THE MANDIBULAR CYCLE AND REVERSED-SONORITY ONSET CLUSTERS IN RUSSIAN

Melissa Annette Redford
University of Texas, Austin, USA

ABSTRACT

The sonority principle is dramatically violated by some Russian onset clusters (e.g., [lba]) and not by others. Russian onset clusters therefore provide a good test of a phonetically-motivated, alternative hypothesis to the sonority hierarchy; namely, the hypothesis that the primary constraint on the sequential organization of segments is the relatively independent close-open mandibular cycle. The jaw movement of 3 native Russian speakers was recorded during the production of simple CV syllables as well as during the production of syllables with standard onset clusters and those with reversed-sonority clusters. Measurements of jaw height during segment production and segment duration indicate that while reversed-sonority clusters may violate the sonority principle, they behave like more standard syllables and conform to the mandibular cycle.

1. INTRODUCTION

Syllables are generally organized according to a manner hierarchy such that segments increase in sonority or loudness until the syllable nucleus and decrease thereafter. The principle underlying this organization has been termed the sonority principle. Although the sonority principle characterizes cross-language segmental organization within syllables, it does not provide an extralinguistic definition of syllables nor an explanation for why certain sequences occur more frequently than others. Also, the principle is occasionally dramatically violated, for example, by the sonorant-stop onsets of some monosyllabic Russian words (e.g., [lba] "forehead", [lgat^{j}] "to lie"). These reversed-sonority onset clusters, though considered ill-formed, cannot be explained in a non-circular fashion by the sonority principle.

One phonetically-motivated alternative to the sonority principle emerges from the characterization of syllables as close-open cycles of the mandible. In articulatory terms, consonants and vowels are most easily contrasted along one dimension -- the degree to which the vocal tract is constricted. Consonants, relative to vowels, are produced with a greater degree of vocal tract constriction. Constriction of the vocal tract can be achieved in a variety of ways, including the very simple act of opening and closing the mouth. MacNeilage and Davis [4,1] have argued that infants' first speech-like behavior, when segments are sequentially organized into syllable-like strings, can be largely understood in terms of the constant open-close motion of the mandible basic to speech (and to many nonspeech activities). They have shown that most of the variance in babbling can be attributed to this movement of the mandible with little contribution from the tongue as an independent articulator. The most extreme instance of this is demonstrated by the 'pure frames' of babbling -- those sequences with labial consonants and central vowels (e.g., baba) that are probably achieved only by the open-close movement of the jaw during phonation. This pattern of 'frame dominance' observed in babbling has also been noted in the production of first words [5].

In adult consonants and vowels, the actual constriction for various places of articulation is achieved ultimately with the lips or tongue. It is notable, however, that the degree of constriction required for a particular segment is correlated with the degree to which the jaw is raised or lowered [3,2]. For example, voiceless fricatives, which require a narrow constriction of the vocal tract, are associated with a more closed jaw position than liquids or glides, which are more open. Lindblom [3] noted the clear correlation between sonority and jaw position and suggested that the sonority principle reflected speakers' "propensity to coarticulate" segments.

The view that jaw height reflects coarticulatory constraints on segments suggests that segments drive mandible height and not vice versa. When mandible height is dependent on the flow of segments, the question of why languages universally organize segments into syllables remains mysterious. If, however, syllables emerge from the basic mandibular cycle and this cycle is relatively independent from the action of the other articulators, then the sequential organization of phonemes is naturally constrained in the manner described by the sonority principle. One test of this view would be to determine whether syllables that violate the sonority principle nevertheless conform to a close-open mandibular cycle. The present study was conducted to provide such a test of the hypothesis that the mandibular cycle constrains the sequential organization of segments.

Data were collected on the jaw movement of 3 native Russian speakers while they produced different types of legal Russian syllables. These included simple syllables with a consonantal onset, syllables with initial clusters that obeyed the sonority principle, and syllables with reversed-sonority clusters. Measurements were taken on the relative jaw position during articulation of the segments and on the relative duration of the segments. It was predicted that syllable position would be a stronger constraint on the articulation of a particular segment, than its segment class. Specifically, it was predicted that stop or liquid segments in the first consonantal (C1) position of a cluster would be articulated with a relatively closed jaw configuration compared with when the same consonants occurred in the second consonantal (C2) position of the cluster. In addition to jaw height, segment duration was predicted to be constrained by the cycle. It was predicted that segments associated with greater jaw opening would be greater in duration and those associated with less jaw opening would be shorter in duration. The simple consonant-vowel (CV) syllables provided a control case for the two consonant types. The confirmation of these predictions would provide evidence that both the standard clusters of Russian (e.g., [bl-]) and the unusual ones (e.g., [lb-]) conform to the basic mandibular cycle.

2. METHOD

2.1. Stimuli

One female and two male native Russian speakers produced 42 single syllables in a frame sentence. The tokens were obstruent-vowel (OV), sonorant-vowel (SV), obstruent-sonorant-vowel (OSV), and sonorant-obstruent-vowel (SOV) syllables. The obstruents were the voiced stops [b] and [g], the sonorant was the liquid [l], and the vowels were the point vowels [i], [u], [a]. Most of the SOV tokens were actual monosyllabic Russian words, for example, [lba] -> "forehead" (sing. gen.), [lgu] -> "I lie" (pres.). In contrast, the CV, SV, and OSV tokens, though also legal syllables in Russian, were not actual Russian words, for example, [glu] -> [glu.xa] -> "deaf" (fem.). Each syllable type was said twice in the sentence [poi ___ s nova].

The speakers read the written form (Cyrillic) of the tokens from a randomized list of the tokens. The sentences were recorded with a Shure SM48 microphone directly into a pentium PC with a sampling rate of 11025 Hz. In addition to audio recordings, kinematic recordings of the stimuli were made. The speakers' jaw movement during production was recorded using two strain gauges attached to a depressor. The depressor was fixed under the speakers' chin by securing it to a light-weight head-mount, which the speakers wore while producing the stimuli. Jaw movement was sampled at 100 Hz. Movement calibration was achieved by recording the speakers with a clenched jaw and with a 1 cm spacer inserted between the premolars. The calibration recordings were made at the beginning and end of each 10 minute recording session.

2.2. Measurements

The temporal onset and offset of each segment of a token was measured. The temporal onset and offset of a segment was determined by visual inspection of the waveform and by auditory analysis. The onset/offset of stop segments corresponded to abrupt changes in the amplitude envelope of the waveform and/or to the onset of periodicity. The boundary between a liquid and a vowel corresponded to changes in the shape of the waveform. The demarcation of this boundary was coupled with auditory judgments. Vowel offsets corresponded to the onset of frication of the following [s] from the frame sentence. The midpoint of each segment equaled the exact midpoint between the onset and offset of the segment.

Jaw displacement measurements were made with reference to the acoustic data. Measurements were taken at the midpoint of the obstruent, sonorant, and vowel. The midpoint of the segment was determined from the acoustic measures of segment onset and offset.

2.3. Analyses

Syllables with different stop types were collapsed in the analyses. The collapsing of stop types meant that there were fewer observations for SV syllables than for any other syllable type. Parity between SV syllable observations and observations for other syllable types was restored by using average values for missing observations.

3. RESULTS

3.1. Jaw height

Separate analyses were performed on jaw height during the production of consonants and vowels. A three-way analysis of variances (consonant type x syllable type x vowel nucleus) was performed to establish whether any significant difference in jaw height occurred for the stop and liquid segments in the different syllable positions. Main effects were observed for cumulative jaw height differences dependent on syllable type and vowel nucleus [syllable type: $F(2,22)=4.431$, $p<.05$; vowel nucleus: $F(2,22)=24.635$, $p<.01$], but not on consonant type. Consonants in CV syllables were articulated with more jaw opening than consonants in either OSV or SOV syllables. Consonants in syllables with a low central vowel nucleus were articulated with more jaw opening than consonants in syllables with high front or back vowels. A significant interaction between syllable type and vowel nucleus [$F(4,44)=2.641$, $p<.05$] also indicated that jaw height during consonant production was greater when the vowel nucleus was a low central [a] vowel than when it was either a high front [i] or a high back [u] vowel.

No significant interaction was found for the production of stop and liquid consonants in different syllable types, but mean comparisons showed certain significant patterns of interaction nonetheless. Figure 1 shows a graph of the interaction between syllable type and consonant type.

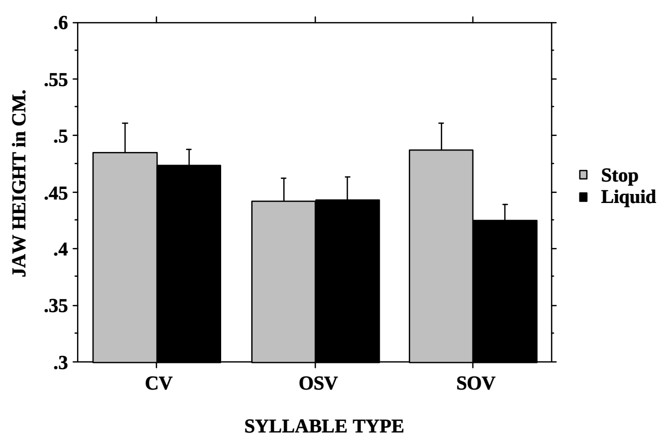

Figure 1: Jaw height as a function of syllable position is displayed for stop and liquid segments.

Figure 1 shows and mean comparisons confirm that both stop and liquid consonants were articulated with the same degree of jaw opening in CV syllables. The C1 stop and C2 liquid consonant of OSV syllables were also articulated with the same degree of jaw opening. In contrast, the C2 stop consonants in

SOV syllables were articulated with a more open jaw configuration than the C1 liquid consonant [F(1,22)=9.688, p<.01]. Thus, the prediction that segments would be articulated with different degrees of jaw opening depending on their syllable position was confirmed in this first test for SOV syllables, but not for OSV syllables.

Both stop and liquid consonants in the C1 position of a cluster were produced with less jaw opening than stops or liquids in simple consonantal onsets (CV syllables) [stops, F(1,22)=4.591, p<.05; liquids, F(1,22)=5.996, p<.05]. When stops and liquids were in C2 position, however, they were articulated with the same degree of jaw opening as when they occurred in simple CV syllables. These results confirmed the hypothesis that syllable position effects jaw height for both stops and liquids.

A main effect was found for different vowel nuclei [F(3,33)=19.356, p<.01]. As expected, low central vowels were articulated with significantly more jaw opening than high front or high back vowels [F(1,33)=32.5, p<.01]. Mean comparisons also indicated a difference between high front and high back vowels, such that high front vowel were associated with more jaw opening than high back vowels [F(1,33)=6.19, p<.05].

3.2. Segment duration

Separate analyses were performed on consonant and vowel duration. A three-way analysis of variances (consonant type x syllable type x vowel nucleus) was performed to establish whether any significant differences in consonant duration occurred for the stop and liquid segments in different syllable positions. A main effect of consonant and syllable type occurred [consonant type: F(1,11)=30.856, p < .01; syllable type: F(2,22)=9.058, p < .01], but not of vowel nucleus. The overall duration of stop consonants was greater than the overall duration of liquid consonants. The cumulative duration of consonants in OSV syllables was less than the cumulative duration of the consonants in CV and SOV syllables.

A significant interaction occurred between consonant duration and syllable type [F(2,22)=12.608, p < .01]. This interaction can be seen in Figure 2.

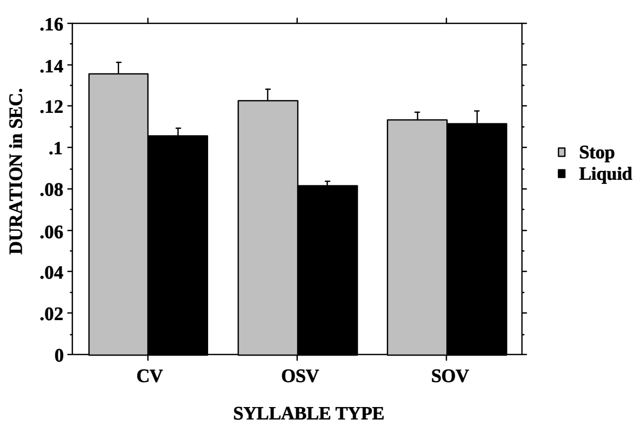

Figure 2: Stop and liquid duration as a function of syllable position.

As illustrated in Figure 2 and confirmed by mean comparisons, the duration of liquid consonants was much shorter in C2 position than either in C1 position [F(1,22)=27.718, p<.01] or than when they occurred as single consonantal onsets [F(1,22)=17.638, p<.01]. The stop consonants were also shorter in duration as C2 consonants than when they occurred as single consonantal onsets [F(1,22)=14.963, p<.01], but were not significantly shorter than stops in C1 position. Nevertheless, stops in C1 position were shorter in duration than stops that were single consonantal onsets [F(1,22)=5.029, p<.05]. In contrast, [l] in C1 position did not differ in duration from [l] as a single consonantal onset.

Vowel duration also differed according to syllable type and vowel type. Overall vowels were shorter in SV syllables than in any other syllable type. Vowel duration in OV, OSV, and SOV syllables was not significantly different. The low central vowels were significantly greater in duration than either the high front vowels [F(1,33)=15.720, p<.01] or high back vowels [F(1,33)=44.342, p<.01]. High front vowels were also greater in duration than high back vowel [F1,33)=7.258, P<.05].

4. DISCUSSION

The results of this study provide general support for the view that the mandibular cycle provides a major constraint on the sequential organization of segments. Russian syllables that violate the sonority principle nevertheless conform to a close-open mandibular cycle. Segments that belong to manner classes considered by the sonority principle to be more or less fixed with respect to openness were articulated with different degrees of jaw opening in different syllable contexts. Both stop and liquid consonants were articulated with more jaw closure when they occurred in C1 position than when they occurred either as lone onsets or in C2 position.

A somewhat surprising result was that syllables that obeyed the sonority principle showed less evidence of articulation according to the jaw cycle than syllables that had reversed-sonority onset clusters. Liquids and stops in OSV syllables were articulated with the same relative degree of jaw closure, but, in SOV syllables, C1 liquids were articulated with a significantly more closed jaw configuration than the C2 stops. The SOV case provides clear confirmation that the mandibular cycle organizes segments within a syllable. While the OSV case still obeys the cycle, the fact that the C2 liquid consonant was as closed as the C1 stop consonant suggests that the mandibular cycle is not entirely independent from the characteristics of the target segment or from the action of the other articulators. This more moderated view of the cycle is supported by the result of clear differences in jaw height during production of specific vowels. The [a] vowels were consistently articulated with more jaw opening than the [i] or [u] vowels. This results was consistent with the normal characterization of these vowels as low and high.

The view that the mandible is influenced by the action of other articulators is supported by data from Keating, et al. [2]. Keating et al. found that in English and Swedish alveolar stops and fricatives are typically articulated with a more closed jaw configuration than consonants in other places of articulation. It may be that, in the case of alveolars, the target tongue configuration is aided, in part, by the positioning of the mandible. Interestingly, and consistent with the findings of this study, Keating et al. found that the mean jaw height value associated with the production of the alveolar liquid [l] was less than the values associated with the voice labial stop [b] and the voiceless velar stop [k] in English. Additionally, analysis of the Keating et al. English data suggests that labial and velar stops in different vowel contexts were articulated at more different (and greater) jaw heights than the alveolar liquid [l]. In light of these data, the result from the present study -- that liquids in C2 position were articulated with the same relatively closed jaw configuration of the stop in C1 position -- is less surprising than it may initially appear.

The effect of the mandibular cycle on the sequential organization of segments was also evident from the differences observed in segment duration. Generally, segments that were articulated with greater jaw opening were longer in duration. Liquids, which were articulated with a relatively closed jaw configuration in all positions, were relatively short in duration in all positions. Stops, which were articulated overall with a more open jaw configuration, were relatively longer in duration. The most direct relationship between jaw height and duration, however, was observed for the vowels. The low central vowels were articulated with the greatest jaw opening and duration, followed by the high front vowels, and finally by the high back vowels. If a trading relationship exists between movement, time and energy in the manner described by Lindblom [3], then the pattern of results observed in this study might also be explained in terms of the mandibular cycle. Segments articulated with more open jaw configurations require greater displacement from the resting (relatively closed) jaw position than those articulated with a more closed jaw position. If input to the system is relatively stable, then the increased distance traveled by the articulator will be reflected in an increase in the time it takes to reach the target.

5. CONCLUSION

The results from this study indicate that both the Russian clusters that obey the sonority principle [e.g., bl-] and those that do not [e.g., lb-] conform to a mandibular cycle. The jaw height associated with the production of the individual segments is a better indicator of where the segment occurs within the cycle than it is of the consonant or vowel class to which the segment belongs. The mandibular cycle is not, however, completely independent in its action. The different tongue configurations necessary for the articulation of different segments may influence jaw height, particularly when these articulations involve the tongue tip. Finally, the positive relationship between jaw height and duration may also be explained to emerge from the mandibular cycle. Increased cycle amplitude takes longer to realize.

ACKNOWLEDGEMENTS

This work was supported in part by a University Fellowship. The author is grateful to Peter F. MacNeilage for his insightful comments and criticisms. Any errors are my own.

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