AN ONSET IS AN ONSET:
EVIDENCE FROM ABSTRACTION OF NEWLY-LEARNED PHONOTACTIC CONSTRAINTS

BY

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THESIS

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ABSTRACT

Phonotactic constraints involve language-specific patterns for sequences of speech sounds. Traditionally, phonotactic constraints are characterized by listing which sounds or sound sequences can occur at certain syllable positions (e.g. /h/ must begin syllables in English). However, most studies of these patterns have used monosyllabic stimuli (e.g., 'pef') and, thus, they do not tell us whether the patterns concern syllable or word positions. In a series of experiments we investigated the learning of new phonotactic constraints in an experimental setting that is informative as to whether these constraints truly concern syllable positions. In a continuous recognition-memory task, participants heard training nonwords which restricted particular consonants to either the syllable onset or coda position, mixed in with novel test nonwords that either followed (legal) or violated (illegal) the training constraints. Participants more often falsely recognized legal than illegal test nonwords, whether or not they matched the training nonwords in word structure or position of the restricted consonants. For example, having learned that /f/ is an onset and /p/ is a coda, participants generalized from one- to two-syllable items, and from word-edge to word-medial positions (or the reverse). These results suggest abstract representations of newly-learned phonotactic constraints in which the syllable, rather than the word, governs how those constraints are represented: an onset is an onset, a coda is a coda, regardless of word structure and word position.

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CHAPTER 1: INTRODUCTION

Languages vary in the sound sequences they allow, and knowledge of these phonotactic patterns affects online speech processing and facilitates word learning (e.g., McQueen, 1998; Storkel, 2001). For example, to an English speaker, learning a novel word like 'feng' is easier than learning one like 'nges'. This is because 'f' frequently begins English syllables (e.g., 'fan', 'fit'), while 'ng' never does (although it can begin syllables in Thai or Vietnamese). When learning which sequences of consonants and vowels are acceptable, over what unit are we representing the constraints? Do we learn that 'f' is a good start to the word 'feng' mostly from hearing words of a similar structure (e.g., other monosyllabic words like 'fan'), or does hearing any word that has 'f' in syllable-initial position also facilitate learning of the f-initial constraint in 'feng', even though the words themselves may have a different structure (e.g., different number of syllables, as in 'forget', 'furniture') and even though the 'f' is not *word*-initial (e.g., 'confide')?

Sensitivity to phonotactic patterns emerges as early as 9 month of age (e.g., Jusczyk & Luce, 1994) and some adaptability remains in adulthood, allowing infants and adults to quickly learn new phonotactic constraints from brief exposure to artificial languages (e.g., Chambers, Onishi, & Fisher, 2010; Dell, Reed, Adams & Meyer, 2000; Goldrick & Larson, 2008; Onishi, Chambers, & Fisher, 2002; Seidl, Cristià, Bernard, & Onishi, 2009; Warker & Dell, 2006). For example, after listening to consonant-vowel-consonant (CVC) syllables that have 'b's in initial position, and 'p's in final position (e.g., 'bip'), adults were faster to identify and repeat new syllables that followed these constraints (e.g., 'bap') than syllables that violated them (e.g., 'pab') demonstrating that they had learned these novel phonotactic constraints (e.g., Onishi et al., 2002). Here we investigate how phonotactic constraints are represented, by investigating how newly-learned constraints are generalized to novel word structures and novel word positions.

One possibility is that listeners primarily represent and generalize phonotactic patterns at the level of the syllable, where a syllable can be thought of as having initial (onset) and final (coda) positions. Thus, a constraint such as 'b is an onset' would be represented as a generalizable fact about syllables (e.g., 'b' can start syllables) regardless of their position within the word, and independent of the word's structure. This level of representation would accord with traditional linguistic descriptions of phonotactic patterns, which have long aimed to describe the possible *words* of a language as legal combinations of the possible *syllables* of that language (see Goldsmith, 2009, for a review). Indeed, many of the restrictions on word-medial onset and coda positions are redundant with restrictions on word-initial and word-final positions. For example, /pkm/ cannot occur as a word-medial consonant cluster in English, but this fact is predictable from syllable-level phonotactics (e.g., Ewen & van der Hulst, 2001). One could parse this sequence as a syllable-final cluster /pk/ followed by a syllable-initial /m/ thus processing it as /pk.m/, or a syllable-final /p/ followed by a syllable-initial cluster /km/ thus processing it as /p.km/. Both parsings would result in illegal syllable-level clusters: /pk/ cannot end and /km/ cannot start syllables in English. Thus, the illegality of /pkm/ in the middle of a word is predictable from knowing the set of possible syllable onsets and codas.

Accordingly, phonotactic learning in the experiments described above could be described as constraints at the level of the syllable, such that infants and adults might have rapidly learned that particular consonants are restricted to syllable onset or coda position (e.g., Chambers et al., 2010; Goldrick & Larson, 2008; Onishi et al., 2002; Seidl et al., 2009; Warker & Dell, 2006). Describing phonotactic constraints at the level of the syllable predicts that constraints that are learned in one syllable-onset position (e.g., word initial in a disyllable, <u>C</u>VC.CVC, such as the 'f' in 'faction'[1]) should readily be generalized to other syllable-onset positions even when in a different positions in the word (e.g., word medial; CVC.CVC, as in 'comfit').

One argument against syllable-based representations of phonotactic constraints is the fact that syllable boundaries are not clear in all languages. The role of the syllable as a useful representational unit for English in particular has been debated (e.g., Treiman & Danis, 1988; Treiman & Zukowski, 1990). For instance, while syllable units seem to play a primary role in word identification for speakers of French, syllable units do not appear to be used in this way by speakers of English (e.g., Cutler, Mehler, Norris, & Segui, 1986).

Some of the strongest evidence for syllable-sized units comes from studies of syllable-internal constituent structure. The syllable, in hierarchical models, is thought of as composed of sub-constituents. As can be seen in Figure 1, a schematic syllable can be thought of consisting of 3 sub-constituents, onset (C), nucleus (V), and coda (C), which hierarchically combine into onset (C) and rime (VC) constituents (in English; syllables in other languages may have different hierarchical structures). Kessler and Treiman (1997) found support for syllabic constituents in English CVC syllables, finding associations between vowel-consonant (VC) sequences which were more frequent than would be predicted by chance, but not finding similar associations for consonant-vowel (CV) sequences. Similarly, Lee and Goldrick (2008) showed that English and Korean speakers were sensitive to the predominant pattern of sub-syllabic associations of their language. In both English and Korean, syllable constituency (i.e., onset-rime and body (CV)-coda (V) respectively) appeared meaningful in describing the patterns of associations that were found in the language.

[1] Throughout this paper, a period ('.') will be used to mark syllabic breaks, single underlining (e.g., C) will be used to mark syllable-onset positional constraints, and double underlying (e.g., C) will be used to mark syllable-coda positional constraints.

Studies of syllable constituency have mostly focused on monosyllabic words (i.e., CVCs); thus the patterns of association found (e.g., patterning of initial-Cs and associations of VCs in English) could either reflect syllable-based representations (i.e., onset-rime structure) or word-based representation (i.e., word-initial vs. word-remainder; e.g., Davis, 1989). However, several lines of work have also found syllable effects in multisyllabic words in English. Treiman, Fowler and colleagues taught adults word-games in which they learned to substitute a phoneme or pair of phonemes into a two- or three-syllable word (e.g., Fowler 1993; Treiman, Fowler, Gross, Berch, & Weatherston, 1995). English-speaking adults found it easier to learn such games when the rule to be learned honored the onset-rime structure of syllables within longer words (e.g., onset consonants or entire rimes, rather than onset and vowel or coda consonants). English speakers also showed sensitivity to syllable structure in a speeded production task, being faster to repeat a disyllabic word if its first syllable shared the consonant-vowel structure of the preceding monosyllabic word than if it had a different structure (e.g., Sevald, Dell, & Cole, 1995). Finally, Mattys and Melhorn (2005) showed that participants who were presented with words dichotically (e.g., hearing 'kirphin' in the left ear and 'dolmal' in the right ear) more often erroneously reported having heard words that would result from movements of an entire syllable (e.g., reporting 'dolphin') rather than movement of a part of a syllable (e.g., hearing 'dilphin' and 'kormal' and reporting 'dolphin'), thus supporting the cohesiveness of syllable-size units.

However, there is reason to believe that natural-language phonotactics cannot be stated uniformly at the level of the syllable. The description of some naturally-occurring phonotactic constraints seems to require reference to morpheme and word boundaries, or to sequences that cross syllable boundaries. For example, Korean restricts consonant contact across syllable boundaries and native listeners are sensitive to these constraints which cannot be reduced to restrictions on syllable codas and onsets (e.g., Kabak & Idsardi, 2007). For instance, /k/ is a permissible syllable coda in Korean and /m/ is a permissible syllable onset; however, /k/ cannot occur as a coda within a word if the following syllable begins with /m/ (e.g., /k.t/ is legal but /k.m/ is not). Similarly, adult speakers of English are sensitive to the frequency of nasal-obstruent clusters that cross syllable boundaries (Hay, Pierrehumbert, & Beckman, 2004). Infants also show sensitivity to the frequency with which clusters occur within vs. across words in English; they parsed out of continuous speech words that were edged by clusters that rarely occur within words in English more readily than words that were edged by clusters that occur within words more frequently in English (Mattys, Jusczyk, Luce, & Morgan, 1999). If phonotactic constraints were solely represented at the level of the syllable, no information should be available regarding permissible consonant sequences across syllable boundaries yet speakers show sensitivity to this cross-syllabic information.

Thus, units of representation other than the syllable must be available to represent phonotactic constraints. One alternative proposed is that phonotactic learning could be explained solely by referring to restrictions on the linear sequence of sounds and the notion of word edges, without reference to the syllable (e.g., Steriade, 1999). Thus, a constraint such as 'f is an onset' might roughly be represented as generalizable facts about words (e.g., 'f' can start words). This level of representation would allow for the description of constraints that cannot be captured uniquely by a representation at the level of the syllable, including the consonant contact restrictions mentioned above. On this account, the apparent redundancy between constraints on word-edge and word-medial syllable positions, found in natural languages, would be explained as the result of word-formation processes and not due to the representation of phonotactic knowledge at the syllable level.

Support for the participation of word-sized units of representation in speech processing comes from the fact that adults and infants seem able to encode word-initial and word-medial onsets independently. For instance, in sound-substitution word games similar to those mentioned above, adults found it easier to replace a word-initial onset consonant (e.g., /v/ in vap.kem) than a word-medial onset (e.g., /k/ in vap.kem; e.g., Fowler et al. 1993). This suggests that word-edge onset positions have a special status not shared with word-medial onset positions.

Recent experimental evidence also suggests that adults may exploit word-based sequential representations in phonotactic learning. In a brief experiment, adults learned experimental constraints on onset and coda consonants more easily when the restricted consonants were at word-edges, marked by pauses, than when they were in word-medial positions (e.g., Endress & Mehler, 2010). For example, it was easier to learn that particular consonants were restricted to either word-initial onset or word-final coda position (e.g., 'f' is onset and 'p' is coda in 'fal.nip') than it was for them to learn that particular consonants were restricted to either word-medial onset or word-medial coda position (e.g., 'f' is onset and 'p' is coda in 'lap.fin'). Based on these results, and given that discrimination of these medial consonants was near ceiling, the authors argued that phonotactic knowledge is guided by a general sequence-learning mechanism in which position is represented linearly relative to perceptually-marked edges (e.g., silent pauses at the edges of words), with no reference to word-internal syllable structure. Similarly, 9-month-old infants learned that classes of consonants (e.g., fricatives) could occur word initially but not intervocalically (e.g., sa.pa but not pa.sa) suggesting that they were able to represent the word-edge and word-medial onset positions independently despite the fact that both could have been represented jointly as syllable onsets (Seidl & Buckley, 2005). These results provide further support for word-based representations in phonotactic learning.

Differences between word-edge and word-medial constraints could be explained by representations relative to the nearest word edge, as proposed by Endress and Mehler (2010). The further a given segment is from a word edge, the harder it is to represent its position accurately. Thus, constraints on the segments that appear in word-initial and word-final positions should be more easily represented and learned than constraints on word-medial positions. For example, the positions of 'f' and 'p' in 'fin.lap' can be represented accurately relative to immediately adjacent word edges; in contrast, the positions of 'p' and 'f' in 'lap.fin' would be represented in this scheme as third from the left and fourth from the right edge, and fourth from the left and third from the right edge, respectively. Positions so distant from the well-marked edges are represented with more errors, and therefore constraints on segments that appear in these positions are difficult to learn.

Thus, previous results suggest that word-edge and word-medial onset and coda positions can be represented independently, allowing word-edge constraints to be learned more easily (e.g., Endress & Mehler, 2010), and for word-specific positional constraints to be learned (e.g., Seidl & Buckley, 2005). However, these results do not provide evidence that adults cannot treat the word-edge onsets and word-medial onsets, and word-edge codas and word-medial codas similarly, as might be expected only if syllable-level representations are available.

Since previous studies of phonotactic learning did not vary the structure of the training and test items, it is still unknown whether new phonotactic constraints learned in items of one word structure can be generalized to items of a novel structure. Both syllable-based and word-based representations would predict generalization to novel word structures, as long as the word-edge relationship is maintained (e.g., word initial, CVC, to word initial, CVC.CVC; see Figure 2).

Moreover, describing phonotactics at the level of the syllable also predicts generalization of syllable-position constraints across different word positions, as long as the syllable-edge relationship is maintained (e.g., syllable initial, CVC.CVC, to syllable initial, CVC.CVC). In contrast, describing phonotactic constraints at the level of the word suggests that constraints that are learned in word-initial syllable onset position (e.g., word initial, CVC.CVC) should not be generalized to other word positions (e.g., word medial; CVC.CVC).

At this point, it seems clear that one can make use of syllable as a unit when describing phonotactic knowledge (e.g. characterizing positions such as syllable onset or syllable coda), but the syllable may not be *required* to characterize that knowledge (e.g. Endress & Mehler, 2010). Similarly, experimental findings in which participants learn sound patterns in the laboratory can be characterized in terms of syllable units, but no study has thus far shown that the syllable unit is necessary. Moreover, a number of studies have convincingly shown that the syllable by itself is not enough; one needs levels of organization such as the word or morpheme to explain phonotactics and how they are learned.

In our experiments, we asked whether listeners tend to represent newly-learned phonotactic constraints at the level of the syllable, by asking whether they generalize such constraints to new word positions and word structures. We trained participants on nonwords in which particular consonants were restricted to syllable-onset or syllable-coda positions then tested them on novel nonwords. Critically, as can be seen in Figure 2, we manipulated whether the training and test items shared the same word structure (i.e., same or different number of syllables) and word position (i.e., restrictions in the same word position or in different word positions). We used a recognition-memory task, in which participants were presented with a series of nonsense words and were asked to indicate whether they had encountered each nonword before in the experiment (e.g., Mintz, 2002). The measure of interest was the rate of false recognition responses to novel test items. The expectation was that if the experimental phonotactic constraints presented during training were learned and generalized, novel test items that followed those constraints (*legal* items) should be more often falsely recognized as having been heard than would items that violated these constraints (*illegal* items).

Experiment 1 was a pre-test designed to ensure that the recognition-memory task could be used to examine phonotactic learning. It used the continuous recognition method to replicate previous experiments showing that new phonotactic constraints that restrict particular consonants in CVC items can be learned and generalized to novel CVC items. In Experiment 2, we asked a substantive question about the role of the syllable in phonotactic learning, specifically whether patterns could be generalized across different word structures based on syllabic representations. We trained participants on monosyllabic items (CVC, e.g., 'pef') that displayed the experimental constraints (e.g. 'p' is onset and 'f' is coda in CVC items), and tested them on disyllabic items (CVC.CVC, e.g., 'put.vif') that contained only novel CVCs. Thus, 'p' might appear in onset position in the monosyllabic training items, and then, appear either in the onset or the coda position of the first or second syllable in the disyllabic test items. A tendency to falsely recognize a test item in which the 'p' is an onset (rather than a coda) of the first or the second syllable would support the proposal that newly-learned constraint about the positioning of 'p' concerned its *syllabic* position. In Experiment 3, we asked whether patterns could be generalized across positions within the word. We trained participants on disyllabic items that displayed the experimental constraints in word-edge positions (CVC.CVC, e.g., 'put.vif'), and tested them on disyllabic items that followed or violated the constraints in word-medial positions (CVC.CVC, e.g., 'buf.pak) or the reverse.

CHAPTER 2: EXPERIMENT 1

In Experiment 1, participants listened to CVC training items in which particular consonants were restricted to onset or coda position (e.g., 'p' and 'z' are onsets, 'd' and 'f' are codas) intermixed among filler items. Only the training items contained the restricted consonants and displayed the experimental constraints to be learned (e.g., 'paf'), while filler items contained only unrestricted consonants, that is, consonants that could occur in either onset or coda positions. Filler items either shared the word structure of the training items (e.g., 'tav') or had a different structure (e.g., 'biv.tuk'). First, participants received a Familiarization block in which they received 2 repetitions of the training and filler items to establish the experimental constraints. Then, in each of the following 2 Test blocks, they received novel test items intermixed with another repetition of the training and filler items. Test items shared the word structure of the training items and were either legal (e.g., 'pav') or illegal (e.g., 'fav'). Thus, during the course of the experiment, the training and test items were intermixed, allowing for continuous testing while training on the experimental constraints was still ongoing.

Method

Participants

Thirty-two college-aged adults, all native speakers of English (26 females) participated for course credit or a small payment. No participant reported a hearing impairment.

Design

The key manipulation involved restricting particular consonants to the onset or coda position of CVC nonwords. We then tested for generalization of these experimental consonant-position constraints to new nonwords of the same structure (CVC). For each participant, 4 consonants were restricted: 2 were restricted to onset position, 2 were restricted to coda position;

4 other consonants were unrestricted and occurred freely in both onset and coda positions. The assignment of particular consonants to restricted or to unrestricted status, and to onset or coda position within restricted status, was counterbalanced across participants.

Each participant received 24 training items, 48 test items, and 36 filler items. The training items served to establish the experimental constraints. In the training items, restricted consonants appeared only in the position that was legal for this participant's experimental constraints: onset-restricted consonants appeared in onset position, and coda-restricted consonants appeared in coda position. The 24 training items comprised 8 CVC syllables in which both the onset and the coda positions contained restricted consonants (CVC), 8 CVCs in which the onset position contained a restricted consonant but the coda position contained an unrestricted consonant (CVC) and 8 CVCs in which the onset position contained an unrestricted consonant but the coda position contained a restricted consonant (CVC). These different types of training items were included to increase the variety of syllables that gave evidence for the experimental constraints. The 48 test items had the same word structure as the training items (monosyllabic CVC nonwords); but half were legal, containing an onset-restricted consonant in onset positions or a coda-restricted consonant in coda positions (12 CVCs, 12 CVCs), whereas half were illegal, containing a coda-restricted consonant in onset positions or an onset-restricted consonant in coda positions (12 CVCs, 12 CVCs). None of the syllables from the training items were repeated in the test items. The 36 filler items consisted of 12 CVC monosyllables, and 24 CVC.CVC disyllables. Filler items contained only unrestricted consonants; they were included to increase the diversity of the repeating items, and to introduce disyllabic items into the experiment for comparability with Experiments 2 and 3.

In a continuous study-test design, each participant received 3 blocks: a Familiarization block and 2 Test blocks. In the Familiarization block, all training and filler items were presented twice in a random order. This insured that items were experienced as repeating early on in the experiment, such that the correct answer to the recognition-memory question was sometimes 'Yes' (i.e., I have heard this item before) from the beginning of the experiment. Within each subsequent Test block, the training and filler items were repeated once more, in addition to a novel set of test items each presented only once during the experiment. See Figure 3 for a sample sequence showing the distribution of items across blocks.

Stimuli

Eight consonants (/b, d, f, k, p, t, v, z/) and 4 vowels (/ɪ/ as in 'pit', /ʌ/ as in 'putt', /ɛ/ as in 'pet', /æ/ as in 'pat') were used to create the stimuli. All consonants were legal onsets and codas in English, and were also chosen to ensure that the two medial consonants in disyllabic items would be perceived as separated by a syllable boundary (e.g., 'biv.tuk' and not 'bi.vtuk' or 'bivt.uk'). Consonants were divided into pairs (/p, z/, /d, f/, /b, k/, /t, v/) for counterbalancing purposes; for a given participant one pair was restricted to onset position and another to coda position, while the two remaining pairs were unrestricted. Each participant received one of four assignments of consonant pairs to roles in the experiment (see Table 1).

For example, participants who were assigned /p, z/ as onsets, /d, f/ as codas, and /b, k, t, v/ as unrestricted consonants would be trained on items such as 'pef', 'pat', 'buf' and be tested with legal items such as 'pib' and illegal items such as 'fib' (see Figure 3). Filler items included items such as 'tav' and 'biv.tuk'. Test items that were legal for participants who were assigned /p, z/ as onsets and /d, f/ as codas were illegal for participants who were assigned /d, f/ as onsets and /p, z/ as codas (and vice versa). The four assignments of consonant-pairs to roles in the experiment, shown in Table 1, ensured that, across participants, each consonant was restricted to each position and that each test item served equally often as a legal and as an illegal item.

The nonwords were recorded in a randomized order, intermixing items with different consonant assignments and word structures (1- or 2-syllable). A female native English speaker from the Chicago area, unaware of the experimental questions and design, produced multiple tokens of each nonword. The speaker produced the disyllables with 2 strong syllables but greater stress on the first syllable (as in 'napkin'). For each nonword, a single token was selected; tokens were chosen to be clear, well-articulated recordings of the nonwords containing the desired consonants and vowels.

Procedure

Participants were tested individually. The experiment was run using E-prime software (Schneider, Eschmann, & Zuccolotto, 2002), and stimuli were presented at a comfortable listening level over headphones. Before the start of the experiment, participants were told that we were interested in their memory for spoken nonsense words, and that the experiment would involve listening to nonsense words over headphones and answering questions using the response box. Detailed instructions were provided on the computer screen.

Participants were asked to 'listen to each word carefully and decide whether this word has already been presented, or whether this is the first time you have heard this word in the experiment'. They listened to a series of nonwords and indicated whether they had (or had not) heard the nonwords earlier in the study ('Have you heard it before?' Yes/No) by pressing one of two buttons labeled 'Yes' and 'No' on a response box. The session began with two practice trials in which the nonwords were filler items, then proceeded to the main experiment.

The Familiarization block consisted of 120 trials in which the training (all CVCs) and filler items (CVCs and CVC.CVCs) were each presented twice, in a random order. Each of the following 2 Test blocks consisted of 84 trials in which all training and filler items were presented once more, intermixed amongst novel test items (all CVCs) half of which were legal, half illegal. Thus, across all 3 blocks, there were a total of 288 trials: for 180 trials (24 training and 36 filler items being repeated 3 times each) the correct response was 'Yes', whereas for the remaining 108 trials (the first presentation of the 24 training and 36 filler items, and the sole presentation of the 48 test items), the correct answer was 'No'. Across all trials, 192 presented monosyllabic and 96 presented disyllabic items. A participant with perfect memory should never recognize the test items as having been heard before, yet if participants learned the experimental constraints from the training items they might be more likely to falsely recognize legal but not illegal test items because the legal, but not the illegal items, followed the phonotactic constraints exhibited by most of the items as a group.

Results

Table 2 shows the proportion of 'Yes' recognition responses as a function of item type, averaged across the two test blocks. Perfect accuracy would be 'Yes' for all training items (i.e., 1.000) and 'No' to all test items, whether legal or illegal (i.e., 0.000). As the table shows, participants were more likely to falsely recognize legal (.454) than illegal (.240) test items reflecting sensitivity to the experimental phonotactic constraints displayed in the training items. In addition, although the overall rate of false recognition was high, participants still differentiated legal items that were repeating (training items) from those that were novel (legal-test items) as demonstrated by higher recognition rates for training (.773) than for legal-test (.454) items.

Because the data were categorical, we analyzed responses to the test items using a multi-level logit model predicting the log odds of a false recognition on each test trial (e.g., Jaeger, 2008). The model included fixed effects for Legality (legal, illegal) with crossed random intercepts for Participant and Items. The model was fit in the R software package (R Development Core Team, 2008) using the lmer() function of the lme4 package (Bates, Maechler & Dai, 2008). Table 3 displays the parameter estimates for the model. A likelihood-ratio test showed that the model's fit was significantly improved by the inclusion of the fixed effect of Legality [$\chi^2(1) = 102.94$, $p < .001$]. The odds of false recognition were approximately 3.4 times greater for legal items (*M* = 45% 'Yes') than for illegal items (*M* = 24% 'Yes').

Discussion

Adult English speakers learned novel phonotactic restrictions and generalized them to novel items of the same word structure. This learning was shown by a higher rate of false recognition for legal than illegal test items (see Figure 6 for plotted differences in false recognition of legal vs. illegal items). These results confirm that the continuous recognition memory task can be used to assess phonotactic learning and generalization (see also Schecter & Goldrick, 2011). This task is better suited to assessing the influence of legal and illegal consonants in particular positions in the test items than response time paradigms (e.g. shadowing response time, Onishi et al., 2002, which of necessity must measure time from some point in the word). Moreover, it is a more implicit measure of phonotactic knowledge than grammaticality judgment tasks (e.g. Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997).

The current results also confirm that adults can learn and generalize phonotactic patterns even in an environment with few items displaying the experimental constraints and many distractor or filler items. We next use this paradigm to determine whether phonotactic patterns can be extended across word structures and positions.

CHAPTER 3: EXPERIMENT 2

In Experiment 2, we asked whether adults would spontaneously generalize patterns they learned in one word structure (monosyllabic) to words of another structure (disyllabic) while maintaining syllable-level constraints. Participants received the same training and filler items as in Experiment 1; training items contained the restricted consonants and reflected the new phonotactic constraints to be learned (e.g., 'p' is an onset, 'f' is a coda; 'pef'), while filler items contained only unrestricted consonants (CVCs and CVC.CVCs; e.g., 'tav' and 'biv.tuk'). As in Experiment 1, participants were tested on items that either followed or violated the experimental constraints. In contrast to Experiment 1, however, Experiment 2 varied word structure from training to test. The training items were CVC monosyllables as in Experiment 1, but the test items were CVC.CVC disyllables. There were two types of test disyllables and this was manipulated in a between-participants fashion. The test items for one group of participants had restricted consonants in the word-initial onset position and the word-final coda position, but unrestricted consonants elsewhere (e.g., legal 'piv.baf' vs. illegal 'fiv.bap'; *CVC-to-Edge* group). The test items for the second group had restricted consonants in the word-medial coda and word-medial onset position but unrestricted consonants elsewhere (e.g., legal 'baf.piv' vs. illegal 'bap.fiv'; *CVC-to-Medial* group). If participants can represent the experimental constraints at the syllable level, they may extend them from the training monosyllables to the test disyllables and thus be more likely to falsely recognize legal than illegal test items. In contrast, if they represent the constraints at the word-level, they should show similar recognition for legal and illegal test items, particularly when the restricted consonants appear in word-medial positions since they do not share the word-edge relationship of the training items.

Method

Participants

Sixty-four college-aged adults, all native speakers of English (45 females) participated for course credit or a small payment; 32 participants were assigned to each group (CVC-to-Edge, CVC-to-Medial). No participant reported a hearing impairment. None of the participants from Experiment 1 participated in Experiment 2.

Design

As in Experiment 1, the key manipulation involved restricting particular consonants to either the onset or coda position of syllables. The training (CVCs) and filler items (CVCs and CVC.CVCs) were those of Experiment 1, but the test items differed, allowing us to test for spontaneous generalization of the consonant position constraints to a novel word structure (from CVC monosyllables to CVC.CVC disyllables). Test disyllables were of two types based on where restricted consonants occurred: some had restricted consonants occurring at word edges but unrestricted consonants word-medially (12 legal CVC.CVC, 12 illegal CVC.CVC test items; CVC-to-Edge group) others had restricted consonants occurring word-medially, at the syllable boundary, but unrestricted consonants in word edges (12 legal CVC.CVC, 12 illegal CVC.CVC test items; CVC-to-Medial group). The Edge- and Medial-restricted items were composed of the same syllables, in reversed order (e.g., a participant in the CVC-to-Edge group would be tested on 'zev.bud' while a different participant, in the CVC-to-Medial group, would be tested on 'bud.zev'). None of the syllables in the training items were repeated in the test items (see Figure 4).

Stimuli

The same training and filler items as in Experiment 1 were used. The test disyllables were created using the same 8 consonants and 4 vowels as in Experiment 1 and were recorded intermixed with those of Experiment 1.

Procedure

The procedure was identical to that of Experiment 1. As in Experiment 1, there were a total of 288 trials: for 180 trials (24 training and 36 filler items being repeated 3 times each) the correct response was 'Yes', whereas for the remaining 108 trials (the first presentation of the 24 training and 36 filler items, and the sole presentation of the 48 test items), the correct answer was 'No'. Across all trials, 144 presented monosyllabic and 144 presented disyllabic items.

Results

As shown in Table 2, participants in each of the CVC-to-Edge and the CVC-to-Medial group were more likely to falsely recognize legal than illegal test items (.443 vs. .354, and .458 vs. 326, respectively), suggesting that they learned the experimental constraints and spontaneously extended them to the new word structure, regardless of word position. Participants in each group also correctly recognized the training items more often than they falsely recognized the test items (.814 vs. .443, and .804 vs. .458).

As in Experiment 1, we analyzed responses to the test items using a multi-level logit model predicting the log odds of a false recognition on each test trial. The model included fixed effects for Legality (legal, illegal) and Group (CVC-to-Edge, CVC-to-Medial), the interaction of Legality by Group, and crossed random intercepts for Participants and Items. Table 4 displays the parameter estimates for the model with the full factorial design of the experiment. The odds of false recognition were approximately 1.6 times greater for legal (*M* = 46% 'Yes') than for illegal test items (*M* = 35% 'Yes'). A likelihood-ratio test showed that the model's fit was significantly improved by the inclusion of the fixed effect of Legality [$\chi^2(1) = 51.88$, $p < .001$] but not by the inclusion of the interaction of Legality x Group [$\chi^2(2) = 2.54$, $p = .281$]. Separate models for each group (CVC-to-Edge, CVC-to-Medial) that included fixed effects for Legality and crossed random intercepts for Participants and Items confirmed that the main effect of Legality held within each group.

Discussion

In Experiment 2, adult English speakers spontaneously extended patterns learned in one word structure to items of a different word structure using a syllable-size unit; restrictions on syllable onset or coda were maintained regardless of their position in the word (at the edge or in the middle; see Figure 6). Since the disyllabic test items had never displayed the experimental constraints, differences in false recognition of legal and illegal test items reflect extension of the constraints which were learned in the monosyllabic training items. Participants generalized whether the position of the restriction relative to the word matched from training to test (from word-edge in CVCs to word-edge in edge-restricted CVC.CVCs), or not (from word-edge in CVCs to word-medial in medial-restricted CVC.CVCs), suggesting that the syllable may be a privileged unit of generalization. The current results thus suggest that phonotactic constraints can be represented relative to syllable-sized units, where an onset is an onset, and a coda is a coda, regardless of word position.

However, it is possible that the current generalization was facilitated by some features of the design. We may have encouraged syllable-based generalization by exposing participants to monosyllabic CVC items (training and fillers). For instance, the presence of CVC items may have led participants to treat the disyllables as a joint set of monosyllables (e.g., CVC_1+CVC_2)

rather than treating them as single disyllabic words. To minimize this possibility, Experiment 3 included only disyllable training, filler, and test items.

CHAPTER 4: EXPERIMENT 3

In Experiment 3, we again asked whether participants would spontaneously extend phonotactic constraints from one word position to another, thus treating word-edge and word-medial onsets and codas as the same. We modified the structure of the items to reduce the likelihood that participants were cued to pay particular attention to CVC units as a result of being exposed to CVC monosyllables intermixed with the CVC.CVC disyllables. Participants were trained on the same experimental phonotactic constraints as in Experiment 1 and 2 (e.g., 'p' and 'z' are syllable onsets, 'd' and 'f' are syllable codas), but these constraints were now displayed in disyllabic, rather than monosyllabic, training items (e.g. 'pak.buf'). In addition, all filler items were disyllabic (as opposed to a mixture of CVCs and CVC.CVCs). As a result, participants heard only disyllabic items during the experiment. Participants were either trained on Edge-restricted items and tested on Medial-restricted items (e.g., train on 'pak.buf' and test on 'vif.put' vs. 'vip.fut'; *Edge-to-Medial* group), or the reverse (e.g., train on 'buf.pak' and test on 'put.vif' vs. 'fut.vip'; *Medial-to-Edge* group). If participants can represent the experimental constraints at the syllable level, they should extend them from one word position to another, and thus be more likely to falsely recognize legal than illegal test items.

Method

Participants

Sixty-four college-aged adults, all native speakers of English (41 females) participated for course credit or a small payment; 32 participants were assigned to each group (Edge-to-Medial, Medial-to-Edge). No participant reported a hearing impairment. None of the participants from Experiment 1 or 2 participated in Experiment 3.

Design and stimuli

All disyllabic nonwords from Experiment 2 were used again in Experiment 3 (filler, Edge-restricted and Medial-restricted items). In addition, new fillers, Edge-restricted, and Medial-restricted disyllabic items were recorded in the same manner as before. As in Experiments 1 and 2, no syllables were shared between the training and the test items and, therefore, sensitivity to the legality of the test items required generalization to new syllables. Across participants, Edge-restricted and Medial-restricted items occurred equally often as training and test items, and equally often as legal and illegal test items. Participants were either trained on Edge-restricted items and tested on Medial-restricted (*Edge-to-Medial* group) or were trained on Medial-restricted items and tested on Edge-restricted (*Medial-to-Edge* group; see Figure 5).

Procedure

The procedure was identical to that of Experiments 1 and 2.

Results

As shown in Table 2, participants in both the Edge-to-Medial and the Medial-to-Edge group were more likely to falsely recognize legal than illegal test items (.385 vs. .297, and .396 vs. .268, respectively). This pattern suggests that they implicitly learned the experimental phonotactic constraints from the training items, and extended them to the test items, thus spontaneously generalizing phonotactic constraints from word-edge onset and coda positions to word-medial onset and coda positions, or the reverse. As in Experiments 1 and 2, participants also correctly recognized the training items as more frequent than the test items (.791 vs. .385 and .758 vs. .396).

As in Experiment 1 and 2, we analyzed responses to the test items using a multi-level logit model predicting the log odds of a false recognition on each test trial. The model included fixed effects for Legality (legal, illegal) and Group (Edge-to-Medial, Medial-to-Edge), the interaction of Legality by Group, and crossed random intercepts for Participant and Items. Table 5 displays the parameter estimates for the model with the full factorial design of the experiment. The odds of false recognition were approximately 1.6 times greater for legal items (M = 39 %'Yes') than for illegal items (M = 28% 'Yes'). A likelihood-ratio test showed that the model's fit was significantly improved by the inclusion of the fixed effect of Legality [$\chi^2(1) = 47.99$, $p < .001$] but not by the inclusion of the interaction of Legality x Group [$\chi^2(2) = 1.33$, $p = .514$] (Table 5). Separate models for each group (Edge-to-Medial, Medial-to-Edge) that included fixed effects for Legality and crossed random intercepts for Participants and Items confirmed that the main effect of legality held within each group.

Discussion

In Experiment 3, adult English speakers again demonstrated spontaneous generalization of phonotactic constraints using a syllable-sized unit of representation (see Figure 6). Phonotactic restrictions learned in word-edge positions were extended to word-medial positions, and the reverse. Since the restricted consonants never occurred in the same word position across training and test, differences in false recognition to legal and illegal test items reflect extension of constraints learned in a different word positions. Moreover, participants generalized across word positions regardless of which position (word-edge, word-medial) was restricted in training, suggesting that restrictions in both positions were roughly equally learnable and extendable under the current circumstances.

CHAPTER 5: GENERAL DISCUSSION

Listening or speaking experience leads to the implicit learning of new phonotactic constraints. The unit size over which this learning is represented has important implications for how phonotactic knowledge is represented, which in turn has implications for the many aspects of language learning and processing that are affected by phonotactics. The current experiments examined whether the syllable acts as an organizing schema for determining how newly-learned phonotactic constraints are generalized. The first experiment demonstrated a simple form of generalization - generalization from monosyllabic to monosyllabic items. For instance, having learned that 'p' is restricted to word-initial onset positions in a given word structure (e.g., monosyllabic 'pef'), participants generalized the restriction to novel items of the same word structure (e.g., 'pav'; CVC-to-CVC, Experiment 1). This result was expected from previous studies.

The second experiment provided new and unique evidence for the role of syllables. Constraints learned from monosyllabic training items (e.g., 'pef') were spontaneously extended to novel items of a different word structure (e.g., disyllabic 'put.vif'), whether the word-edge relative positions were maintained or not. For instance, having learned that 'p' is restricted to word-initial onset position from items such as 'pef', participants extended this restriction both to novel items in which the restricted consonant was in a similar position relative to a word edge (e.g., 'p' is word-initial in 'put.vif'; CVC-to-Edge) and to items in which the restricted consonant was in a different word position (e.g., 'p' is word-medial in 'vif.put'; CVC-to-Medial, Experiment 2: CVC-to-Medial).

The third experiment provided further support for the spontaneous extension of newly-learned phonotactic constraints to novel word positions. For instance, having learned that 'p' is restricted to word-initial onset positions in 'pak.buf', participants extended this restriction to different word positions within the same word structure (e.g., 'p' is word-medial in 'vif.put'; Experiment 3: Edge-to-Medial).

These results would be expected if phonotactic constraints were represented at the level of the syllable, where a constraint on a syllable-onset or syllable-coda position applies to any syllable-onset or syllable-coda position regardless of its position within a word. The experimental constraints exhibited by the training items could have been encoded such that 'p' is syllable-initial and 'f' is syllable-final; thus being easily extended to both novel monosyllables (e.g., 'pav', 'vif') and disyllables (e.g., 'put.vif', 'vif.put') as long as the syllable-based relationship was maintained.

Extension to a new word structure (e.g., 'pef' to 'put.vif'), would be predicted if phonotactic constraints were represented at the level of the word, with their position being encoded relative to word edges (e.g., Endress & Mehler, 2010). The experimental constraints of the CVC items could have been encoded such that 'p' is word-initial and 'f' is word-final in 'pef'; and thus can be extended to either novel monosyllables (e.g., 'pav', 'vif') or disyllables as long as the word-edge relationship is maintained (e.g., 'put.vif').

Extension to new word positions (e.g., 'pef' to 'vif.put', 'pak.buf' to 'vif.put'), on the other hand, would not be predicted if phonotactic constraints were represented at the level of the word. Word-edge relative encoding would not allow for the extension of the experimental constraints to different word positions: learning that 'p' is word-initial and 'f' is word-final in 'pef' would have no consequences for processing the medial-restricted items (e.g., 'vif.put') in which both 'p' and 'f' are word-medial. Thus, the current results suggest that adults can represent newly-learned phonotactic constraints relative to a syllable-sized unit.

We found no evident difference in the representation of word-edge and word medial constraints; in Experiment 2 and 3, no difference was found between the Edge- vs. Medial-restricted items. Thus, while Endress and Mehler (2010) found that phonotactic constraints were easier to learn at word edges than in word-medial positions, the current results suggest that both word-edge and word-medial phonotactic constraints can be learned and extended across word positions rapidly. What might account for this difference? Our experiments and those of Endress and Mehler differed in their basic design. The current experiments used a continuous study-test design rather than the blocked study-then-test design of Endress and Mehler. In a study-then-test design, equal numbers of legal and illegal items are presented in the test phase; participants may then 'unlearn' the experimental constraints in the test phase (Onishi et al. 2002; Taylor & Houghton, 2005). Our task could therefore have been more sensitive to learning effects that might have been harder to detect in a study-then-test design. Supporting this last point, we found that the effect of legality was stronger in the first than in the second test block of our experiment; suggesting that as evidence for the phonotactic pattern became weaker, participants found it more difficult to differentiate novel legal and illegal items.

The critical difference between Endress and Mehler's (2010) studies and the present findings, however, was that Endress and Mehler asked only whether it was easier to learn phonotactic constraints when the evidence for those constraints was presented only in word edges, or only in word middles. The present experiments asked a different question, whether constraints learned in word-edge (or word-medial) positions would spontaneously be extended to segments in the same syllable-positions in different word-positions. Evidence for such spontaneous extension provides powerful evidence that onset (or coda) positions at word-edges and word-middles are treated by listeners as one and the same position.

In light of previous findings, our results suggest that multiple levels of representation (word-level, syllable-level) may be available during phonotactic learning, and that the level of representation recruited may be context-dependent. Thus, while word-level representations might allow participants to learn word-edge constraints independently of word-medial constraints in some contexts (e.g., Seidl & Buckley, 2005), syllable-level representations may support rapid and spontaneous generalization of constraint to novel word structures and positions (e.g., the current experiments). The availability of multiple levels of representation might help to explain why natural phonotactic constraints can be substantially, though not fully, described by reference to a syllabic structure. It also provides further evidence for the view that the syllable is a useful linguistic structure for the representation of positional constraints, and that patterns can be learned at that level. Further support for the availability of multiple levels of representation is also found in speech production, leading to syllable-level effects surfacing under certain condition (e.g., word repetition; Sevald et al., 1995) but not others (e.g., word identification; Cutler et al., 1986).

Although the current experiments support the role of the syllable in phonotactic learning, it must be recognized that the disyllabic items examined here had particularly clear syllable boundaries. Thus, it remains to be seen whether the evidence for the role of syllable in phonotactic learning applies more generally in English, and in other languages, and whether it applies in other phonotactic learning tasks such as production. Nonetheless, given the materials and methods of these experiments, the current results provide additional support for the view that even English speakers employ syllable-sized units in speech processing. At least in phonotactic learning, an onset is an onset, and a coda is a coda, regardless of word structure or position. The perceived equivalence of onsets and codas across word structures and positions reveals the abstract and flexible nature of phonological representations. Evidently, our perception that a sequence such as 'feng' is a plausible English word results from our cumulative experience with 'f' in syllable-onset position, in similar words (e.g., 'fan') and very different ones (e.g., 'confide'). Such abstract phonological representations allow phonotactic knowledge to facilitate speech processing broadly, guiding word identification, word segmentation and word learning in contexts beyond those in which the constraints were experienced.

TABLES AND FIGURES

Table 1

	Onset-restricted	Coda-restricted	Unrestricted
1.	/p, z/	/d, f/	/b, k, t, v/
2.	/d, f/	/p, z/	/b, k, t, v/
3.	/b, k/	/t, v/	/p, z, d, f/
4.	/t, v/	/b, k/	/p, z, d, f/

The four experimental assignments of consonant pairs to roles.

Table 2

	Group	Training	Legal-test	Illegal-test	Legality effect
Experiment 1	CVC-to-CVC	.773 (.175)	.454 (.202)	.240 (.145)	.215
Experiment 2	CVC-to-Edge	.814 (.121)	.443 (.202)	.354 (.185)	.089
	CVC-to-Medial	.804 (.122)	.458 (.241)	.326 (.214)	.133
Experiment 3	Edge-to-Medial	.791 (.164)	.385 (.239)	.297 (.196)	.089
	Medial-to-Edge	.758 (.161)	.396 (.209)	.268 (.157)	.128

Mean (standard deviation) proportion 'Yes' recognition responses in blocks containing test items (blocks 2 and 3), by item type, for each group, Experiment 1 through 3.

Table 3

Fixed effect	Coefficient	Std. Error	Wald z	Pr(>|z|)
(intercept)	-0.841	0.1789	-4.699	< .001 *
Legality	1.224	0.122	10.045	< .001 *

* $p < 0.05$ (on normal distribution)

Fixed effect estimates of model for Experiment 1, assessing constraint learning (CVC-to-CVC).

Table 4

Fixed effect	Coefficient	Std. Error	Wald z	Pr(>|z|)
(intercept)	-0.378	0.181	-2.088	0.0368 *
Legality	0.479	0.111	4.296	0.0001 *
Group	-0.178	0.255	-0.698	0.4849
Legality x Group	0.239	0.162	1.474	0.1404

* $p < 0.05$ (on normal distribution)

Fixed effect estimate of model with full experimental (including Legality and Group) structure for Experiment 2, crossing word structure (CVC-to-Edge, CVC-to-Medial).

Table 5

Fixed effect	Coefficient	Std. Error	Wald z	Pr(>|z|)
(Intercept)	-0.823	0.180	-4.583	4.58E-06 *
Legality	0.486	0.118	4.103	4.08E-05 *
Group	-0.016	0.253	-0.061	0.951
Legality x Group	0.196	0.167	1.172	0.241

* $p < 0.05$ (on normal distribution)

Fixed effect estimate of model with full experimental structure (including Legality and Group) for Experiment 3, crossing word positions (Edge-to-Medial, Medial-to-Edge).

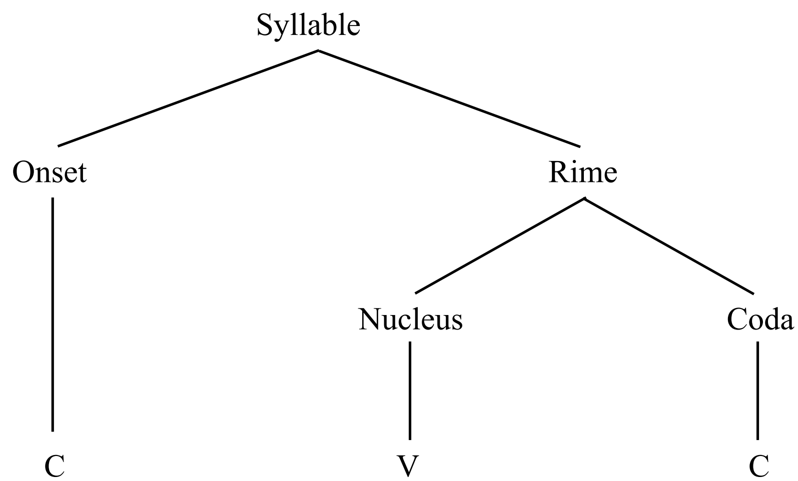

Figure 1. A simplified model of the syllable structure

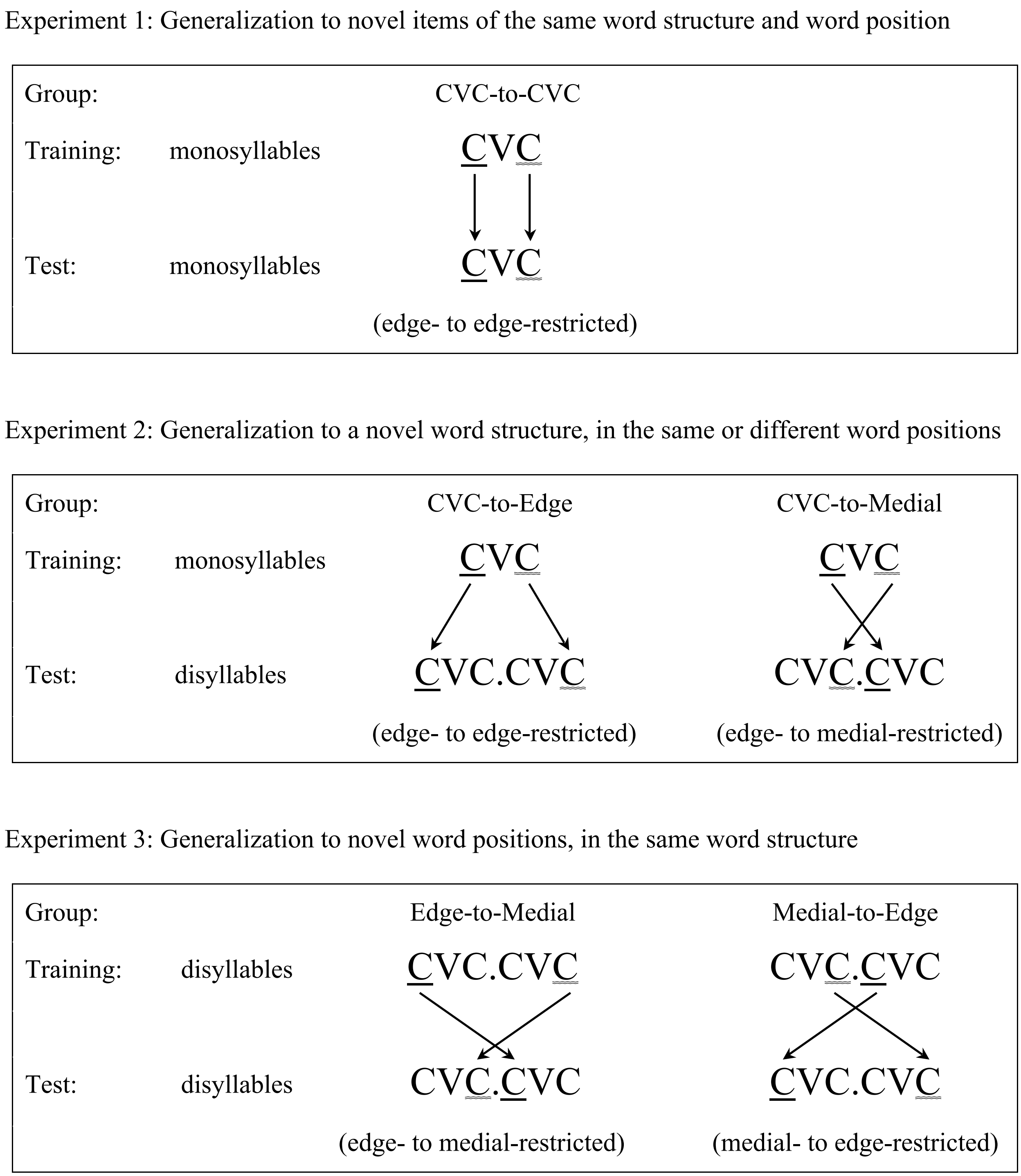

Figure 2. Schematic generalization patterns for each group, Experiment 1 through 3.

Experiment 1: Generalization to novel items of the same word structure and word position

Familiarization Block*		**Test Block 1**		**Test Block 2**	
48 training items		24 (repeating) training items		24 (repeating) training items	
- $\underline{C}$VC (8)	'$\underline{p}$at'	- $\underline{C}$VC (8)	'$\underline{p}$at'	- $\underline{C}$VC (8)	'$\underline{p}$at'
- CV$\underline{\underline{C}}$ (8)	'bu$\underline{\underline{f}}$'	- CV$\underline{\underline{C}}$ (8)	'bu$\underline{\underline{f}}$'	- CV$\underline{\underline{C}}$ (8)	'bu$\underline{\underline{f}}$'
- $\underline{C}$V$\underline{\underline{C}}$ (8)	'$\underline{p}$e$\underline{\underline{f}}$'	- $\underline{C}$V$\underline{\underline{C}}$ (8)	'$\underline{p}$e$\underline{\underline{f}}$'	- $\underline{C}$V$\underline{\underline{C}}$ (8)	'$\underline{p}$e$\underline{\underline{f}}$'
36 fillers items		36 (repeating) fillers items		36 (repeating) fillers items	
- CVC (12)	'tav'	- CVC (12)	'tav'	- CVC (12)	'tav'
- CVC.CVC (24)	'biv.tuk'	- CVC.CVC (24)	'biv.tuk'	- CVC.CVC (24)	'biv.tuk'
		12 Legal test items		12 Legal test items	
		- $\underline{C}$VC (6)	'$\underline{p}$av'	- $\underline{C}$VC (6)	'$\underline{p}$ib'
		- CV$\underline{\underline{C}}$ (6)	'vi$\underline{\underline{f}}$'	- CV$\underline{\underline{C}}$ (6)	'tu$\underline{\underline{f}}$'
		12 Illegal test items		12 Illegal test items	
		- $\underline{C}$VC (6)	'$\underline{f}$av'	- $\underline{C}$VC (6)	'$\underline{f}$ib'
		- CV$\underline{C}$ (6)	'vi$\underline{p}$'	- CV$\underline{C}$ (6)	'tu$\underline{p}$'

*Each item is presented twice

Figure 3. Example items for a participant, in Experiment 1, assigned to /p, z/ as onsets, /d, f/ as codas, and /b, k ,t ,v/ as unrestricted. Periods ('.') mark syllabic breaks, single underlining (e.g., $\underline{C}$) marks syllable-onset positional constraints, and double underlying (e.g., $\underline{\underline{C}}$) marks syllable-coda positional constraints.

Experiment 2: Generalization to a novel word structure, in the same or different word positions

Familiarization Block*		**Test Block 1**		**Test Block 2**	
48 training items		24 (repeating) training items		24 (repeating) training items	
- CVC (8)	'pat'	- CVC (8)	'pat'	- CVC (8)	'pat'
- CVC (8)	'buf'	- CVC (8)	'buf'	- CVC (8)	'buf'
- CVC (8)	'pef'	- CVC (8)	'pef'	- CVC (8)	'pef'
36 fillers items		36 (repeating) fillers items		36 (repeating) fillers items	
- CVC (12)	'tav'	- CVC (12)	'tav'	- CVC (12)	'tav'
- CVC.CVC (24)	'biv.tuk'	- CVC.CVC (24)	'biv.tuk'	- CVC.CVC (24)	'biv.tuk'
		Additional items for Edge-restricted group:			
		12 Legal test items		12 Legal test items	
		- CVC.CVC (6)	'put.vif'	- CVC.CVC (6)	'piv.baf'
		12 Illegal test items		12 Illegal test items	
		- CVC.CVC (6)	'fut.vip'	- CVC.CVC (6)	'fiv.bap'
		Additional items for Medial-restricted group:			
		12 Legal test items		12 Legal test items	
		- CVC.CVC (6)	'vif.put'	- CVC.CVC (6)	'baf.piv'
		12 Illegal test items		12 Illegal test items	
		- CVC.CVC (6)	'vip.fut'	- CVC.CVC (6)	'bap.fiv'

*Each item is presented twice

Figure 4. Example items for a participant, in Experiment 2, assigned to /p, z/ as onsets, /d, f/ as codas, and /b, k, t, v/ as unrestricted .

Experiment 3: Generalization to novel word positions, in the same word structure

Familiarization Block*	**Test Block 1**	**Test Block 2**
Edge-to-Medial group:		
48 training items - CVC.CVC (24) 'pak.buf'	24 (repeating) training items - CVC.CVC (24) 'pak.buf'	24 (repeating) training items - CVC.CVC (24) 'pak.buf'
36 fillers items - CVC.CVC (24) 'biv.tuk'	36 (repeating) fillers items - CVC.CVC (24) 'biv.tuk'	36 (repeating) fillers items - CVC.CVC (24) 'biv.tuk'
	12 Legal test items - CVC.CVC (6) 'vif.put' 12 Illegal test items - CVC.CVC (6) 'vip.fut'	12 Legal test items - CVC.CVC (6) 'baf.piv' 12 Illegal test items - CVC.CVC (6) 'bap.fiv'
Medial-to-Edge group:		
48 training items - CVC.CVC (24) 'buf.pak'	24 (repeating) training items - CVC.CVC (24) 'buf.pak'	24 (repeating) training items - CVC.CVC (24) 'buf.pak'
36 fillers items - CVC.CVC (24) 'biv.tuk'	36 (repeating) fillers items - CVC.CVC (24) 'biv.tuk'	36 (repeating) fillers items - CVC.CVC (24) 'biv.tuk'
	12 Legal test items - CVC.CVC (6) 'put.vif' 12 Illegal test items - CVC.CVC (6) 'fut.vip'	12 Legal test items - CVC.CVC (6) 'piv.baf' 12 Illegal test items - CVC.CVC (6) 'fiv.bap'

*Each item is presented twice

Figure 5. Example items for a participant, in Experiment 3, assigned to /p, z/ as onsets, /d, f/ as codas, and /b, k, t, v/ as unrestricted.

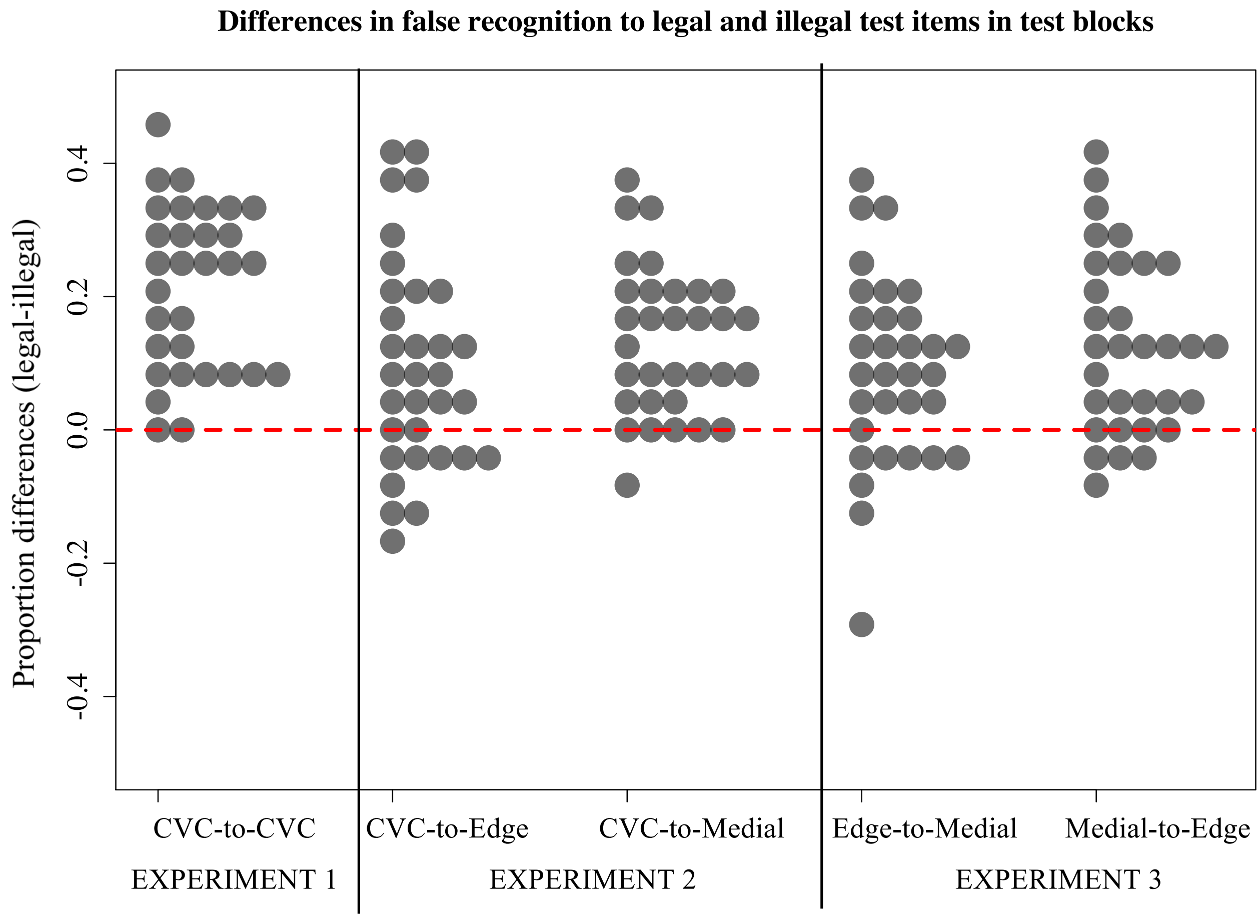

Figure 6. Differences in false recognition between legal and illegal test items, for each group, Experiment 1 through 3. Each symbol represents one participant's performance.

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