188496
b	ɪ	16	195	228	2083	0.076	-0.023	0.066	-0.020	-0.021	7.938	1.153096
ð	ɪ	1	13	243	2265	0.071	-0.025	0.004	-0.002	-0.006	7.938	0.103281
tʃ	ɪ	8	75	236	2203	0.096	0.000	0.033	0.000	0.000	7.936	0.000129
ʃ	ɪ	6	74	238	2204	0.075	-0.022	0.025	-0.008	-0.013	7.938	0.447197
θ	ɪ	7	16	237	2262	0.304	0.210	0.029	0.022	0.067	7.932	11.44734

d	ɪ	15	127	229	2151	0.106	0.009	0.061	0.006	0.007	7.936	0.135936
f	ɪ	14	118	230	2160	0.106	0.010	0.057	0.006	0.007	7.936	0.138214
g	ɪ	5	86	239	2192	0.055	-0.043	0.020	-0.017	-0.027	7.941	1.887881
h	ɪ	14	141	230	2137	0.090	-0.007	0.057	-0.005	-0.006	7.936	0.078038
j	ɪ	1	37	243	2241	0.026	-0.072	0.004	-0.012	-0.029	7.952	2.190150
k	ɪ	14	150	230	2128	0.085	-0.012	0.057	-0.008	-0.010	7.937	0.260067
l	ɪ	8	176	236	2102	0.043	-0.057	0.033	-0.044	-0.051	7.943	6.445196
m	ɪ	11	136	233	2142	0.075	-0.023	0.045	-0.015	-0.018	7.938	0.858171
n	ɪ	9	96	235	2182	0.086	-0.012	0.037	-0.005	-0.008	7.937	0.152649
p	ɪ	18	168	226	2110	0.097	0.000	0.074	0.000	0.000	7.936	0.000001
r	ɪ	23	172	221	2106	0.118	0.023	0.094	0.019	0.021	7.935	1.086941
s	ɪ	13	135	231	2143	0.088	-0.009	0.053	-0.006	-0.008	7.937	0.142857
t	ɪ	16	121	228	2157	0.117	0.021	0.066	0.012	0.016	7.935	0.665743
v	ɪ	1	32	243	2246	0.030	-0.067	0.004	-0.010	-0.026	7.949	1.689324
w	ɪ	29	141	215	2137	0.171	0.079	0.119	0.057	0.067	7.934	11.37318
z	ɪ	4	11	240	2267	0.267	0.171	0.016	0.012	0.044	7.932	4.985488
b	ʊ	8	203	37	2274	0.038	0.022	0.178	0.096	0.046	5.506	5.293561
ʃ	ʊ	2	78	43	2399	0.025	0.007	0.044	0.013	0.010	5.514	0.241493
f	ʊ	6	126	39	2351	0.045	0.029	0.133	0.082	0.049	5.504	6.059750
g	ʊ	2	89	43	2388	0.022	0.004	0.044	0.009	0.006	5.517	0.092111
h	ʊ	4	151	41	2326	0.026	0.008	0.089	0.028	0.015	5.513	0.597633
k	ʊ	2	162	43	2315	0.012	-0.006	0.044	-0.021	-0.011	5.537	0.319274
l	ʊ	2	182	43	2295	0.011	-0.008	0.044	-0.029	-0.015	5.543	0.550758
n	ʊ	1	104	44	2373	0.010	-0.009	0.022	-0.020	-0.013	5.550	0.432682
p	ʊ	9	177	36	2300	0.048	0.033	0.200	0.129	0.065	5.503	10.69035
r	ʊ	2	193	43	2284	0.010	-0.008	0.044	-0.033	-0.017	5.546	0.694106
s	ʊ	2	146	43	2331	0.014	-0.005	0.044	-0.014	-0.008	5.533	0.168169
w	ʊ	5	165	40	2312	0.029	0.012	0.111	0.044	0.023	5.511	1.392142
dʒ	ɛ	6	63	153	2300	0.087	0.025	0.038	0.011	0.017	7.319	0.686646
b	ɛ	10	201	149	2162	0.047	-0.017	0.063	-0.022	-0.019	7.324	0.954965
ð	ɛ	3	11	156	2352	0.214	0.152	0.019	0.014	0.046	7.315	5.451439
tʃ	ɛ	6	77	153	2286	0.072	0.010	0.038	0.005	0.007	7.320	0.124152
ʃ	ɛ	5	75	154	2288	0.063	-0.001	0.031	0.000	0.000	7.321	0.000415
d	ɛ	12	130	147	2233	0.085	0.023	0.075	0.020	0.022	7.319	1.173328
f	ɛ	6	126	153	2237	0.045	-0.019	0.038	-0.016	-0.017	7.325	0.729649
g	ɛ	3	88	156	2275	0.033	-0.031	0.019	-0.018	-0.024	7.330	1.445884
h	ɛ	11	144	148	2219	0.071	0.008	0.069	0.008	0.008	7.320	0.175483
j	ɛ	8	30	151	2333	0.211	0.150	0.050	0.038	0.075	7.315	14.20624
k	ɛ	4	160	155	2203	0.024	-0.041	0.025	-0.043	-0.042	7.336	4.436953

l	ε	10	174	149	2189	0.054	-0.009	0.063	-0.011	-0.010	7.323	0.254170
m	ε	4	143	155	2220	0.027	-0.038	0.025	-0.035	-0.037	7.333	3.393332
n	ε	9	96	150	2267	0.086	0.024	0.057	0.016	0.019	7.319	0.953136
p	ε	9	177	150	2186	0.048	-0.016	0.057	-0.018	-0.017	7.324	0.730415
r	ε	14	181	145	2182	0.072	0.009	0.088	0.011	0.010	7.320	0.273902
s	ε	10	138	149	2225	0.068	0.005	0.063	0.004	0.005	7.321	0.054436
t	ε	5	132	154	2231	0.036	-0.028	0.031	-0.024	-0.026	7.328	1.728614
v	ε	3	30	156	2333	0.091	0.028	0.019	0.006	0.013	7.319	0.439487
w	ε	18	152	141	2211	0.106	0.046	0.113	0.049	0.047	7.318	5.662747
z	ε	3	12	156	2351	0.200	0.138	0.019	0.014	0.044	7.315	4.791437
dʒ	i	2	67	201	2252	0.029	-0.053	0.010	-0.019	-0.032	7.684	2.542778
b	i	17	194	186	2125	0.081	0.000	0.084	0.000	0.000	7.672	0.000018
ð	i	1	13	202	2306	0.071	-0.009	0.005	-0.001	-0.002	7.673	0.015624
tʃ	i	12	71	191	2248	0.145	0.066	0.059	0.028	0.043	7.669	4.762552
ʃ	i	8	72	195	2247	0.100	0.020	0.039	0.008	0.013	7.670	0.424837
θ	i	3	20	200	2299	0.130	0.050	0.015	0.006	0.018	7.669	0.782260
d	i	8	134	195	2185	0.056	-0.026	0.039	-0.018	-0.022	7.675	1.186083
f	i	6	126	197	2193	0.045	-0.037	0.030	-0.025	-0.030	7.677	2.310316
h	i	13	142	190	2177	0.084	0.004	0.064	0.003	0.003	7.672	0.025481
k	i	6	158	197	2161	0.037	-0.047	0.030	-0.039	-0.043	7.680	4.568696
l	i	26	158	177	2161	0.141	0.066	0.128	0.060	0.063	7.669	9.917449
m	i	12	135	191	2184	0.082	0.001	0.059	0.001	0.001	7.672	0.002745
n	i	7	98	196	2221	0.067	-0.014	0.034	-0.008	-0.011	7.673	0.282931
p	i	19	167	184	2152	0.102	0.023	0.094	0.022	0.022	7.670	1.272770
r	i	17	178	186	2141	0.087	0.007	0.084	0.007	0.007	7.671	0.127715
s	i	19	129	184	2190	0.128	0.051	0.094	0.038	0.044	7.669	4.871350
t	i	10	127	193	2192	0.073	-0.008	0.049	-0.006	-0.007	7.673	0.110071
v	i	1	32	202	2287	0.030	-0.051	0.005	-0.009	-0.021	7.684	1.137989
w	i	15	155	188	2164	0.088	0.008	0.074	0.007	0.008	7.671	0.147685
z	i	1	14	202	2305	0.067	-0.014	0.005	-0.001	-0.004	7.673	0.038967
dʒ	u	5	64	116	2337	0.072	0.025	0.041	0.015	0.019	6.926	0.931202
b	u	12	199	109	2202	0.057	0.010	0.099	0.016	0.013	6.928	0.398802
tʃ	u	1	82	120	2319	0.012	-0.037	0.008	-0.026	-0.031	6.965	2.425653
ʃ	u	3	77	118	2324	0.038	-0.011	0.025	-0.007	-0.009	6.933	0.198582
d	u	3	139	118	2262	0.021	-0.028	0.025	-0.033	-0.031	6.945	2.375150
f	u	4	128	117	2273	0.030	-0.019	0.033	-0.020	-0.019	6.937	0.952666
g	u	6	85	115	2316	0.066	0.019	0.050	0.014	0.016	6.927	0.666417
h	u	6	149	115	2252	0.039	-0.010	0.050	-0.012	-0.011	6.933	0.310580
j	u	5	33	116	2368	0.132	0.085	0.041	0.028	0.048	6.923	5.903563

k	u	10	154	111	2247	0.061	0.014	0.083	0.019	0.016	6.928	0.648781
l	u	15	169	106	2232	0.082	0.036	0.124	0.054	0.044	6.925	4.889441
m	u	8	139	113	2262	0.054	0.007	0.066	0.008	0.008	6.929	0.141911
n	u	3	102	118	2299	0.029	-0.020	0.025	-0.018	-0.019	6.938	0.903355
p	u	7	179	114	2222	0.038	-0.011	0.058	-0.017	-0.014	6.933	0.470352
r	u	16	179	105	2222	0.082	0.037	0.132	0.058	0.046	6.925	5.371914
s	u	5	143	116	2258	0.034	-0.015	0.041	-0.018	-0.017	6.935	0.693504
t	u	6	131	115	2270	0.044	-0.004	0.050	-0.005	-0.005	6.931	0.055474
w	u	4	166	117	2235	0.024	-0.026	0.033	-0.036	-0.031	6.942	2.385446
z	u	2	13	119	2388	0.133	0.086	0.017	0.011	0.031	6.923	2.406900
dʒ	ʌ	4	65	236	2217	0.058	-0.038	0.017	-0.012	-0.021	7.916	1.139589
b	ʌ	28	183	212	2099	0.133	0.041	0.117	0.036	0.039	7.911	3.768364
ð	ʌ	1	13	239	2269	0.071	-0.024	0.004	-0.002	-0.006	7.914	0.092098
tʃ	ʌ	8	75	232	2207	0.096	0.001	0.033	0.000	0.001	7.912	0.001490
ʃ	ʌ	6	74	234	2208	0.075	-0.021	0.025	-0.007	-0.012	7.914	0.390071
θ	ʌ	5	18	235	2264	0.217	0.123	0.021	0.013	0.040	7.909	4.027324
d	ʌ	21	121	219	2161	0.148	0.056	0.088	0.034	0.044	7.910	4.857903
f	ʌ	11	121	229	2161	0.083	-0.012	0.046	-0.007	-0.009	7.913	0.226359
g	ʌ	12	79	228	2203	0.132	0.038	0.050	0.015	0.024	7.911	1.477163
h	ʌ	16	139	224	2143	0.103	0.009	0.067	0.006	0.007	7.912	0.124698
j	ʌ	2	36	238	2246	0.053	-0.043	0.008	-0.007	-0.018	7.917	0.810496
k	ʌ	15	149	225	2133	0.091	-0.004	0.063	-0.003	-0.003	7.913	0.027874
l	ʌ	13	171	227	2111	0.071	-0.026	0.054	-0.021	-0.023	7.914	1.384784
m	ʌ	19	128	221	2154	0.129	0.036	0.079	0.023	0.029	7.911	2.106657
n	ʌ	11	94	229	2188	0.105	0.010	0.046	0.005	0.007	7.912	0.117247
p	ʌ	14	172	226	2110	0.075	-0.021	0.058	-0.017	-0.019	7.914	0.922957
r	ʌ	20	175	220	2107	0.103	0.008	0.083	0.007	0.007	7.912	0.134459
s	ʌ	15	133	225	2149	0.101	0.007	0.063	0.004	0.005	7.912	0.069935
t	ʌ	15	122	225	2160	0.109	0.015	0.063	0.009	0.012	7.912	0.345318
w	ʌ	4	166	236	2116	0.024	-0.077	0.017	-0.056	-0.066	7.930	10.86295
dʒ	a	9	60	196	2257	0.130	0.051	0.044	0.018	0.030	7.683	2.294856
b	a	16	195	189	2122	0.076	-0.006	0.078	-0.006	-0.006	7.686	0.091765
tʃ	a	5	78	200	2239	0.060	-0.022	0.024	-0.009	-0.014	7.688	0.508940
ʃ	a	7	73	198	2244	0.088	0.006	0.034	0.003	0.004	7.685	0.042739
θ	a	1	22	204	2295	0.043	-0.038	0.005	-0.005	-0.013	7.692	0.444271
d	a	14	128	191	2189	0.099	0.018	0.068	0.013	0.015	7.685	0.603535
f	a	5	127	200	2190	0.038	-0.046	0.024	-0.030	-0.037	7.694	3.514220
g	a	6	85	199	2232	0.066	-0.016	0.029	-0.007	-0.011	7.688	0.297895
h	a	10	145	195	2172	0.065	-0.018	0.049	-0.014	-0.016	7.688	0.621842

i	a	5	33	200	2284	0.132	0.051	0.024	0.010	0.023	7.683	1.306845
k	a	20	144	185	2173	0.122	0.043	0.098	0.035	0.039	7.684	3.884449
l	a	18	166	187	2151	0.098	0.018	0.088	0.016	0.017	7.685	0.727231
m	a	12	135	193	2182	0.082	0.000	0.059	0.000	0.000	7.686	0.000253
n	a	14	91	191	2226	0.133	0.054	0.068	0.029	0.040	7.683	3.974538
p	a	13	173	192	2144	0.070	-0.012	0.063	-0.011	-0.012	7.687	0.348989
r	a	12	183	193	2134	0.062	-0.021	0.059	-0.020	-0.021	7.688	1.103474
s	a	12	136	193	2181	0.081	0.000	0.059	0.000	0.000	7.686	0.000087
t	a	10	127	195	2190	0.073	-0.009	0.049	-0.006	-0.007	7.687	0.133384
w	a	16	154	189	2163	0.094	0.014	0.078	0.012	0.013	7.685	0.401994

Measures of association of English vowel-coda sequences

V	C	a	b	c	d	TP	DP	TP'	DP'	Rho	MI	Chisq
eɪ	dʒ	14	224	46	2218	0.059	0.039	0.233	0.142	0.074	5.916	13.6423596
ɚ	dʒ	8	141	52	2301	0.054	0.032	0.133	0.076	0.049	5.917	5.9751401
o	dʒ	1	164	59	2278	0.006	-0.019	0.017	-0.050	-0.031	5.998	2.4236862
ɑʊ	dʒ	2	58	58	2384	0.033	0.010	0.033	0.010	0.010	5.924	0.2297353
a	dʒ	8	115	52	2327	0.065	0.043	0.133	0.086	0.061	5.915	9.3177290
æ	dʒ	3	238	57	2204	0.012	-0.013	0.050	-0.047	-0.025	5.952	1.5154519
ɪ	dʒ	3	241	57	2201	0.012	-0.013	0.050	-0.049	-0.025	5.952	1.5774037
ɑ	dʒ	5	200	55	2242	0.024	0.000	0.083	0.001	0.001	5.930	0.0015992
ɛ	dʒ	6	153	54	2289	0.038	0.015	0.100	0.037	0.023	5.922	1.3725025
i	dʒ	3	200	57	2242	0.015	-0.010	0.050	-0.032	-0.018	5.945	0.7993423
ʌ	dʒ	7	233	53	2209	0.029	0.006	0.117	0.021	0.011	5.926	0.3050168
eɪ	b	1	237	69	2195	0.004	-0.026	0.014	-0.083	-0.047	6.260	5.4673406
ɑɪ	b	3	167	67	2265	0.018	-0.011	0.043	-0.026	-0.017	6.161	0.7157615
ɚ	b	5	144	65	2288	0.034	0.006	0.071	0.012	0.009	6.146	0.1813611
o	b	3	162	67	2270	0.018	-0.010	0.043	-0.024	-0.016	6.160	0.6233118
a	b	4	119	66	2313	0.033	0.005	0.057	0.008	0.006	6.146	0.0981613
æ	b	9	232	61	2200	0.037	0.010	0.129	0.033	0.019	6.144	0.8603942
ɪ	b	11	233	59	2199	0.045	0.019	0.157	0.061	0.034	6.141	2.9085686
ɑ	b	18	187	52	2245	0.088	0.065	0.257	0.180	0.108	6.135	29.3894460
ɛ	b	3	156	67	2276	0.019	-0.010	0.043	-0.021	-0.014	6.159	0.5181227
u	b	2	119	68	2313	0.017	-0.012	0.029	-0.020	-0.016	6.163	0.6128272
ʌ	b	11	229	59	2203	0.046	0.020	0.157	0.063	0.035	6.141	3.1122427
eɪ	ð	3	235	14	2250	0.013	0.006	0.176	0.082	0.023	4.132	1.3158634
ɑɪ	ð	5	165	12	2320	0.029	0.024	0.294	0.228	0.074	4.106	13.8256216
o	ð	1	164	16	2321	0.006	-0.001	0.059	-0.007	-0.002	4.179	0.0141012
ɑʊ	ð	1	59	16	2426	0.017	0.010	0.059	0.035	0.019	4.121	0.8877925
ɪ	ð	1	243	16	2242	0.004	-0.003	0.059	-0.039	-0.011	4.221	0.2912446
i	ð	4	199	13	2286	0.020	0.014	0.235	0.155	0.047	4.116	5.4561632
u	ð	2	119	15	2366	0.017	0.010	0.118	0.070	0.027	4.121	1.7853670
ɚ	tʃ	12	137	76	2277	0.081	0.048	0.136	0.080	0.062	6.466	9.6083566
o	tʃ	4	161	84	2253	0.024	-0.012	0.045	-0.021	-0.016	6.482	0.6218174
ɑʊ	tʃ	4	56	84	2358	0.067	0.032	0.045	0.022	0.027	6.467	1.7969061
a	tʃ	6	117	82	2297	0.049	0.014	0.068	0.020	0.017	6.471	0.7059617
æ	tʃ	13	228	75	2186	0.054	0.021	0.148	0.053	0.033	6.470	2.7687844
ɪ	tʃ	13	231	75	2183	0.053	0.020	0.148	0.052	0.032	6.470	2.6121164
ɑ	tʃ	6	199	82	2215	0.029	-0.006	0.068	-0.014	-0.010	6.478	0.2293318
ʊ	tʃ	2	43	86	2371	0.044	0.009	0.023	0.005	0.007	6.472	0.1161049

ɛ	tʃ	7	152	81	2262	0.044	0.009	0.080	0.017	0.013	6.472	0.3921721
i	tʃ	10	193	78	2221	0.049	0.015	0.114	0.034	0.023	6.471	1.2923288
u	tʃ	3	118	85	2296	0.025	-0.011	0.034	-0.015	-0.013	6.482	0.4035850
ʌ	tʃ	8	232	80	2182	0.033	-0.002	0.091	-0.005	-0.003	6.476	0.0264424
æ	ŋ	14	227	40	2221	0.058	0.040	0.259	0.167	0.082	5.764	16.8330360
ɪ	ŋ	17	227	37	2221	0.070	0.053	0.315	0.222	0.109	5.763	29.6088337
ɑ	ŋ	14	191	40	2257	0.068	0.051	0.259	0.181	0.096	5.763	23.0711051
ʌ	ŋ	9	231	45	2217	0.038	0.018	0.167	0.072	0.036	5.770	3.1850213
o	ʃ	1	164	60	2277	0.006	-0.020	0.016	-0.051	-0.032	6.022	2.4925004
ɪə	ʃ	1	50	60	2391	0.020	-0.005	0.016	-0.004	-0.004	5.959	0.0498552
a	ʃ	2	121	59	2320	0.016	-0.009	0.033	-0.017	-0.012	5.965	0.3586102
æ	ʃ	20	221	41	2220	0.083	0.065	0.328	0.237	0.124	5.937	38.5106277
ɪ	ʃ	6	238	55	2203	0.025	0.000	0.098	0.001	0.000	5.953	0.0004997
ɑ	ʃ	13	192	48	2249	0.063	0.043	0.213	0.134	0.076	5.939	14.3036332
ʊ	ʃ	5	40	56	2401	0.111	0.088	0.082	0.066	0.076	5.935	14.4916059
ɛ	ʃ	2	157	59	2284	0.013	-0.013	0.033	-0.032	-0.020	5.975	0.9942405
i	ʃ	1	202	60	2239	0.005	-0.021	0.016	-0.066	-0.037	6.043	3.5152521
u	ʃ	1	120	60	2321	0.008	-0.017	0.016	-0.033	-0.024	5.998	1.3883743
ʌ	ʃ	9	231	52	2210	0.038	0.015	0.148	0.053	0.028	5.945	1.9209577
eɪ	θ	2	236	32	2232	0.008	-0.006	0.059	-0.037	-0.015	5.154	0.5276725
ɚ	θ	8	141	26	2327	0.054	0.043	0.235	0.178	0.087	5.098	19.0080437
o	θ	3	162	31	2306	0.018	0.005	0.088	0.023	0.011	5.118	0.2779696
ɑʊ	θ	3	57	31	2411	0.050	0.037	0.088	0.065	0.049	5.098	6.0800280
a	θ	5	118	29	2350	0.041	0.028	0.147	0.099	0.053	5.101	7.0671631
ɪ	θ	3	241	31	2227	0.012	-0.001	0.088	-0.009	-0.004	5.133	0.0337756
ɑ	θ	3	202	31	2266	0.015	0.001	0.088	0.006	0.003	5.126	0.0181919
i	θ	4	199	30	2269	0.020	0.007	0.118	0.037	0.016	5.116	0.6163553
u	θ	3	118	31	2350	0.025	0.012	0.088	0.040	0.022	5.110	1.1907762
eɪ	ʒ	2	236	2	2262	0.008	0.008	0.500	0.406	0.055	2.066	7.6299268
u	ʒ	2	119	2	2379	0.017	0.016	0.500	0.452	0.084	2.034	17.7568933
eɪ	d	9	229	164	2100	0.038	-0.035	0.052	-0.046	-0.040	7.449	4.0110253
ɑɪ	d	15	155	158	2174	0.088	0.020	0.087	0.020	0.020	7.441	1.0327764
ɚ	d	12	137	161	2192	0.081	0.012	0.069	0.011	0.011	7.441	0.3194685
ɔɪ	d	3	30	170	2299	0.091	0.022	0.017	0.004	0.010	7.440	0.2461120
o	d	13	152	160	2177	0.079	0.010	0.075	0.010	0.010	7.441	0.2552192
ɑʊ	d	3	57	170	2272	0.050	-0.020	0.017	-0.007	-0.012	7.446	0.3500647

ɪə	d	3	48	170	2281	0.059	-0.011	0.017	-0.003	-0.006	7.444	0.0861648
ɛə	d	1	45	172	2284	0.022	-0.048	0.006	-0.014	-0.026	7.460	1.6361919
ʊə	d	1	7	172	2322	0.125	0.056	0.006	0.003	0.012	7.439	0.3890173
a	d	13	110	160	2219	0.106	0.038	0.075	0.028	0.033	7.439	2.6843896
æ	d	12	229	161	2100	0.050	-0.021	0.069	-0.029	-0.025	7.446	1.5517487
ɪ	d	8	236	165	2093	0.033	-0.040	0.046	-0.055	-0.047	7.452	5.5527406
ɑ	d	17	188	156	2141	0.083	0.015	0.098	0.018	0.016	7.441	0.6589809
ʊ	d	9	36	164	2293	0.200	0.133	0.052	0.037	0.070	7.437	12.1909183
ɛ	d	19	140	154	2189	0.119	0.054	0.110	0.050	0.052	7.439	6.6881740
i	d	22	181	151	2148	0.108	0.043	0.127	0.049	0.046	7.439	5.2824253
u	d	4	117	169	2212	0.033	-0.038	0.023	-0.027	-0.032	7.451	2.5725856
ʌ	d	9	231	164	2098	0.038	-0.035	0.052	-0.047	-0.041	7.449	4.1301564
eɪ	f	5	233	86	2178	0.021	-0.017	0.055	-0.042	-0.027	6.534	1.7711186
ɑɪ	f	6	164	85	2247	0.035	-0.001	0.066	-0.002	-0.002	6.523	0.0060340
ɚ	f	5	144	86	2267	0.034	-0.003	0.055	-0.005	-0.004	6.524	0.0357925
ɔɪ	f	1	32	90	2379	0.030	-0.006	0.011	-0.002	-0.004	6.526	0.0351309
o	f	2	163	89	2248	0.012	-0.026	0.022	-0.046	-0.034	6.554	2.9638824
a	f	9	114	82	2297	0.073	0.039	0.099	0.052	0.045	6.515	4.9983374
æ	f	4	237	87	2174	0.017	-0.022	0.044	-0.054	-0.034	6.542	2.9751042
ɪ	f	8	236	83	2175	0.033	-0.004	0.088	-0.010	-0.006	6.525	0.0990899
ɑ	f	4	201	87	2210	0.020	-0.018	0.044	-0.039	-0.027	6.536	1.8107761
ɛ	f	3	156	88	2255	0.019	-0.019	0.033	-0.032	-0.024	6.537	1.4841305
i	f	13	190	78	2221	0.064	0.030	0.143	0.064	0.044	6.516	4.8256052
u	f	8	113	83	2298	0.066	0.031	0.088	0.041	0.036	6.516	3.2097512
ʌ	f	23	217	68	2194	0.096	0.066	0.253	0.163	0.103	6.513	26.7810291
eɪ	g	1	237	91	2173	0.004	-0.036	0.011	-0.087	-0.056	6.654	7.8770543
ɚ	g	1	148	91	2262	0.007	-0.032	0.011	-0.051	-0.040	6.606	4.0418061
o	g	3	162	89	2248	0.018	-0.020	0.033	-0.035	-0.026	6.554	1.7233892
æ	g	25	216	67	2194	0.104	0.074	0.272	0.182	0.116	6.529	33.7640425
ɪ	g	17	227	75	2183	0.070	0.036	0.185	0.091	0.057	6.531	8.2633393
ɑ	g	14	191	78	2219	0.068	0.034	0.152	0.073	0.050	6.531	6.2644101
ɛ	g	7	152	85	2258	0.044	0.008	0.076	0.013	0.010	6.536	0.2522933
i	g	2	201	90	2209	0.010	-0.029	0.022	-0.062	-0.043	6.580	4.5197199
ʌ	g	22	218	70	2192	0.092	0.061	0.239	0.149	0.095	6.529	22.5869923
eɪ	k	20	218	228	2036	0.084	-0.017	0.081	-0.016	-0.016	7.960	0.6704522
ɑɪ	k	15	155	233	2099	0.088	-0.012	0.060	-0.008	-0.010	7.960	0.2420283
ɚ	k	16	133	232	2121	0.107	0.009	0.065	0.006	0.007	7.959	0.1211086
o	k	17	148	231	2106	0.103	0.004	0.069	0.003	0.003	7.959	0.0302375

a	k	20	103	228	2151	0.163	0.067	0.081	0.035	0.048	7.957	5.8378570
æ	k	31	210	217	2044	0.129	0.033	0.125	0.032	0.032	7.958	2.6008259
ɪ	k	24	220	224	2034	0.098	-0.001	0.097	-0.001	-0.001	7.959	0.0017491
ɑ	k	29	176	219	2078	0.141	0.046	0.117	0.039	0.042	7.958	4.4833900
ʊ	k	11	34	237	2220	0.244	0.148	0.044	0.029	0.066	7.956	10.8376924
ɛ	k	18	141	230	2113	0.113	0.015	0.073	0.010	0.012	7.959	0.3773189
i	k	23	180	225	2074	0.113	0.015	0.093	0.013	0.014	7.959	0.4974540
ʌ	k	24	216	224	2038	0.100	0.001	0.097	0.001	0.001	7.959	0.0022985
eɪ	l	42	196	218	2046	0.176	0.080	0.162	0.074	0.077	8.025	14.8686961
ɑɪ	l	15	155	245	2087	0.088	-0.017	0.058	-0.011	-0.014	8.028	0.4816733
ɚ	l	14	135	246	2107	0.094	-0.011	0.054	-0.006	-0.008	8.028	0.1686887
ɔɪ	l	13	20	247	2222	0.394	0.294	0.050	0.041	0.110	8.023	30.2071169
o	l	35	130	225	2112	0.212	0.116	0.135	0.077	0.094	8.025	22.2109737
ɑʊ	l	12	48	248	2194	0.200	0.098	0.046	0.025	0.049	8.025	6.0947075
ɪə	l	3	48	257	2194	0.059	-0.046	0.012	-0.010	-0.021	8.032	1.1368537
a	l	1	122	259	2120	0.008	-0.101	0.004	-0.051	-0.071	8.091	12.7460267
æ	l	3	238	257	2004	0.012	-0.101	0.012	-0.095	-0.098	8.067	23.9615426
ɪ	l	28	216	232	2026	0.115	0.012	0.108	0.011	0.012	8.027	0.3410009
ɑ	l	6	199	254	2043	0.029	-0.081	0.023	-0.066	-0.073	8.041	13.3625350
ʊ	l	10	35	250	2207	0.222	0.120	0.038	0.023	0.052	8.024	6.8876192
ɛ	l	22	137	238	2105	0.138	0.037	0.085	0.024	0.029	8.026	2.1637328
i	l	25	178	235	2064	0.123	0.021	0.096	0.017	0.019	8.026	0.8778746
u	l	17	104	243	2138	0.140	0.038	0.065	0.019	0.027	8.026	1.8270171
ʌ	l	14	226	246	2016	0.058	-0.050	0.054	-0.047	-0.049	8.032	5.9236252
eɪ	m	16	222	146	2118	0.067	0.003	0.099	0.004	0.003	7.348	0.0266855
ɑɪ	m	13	157	149	2183	0.076	0.013	0.080	0.013	0.013	7.347	0.4138886
ɚ	m	11	138	151	2202	0.074	0.010	0.068	0.009	0.009	7.347	0.2155802
o	m	13	152	149	2188	0.079	0.015	0.080	0.015	0.015	7.347	0.5750036
a	m	14	109	148	2231	0.114	0.052	0.086	0.040	0.045	7.344	5.1442944
æ	m	24	217	138	2123	0.100	0.039	0.148	0.055	0.046	7.345	5.3447273
ɪ	m	11	233	151	2107	0.045	-0.022	0.068	-0.032	-0.026	7.352	1.7267893
ɑ	m	5	200	157	2140	0.024	-0.044	0.031	-0.055	-0.049	7.363	6.0059577
ɛ	m	5	154	157	2186	0.031	-0.036	0.031	-0.035	-0.035	7.358	3.1094792
i	m	10	193	152	2147	0.049	-0.017	0.062	-0.021	-0.019	7.351	0.8750428
u	m	13	108	149	2232	0.107	0.045	0.080	0.034	0.039	7.345	3.8265339
ʌ	m	27	213	135	2127	0.113	0.053	0.167	0.076	0.063	7.344	9.9960669
eɪ	n	34	204	214	2050	0.143	0.048	0.137	0.047	0.047	7.958	5.6343485
ɑɪ	n	30	140	218	2114	0.176	0.083	0.121	0.059	0.070	7.957	12.2206988

ɚ	n	10	139	238	2115	0.067	-0.034	0.040	-0.021	-0.027	7.962	1.8176071
ɔɪ	n	7	26	241	2228	0.212	0.115	0.028	0.017	0.044	7.956	4.7820044
o	n	19	146	229	2108	0.115	0.017	0.077	0.012	0.014	7.959	0.5083848
ɑʊ	n	10	50	238	2204	0.167	0.069	0.040	0.018	0.035	7.957	3.1409478
ɛə	n	2	44	246	2210	0.043	-0.057	0.008	-0.011	-0.025	7.967	1.6247935
a	n	9	114	239	2140	0.073	-0.027	0.036	-0.014	-0.020	7.961	0.9755303
æ	n	17	224	231	2030	0.071	-0.032	0.069	-0.031	-0.031	7.962	2.4396992
ɪ	n	26	218	222	2036	0.107	0.008	0.105	0.008	0.008	7.959	0.1674479
ɑ	n	11	194	237	2060	0.054	-0.050	0.044	-0.042	-0.045	7.964	5.1683207
ɛ	n	22	137	226	2117	0.138	0.042	0.089	0.028	0.034	7.958	2.9283932
i	n	16	187	232	2067	0.079	-0.022	0.065	-0.018	-0.020	7.961	1.0198411
u	n	9	112	239	2142	0.074	-0.026	0.036	-0.013	-0.019	7.961	0.8715666
ʌ	n	26	214	222	2040	0.108	0.010	0.105	0.010	0.010	7.959	0.2523145
eɪ	p	11	227	162	2102	0.046	-0.025	0.064	-0.034	-0.029	7.446	2.1478843
ɑɪ	p	7	163	166	2166	0.041	-0.030	0.040	-0.030	-0.030	7.448	2.2166451
ɚ	p	4	145	169	2184	0.027	-0.045	0.023	-0.039	-0.042	7.455	4.4042486
o	p	19	146	154	2183	0.115	0.049	0.110	0.047	0.048	7.439	5.8091982
a	p	6	117	167	2212	0.049	-0.021	0.035	-0.016	-0.018	7.446	0.8334730
æ	p	28	213	145	2116	0.116	0.052	0.162	0.070	0.061	7.439	9.1676587
ɪ	p	27	217	146	2112	0.111	0.046	0.156	0.063	0.054	7.439	7.2383524
ɑ	p	26	179	147	2150	0.127	0.063	0.150	0.073	0.068	7.439	11.5440639
ɛ	p	4	155	169	2174	0.025	-0.047	0.023	-0.043	-0.045	7.457	5.1042127
i	p	23	180	150	2149	0.113	0.048	0.133	0.056	0.052	7.439	6.6923565
u	p	11	110	162	2219	0.091	0.023	0.064	0.016	0.019	7.440	0.9357632
ʌ	p	7	233	166	2096	0.029	-0.044	0.040	-0.060	-0.051	7.454	6.5918524
eɪ	s	17	221	108	2156	0.071	0.024	0.136	0.043	0.032	6.973	2.5540433
ɑɪ	s	7	163	118	2214	0.041	-0.009	0.056	-0.013	-0.011	6.979	0.2964725
ɚ	s	10	139	115	2238	0.067	0.018	0.080	0.022	0.020	6.974	0.9822477
ɔɪ	s	4	29	121	2348	0.121	0.072	0.032	0.020	0.038	6.970	3.5769328
o	s	2	163	123	2214	0.012	-0.041	0.016	-0.053	-0.046	7.012	5.3287227
ɑʊ	s	7	53	118	2324	0.117	0.068	0.056	0.034	0.048	6.970	5.7632356
ɪə	s	2	49	123	2328	0.039	-0.011	0.016	-0.005	-0.007	6.980	0.1266221
ʊə	s	1	7	124	2370	0.125	0.075	0.008	0.005	0.020	6.970	0.9521416
a	s	3	120	122	2257	0.024	-0.027	0.024	-0.026	-0.027	6.989	1.7819177
@	s	1	0	124	2377	1.000	0.950	0.008	0.008	0.087	6.966	19.0236034
æ	s	8	233	117	2144	0.033	-0.019	0.064	-0.034	-0.025	6.982	1.5792355
ɪ	s	9	235	116	2142	0.037	-0.014	0.072	-0.027	-0.020	6.981	0.9737731
ɑ	s	11	194	114	2183	0.054	0.004	0.088	0.006	0.005	6.976	0.0643529
ʊ	s	1	44	124	2333	0.022	-0.028	0.008	-0.011	-0.017	6.991	0.7428043

ɛ	s	10	149	115	2228	0.063	0.014	0.080	0.017	0.015	6.974	0.5983420
i	s	8	195	117	2182	0.039	-0.011	0.064	-0.018	-0.014	6.980	0.5181800
u	s	14	107	111	2270	0.116	0.069	0.112	0.067	0.068	6.970	11.5781836
ʌ	s	10	230	115	2147	0.042	-0.009	0.080	-0.017	-0.012	6.979	0.3846830
eɪ	t	25	213	264	2000	0.105	-0.012	0.087	-0.010	-0.011	8.180	0.2819743
ɑɪ	t	35	135	254	2078	0.206	0.097	0.121	0.060	0.076	8.177	14.5813367
ɚ	t	8	141	281	2072	0.054	-0.066	0.028	-0.036	-0.049	8.185	5.9258858
ɔɪ	t	1	32	288	2181	0.030	-0.086	0.003	-0.011	-0.031	8.193	2.3762998
o	t	15	150	274	2063	0.091	-0.026	0.052	-0.016	-0.020	8.181	1.0462254
ɑʊ	t	14	46	275	2167	0.233	0.121	0.048	0.028	0.058	8.177	8.3535023
a	t	18	105	271	2108	0.146	0.032	0.062	0.015	0.022	8.178	1.2037863
æ	t	26	215	263	1998	0.108	-0.008	0.090	-0.007	-0.008	8.180	0.1517188
ɪ	t	21	223	268	1990	0.086	-0.033	0.073	-0.028	-0.030	8.181	2.2939490
ɑ	t	23	182	266	2031	0.112	-0.004	0.080	-0.003	-0.003	8.179	0.0239817
ʊ	t	7	38	282	2175	0.156	0.041	0.024	0.007	0.017	8.178	0.7193676
ɛ	t	28	131	261	2082	0.176	0.065	0.097	0.038	0.049	8.178	6.1017289
i	t	20	183	269	2030	0.099	-0.018	0.069	-0.013	-0.016	8.180	0.6238679
u	t	23	98	266	2115	0.190	0.078	0.080	0.035	0.053	8.177	6.9214287
ʌ	t	25	215	264	1998	0.104	-0.013	0.087	-0.011	-0.012	8.180	0.3341938
eɪ	v	15	223	56	2208	0.063	0.038	0.211	0.120	0.068	6.158	11.4517874
ɑɪ	v	12	158	59	2273	0.071	0.045	0.169	0.104	0.069	6.157	11.7866116
ɚ	v	8	141	63	2290	0.054	0.027	0.113	0.055	0.038	6.160	3.6821690
o	v	4	161	67	2270	0.024	-0.004	0.056	-0.010	-0.007	6.173	0.1095389
a	v	3	120	68	2311	0.024	-0.004	0.042	-0.007	-0.005	6.173	0.0745819
æ	v	2	239	69	2192	0.008	-0.022	0.028	-0.070	-0.039	6.217	3.8994152
ɪ	v	5	239	66	2192	0.020	-0.009	0.070	-0.028	-0.016	6.177	0.6097368
ɛ	v	2	157	69	2274	0.013	-0.017	0.028	-0.036	-0.025	6.194	1.5370399
i	v	11	192	60	2239	0.054	0.028	0.155	0.076	0.046	6.160	5.3376257
u	v	3	118	68	2313	0.025	-0.004	0.042	-0.006	-0.005	6.172	0.0592323
ʌ	v	6	234	65	2197	0.025	-0.004	0.085	-0.012	-0.007	6.172	0.1098186
eɪ	z	21	217	57	2207	0.088	0.063	0.269	0.180	0.106	6.291	28.3532163
ɑɪ	z	7	163	71	2261	0.041	0.011	0.090	0.022	0.016	6.299	0.6040565
ɚ	z	1	148	77	2276	0.007	-0.026	0.013	-0.048	-0.035	6.368	3.1393632
ɔɪ	z	4	29	74	2395	0.121	0.091	0.051	0.039	0.060	6.290	8.9757381
o	z	10	155	68	2269	0.061	0.032	0.128	0.064	0.045	6.294	5.0660560
ɑʊ	z	4	56	74	2368	0.067	0.036	0.051	0.028	0.032	6.293	2.5638441
ɪə	z	1	50	77	2374	0.020	-0.012	0.013	-0.008	-0.010	6.314	0.2306319
ɛə	z	2	44	76	2380	0.043	0.013	0.026	0.007	0.010	6.298	0.2348553

a	z	2	121	76	2303	0.016	-0.016	0.026	-0.024	-0.020	6.320	0.9527652
æ	z	2	239	76	2185	0.008	-0.025	0.026	-0.073	-0.043	6.353	4.6208612
ɪ	z	6	238	72	2186	0.025	-0.007	0.077	-0.021	-0.012	6.308	0.3881490
ɛ	z	1	158	77	2266	0.006	-0.027	0.013	-0.052	-0.037	6.374	3.4814572
i	z	8	195	70	2229	0.039	0.009	0.103	0.022	0.014	6.299	0.4958989
u	z	6	115	72	2309	0.050	0.019	0.077	0.029	0.024	6.296	1.4270831
ʌ	z	3	237	75	2187	0.013	-0.021	0.038	-0.059	-0.035	6.330	3.0653308

4.

English STM stimuli

CV high + VC low stimuli (**CV** + vc)	kɔɪd,jɛtʃ,geɪs,daʊð,θɪb,dʒætʃ,zɪtʃ,liθ,waɪm,tʃil,θʌŋ,ʃeɪð,wɚb, zul,naθ,kɔɪd,jɛdʒ,veɪm,geɪs,ðætʃ,waɪm,ðɛs,wɚb,roʊk,daʊð, mæb,zul,θɪl,ʃeɪð,jup
CV low + VC high stimuli (cv + **VC**)	θip,ðaɪt,dʒuʒ,gum,laʃ,tɔɪn,kaʊs,ʃab,joʊp,wak,fɪp,bus,hið,sʌg, maʊt,fɔɪz,ʃʌg,kaʊt,sɔɪn,ðaɪt,ʃab,mɪv,hʊʃ,naʊθ,ʃaʊl,vaɪð,kæŋ, hið,seɪʒ,waŋ
CV low + VC low stimuli (cv + vc)	θil,guð,tɪb,dʒuθ,nʌk,hʊt,naʊz,daθ,gʊtʃ,hik,ʃadʒ,poʊθ,sʌdʒ, maʊtʃ,joʊd,ʃʊtʃ,moʊθ,hæb,wiθ,mul,fɪtʃ,rʌdʒ,tɪb,ðoʊk,riz,bup, tʃɛg,nʌʃ,joʊd,dʒaɪm,tʃʌn,sɔɪd,kaʊdʒ,θil,guð,tɪb,miz,ʃaʊð,sɛg, dʒuθ,nʌk,hʊt,ðoʊk,naʊz,dʒaɪm,hæb,gʊtʃ,rɛs,hik,ʃadʒ,poʊθ,nɛtʃ ,bɚs,faɪd,sʌdʒ,rɪn,maʊtʃ,tɚb,joʊd,vɛl
CV high + VC high stimuli (**CV** + **VC**)	kɔɪz,waɪv,jɛd,tʃið,geɪʒ,θʌf,jaʃ,vɔɪn,θɪg,wɚtʃ,ðæp,zut,pʊk,naŋ, taɪð,gaʊθ,veɪdʒ,juʒ,fʊʃ,koʊz,ðɛt,mæŋ,siv,daʊθ,rus,zoʊl,bʊd, dʒæʃ,tʃɚθ,jaʊt

5.

English wordlikeness stimuli

Vowel-Coda Varying				Onset-Vowel Varying			
Set A		Set B		Set C		Set D	
H+**H** vs. H+**L**		L+**H** vs. L+**L**		**H**+H vs. **L**+H		**H**+L vs. **L**+L	
ðæg	ðæb	me^{j}dʒ	me^{j}ð	sa^{j}v	ða^{j}v	wa^{j}m	dʒa^{j}m
jap	jaθ	ʃaʊl	ʃaʊð	vɔ^{j}z	fɔ^{j}z	pɚb	tɚb
fʊʃ	fʊtʃ	tæʃ	tætʃ	gaʊθ	kaʊθ	kɔ^{j}d	sɔ^{j}d
lið	liθ	fɪp	fɪtʃ	naŋ	ʃaŋ	θɪb	tɪb
vɚtʃ	vɚk	mip	miz	jɛd	tʃɛd	bʊt	hʊt
ve^{j}z	ve^{j}m	tʃʌf	tʃʌn	sif	hif	θʌk	nʌk

6. Magnitude estimation instruction (adopted from Bard et al., 1996)

Instructions (Wordlikeness Judgments)

The purpose of this experiment is to get you to judge the sounds of English (Korean) words.
You will hear a series of words.
Some will seem perfectly okay to you, but others will not.
Your task is to judge how good or bad each word is by assigning a number to it.
You can use any number that seems appropriate to you.
For each word after the first word, assign a number to show how good or bad that word is in proportion to the reference word.
For example, if the first word is "(sound)", and you gave it a 1, and if the next word is "(sound)", and seemed 20 times better, you'd give it twenty.
If it seems half as good as the reference word, give it the number 0.5.
You can use any range of positive numbers you like including, if necessary, fractions or decimals.
You should not restrict your responses to, say, an academic grading scale.
You may not use minus numbers or zero, of course, because they aren't proper multiples or fractions of positive numbers.
If you forget the reference word, don't worry; if each of your judgments is in proportion to the first, you can judge the new word relative to any of them that you do remember.
There are no 'correct' answers, so whatever seems right to you is a valid response. Nor is there a 'correct' range of answers or a 'correct' place to start.
Any convenient positive number will do for the reference.
We are interested in your first impressions, so don't spend too long thinking about your judgment.
If you have any questions, ask now.
Thank you for participating in this study.

7.

Korean Wordlikeness experiment stimuli

Onset-Vowel Varying		Vowel-Coda Varying	
H+L	**L**+L	L+**H**	L+**L**
kyuŋ	syuŋ	syop	syol
s'ap	p'ap	næk	næp
p'əp	məp	t^{h}ɛm	t^{h}ɛl
mup	p'up	s'ɨŋ	s'ɨt
tʃit	k^{h}it	p'yən	p'yək
k'ɨk	t'ɨk	k^{h}un	k^{h}ul
tʃit	hit	t'ɨŋ	t'ɨp
t^{h}ot	k^{h}ot	s'ul	s'um
k'ɨp	t'ɨp	p'yəŋ	p'yəp
k^{h}yaŋ	syaŋ	p'uk	p'ut
t'ap	p'ap	t'æk	t'æp
myəp	p'yəp	tʃɛt	tʃɛp

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