Sonority as a Primitive: Evidence from Phonological Inventories

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1. Introduction

The nature of sonority remains a controversial subject in both phonology and phonetics. Previous discussions on sonority have generally been situated in synchronic phonology through syllable structure constraints (Clements, 1990) or in phonetics through physical correlates to sonority (Parker, 2002). This paper seeks to examine the sonority hierarchy through a new dimension by exploring the relationship between sonority and phonological inventory structure. The investigation will shed light on the nature of sonority as a phonological phenomenon in addition to addressing the question of what processes underlie the formation and structure of speech sound inventories.

This paper will examine a phenomenon present in phonological inventories that has yet to be discussed in previous literature and cannot be explained by current theories of inventory formation. I will then suggest implications of this phenomenon as evidence for sonority as a grammatical primitive. The data described here reveals that sonority has an effect in the formation of phonological inventories by determining how many segments an inventory will have in a given class of sounds (voiced fricatives, etc.). Segment classes which are closest to each other along the sonority hierarchy tend to be correlated in size except upon crossing the sonorant/obstruent and consonant/vowel boundaries. This paper argues that inventories are therefore composed of three distinct classes of obstruents, sonorants, and vowels which independently determine the size and structure of the inventory. The prominence of sonority in inventory formation provides evidence for the notion that sonority is a phonological primitive and is not simply derived from other aspects of the grammar or a more basic set of features.

2. The structure of phonological inventories

Research on sound systems has already yielded a number of productive theories that explain the principles governing the structure of sound inventories. Dispersion theory (Lindblom & Maddieson, 1988; Schwartz et al., 1997) makes excellent predictions for the occurrence of segments in vowel inventories. The theory is based on the notion that vowel systems tend to be symmetrical and maximally distinct to aid in perception; therefore vowels concentrate along the periphery of the vowel space. Feature Economy (Clements, 2003) predicts that segments will be more common in inventories where their distinctive features are already present among other segments. Languages tend to increase economy by maximizing the ratio of segments to features in their phonological inventories.

Knowledge of processes that govern inventory structure is lacking in regards to factors that control inventory size. Current theories provide accurate predictions for what types of segments will occur in inventories. For example, if we know how many vowels a language has, we can generally predict what vowels they will be based on dispersion theory. However, we do not know if there are any factors which can be used as predictors for the number of vowels in an inventory. Processes that control the sizes of inventories (and more specifically, how many segments a language will have in a specific class such as voiced fricatives) have gone largely uninvestigated. This question is worth examining considering the great variation in size among inventories.

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3. The sonority scale

The sonority scale is a phonological hierarchy of segments ranking sounds (generally speaking) on relative loudness, although exact physical correlates for sonority are debated. Many propositions have been made including but not limited to openness of the vocal tract (Lindblom, 1983) and acoustic energy (Ladefoged, 1971). Recently, Parker (2002) has demonstrated a correlation between sonority and the physical property of intensity using data from English and Spanish. The relationship between sonority level and intensity is linear; intensity inscreases with sonority. The general levels of sonority are consistent across all languages (obstruents, sonorants, vowels) but language dependent variations in sonority have been documented (Jany et al., 2007). Some finer points of the sonority scale such as voiceless fricatives vs. voiced stops, and laterals vs. rhotics may differ in ranking between languages.

The existence of the sonority scale has been contested within phonetic and phonological research. Ohala (1990) rejects sonority altogether and claims sonority "should be abandoned for explaining universal sequential constraints" due to the lack of universality in sonority effects and physical correlates cross linguistically. Clements (1990) rejects the idea of sonority as a primitive single property of sounds, but proposes the sonority hierarchy is derived from a set of binary features. The data examined here provides support for the importance of sonority and its existence as a primitive hierarchy in phonological grammar. Although a precise phonetic correlate is difficult to isolate, various phonological phenomena have been cited as evidence that sonority is a grammatical primitive.

4. Sonority as a predictor of class size in phonological inventories

4.1. Method

Data was collected from the phoneme inventories of P-base (Mielke, 2008), a database of phoneme inventories from 628 varieties of 549 languages. The database also includes feature information encoded in different feature systems. In this analysis The Sound Pattern of English (Chomsky & Halle, 1968) features were used for distinguishing segments based on sonority. See the Appendix for the full featural specifications which were employed to distinguish segment classes.

The sonority hierarchy used here is based on the distinctions made by Parker (2002), which were determined using intensity measurements as a physical correlate. While the exact ordering of the sonority scale is still a topic for debate, the ordering of the classes of obstruents, sonorants, and vowels (which are most crucial for this analysis) are well defined and generally uncontested. The database was scanned for the number of segments in each sonority level in every language. The number of segments of each type was then compared against the number of segments of every other type in the language and a simple linear regression model was employed to determine the correlation coefficient between each pair of segment classes across all languages in the database. For example, the number of voiced fricatives was plotted against the number of voiceless fricatives in each language. Treating all languages as independent data points, a linear regression of the resulting scatterplot was taken to determine the correlation coefficient (r) value between the sizes of the two segment classes.

4.2. Results

The cross linguistic analysis showed that the number of segments in adjacent classes along the sonority hierarchy serves as the best predictor of class size except upon crossing the sonorant/obstruent and consonant/vowel boundaries. The number of voiceless stops in an inventory will be a good predictor for the number of voiceless fricatives in the inventory, a worse predictor for the number of voiced fricatives and a bad predictor for the number of rhotics or vowels in the inventory. All correlation and significance values are given in the Appendix. Figure 1 shows the data with regards to voiced fricatives. The correlation coefficient is shown as a function of the sonority class with which the voiced fricatives are associated.

Consider the circled point. This point represents a correlation where r = 0.63 ($p < .0001$) between the number of voiced fricatives and the number of voiceless fricatives in phonological inventories.

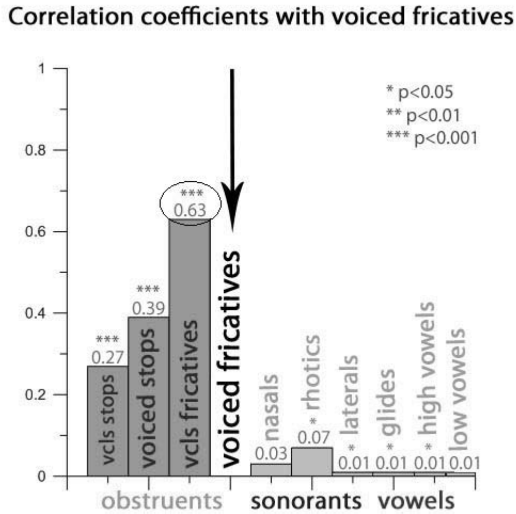

Figure 1: Correlations among obstruents - voiced fricatives

The correlation coefficients between classes gradually decrease as the distance along the sonority scale increases. The correlations between each group maintain this gradient relationship among the obstruents, but the correlation is lost once the sonorant/obstruent boundary is crossed. There is no correlation between the number of voiced fricatives and the number of nasals in inventories even though these two are adjacent on the sonority scale. This contrasts with the large correlation between voiced fricatives and voiceless fricatives, which are also adjacent. Through these correlations we see the obstruents patterning as a distinct class. Sonority can be employed as a predictor for number of segments, but only within the larger classes of obstruents, sonorants, and vowels.

The gradient correlation effect is also visible among the sonorants, shown here with laterals:

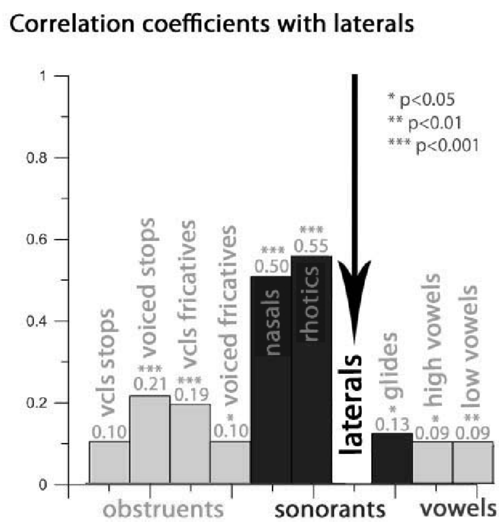

Figure 2: Correlations among sonorants - laterals

In Figure 2, we see the sonorants patterning as a distinct class. The correlations between the number of laterals in inventories and the number of rhotics or nasals are higher than the correlations between the number of laterals and the number of fricatives or stops. Even though laterals are fairly close to vowels in sonority, there is no correlation between the number of segments in these two classes. The correlations between the number of laterals and the number of segments in the obstruent groups are greater than the correlations with vowels but still not as high as the correlations within the sonorant group. The vowels do not show any gradient correlation effects and form a class distinct from all consonants, shown in Figure 3.

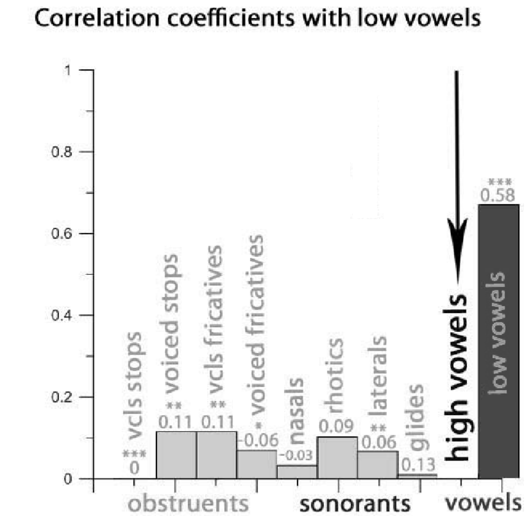

Figure 3: Correlations among vowels - high vowels

The glides are an interesting category in that they do not pattern with the sonorants (rhotics, liquids) or the vowels despite having similar feature representations. Perhaps glides form their own category in inventory formation due to the limited number of glide sounds. However, more investigation on the nature of glides in inventories is necessary. The relationships between each sonority class with every other class have been amalgamated into the graph in Figure 4.

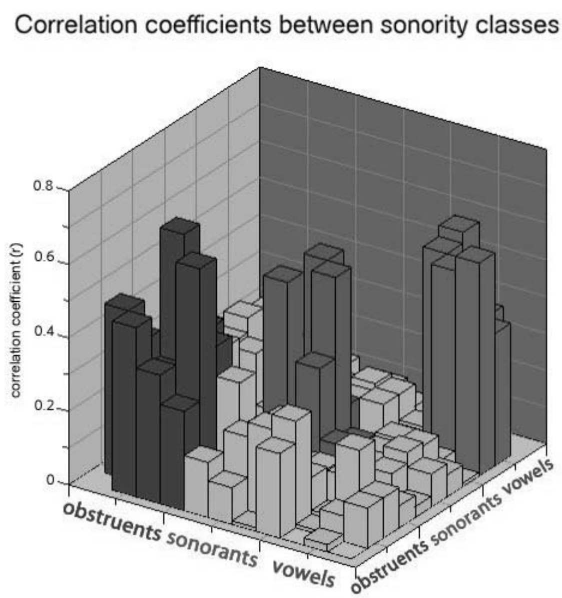

Figure 4: Correlations among all classes

Here, it is evident that the highest correlations between the numbers of segments in any two classes only appear within the boundaries of the sub-systems of obstruents, sonorants, and vowels. Correlations which cross those boundaries (depicted in light grey) are lower. This shows that inventories are composed of these three separate sub-systems which independently determine the size and structure of the inventory based on correlations between individual classes.

5. Discussion

This data has demonstrated that predictability of class size and the distance along the sonority scale are related with the exception of the consonant/vowel boundary and the sonorant/obstruent boundary. This divides phonological inventories into three separate sub-systems based on sonority, demonstrating the importance of the sonority hierarchy for sound system inventory formation.

5.1. The relationship between consonant and vowel inventories

The correlations between vowels and any consonants are equally low (approaching zero) regardless of the distance along the sonority scale. Rhotics are no better correlated with vowels in class size than voiceless stops even though they are closer along the sonority scale. The two inventories act as completely separate systems governed by different rules (dispersion vs. economy). The lack of relation between vowel and consonant inventories in languages reaches further than the sonority effect discussed here.

The relation of total vowel inventory size to total consonant inventory size is less significant than previously thought. Previous studies (Maddieson, 1984) have suggested a modest correlation between the number of consonants and vowels in sound system inventories ($r = 0.38$). These tests were run in the original UPSID database with only 317 languages. In P-base, a database of 628 varieties of 549 languages, the correlations were even slighter ($r = 0.15$) across all languages. When the languages were broken down into family and geographical groups to prevent data skewing in the overall set, some groups even exhibited negative correlations between the number of vowels and the number of consonants, shown in Table 1.

Area (languages)	Correlation coefficient
All (628)	r = 0.154
Africa (196)	r = 0.042
Americas (159)	r = -0.138
Australasia (120)	r = 0.368
Eurasia (148)	r = -0.017
Average of areas	r = 0.064

Table 1: Correlations between sizes of vowel and consonant inventories

From this data we can effectively conclude that there is no cross linguistically valid positive correlation between the sizes of consonant and vowel inventories. Any size consonant inventory can be paired with any size vowel inventory in the formation of a natural language sound system.

There are also no predictive dependencies between consonant and vowel inventories with regards to phonological features. Even consonants which share features with vowels do not show any interaction in inventories. For example, palatal glides and high vowels are assumed to have the same set of features, but they show no interactions in phonological inventory structure. Having many high vowels does not make a language any more likely to have a palatal glide (although the nature of glides in the structure of phonological inventories needs more investigation, as previously mentioned). In the same way, having many nasal consonants does not increase the likelihood that a language will have nasal vowels even though this would increase the economy of the inventory. Vowels conform to their own systematic rules of adaptive dispersion (Lindblom & Maddieson, 1988; Schwartz et al., 1997) to structure the vowel inventory without any reference to the consonant inventory of the language.

5.2. The relationship between sonorant and obstruent inventories

The data presented here also suggests that there is a stiff boundary between sonorants and obstruents, although not as strong and the consonant/vowel boundary. Previous research on consonant inventories has shown a cross linguistic tendency for inventories to be composed of 70% obstruents and 30% sonorants, which is also a reflection of the distribution of the phonetic space for consonants (Lindblom & Maddieson, 1988).

This aspect of inventory structure is indeed a tendency and not a firm rule. There are many examples of languages which do not have consonant inventories structured according to the 70/30 distinction. For example, Juhoansi has a consonant system composed of 95% obstruents and only 5% sonorants (Miller-Ockhuizen, 2003). If consonant systems were perfectly structured according to the 70/30 division, we would expect to see a high correlation between the number of obstruents and the number of sonorants in all languages, but that correlation (r = 0.23) is only slightly better than the correlation between number of vowels and number of consonants (r = 0.15).

5.3. Rejecting an alternative hypothesis

The sonority effect explored here is not caused by featural relatedness and economy. These results cannot wholly be attributed to Feature Economy effects (Clements, 2003) since the feature [+sonorant] induces more drastic effects than other features (voicing, etc.). Feature Economy states that languages tend to maximize the ratio of segments to feature in their inventories. A prediction of Feature Economy is mutual attraction between segments which share features. For example, a voiced labial fricative is more likely to occur in an inventory with a voiced alveolar fricative since the features [+voice] and [+cont] are already present in the inventory. Clements has also shown that Feature Economy applies not only to distinctive features but also features which are locally redundant; therefore all features are relevant and should induce the same economy effects.

A Feature Economy model cannot correctly predict the correlations examine here. For example, voiced fricatives share five features with rhotics ([+cons, +cont, -lat, -nas, +voice]), yet there is no interaction between those classes. Voiced fricatives also share five features with voiced stops ([+cons, -son, -approx, -lat, -nas]) and these classes do exhibit a correlation in size (r = 0.39). A difference in sonority causes a bigger effect than a difference in continuancy. Since [+son] induces different effects than those caused by other features, this data cannot be fully explained by featural similarity.

If these effects were being induced solely by feature differences, we would expect to see a relationship between number of shared features and class size instead of place along the sonority hierarchy and class size. The featural differences between each place along the sonority scale are not always increasing at the same rate at which the correlation coefficients between each class are decreasing. The sonority scale therefore cannot simply be viewed as a ranking of feature differences, since features cannot predict these correlations. There are many cases where the number of shared features cannot predict the extent to which two classes will be related in size.

vcls stops	*vcd stops*	*vcls fricatives*	*vcd fricatives*	*nasals*	*rhotics*	*laterals*	*glides*
r = 0.10	r = 0.19	r = 0.21	r = 0.06	r = 0.50	r = 0.55	r = (1)	r = 0.12
3	**4**	3	**4**	**4**	7	-	6
+cons	+cons	+cons	+cons	+cons	+cons	+cons	-cons
-son	-son	-son	-son	+son	+son	+son	+son
-approx	-approx	-approx	-approx	-approx	+approx	+approx	+approx
-cont	-cont	+cont	+cont	-cont	+cont	+cont	+cont
-strid	-strid	+strid	+strid	-strid	-strid	-strid	-strid
-lat	-lat	-lat	-lat	-lat	-lat	+lat	-lat
-nas	-nas	-nas	-nas	+nas	-nas	-nas	-nas
-voice	+voice	-voice	+voice	+voice	+voice	+voice	+voice

Table 2: Correlations between class sizes with features - laterals

Table 2 shows the shared features between laterals and other segment classes and the actual observed correlations. In this table, we see that the voiced stops, voiced fricatives, and nasals all share four features with laterals. If our model only makes correlation predictions based on featural similarity, we would expect the correlations between these three classes and laterals to all be similar. However, the data actually shows that the correlations with nasals are much higher than those with the stops or fricatives. Laterals have lower than expected correlations with the segment classes outside the sonority class of sonorants.

Table 3 showcases another example of featural similarity and class size correlation discrepancy with size correlations between nasals and other segment classes.

vcls stops	*vcd stops*	*vcls fricatives*	*vcd fricatives*	*nasals*	*rhotics*	*laterals*	*glides*
r = 0.15	r = 0.30	r = 0.03	r = 0.03	r = (1)	r = 0.55	r = 0.33	r = 0.13
5	**6**	3	4	-	**5**	4	4
+cons	+cons	+cons	+cons	+cons	+cons	+cons	-cons
-son	-son	-son	-son	+son	+son	+son	+son
-approx	-approx	-approx	-approx	-approx	+approx	+approx	+approx
-cont	-cont	+cont	+cont	-cont	+cont	+cont	+cont
-strid	-strid	+strid	+strid	-strid	-strid	-strid	-strid
-lat	-lat	-lat	-lat	-lat	-lat	+lat	-lat
-nas	-nas	-nas	-nas	+nas	-nas	-nas	-nas
-voice	+voice	-voice	+voice	+voice	+voice	+voice	+voice

Table 3: Correlations between class sizes with features - nasals

Feature similarity and economy predicts that nasals should have the highest correlation with voiced stops, but the data shows that nasals actually have the highest correlation in class size with rhotics. We would also predict that voiceless stops would have a high correlation with nasals as they share five features. Even though these predictions are not fully demonstrated in the data, feature similarity does seem to have a small effect, since voiced stops have higher correlations with nasals than the other obstruents. However, featural similarity cannot derive all the correlations shown here. In order to account for all the data, the sonority hierarchy must be taken into account as a separate phonological hierarchy and not derived from segmental features. If the sonority hierarchy was featurally derived, we would be able to account for these effects solely with a feature model.

6. Conclusion

This paper has attempted to provide an explanation for a phenomenon present in phonological inventories that cannot be explained by current theories of inventory formation. The phenomenon deals with the correlations between the number of segments in individual segment classes along the sonority hierarchy. Segment classes which are closer along the hierarchy are related in size but only wihtin the three distinct sub-systems of obstruents, sonorants, and vowels. These three classes independently determine the size and structure of the inventory. The proposed explanation is that the sonority hierarchy is a determining factor for inventory structure. Therefore, it cannot merely be derived from other aspects of phonology or feature representations. The analysis has demonstrated that a model which encodes the segment classes with features, but does not reference the sonority hierarchy cannot predict that patterns examined here. The sub-systems of obstruents, sonorants, and vowels are more crucially separated by the sonority hierarchy and this divide cannot be explained merely by feature differences. If the sonority hierarchy were solely derived from feature specifications, feature differences and sonority differences among segment classes would make the same predictions about class size correlations, but this is not seen here. Distance along the sonority scale is the best predictor for segment class size, not number of shared features.

These results have further proven that the vowel and consonant systems of languages are completely separate inventories and make no reference to each other despite articulatory similarities and common assimilatory processes between consonant and vowels in phonology. The sound systems of consonants and vowels are governed by completely different (and opposing) processes. In addition to the consonant/vowel divide, the data examined here provides evidence for a second critical divide in inventory structure between sonorants and obstruents.

The data analyzed here has displayed the prominence of sonority in phonological inventory formation, furthering evidence for its existence as a grammatical primitive. The effect of sonority on inventory structure manifests in the separation of three distinct classes of obstruents, sonorants, and vowels. The individual segment classes are related in size but only among the larger sub-systems of obstruents, sonorants, and vowels. However, the number of segments in one class cannot be used to predict the number of segments in a class outside of its sub-system of obstruents, sonorants, or vowels. These findings have provided a new domain for exploring the effects of sonority, provided evidence for its importance, and added to the current understanding of the processes that underlie the formation of phonological inventories.

7. Appendix

Voiceless stops	[-cont, -voice, -nas, -son, -cont]
Voiced stops	[-cont, +voice, -nas, -son, +cons]
Voiceless fricatives	[+cont, -voice, -nas, -son, +cons]
Voiced fricatives	[+cont, +voice, -nas, -son, +cons]
Nasals	[+nas, +son, +cons]
Laterals	[+cont, +voice, -nas, +son, +lat]
Rhotics	[+cont, +voice, -nas, +son, -lat]
Glides	[+cont, +voice, -nas, +son, +voc, +cons]
High vowels	[+cont, +voice, +son, +voc, -cons, +high, -low]
Mid vowels	[+cont, +voice, +son, +voc, -cons, -high, -low]
Low vowels	[+cont, +voice, +son, +voc, -cons, -high, +low]

Table 4: Sonority scale and SPE feature specifications used for deriving classes

	vcls stops	*vcd stops*	*vcls fric*	*vcd fric*	*nasals*	*rhotics*	*laterals*	*glides*	*high v*	*mid v*	*low v*
vcls stops	(1)	0.35	0.46	0.27	0.15	0.10	0.01	0.23	0	0.02	0.20
vcd stops	0.35	(1)	0.28	0.39	0.30	0.24	0.18	0.11	0.02	0.22	0.11
vcls fric	0.46	0.28	(1)	0.63	0.03	0.21	0.25	0.29	-0.01	0.07	0.11
vcd fric	0.27	0.39	0.63	(1)	0.03	0.10	0.10	0.10	-0.10	0	-0.06
nasals	0.15	0.30	0.03	0.03	(1)	0.33	0.50	0.14	0	0.01	-0.03
rhotics	0.10	0.24	0.21	0.10	0.33	(1)	0.55	0.02	0.11	0.13	0.09
laterals	0.10	0.19	0.21	0.10	0.50	0.55	(1)	0.12	0.11	0.13	0.09
glides	0.23	0.11	0.29	0.10	0.13	0.02	0.11	(1)	-0.04	0.05	0.01
high v	0	0.02	0.01	0.10	0	0.11	0.12	0.04	(1)	0.54	0.57
mid v	0.02	0.22	0.07	0	0.10	0.13	0.12	0.05	0.54	(1)	0.36
low v	0	0.11	0.11	0.06	0.03	0.09	0.06	0.01	0.58	0.36	(1)

Table 5: All correlations

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