

*Syllable structure and phonetic models**

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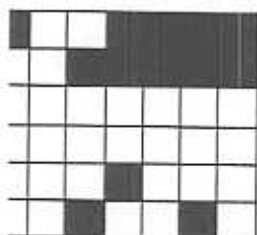
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1 Introduction: some phonetic models

Through construction of predictive models, phoneticians are making increasingly sophisticated attempts to account for certain aspects of the phonological structure of languages from very general principles (Stevens 1989; Lindblom 1984; Ohala 1990, 1992).

One of the most elaborated of these models is the theory that Lindblom has named the Theory of Adaptive Dispersion (TAD). TAD incorporates the often-mentioned principles of ease of articulation and perceptual distinctiveness (e.g. Ladefoged 1982: 241–242). Support for TAD has been drawn from its success in predicting the composition of phonological inventories, especially systems of vowel contrasts. Lindblom (1986) has shown that his theoretical predictions concerning the structure of vowel systems match well with the most typical patterns reported in cross-language surveys such as Crothers (1978) and Maddieson (1984). These predictions arise from computer simulations of how a set of n vowels will be dispersed within a phonetic space in accord with the articulatory and perceptual principles implemented in the model. The success of the simulations has been judged in terms of predicting segment inventories, where segments are considered in isolation, not as part of larger units: a three-vowel inventory typically contains the predicted /i a u/ rather than, say /y ø œ/. Yet the principles in the TAD model propose that segments arise from favouring *sequences* of articulatory gestures which involve less articulatory movement in the transition from one segment to the next, and acoustic *sequences* with sufficient auditory contrast. To give a highly simplified example, the three-vowel system consisting of /i a u/ might arise because, say, the three syllables [di], [ga] and [bu] constitute a good contrastive set and are articulatorily economical. Figure 1, redrawn from Lindblom (1990), shows the results of a rather well-known simulation of Lindblom's, demonstrating how the sequential considerations act to pick out certain preferred syllables, marked as black squares, from a set of possible combinations of syllable onsets and endpoints. The simulation shows how, in principle, an inventory of vowels or consonants might be

e ʌ ɔ æ ɑ a



set of 6 onsets and 19

considered in this case, only set of 24 optimal syllables ar with a different range of f articulatory and acoustic : frequencies of particular : frequencies of particular segments

proposed by Stevens (1972, 1. Stevens' theory proposes relationships between changes acoustic/auditory responses, (from Stevens 1989: 4). This type Stevens refers to. The articulatory parameter on a of raising of the tongue tip. some acoustic or auditory articulatory parameter. For litude of the signal. Region re acoustics for small shifts is relatively little difference shifts, but the difference the example we have used, ween continuant and stop. vement the acoustic output litude. Many other pairs of gests the general principle they cross regions such as ges that serve as landmarks es:

be an alternation between ameters remain relatively

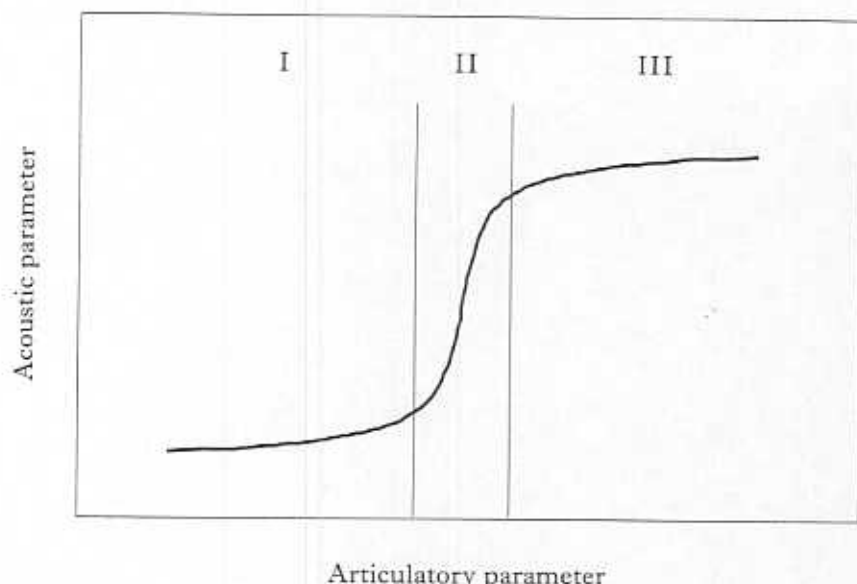


Figure 2

Model of a 'quantal' change in acoustic response as values of some articulatory parameter are adjusted

steady, and narrow regions marked by acoustic events where there are rapid changes. These somewhat discontinuous attributes of the acoustic signal occur in spite of rather continuous movements or changes in the articulatory parameters.

The primacy of acoustic distinctiveness implicit in Stevens (1989) was more directly advocated by Kawasaki in her 1982 dissertation and in Ohala & Kawasaki (1984). Kawasaki argued that universal constraints on sound sequences arise because particular segment sequences which contain salient acoustic change are preferred to those that do not have large acoustic changes. Both Stevens and Kawasaki therefore predict that we should be able to see cross-linguistic preferences for sound sequences that have large acoustic change.

2 Janson's study of CV frequencies

However, comparatively little is known about the cross-linguistic frequency of particular sound sequences. We therefore know relatively little about the linguistic basis for inferring the role of principles of conservation of articulatory effort and optimisation of acoustic or auditory contrast in their construction. A significant beginning was made by Janson (1986) in an article written mainly in response to Kawasaki's work. He

reasoned that more favoured sequences will tend to occur more frequently in texts. By looking across a sample of unrelated or distantly related languages, it should be possible to extract universal tendencies for favoured CV sequences.

Janson reached a strong conclusion, suggesting that CVs requiring smaller articulatory movements were preferred, rather than CV transitions that show strong auditory/acoustic contrast. As he put it: 'The combinations that are favoured are mainly the ones in which the articulators do not have to make extensive movements from the consonant gesture to the vowel gesture.' In particular, he claims to have shown tendencies for rounded vowels to be preferred with labial consonants, front vowels with coronal (i.e. dental or alveolar) consonants and back vowels with velar consonants. Because, to a very rough approximation, CV syllables with small articulatory movements will tend to have smaller acoustic transitions than those with large movements, he adds that: 'the trend to make things easier for the speaker clearly overrides the considerations of the needs of the listener'. However, Janson stated his conclusions rather more strongly than his results actually warrant, as we shall presently show in a reanalysis of his data.¹

Janson's language sample consisted of Finnish, Latin, Latvian, SeTswana and Turkish. Syllables containing consonant clusters, including affricates, were discarded and the onset CV sequences of the remaining syllables in texts of varying lengths were counted. Janson collapsed across classes of vowels, so that all languages are represented as having a set of front unrounded vowels, a set of back rounded vowels, and a low central vowel /a/ either alone or as the first element of a diphthong. To simplify our presentation, we will omit vowels in Finnish and Turkish that do not fit into these groups.

For each language Janson compared the observed frequency of any CV combination with its expected frequency. The expected frequency is simply derived from the overall frequency of the individual segments which comprise the sequence. Percentage deviations from the expected score were then calculated for each consonant with each vowel class. These deviation scores indicate the percentage by which a vowel class is more or less frequent than expected following a given consonant. Janson discusses these results consonant by consonant on the basis of tables such as Table I, reporting on occurrence of the nasal /n/ with the different classes of vowels. The table indicates, for example, that there were 12.86% more CVs with /n/ followed by front unrounded vowels in Finnish than expected.

Janson points to the fact that all values in the first column are positive, that is, in each language there are more instances of coronal nasals with front vowels than expected. This is taken as indicating that this type of sequence - coronal consonant with front vowel - is favoured. However, note that three of the positive values in the first column are quite low, indicating no real preference, and that except for Finnish, every language has a higher positive value in another column. It is obvious that this nasal

	(front
Finnish	1
Latin	
Latvian	
SeTswana	
Turkish	

[Table I. *Class*

is unexpectedly frequent vowels in Latvian, and to by itself this table does consonants are preferenti the tables for other conse

What is missing is dem the consonants at a give vowels. We therefore re: magnitude and the consi Deviation scores for con: values provided in Janso consonant articulation ac

(1) *Consonants includ*

	la
Finnish	p
Latin	p
Latvian	p
SeTswana	p
Turkish	p

The means of the dev consonant place are sho associating particular vow the set of deviation scores have a mean that is signif of these mean values are r coronal consonants, where there is a significant place $F(4, 145) = 4.9, p < 0.001$ which the inequalities of

	I (front unrounded)	A (low central)	U (back round)
Finnish	12.86	-29.86	-5.19
Latin	3.69	-22.11	6.69
Latvian	1.34	-26.74	54.43
SeTswana	9.46	36.04	-71.68
Turkish	0.10	-27.24	4.58

[Table I. *Classes of vowels after /n/ from Janson (1986)*]

is unexpectedly frequent with low vowels in SeTswana, and with back vowels in Latvian, and to a lesser degree in Latin and Turkish too. Taken by itself this table does not provide very strong evidence that front consonants are preferentially paired with front vowels. Results in some of the tables for other consonants are even more varied than this.

What is missing is demonstration of an overall cross-linguistic trend for the consonants at a given place to associate with particular classes of vowels. We therefore reanalysed his results in a way that looks at the magnitude and the consistency of the deviations in the entire data set. Deviation scores for consonant/vowel pairs were recalculated from raw values provided in Janson's article, and the results grouped by place of consonant articulation according to the categories shown in (1):

(1) *Consonants included in Janson's data*

	labial	coronal	velar
Finnish	p v m	t s n l r	k
Latin	p b f m	t d s n l r	k g
Latvian	p b v m	t d s n l r	—
SeTswana	p b f m	t s n r	k x
Turkish	p b f m	t d s n l r	—
	19	27	5

The means of the deviation scores for each vowel class with each consonant place are shown in Table II. If there are overall effects associating particular vowel classes with particular consonant places, then the set of deviation scores for those consonant-place/vowel-class pairs will have a mean that is significantly different from zero. Note first that most of these mean values are relatively low, especially in the case of labial and coronal consonants, where a larger number of cases are present. Although there is a significant place by vowel interaction in an analysis of variance, $F(4, 145) = 4.9$, $p < 0.001$, this could reflect a number of possible ways in which the inequalities of the scores are distributed, many of them not

	front unround	low central	back round
labial (n=19)	-3.98	2.83	1.11
<i>p</i> =	.131	.234	.634
coronal (n=27)	4.34	-1.44	-2.95
<i>p</i> =	.031	.315	.053
velar (n=5)	-8.76	1.02	5.53
<i>p</i> =	.181	.785	.520

[Table II. *Reanalysis of Janson's data by consonant group. Mean deviation from expected, and significance level (of the individual t-tests)*]

compatible with Janson's hypothesis. It is therefore necessary to look at effects within individual cells of this table. The deviation scores within each cell were compared with an expected mean of 0 using t-tests. There are a number of problems involved in making such sets of multiple independent comparisons.² In order to control for some of these, significance levels were calculated from tables of Duncan's studentised multiple range test, provided in Edwards (1960). None of the comparisons was significant at the critical level of $p < .05$, suggesting that all the mean deviations are within chance. This evaluation is a conservative one which risks a 'type 1' error (false acceptance of the null hypothesis). Individual comparisons suggest that this is unlikely to be the case here. The significance levels from separate two-tailed t-tests are shown below the mean for each cell. There is a weakly significant association between coronal place and front vowels, where the significance level is .03, and a hint in the mean values that velars may combine more naturally with back than with front vowels, but the results as a whole cannot be said to support the strong assertion that Janson makes about preference for small articulatory trajectories; neither do they clearly suggest that preferences are based on auditory considerations.

The failure of such trends to emerge could mean that the phonological (syllabic) structure of languages is not in fact shaped by phonetic factors of the kind proposed by Kawasaki, Stevens, Ohala, Lindblom and others, but it may have other explanations. The language sample may have been too small or too skewed in some way, or the chosen method of counting (frequency in texts) may have been inappropriate; the categories to which Janson assigned segments may have obscured important phonetic differences between the languages, including the different numbers of vowels grouped together and the role of coda consonants and consonant clustering.

3 Syllable frequency in languages

It is obvious that the frequency of segment sequences is a feature of a large-scale study rather than text-frequency counts. The geographical and general linguistic context used by Janson. By using text counts of frequency in noun class concord prefixes the languages chosen for the inventories and simple word lists readily included in the study are shown in (2), which are assumed for this study. In the Pacific, Rotokas is a Papuan language, Pirahã is a language of an Andean language family. The consonants and between vowels occur. The total number of segments is shown in (2):

- (2) *Phoneme inventories*
- | | |
|-----------------|-------|
| <i>Hawaiian</i> | p m n |
| <i>Rotokas</i> | p β; |
| <i>Pirahã</i> | p b; |

Two additional languages with slightly less limited inventories are a Western Austronesian language spoken in Peru with about 15 consonants; both of these inventories are shown in places of articulation other than those from the table. Nasalised consonants with their plain counterparts

- (3) *Kadazan and Shipibo*
- | | |
|----------------|---------|
| <i>Kadazan</i> | p b β t |
| <i>Shipibo</i> | p β m |

The five languages show independence from each other. The Austronesian, but are in fact closely related. It is also

3 Syllable frequency analysis of five 'small inventory' languages

It is obvious that the issue is not resolved, and further study of patterns of segment sequences is needed. The remainder of this paper reports part of a large-scale study using lexical-frequency counts of syllables rather than text-frequency counts, which will include a much larger and geographically and genetically more diverse language sample than that used by Janson. By using lexical counts it is hoped that undue influence in text counts of frequently occurring grammatical elements, such as the noun class concord prefixes of SeTswana, can be reduced.³ One subset of the languages chosen comprises ones with particularly limited segment inventories and simple phonotactics, so that all possible syllables can be readily included in the counts. The three primary languages in this set are shown in (2), which also displays the complete segment inventories assumed for this study. Hawaiian is a Polynesian language of the Central Pacific, Rotokas is a Papuan language spoken on Bougainville Island and Pirahã is a language of Brazil that is sometimes classified as a member of an Andean language family. These languages have between 6 and 8 consonants and between 3 and 5 vowels. Only CV and CVV syllables occur. The total number of syllables counted for each language is also shown in (2):

(2) *Phoneme inventories of 'small inventory' languages*

<i>Hawaiian</i>	p m w; n l; k; ? h; i e a o u	11090 syllables
<i>Rotokas</i>	p β; t r; k g; i e a o u	9400 syllables
<i>Pirahã</i>	p b; t s; k g; ? h; i a o	10567 syllables

Two additional languages, Eastern (Labuk) Kadazan and Shipibo, with slightly less limited inventories, are also included in our report. Kadazan is a Western Austronesian language spoken in Sabah. Shipibo is a Panoan language spoken in Peru. These two languages have only 4 vowels and about 15 consonants; both allow a very limited number of CVC sequences. The consonants to be reported on in these languages and their vowel inventories are shown in (3). Consonants of very low frequency or with places of articulation other than labial, dental/alveolar or velar are omitted from the table. Nasalised and glottalised vowels in Shipibo are included with their plain counterparts in the count.

(3) *Kadazan and Shipibo vowels and partial list of consonants*

<i>Kadazan</i>	p b β m; t d n l r s; k g ŋ; i ə a u	5339 syllables
<i>Shipibo</i>	p β m; t n r s t s; k; i ə a u	15520 syllables

The five languages shown in (2) and (3) have a relatively high level of independence from each other. Kadazan and Hawaiian are both Austronesian, but are in quite different branches and not particularly closely related. It is also probable that Pirahã and Shipibo are related at

back round

1.11

-.634

-2.95

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5.53

-.520

consonant group. Mean level (of the individual

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mean that the phonological shaped by phonetic factors hala, Lindblom and others, age sample may have been chosen method of counting ate; the categories to which ured important phonetic g the different numbers of consonants and consonant

some deep level. But overall few shared inherited or areal similarities are likely across this set of languages.

Lexical data for each language were obtained from published and unpublished sources. For Hawaiian we excerpted every fifth headword from the dictionary by Pukui & Elbert (1986). For the other languages all words in the sources used were counted. For Rotokas the source was the trilingual vocabulary of Rotokas by Firchow *et al.* (1973), interpreted according to the analysis provided in Firchow & Firchow (1969). For Pirahã it was a vocabulary of verb roots compiled by Keren Everett and made available to us by Dan and Keren Everett. This contains many example sentences and all words that occur in the examples were extracted, not just the verbal headwords. Interpretations of Pirahã phonology which differ with respect to the relationship posited between [h] and [k] are offered in Everett (1982, 1986). Everett (personal communication 1991) reports that most words with the initial sequence [hi-] can be pronounced with [k-] instead, and are especially likely to be so pronounced by women in one of the three main Pirahã villages. This motivated the analysis of [k-] as a variant of /hi-/ in Everett (1986). But not all words and not all speakers show this variation. For this reason we retain [h] and [k] as distinct segments, as in Everett's 1982 analysis and in the vocabulary used as our lexical data source. The data on Kadazan and Shipibo are from SIL dictionary files compiled by Hope Hurlbut and Dwight Day respectively, and made available through the good offices of Eugene Loos. Hurlbut (1988) and Faust (1973) have been useful in interpreting the data on these two languages.

The lexical data were analysed into syllables, and frequency counts of each consonant-vowel pair were made for each language, counting only the CV portion of CVV and CVC syllables where these occur. These raw scores were then converted into deviation scores in the following way. The total number of occurrences of each consonant was calculated and the frequency of each vowel with that consonant was expressed as a percentage of the total for the consonant. The total number of occurrences of each vowel was calculated and expressed as a percentage of all vowels. The deviation score for a given vowel with a given consonant is then obtained by subtracting the percent occurrence overall for that vowel from the percent occurrence of that vowel with the given consonant. For example, if 19% of the vowels in all the syllables counted in a given language are /i/ but only 16% of the vowels following /p/ are /i/, then the deviation score for the syllable /pi/ is -3. This procedure is essentially equivalent to that employed by Janson and the results can be interpreted in the same way. However, in this procedure the magnitude of the deviation scores is scaled in accord with overall vowel frequency. Results are shown separately for the three major consonant place groupings in Tables III-V below. Zero onsets and 'laryngeal' consonants were included in the calculations but no results are reported, as interactions with vowel type are not expected in the case of such onsets.

Results with labials are shown in Table III. A mean deviation score for

Hawaiian (3C)
Rotokas (2C)
Pirahã (2C)
Kadazan (4C)
Shipibo (3C)

mean across languages
mean across segments
value of *t*

p (2-tail *t*-test)

[Table III. Vowel

the labial consonants in e that occur in the set of 1 same symbols in these 1 nunciation, or have the s symbol represents segm category. The number of parentheses after the lan

Two ways of summar shown, a mean of the de across all of the individ check on the influence of languages. The means c close to each other, indica the mean across segmen represents a larger numbe effects pairing these cons be close to zero. The si segment mean considered is indicated in the final li two-tailed *t*-test on each after results have been pr

Articulatory conveni consonants to precede rou positive with such vowels. In fact, mean scores of la not significantly so. If an results would be slightly salience, although positive been expected in that case of second formant moven

	i	e	a	o	u	ɔ
Hawaiian (3C)	-5.4	-1.1	13.8	-4.2	-3.2	—
Rotokas (2C)	7.6	-0.1	3.6	-10.5	-0.2	—
Pirahã (2C)	6.9	—	-2.3	-4.6	—	—
Kadazan (4C)	-1.5	—	3.1	—	-3.7	0.3
Shipibo (3C)	-14.8	—	6.8	0.2	—	7.8
<i>mean across languages</i>	-1.4	-0.8	5.0	-4.8	-2.3	4.1
<i>mean across segments</i>	-2.7	-0.9	5.5	-4.2	-2.7	3.8
<i>value of t</i>	-1.15	-0.35	2.08	-1.63	-1.22	1.39
<i>p (2-tail t-test)</i>	.27	.74	.06	.14	.26	.21

[Table III. Vowel deviation scores with labials in 5 languages]

the labial consonants in each language is shown for each of the six vowels that occur in the set of languages. Of course, vowels represented by the same symbols in these languages may not be precisely similar in pronunciation, or have the same range of variation: but it is clear that each symbol represents segments that belong in at least the same broad category. The number of labial consonants in each language is shown in parentheses after the language name.

Two ways of summarising the results for each vowel column are also shown, a mean of the deviation scores across the languages, and a mean across all of the individual segments. Comparing these two provides a check on the influence of the varying number of segments in the different languages. The means calculated in these two different ways are quite close to each other, indicating no strong influence of this factor. Therefore the mean across segments is chosen for further analysis because this represents a larger number of data points. Again, if there are no consistent effects pairing these consonants with particular vowels, these means will be close to zero. The significance of the difference from zero of each segment mean considered separately, not as part of a multiple comparison, is indicated in the final line. The test of significance is a relatively simple two-tailed t-test on each column. Overall comparisons will be discussed after results have been presented for each major place of articulation.

Articulatory convenience might be held to predict a preference for labial consonants to precede rounded vowels,⁴ that is, for deviation scores to be positive with such vowels. These languages do not show such a preference. In fact, mean scores of labials with rounded vowels are negative, though not significantly so. If any vowel is preferred it is low central /a/. These results would be slightly more consistent with predictions from acoustic salience, although positive scores with front unrounded vowels might have been expected in that case. These would yield the best contrastive pattern of second formant movement.

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mean deviation score for

	i	e	a	o	u	ə
Hawaiian (2C)	2.9	4.0	-2.7	-1.1	-3.1	—
Rotokas (2C)	3.1	-0.2	-4.1	2.1	-0.8	—
Pirahā (2C)	3.7	—	-3.0	-0.6	—	—
Kadazan (6C)	2.5	—	-2.6	—	4.8	8.2
Shipibo (5C)	1.4	—	0.7	-0.2	—	-1.9
<i>mean across languages</i>	3.0	1.9	-2.3	0.1	0.3	3.2
<i>mean across segments</i>	2.7	1.9	-1.9	0.0	2.1	3.6
<i>value of t</i>	0.86	0.57	-1.08	-0.02	1.23	1.51
<i>p (2-tail t-test)</i>	.40	.61	.30	.99	.23	.16

[Table IV. *Vowel deviation scores with coronals in 5 languages*]

	i	e	a	o	u	ə
Hawaiian (1C)	-0.4	-2.2	-2.3	-1.7	6.6	—
Rotokas (2C)	-11.6	0.8	1.0	10.9	-1.2	—
Pirahā (2C)	-18.7	—	10.9	7.8	—	—
Kadazan (3C)	-0.9	—	3.1	—	0.0	5.0
Shipibo (1C)	-18.4	—	2.3	7.8	—	8.2
<i>mean across languages</i>	-10.0	-0.7	3.0	6.2	1.2	6.6
<i>mean across segments</i>	-9.1	-0.2	3.7	7.3	0.7	5.8
<i>value of t</i>	-1.92	-0.17	1.86	1.17	0.35	1.51
<i>p (2-tail t-test)</i>	.04	.88	.08	.20	.74	.10

[Table V. *Vowel deviation scores with velars in 5 languages*]

Occurrences of the different vowels with coronals are shown in Table IV. Here articulatory convenience predicts positive deviation scores with front vowels. These mean scores are in fact positive but only by small margins. The mean score for the back vowel /u/ is similarly positive, but only because Kadazan has positive values. Positive values with back rounded vowels might be predicted from acoustic salience, since transitions would be large. But neither of these factors is demonstrating a dominant effect. The strongest tendency is for the low vowel /a/ to occur less often than expected after coronals, although even this result is not statistically significant.

Deviation scores of the different vowels with velars is shown in Table V. Articulatory convenience predicts a preference for velars to occur with back vowels, whereas acoustic salience would predict a preference for non-back vowels. The results are quite variable, and are perhaps distorted by some unresolved questions about the actual distribution of /k/ in Pirahā,

which results in very high values. It is not apparent that the languages to confirm a preference for high front vowels show no preference for low vowels.

The data summarised in Table IV were analysed in a two-way analysis of variance procedure. The analysis was analysed in turn to ascertain the effect of place of articulation on deviation scores. Zero point deviation scores are in the fourth place category in significant effect of place of articulation (to be $p < .05$). The near-zero deviation score for the vowel /i/, $F(3, 46) = 2.2$, is the low occurrence of /i/ in the languages conducted to ascertain deviation scores for each place of articulation (III-V). Labials show a preference for /a/, $F(5, 53) = 2.53$, $p < .04$. The frequency of /a/ with labials is significantly lower than those of /i/, /u/ & /ə/ noted above, seems to be as anticipated. The deviation score, $F(5, 64) = 2.2$, is a significant deviation score, but comparing across vowels is significantly lower than expected, related to the anticipated

4 Summary and discussion

Thus, to summarise, over the course of this study, our results indicate a preference for articulatory convenience that preference for acoustic salience. The role of particular phonetic models discussed in this study.

However, our data, especially the data otherwise discussed in this study, are restricted but salient deviations from articulations tend to be a preference for syllables like [wu], [kwu] instances of /w/ with /u/ & /o/.⁵ Shipibo shows no preference for /u/ or /o/ absent or of uniformly low values. The focus of this paper. Further

which results in very high deviation scores for velars in this language. It is not apparent that there is any statistically significant trend across these languages to confirm either predicted preference. Though no language prefers high front vowels with velars, two of the three languages with /u/ show no preference for pairing it with a velar.

The data summarised in Tables III-V were also globally analysed by analysis of variance procedures in two ways. The data for each vowel were analysed in turn to ascertain if there was a main effect of place on the deviation scores. Zero place (zero and laryngeal onsets) was included as a fourth place category in these analyses. For none of the vowels is there a significant effect of place of the preceding consonant (significance is taken to be $p < .05$). The nearest approach to significance is reached with the vowel /i/, $F(3, 46) = 2.46$, $p < .0745$. This effect arises largely because of the low occurrence of /i/ with velars. A second set of analyses was conducted to ascertain if there was a main effect of the vowels on the deviation scores for each consonant place, i.e. across the rows of Tables III-V. Labials show a main effect a little above the significant level, $F(5, 53) = 2.53$, $p < .04$. This arises because of the relatively high frequency of /a/ with labials; the frequency of /a/ is significantly different from those of /i/, /u/ and /o/ by Fisher's PLSD test. This pattern, as noted above, seems unrelated to either the articulatory or acoustic preferences anticipated. Coronals show no reliable effect of vowel on deviation score, $F(5, 64) = 0.81$, $p < .549$. The overall effect of vowel on velar deviation scores is below significance, $F(5, 64) = 2.416$, $p < .062$, but comparing across vowel environments the frequency of velars with /i/ is significantly lower than with /a/, /o/ or /ə/. This pattern is not directly related to the anticipated ones, but will be further discussed below.

4 Summary and discussion

Thus, to summarise, over the set of consonant-place/vowel pairs examined in this study, our results show no overall effect of the predicted speaker preference for articulatory convenience. Equally, there are no indications that preference for acoustically distinct transitions influences the occurrence of particular places with particular vowels in a consistent way. The role given to transitional movements between segments in the phonetic models discussed above may be exaggerated.

However, our data, especially when additional languages which are not otherwise discussed in this paper are included, do show two types of more restricted but salient deviation patterns. First, glides and secondary articulations tend to be avoided before the cognate vowels. For example, syllables like [wu], [kwu] and [ji] are disfavoured. Hawaiian shows no instances of /w/ with /u/ (and only a tiny number of cases of /w/ before /o/).⁵ Shipibo shows no instances of /ji/ or /wo/ (it has no [u]). Glides are absent or of uniformly low frequency in the other languages which are the focus of this paper. Further instances of these glide patterns can be seen

	o	u	ə
	-1.1	-3.1	—
	2.1	-0.8	—
	-0.6	—	—
	—	4.8	8.2
	-0.2	—	-1.9
	0.1	0.3	3.2
	0.0	2.1	3.6
8	-0.02	1.23	1.51
0	.99	.23	.16

Coronals in 5 languages]

	o	u	ə
	-1.7	6.6	—
	10.9	-1.2	—
	7.8	—	—
	—	0.0	5.0
	7.8	—	8.2
	6.2	1.2	6.6
	7.3	0.7	5.8
16	1.17	0.35	1.51
18	.20	.74	.10

Velars in 5 languages]

Coronals are shown in Table III. Deviation scores with /i/ are positive but only by small amounts. /u/ is similarly positive, but only by small amounts. Positive values with back vowels are due to acoustic salience, since transitions to the low vowel /a/ to occur with /u/ is high even this result is not

shown in Table III. Deviation scores for velars to occur with /i/ are perhaps distorted by the distribution of /k/ in Pirahã,

in less intensively analysed lexical data sets from additional languages. Jeh shows avoidance of both /wu/ and /ji/. In Polish, [ji] is absent. Mandarin shows avoidance of both [wu] and [ji], including instances where the glides follow another onset consonant (words transcribed in a way that suggests otherwise, such as the names *Wu* and *Yi*, are actually pronounced as simple vowels). The glides /w/ and /j/ are not common in Korean but follow the pattern found in Mandarin. In Comanche the onsets /w/ and /kw/ are not found before /u/, and /j/ is not found before /i/. Since the articulatory adjustment required to move from a glide to its cognate vowel is low cost, the reason for the relative rarity of such sequences is surely to be found in the lack of adequate contrastivity of the acoustic sequence. But note that these glide-vowel constraints are not parts of more general patterns – for example, labials in general are not disfavoured before back rounded vowels.

The second more restrictive pattern in our data concerns the comparative rarity of velars before high front vowels. The relatively high negative score for /i/ in Table V arises because three of the five languages examined have a high degree of avoidance of sequences such as [ki]. Among the other languages examined so far, Mandarin and Polish show the same avoidance. In Mandarin, former [ki] sequences now have prepalatal affricates. In Polish a palatalised velar (i.e. a markedly fronted articulation) occurs before /i e/. Across the larger set of languages we expect to find that dorsal articulations, meaning those in the palatal-velar region, commonly show coarticulatory adjustments to the location of the following vowel in the front-back dimension, or patterns of restricted distribution reflecting historical changes apparently originally triggered by such coarticulation. But note that this does not seem to be a subpart of a more general strategy to reduce articulatory trajectories between adjacent segments. In terms of a phonological feature hierarchy (Clements 1985), this pattern is restricted to interactions between the features of the dorsal node.

Note that of these two patterns the first is primarily attributable to auditory factors and the second to articulatory ones. However, since the deviation scores in the languages reported here are in general quite low, it means that across this set of languages, predicting the pattern of vowel occurrence after consonants at different places from the overall frequencies of the vowels in the given language comes quite close to the mark. This may suggest that rather than operating to favour particular *sequences* of sounds over others, any speaker or listener-based preferences affect the frequency of individual *segments*. Having made a choice of segments, and determined their relative frequency, these languages for the most part do not further restrict the combinations into which they may enter. Consonant and vowel segments, therefore, emerge as relatively autonomous elements (cf. Ohala 1992), although they may enter into larger structures in which their autonomy is limited (cf. Clements 1992).

Ohala (1980) has commented on the tendency for languages to make 'maximum utilization of the available distinctive features' at the segmental

	%	i
p	10	2
t	20	4
k	15	3
m	5	1
n	20	4
ŋ	10	2
s	15	3
...

A grid of syllable

level by using all compatible segments. For example, a language might have all of these at the onset level, but only one observed here seems so common at this level. It could be labelled 'available segments', but the overall frequency of individual syllabic combinations expected in a language is not shown in Fig. 1 even after all empty cells are filled. It has no empty cells such as [ki] in Fig. 1 even after all empty cells are filled. Imagine a language with the frequencies shown in the cells. Then the percentage of t combinations would represent the percentage of t combinations shown in the cells.

Rather than reflecting the relatively full utilization of the available segments, languages might well be more efficient in their use of the full range of combinatorial possibilities. In other words, a given number of segments might be represented in different sets of combinations. One might envisage the process of lexical 'activation' of a large number of segments. Identification is made as a function of the cohort model of Marslen-Oberlin & McClelland & Elman (1980).

	i	e	a	o	u	ə	...
%	20	10	25	10	15	5	...
p 10	2	1	2.5	1	1.5	0.5	...
t 20	4	2	5	2	3	1	...
k 15	3	1.5	3.75	1.5	2.25	0.75	...
m 5	1	0.5	1.25	0.5	0.75	0.25	...
n 20	4	2	5	2	3	1	...
ŋ 10	2	1	2.5	1	1.5	0.5	...
s 15	3	1.5	3.75	1.5	2.25	0.75	...
...

Figure 3

A grid of syllable frequencies derived from segment frequencies

level by using all compatible combinations of a small set of feature values. For example, a language with voiced and voiceless stops and nasals tends to have all of these at the same places of articulation. What we have observed here seems somewhat akin to this, but operating at the syllabic level. It could be labelled a principle of 'maximum utilisation of the available segments', but it operates within the limits imposed by the overall frequency of individual segments. A grid showing the type of syllabic combination expected under this principle would look like Fig. 3. It has no empty cells such as those that would remain in a grid like that in Fig. 1 even after all empty rows and columns had been deleted. If we imagine a language with (at least) the 6 vowels and 7 consonants shown, with the frequencies shown as percentages at the margins of this figure, then the percentage of the total syllables of the language that each CV combination would represent is the multiplication of these percentages, as shown in the cells.

Rather than reflecting articulatory or auditory sequencing preferences the relatively full utilisation of syllabic potential that we find in these languages might well be attributable to cognitive factors to do with efficiency of storage of, and access to, linguistic knowledge. By using the full range of combinations of a more limited number of articulatory routines, a given number of syllables has a more parsimonious mental representation than would be the case if different subsets of gestures were used in different sets of syllables. Moreover, many psycholinguists envisage the process of lexical access as an outline process involving the 'activation' of a large number of candidate words from which final identification is made as more information becomes available, as in the cohort model of Marslen-Wilson (1987, 1989) or the TRACE II model of McClelland & Elman (1986). In the cohort model, the process is viewed

n additional languages. Japanese sh, [ʃi] is absent. Mandarin g instances where the glides are realized in a way that suggests they are actually pronounced as [g]. This is not common in Korean but is found in many other languages. In many languages the onsets /w/ and /r/ are found before /i/. Since the /i/ is a glide to its cognate vowel, the sequence is surely to be found in the acoustic sequence. But it is not parts of more general patterns that are disfavoured before back

ir data concerns the common vowels. The relatively high frequency of three of the five languages of sequences such as [ki]. Mandarin and Polish show [ki] sequences now have a larger (i.e. a markedly fronted) set of languages we find those in the palatal-velar region to the location of the /i/, or patterns of restricted articulation originally triggered by /i/ do not seem to be a subpart of the articulatory trajectories between adjacent segments (Clements 1985), in the features of the dorsal

s primarily attributable to the articulatory features. However, since the articulatory features are in general quite low, it is interesting that the pattern of vowel sequences is so close to the mark. This is particularly true for our particular sequences of sequences. The articulatory preferences affect the choice of segments, and the articulatory features for the most part do not change as they may enter. Consequently, as relatively autonomous articulatory features enter into larger structures (Clements 1992).

ency for languages to make use of the articulatory features at the segmental

as one which includes considering a cohort of possible words with a given onset and progressively eliminating candidates as more information about later segments is processed. Even if such bottom-up processing is only a part of accessing lexical information, a more equally populated syllable space enhances the efficiency of the search by tending to equalise the size of the cohorts. This follows from basic communication theory (Shannon & Weaver 1949; Cherry 1957); any coding mechanism becomes more efficient the more equal the probability of any possible 'message'.

Note that we are not saying that syllables of different types are equally frequent: they are not, because segments are not equally frequent. However, syllables of different phonetic shapes are more nearly frequent than might have been expected from considering articulatory and auditory factors in sequencing sounds. We suggest that some evening out of the inequalities of syllable frequencies is a desirable trait in language design for what might be called cognitive reasons.⁶

NOTES

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- [1] Janson also specifically critiques the validity of Kawasaki's conclusions, which were based on looking at cooccurrence restrictions in a number of languages and drawing out general patterns of occurrence and avoidance. She concluded, *inter alia*, that labial consonants disfavour following (back) rounded vowels and that coronal consonants disfavour following front vowels. Janson pointed out that Kawasaki had in some cases stated her conclusions in broader terms than were warranted from the data she had gathered. For instance, the conclusion that labial consonants are avoided with following rounded vowels is based on data that actually largely show restrictions on consonants with a secondary articulation of labialisation or the labial-velar approximant /w/ itself, i.e. segments in which there are vocalic features in the consonants. Janson finds only five languages in Kawasaki's survey in which plain labial consonants are involved in cooccurrence restrictions of the relevant sort.
- [2] Most importantly, as the number of comparisons increases, the probability of finding one or more of them significant increases. If significance is set at the .05 level for a single comparison, then one out of every 20 comparisons can be expected to appear significant by chance. The present case can be considered equivalent to multiple comparisons between a 'control' and a variety of 'treatments'. That is, there are 9 comparisons which involve 10 means (one of them is the expected mean of 0). For a useful review, see Klockars & Sax (1986).
- [3] Of course, a different set of biases may be introduced by decisions about which form is selected as the citation form in a lexicon.
- [4] This is Janson's assumption, but it is by no means obvious that the labial activity involved in rounding a vowel is similar enough to that involved in a bilabial stop closure to be sure that articulatory economy is actually involved.
- [5] The /w/ phoneme in Hawaiian is pronounced as a voiced labio-dental fricative before non-rounded vowels, and as [w] before /o/ and, presumably, /u/. Schütz (1981) suggests that it may have earlier been a rounded bilabial fricative.
- [6] Future research will be addressed to the question of whether similar patterns obtain in languages with much richer syllabic inventories, or if this is a tendency

that is particularly strong in syllables.

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that is particularly strong in languages with relatively small numbers of distinct syllables.

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On deriving structural ac relationships

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In this paper, I examine so the syllabification of consor and place of articulation re syllabification of consonan place relationships are dete- repair strategies that apply met, (iii) sonority and place and (iv) place of articulation between consonants as th sonority and for the licen Clements 1990a: 313). Ho independent of sonority res turally defined.

I begin by presenting ba define sonority in a struct various kinds of relation: (sonority, place, stricture), between the consonants an

1 Background

1.1 The structure of rep

In order to make the argur of consonants are structura meant by 'structure'. I assu components, constituency that I assume grows out of following Clements (1985) The particular representat Avery & Rice (1989) and Ri