SPEAKERS' NOTION OF THE SYLLABLE: THE ROLE OF STATISTICAL FACTORS IN ONSET WELLFORMEDNESS JUDGMENTS*

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1. Introduction

The traditional view on syllabification found in both theoretical and experimental literature is that the placement of syllable boundaries is best accounted for with structural factors, including syllable structure markedness, sonority, phonotactics, segmental quality, and word stress. However, it has also been proposed that syllabification may depend on frequency-based factors, such as transitional probability of adjacent segments (Adams 1981), or that syllabification judgments are based on word structure rather than syllable structure (Steriade 1999). Given the increased interest in the syllable as well as the role of quantitative factors in phonology, the present paper explores (i) whether onset wellformedness judgments made by Russian speakers are in fact sensitive to phonotactic frequency, (ii) if factors based on linguistic structure predict the variance in the data better than frequency-based variables, and (iii) if syllable wellformedness evaluation involves the same processes as word wellformedness judgments.

The findings of the current study are based on newly collected data on the relative wellformedness of 26 biconsonantal clusters in the form obstruent+liquid (e.g., /kr/, /pl/, /sr/) embedded in a nonce-word context and controlled for orthographic transparency, morphology, vocalic environment, and stress placement. The clusters are evaluated as complex onsets and word-initial edges. The data is subjected to a series of statistical analyses (Pearson's correlation, stepwise regressions, ANOVAs). Multiple frequency and probability measurements and factors based on linguistic structure (namely, consonant type) are used as predictor variables. The results reveal that structural factors appear to be better predictors of variance than factors based on usage frequency and that syllable wellformedness evaluation is similar but not identical to word wellformedness judgments.

The rest of the paper is organized as follows. Section 2 examines the nature of syllabification judgments and provides more details on the proposals in Adams (1981) and Steriade (1999). The methodology of the present study and the data are introduced in Section 3. The results are discussed in Section 4. General conclusions are offered in Section 5.

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2. Syllabification

2.1 Speakers' judgments. Word-based syllables (Steriade 1999)

Many linguists consider the syllable to be an abstract phonological concept that does not have or need to have any psychological reality. Within this approach, speakers' syllabification judgments are not relevant and syllable structure is observed indirectly via its effects on various phonological processes. At the same time, the ability of both adults and children to produce syllabification judgments is well attested in the experimental literature. Moreover, even though syllabification judgments are often variable and/or the predictions of formal accounts and native speakers' intuitions do not always agree on the syllabic affiliation of specific segments (e.g., intervocalic consonants), there is a substantial overall correspondence between the outputs of syllabification judgments and formal analyses. For example, wordforms containing two vowels are divided into exactly two constituents with a single vowel both allowed and required per constituent, and the resultant output is highly consistent with formal analyses of syllable structure that require each syllable to contain one nucleus. As a result, many researchers believe that speakers' responses can be used as a diagnostic of the syllable and its structure (among others, Fallows 1981; Treiman and Danis 1988; Treiman 1989; Treiman et al. 1992).

One alternative approach to understanding the nature of syllabification judgments can be found in Steriade (1999) who questions the popular view that speakers' judgments reveal implicit knowledge of the syllable and its structure. Steriade argues that syllable boundaries do not have any learnable perceptual correlates and, therefore, are most likely to be learned indirectly by appealing to structurally similar components already known to the speaker, such as the word and its edges. Steriade proposes that syllabification judgments are the result of inference strategies based on word edge phonotactics (the Word-Based Syllables hypothesis) and that speakers obey the Word-to-syllable identity conditions listed in (1) below.

(1) a. W-S(I): For any I, a syllable-initial segment, there is a word such that its initial segment is identical to I.

b. W-S(F): For any F, a syllable-final segment, there is a word such that its final segment is identical to F.

In other words, speakers presumably posit syllable boundaries using the knowledge of word-initial and word-final sequences allowed in their native language and syllable edges are evaluated as potential word edges.

The Word-Based Syllables hypothesis predicts that the segmental composition of syllable edges will be similar to that of the word edges and, consequently, language-specific word-edge phonotactics are predicted to play a crucial role in the determination of syllable wellformedness. At the same time, Steriade does not claim that syllable edges must be possible word edges (the Legality Principle; Treiman and Danis 1988), but rather argues that similarity to word edges is one of several factors that can come into play when evaluating syllable wellformedness.

2.2 Factors affecting syllabification. The role of frequency (Adams 1981)

Corpus studies have repeatedly demonstrated that different syllable types do not have the same frequency of occurrence. As a result, the majority of syllabification analyses rely on the assumption that some syllable structures are more marked than others and that languages exhibit a universal tendency of maintaining a preferred structure (CV, CCV, CVC) by filling and maximizing onsets, disallowing codas or avoiding complex syllable edges (among many others, Kahn 1976; Vennemann 1988; Kager 1999; Prince and Smolensky 2004). However, not all onsets or codas are equally favoured or dispreferred (e.g., most English speakers would agree that /bl/ is a better complex onset than /lb/), which resulted in a number of additional factors being proposed. Namely, many theoretical and experimental linguists argue that syllabification can be affected by sonority, with onsets favouring rising sonority and codas favouring a fall in sonority (e.g., Selkirk 1984; Treiman and Zukowski 1990; Kenstowicz 1994). Others propose that syllabic affiliation can be influenced by stress placement and vowel quality (e.g., Fallows 1981; Treiman and Danis 1988; Gillis and De Schutter 1996). In the case of consonants and consonant clusters, numerous studies have suggested that syllabification is dependent on language-specific word-edge phonotactics, i.e. which segments and sequences of segments are attested at word edges (Vennemann 1988; Treiman and Zukowski 1990; Smith and Pitt 1999; Goslin and Frauenfelder 2001; Blevins 2003; McCrary 2004; Redford and Randall 2005). However, syllabification judgments can vary even for equally attested/unattested clusters found in the exactly same environment. In the latter case, syllabification may be affected by consonant type (Treiman and Danis 1988; Treiman et al. 1992; Gillis and De Schutter 1996) or even such factors as speaker's awareness of the spelling system and etymological origins of words (Treiman and Danis 1988; Goslin and Floccia 2007), morphological composition (Smith and Pitt 1999), presence of phonetic juncture cues (Redford and Randall 2005), and experimental methodology (Côté and Kharlamov, submitted).

Adams (1981) proposes an alternative to the view that syllabification is affected primarily by structural factors. Adams explores the connection between usage frequency and the detection of syllable boundaries in written input and suggests that the human word recognition system possesses a special mechanism for identifying syllables. According to Adams, within-syllable segmental associations are stronger than associations between segments that belong to different syllables, and frequencies of bigrams are higher within syllables than across syllable boundaries. Thus, a syllable boundary is marked by a bigram that has a relatively low frequency or low transitional probability between adjacent segments when compared to the frequency or probability of the bigrams on either side of the boundary. For example, the word *advent* is syllabified as *ad.vent* because the C-to-C transition from the *d* to the *v* is less frequent than either the V-to-C transition from the *a* to the *d* or the C-to-V transition from the *v* to the *e*. Adams further suggests that because of the high frequency and the small number of vowel graphemes in English texts, the C-to-V transitional probability will always be sufficiently high to avoid positing a boundary between a consonant and a following vowel or forming a vowel-less syllable. In contrast, the V-to-C associations are less robust and a VCV sequence will be

syllabified as V.CV rather than VC.V. The C-to-C association links are the weakest because of the number of consonantal graphemes, and the speaker will most likely syllabify a VCCV sequence as VC.CV. At the same time, Adams states that the V.CCV syllabification is not entirely unexpected, in part because certain bigrams are highly frequent and are often co-articulated (e.g., *st, fr, bl*) or correspond to a single phoneme (e.g., *th*).

The view of syllabification as a function of transitional probability of adjacent segments proposed in Adams is in contrast to the more traditional approach according to which syllabification is a process of achieving a preferred syllable structure (while obeying sonority sequencing, phonotactic restrictions and other structural factors), but it may seem increasingly attractive given the ever-increasing body of literature of the role of usage frequency in phonology, including segmental and suprasegmental processes and wellformedness judgments (among others, Bailey and Hahn 2001; Hammond 2004; Bybee 2007). However, the exact role of usage frequency in phonology in general and syllabification in particular remains to be explored, and the present study aims to determine whether quantitative factors are in fact a good predictor of variability in syllabification judgments.

3 The present study

3.1 Research questions and hypotheses

The present study examines the nature of syllabification judgments. I test (i) if the variance in the onset wellformedness scores in Russian can be predicted using statistical factors based on frequency/probability counts (as proposed in Adams 1981) and how much variance in the data such factors can account for, (ii) if the predictive ability of the model differs for factors based on token vs. type frequency, frequency vs. transitional probability, word-initial vs. counts at other positions within the word, (iii) whether categorical factors based on linguistic structure (manner and place of articulation of consonants) can also explain the variance in the data at a statistically significant level, (iv) which factors remain significant when the statistical model includes both structural and frequency-based factors, and (v) if onset wellformedness scores correlate in a significant way with wellformedness scores for corresponding monosyllables, and if the same factors are identified as significant for both datasets.

If syllabification judgments show the effects of usage frequency, then statistical analyses can be predicted to identify one or more frequency-based factors as having a significant effect on wellformedness scores, with the magnitude of the effect denoted by the R^2 values. If word-edge phonotactics play a crucial role in the placement of syllable boundaries, onset wellformedness scores should be sensitive to word-initial frequency/probability and not sensitive or less sensitive to the frequency/probability in other positions within the word. For factors based on linguistic structure, manner and place of articulation of the cluster-initial consonant (C_1) and/or type of the cluster-final consonant (C_2) should be significant if differences associated with the nature of consonantal segments can account for the variance in the data. In the combined model that uses both structure-based and frequency-based predictor variables, only those factors the effects of which cannot be attributed to any other factor will remain

significant. Furthermore, if wellformedness judgments for onsets and word-initial edges involve the same underlying mechanism, then there should be a high degree of correlation between the onset and monosyllable scores and the same factor or a set of factors should be identified as significant for both tasks.

3.2 Materials and method

3.2.1 Stimuli

Twenty six (26) biconsonantal sequences were tested. The C_1 was taken from a set of 13 non-palatalized plosives and fricatives (/p, b, t, d, k, g, f, v, s, z, š, ž, x/). The C_2 was either the /r/ or the /l/. The biphones were embedded in a nonce-word context in the form /xa+C_1C_2+um/ or /C_1C_2+um/ (e.g., /xakrum/, /krum/). The complete list of clusters is in (2).

(2)

pr	tr	kr	fr	sr	šr	xr
br	dr	gr	vr	zr	žr	
pl	tl	kl	fl	sl	šl	xl
bl	dl	gl	vl	zl	žl	

All 26 sequences in (2) above are attested in Russian in word-medially. With the exception of /tl/ and /dl/, the biphones can occur word-initially in their non-palatalized form given above (/tl/ and /dl/ are possible word-initially if the /l/ is palatalized (e.g., /tl^{j}a/ 'greenfly'; /dl^{j}a/ 'for') or as graphemes). The choice of the specific segments/sequences was conditioned by the fact that the stimuli had to be controlled for a number of factors (e.g., using the liquids /r/ and /l/ as C_2, the nasal /m/ as the word-final segment and the vowels /a/ and /u/ as the vocalic environment made it possible to maintain a transparent spelling-to-sound relationship, avoid interference from voicing alternations/palatalization/vowel reduction). To reduce the potential impact of morphology, the stimuli resembled monomorphemic masculine nouns in the Nominative case. The word-initial and word-final biphones (/xa-/, /-um/) were chosen such that they would not be identical to any productive affixes and the relevant parsing of the stimuli items would not result in forms which would be match any existing nominal wordforms (e.g., /krum/ does not correspond to any Russian noun). Participants were also told explicitly that word stress always fell on the second vowel, which appeared to be a more natural-sounding pattern for the items in question.

3.2.2 Procedure and participants

Native speakers of Russian (n=99) were recruited and tested at a university campus in Perm, Russia (both male and female; age range from 18 to 33; none majored in Linguistics). They were asked to evaluate the relative wellformedness of the stimuli items by filling out a written questionnaire. Two types of questionnaires were distributed. In the *onset wellformedness questionnaire*, the C_1C_2 medial cluster was syllabified as the onset of the 2nd

syllable (the "~" symbol was inserted at the syllable boundary; e.g., /xa~krum/) and participants were instructed to evaluate the wellformedness of the syllabification pattern for each of the 26 stimuli items. In the *monosyllable wellformedness questionnaire*, speakers were presented with monosyllabic items that were identical to the syllables of interest in the onset wellformedness task (e.g., /krum/) and were asked to evaluate the wellformedness of the monosyllables. Responses were given on a Likert scale from 1 (completely unnatural) to 5 (very natural) with 2, 3 and 4 as intermediate values. Each participant was assigned to one of the two questionnaire types on a random basis (50 participants filled out the onset questionnaire and 49 did the monosyllable questionnaire). To minimize the likelihood of the results being affected by explicitly taught syllabification rules, the present study followed the methodology of other similar experiments and the word "part" rather than "syllable" was used in the instructions. Participants were told explicitly that there were no correct or incorrect answers and no performance-related feedback was provided during testing.

3.2.3 Data analysis. Statistical factors

Likert scale scores were transformed into standard scores (z-scores) that take into account each speaker's range of responses. The normalized data were then subjected to a correlation analysis, stepwise regression analyses using continuous predictors (i.e., frequency and probability measurements), univariate analyses of variance (ANOVAs) with categorical factors, and ANOVAs using a combination of categorical factors and the continuous variable identified as most significant in the regression analyses. The complete list of factors is given in (3).

(3) a. Continuous predictors:
- Frequency of the /C_1C_2 / sequence (type, token)
- Transitional probability of C_1 followed by C_2
- Transitional probability of C_2 preceded by C_1

b. Categorical predictors:
- Manner of the C_1 segment (plosive, fricative)
- Coronality of the C_1 segment (coronal, non-coronal)
- Type of the C_2 segment (rhotic, lateral)

The measurements in (3a) were calculated on the basis of the Frequency Dictionary for Russian Version 2 (Sharoff 2002). For each factor, separate values were computed based on word-initial (WI), word-medial (WM), word-final (WF) and total frequency of the sequence.

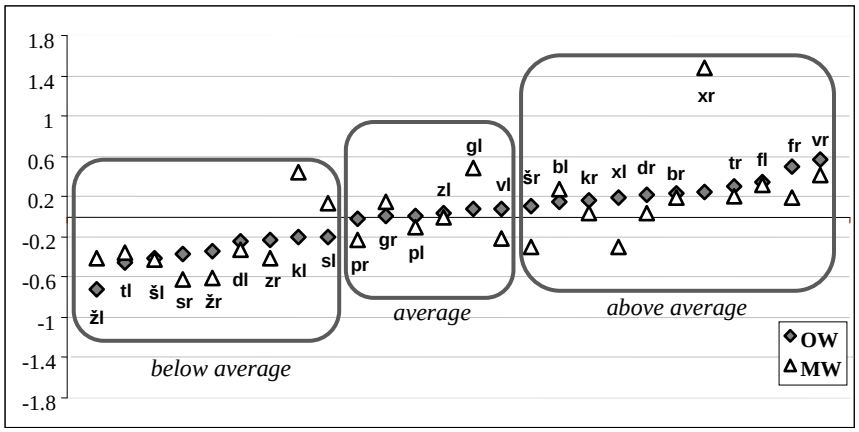
3.3 Results

3.3.1 General results

The results of the 2 experimental tasks are shown in the graph in (4). The graph shows mean z-scores for each of the 26 consonant clusters, with diamonds

representing onset wellformedness (OW) and triangles denoting monosyllable wellformedness (MW) scores. The clusters are arranged in an ascending order based on the onset scores, which are the primary variable of interest in the present study. Values below zero on the y-axis correspond to lower than average scores, and values above zero indicate higher than average scores (e.g., /žl/ and /žr/ scored lower than average; /vr/ and /fr/ scored higher than average).

(4)



As can be seen in (4), there is variability in wellformedness scores of different clusters both within and between experimental tasks. Frequent clusters do not always outperform their infrequent counterparts (e.g., /pr/, the most frequent consonantal sequence in Russian, scored only around zero (i.e. average) in both tasks). Infrequent sequences also do not score substantially worse than other clusters (e.g., /xr/ scored significantly higher than any other cluster in the monosyllable task; /dl/ and /tl/, which are possible in the word-initial position only when C_2 is palatalized, did not score worse than such perfectly attested word-initial sequences as /žl/ and /šl/). For many obstruents, /r/-final clusters scored higher than /l/-final sequences. There also appears to be a difference between coronal and non-coronal obstruents, with non-coronals receiving higher mean scores. In the case of the onset wellformedness data, coronality seems to interact with manner (i.e. scores are lower when C_1 is a coronal fricative). At the same time, no overall difference is apparent between C_1 plosives and C_1 fricatives. The validity of these observations was tested in the ANOVAs and is discussed in Section 3.3.2.

3.3.2 Statistics

For onset wellformedness scores, regression analyses identified a combination of 2 factors as significant at the .05 alpha level: (i) transitional probability of C_1 followed by C_2 at the word-initial edge and (ii) total token frequency of the C_1C_2 sequence. Transitional probability alone could account for 33% of the variance in the averaged data (R^2=.330; p=.002). With the addition of the total token frequency of the C_1C_2 sequence, the predictability of the model improved to

45.9% (R^2=.459; p=.001). For the monosyllable data, the transitional probability of C_1 followed by C_2 at the word-initial edge was only marginally significant and the factor could account for 12.7% of the variance only (R^2 =.127; p=.073). No other factor or combination of factors was identified as significant (factors based on type frequency counts were never significant). Results of the regression analyses are summarized in (5).

(5)

		Factors	
		C_1-to-C_2 trans. prob. (WI; plain Cs)	*C_1-to-C_2 trans. prob. (WI; plain Cs)* and *C_1C_2 token freq. (total; plain Cs)*
Task	*Onset*	R^2 = .330 p = .002	R^2 = .459 p = .001
	Monosyllable	R^2 = .127 p = .073	n.s.

An ANOVA of onset wellformedness scores using categorical factors only showed a significant main effect of the C_2 type ($F_{1,19}$=7.20; p=.015), with /r/-final onsets scoring higher than /l/-final onsets (mean scores of .11 and -.11, respectively). Coronality of C_1 was also significant ($F_{1,19}$=15.98; p=.001), with non-coronal obstruents outscoring coronal segments (mean scores of .17 and -.20, respectively); however, there was also a significant interaction between C_1 coronality and C_1 manner ($F_{1,19}$=8.13; p=.01), revealing that the significance of C_1 coronality was largely due to onsets containing non-coronal fricatives scoring higher than onsets with coronal fricatives (mean scores of .32 and -.27, respectively). No such tendency was observed for plosives, and the manner factor itself was not significant (F<1; p>.1). When the same data was tested using a combination of categorical factors and the continuous predictor identified as most significant in the regression analysis (the transitional probability of C_1 followed by C_2 at the word-initial edge), C_2 type was no longer significant (F<1; p>.1). In contrast, the main effect of C_1 coronality was still present ($F_{1,18}$=7.65; p=.013), and the interaction between C_1 coronality and C_1 manner also remained significant ($F_{1,18}$=6.77; p=.018). The probability factor itself was not significant. No other variable or combination of variables was identified as significant (all Fs<1.5; all ps>.1).

For the monosyllable data, an ANOVA using categorical factors only showed a significant main effect of C_1 coronality ($F_{1,19}$=7.97; p=.011), confirming that monosyllables starting with non-coronal obstruents scored significantly higher than items with initial coronal stops and fricatives (mean scores of .22 and -.25, respectively). Neither the manner of the C_1 nor the type of the C_2 was significant and none of the factors interacted (all Fs<1.5; all ps>.1). When the ANOVA was repeated using categorical predictors and the transitional probability of C_1 followed by C_2 at the word-initial edge as the continuous

covariate (the only marginally significant factor identified in the regression analysis), the coronality of C_1 became only marginally significant ($F_{1,18}$=4.29; p=.053) and no other variable (including the probability factor) or interaction of variables was significant.

Results of the analyses of variance are summarized in the table in (8).

(8)

	Onset		*Monosyllable*	
	Categ. only	*Categ. & cont.*	*Categ. only*	*Categ. & cont.*
C_2 type	p=.015	n.s.	n.s.	n.s.
C_1 coronality	p=.001	p=.013	p=.011	p=.053
C_1 manner	n.s.	n.s.	n.s.	n.s.
C_1 coronalityC_1 manner*	p=.01	p=.018	n.s.	n.s.
C_1 coronalityC_2 type*	n.s.	n.s.	n.s.	n.s.
C_1 mannerC_2 type*	n.s.	n.s.	n.s.	n.s.
C_1-to-C_2 trans. probability	---	n.s.	---	n.s.

Finally, evaluation of the linear relationships between the results of the tasks showed a low-to-moderate statistically significant correlation between onset and monosyllable wellformedness scores (Pearson's r =.590; p=.002).

4. Summary of the results. General discussion

Overall, the results of the present investigation confirm that there is substantial variability in syllable wellformedness judgments even when all consonant clusters are attested in the language of interest. It is also clear that the role of usage frequency is limited. The mean score of /pr/, for example, was on par with the scores of many other clusters even though /pr/ is the most frequent of the 26 sequences. Onsets containing /tl/ and /dl/ did not score substantially worse than the rest of the clusters even though the two sequences are only marginally attested in Russian word-initially. Moreover, the results of the regression analyses revealed that models based on frequency factors alone could account for no more than 46% of the variance in the onset data (33% if using only the transitional probability factor) and less than 13% of the variance and only marginally significant in the case of the monosyllable data.

Regression analyses further revealed that the single most significant or, in the case of monosyllables, the only marginally-significant predictor was based on probability counts at the word-initial edge. The significance of probability rather than frequency is consistent with Kessler and Treiman (1997) who argue that, when dealing with segmental sequences, probability is a better quantitative characteristic than frequency. The fact that word-initial rather than total, word-medial or word-final measurements were significant corroborates the importance of word edge phonotactics in syllable wellformedness judgments. At the same time, the results of the correlation analysis and the observed differences in

significance of factors in regressions and ANOVAs reveal that the types of processes involved in onset wellformedness evaluation are not identical to the processes that speakers rely on when judging the "goodness" of corresponding monosyllabic wordforms. This finding confirms the possibility mentioned in Steriade (1999) that factors other than similarity to word edges could influence syllabification and, therefore, warrants against a strict interpretation of the Word-based syllables hypothesis.

The results of the analyses of variance demonstrated that the apparent frequency effects in the data were best accounted for with predictor variables that refer to manner and place of articulation of consonantal segments – the probability factor identified in the linear regressions was no longer significant when the model included categorical factors based on linguistic structure. In contrast, the coronality of C_1 had a statistically significant effect on the results of both tasks (clusters containing non-coronal obstruents scored higher than sequences with initial coronal segments), and the factor remained significant or marginally significant in all models. In the onset wellformedness data, the coronality of C_1 also appeared to affect fricatives rather than plosives (this finding would need to be verified independently). Unlike place, the manner of C_1 was never significant, suggesting that there was no overall difference in scores between fricative-initial and plosive-initial clusters. The type of C_2 (lateral vs. rhotic) was significant only in the onset data (higher scores for /r/-final sequences) and only in the model that tested categorical factors exclusively. When transitional probability was added into the model, C_2 type became insignificant, revealing that the preference for /Cr/ onsets was largely due to the fact that, for the majority of obstruents tested in the present study, /r/-final clusters were more frequent/probable than /l/-final variants. At the same time, the probability factor itself did not reach significance, which shows that even though the difference in scores between laterals and rhotics appears to be related to distributional properties of the clusters, the frequency effect was not sufficiently robust to have a statistically significant impact on the scores.

The present findings are consistent with a number of studies which show that different consonant types are not always syllabified in the same way (e.g., Treiman and Danis 1988; Treiman et al. 1992; Gillis and De Schutter 1996) and that the explanatory power of usage frequency is often limited to less than 50% of the variance in the data (e.g., Treiman et al. 2000; Bailey and Hahn 2001; Hammond 2004). At the same time, the results of the current investigation would be difficult to reconcile with the proposal in Adams (1981) who argues that syllabification is done *primarily* on the basis of transitional probability of adjacent segments, with less probable sequences split between two syllables and more frequent clusters syllabified together. Additionally, the absence of an overall significant difference between fricative-initial and plosive-initial complex onsets may indicate that the two types of obstruents do not necessarily belong to distinct points on the sonority scale or that the role of sonority in syllabification may be less pronounced than previously thought, which would support the conclusions of a number of recent empirical and experimental studies which argue against sonority playing a decisive role in syllabification (Smith and Pitt 1999; Goslin and Frauenfelder 2001; McCrary 2004; Ohala 2008).

5. Conclusions

In conclusion, analyses of syllabification patterns traditionally refer to syllable structure markedness, sonority, phonotactic legality, segmental quality, stress placement and other similar structural factors, but it has also been proposed that the evaluation of syllables is largely dependent on word structure (Steriade 1999) or that syllabification is done primarily on the basis of phonotactic probability of adjacent segments (Adams 1981). The present study investigated whether syllable wellformedness evaluation is sensitive to word-edge phonotactics as well as the frequency and probability of segmental sequences and if the same factors affect both syllable and word wellformedness scores.

The current findings demonstrate that syllable and word wellformedness evaluation may in fact rely on similar factors and that both types of judgments may be sensitive to word-edge phonotactics, yet syllables and monosyllabic words are not judged in exactly the same way. The role of frequency is at most secondary. Frequency-based factors have a limited explanatory power and frequency effects observed in the data are best accounted for by factors that are not based on usage frequency (e.g., C_1 coronality). Thus, syllabification judgments for complex onsets do not appear to be reducible to mere frequency or probability of segmental sequences and are not exactly identical to the evaluation of word edges.

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