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Major trends in vowel system inventories

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The search for universal tendencies in the languages of the world is a necessary anchor point for any theoretical approach to phonetics. The present typology of vowel systems aims to provide material for testing substance-based theories, including, among others, the Dispersion-Focalization Theory of vowel systems presented in a companion paper (Schwartz, Boë, Vallée & Abry, this issue). It is focused on the *economy* of vowel systems, specifically the way a system of vowels functions as a whole, and the way vowels interact within a given system. The UPSID (*UCLA Phonological Segment Inventory Database,* Maddieson, 1984) inventory is analyzed using an original methodology, with the following main results.
1. Vowel systems first exploit a "primary" system of sounds; with more than 9 vowels, there is a clear trend for exploiting at least one new dimension ("secondary" systems).
2. Primary systems mainly contain 3 to 9 vowels, and secondary systems 1 to 7 vowels, both with a preference for 5 vowels.
3. In both primary and secondary systems, vowels are mainly concentrated at the periphery. For peripheral systems, symmetry (same number of front and back vowels) is the rule; if there is an asymmetry, the number of front vowels is generally greater than the number of back vowels.
4. For "interior" vowels in primary systems, central vowels are preferred; among non-central vowels, front rounded vowels are twice as frequent as back unrounded ones.
5. Schwa is the preferred interior vowel, and it does not seem to interact with other sounds within vowel systems.

1. Introduction

The search for universal tendencies in the languages of the world is a necessary anchor point for any theoretical perspective in phonetics. This approach assumes the definition of phonological or phonetic taxonomies, determining the basic phonetic structures, and establishing the criteria that enable a new system to be associated with one or the other structure. The taxonomic approach in linguistics is complex. Thus, the number of identified languages in the world varies considerably across researchers (e.g., from 5000, Ruhlen, 1987, p. 258; up to 8000, Ladefoged,

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Choi & Schwetze-Coburn, 1990), in part because there is no consensus on the distinction between a language and a dialect, nor on the criteria for differentiating among languages. In the present state of research, we are far from having a representative sample of linguistic descriptions for the world's languages, while a number of them are in fact disappearing (Ladefoged, 1995).

With respect to vowel systems (a long-standing topic for both experimental and theoretical descriptions), following the initial attempt by Troubetzkoy (1939) to derive phonological regularities from the 34 vowel systems "he knew by heart", there have been a number of important contributions, with a major one by Greenberg in the 1950–60s (Greenberg, 1966), and the *Language Universals Project* (1967–1976; Greenberg, Ferguson & Moravcsik, 1978) which allowed the development of the *Stanford Phonology Archives.* More recently, UPSID (*UCLA Phonological Segment Inventory Database*), elaborated by Maddieson (1984) with 317 systems and recently extended to 451 languages by Maddieson & Precoda (1989), and up to 534 languages in SUPERB UPSID (Lindblom, Krull & Stark, 1992), has provided a rich corpus for experimental description and computer simulations.

Tentative trends and rules have been proposed based on these descriptive data (see e.g., Troubetzkoy, 1939; Hockett, 1955; Sedlak, 1969; Crothers, 1978; Lindau, 1978; Hagège, 1982; Maddieson, 1984; Ladefoged & Maddieson, 1990; Vallée, 1994). All of them vary in their content, not only because of the progress in linguistic material, but also because they differ in their focus and in the questions they ask of this material. This has the immediate consequence that the methodology used in the elaboration of taxonomies is itself quite different from one study to the other. In fact, it is obvious that the very elaboration of the taxonomy, which involves a number of choices in the representation and analysis of phonetic systems, is not independent from *a priori* considerations about what is important and what is not in these systems.

The present work does not escape from this rule. It presents one side of a global research program in which linguistic structures are described and analyzed in light of a number of substance-based principles linked to the sensori-motor interactions involved in the speech communication process (the deductive approach to the description of distinctive features, as opposed to the inductive approach, see Lindblom, MacNeilage & Studdert-Kennedy, forthcoming). More precisely, the present typology of vowel systems aims to provide experimental material for testing the so-called Dispersion-Focalization Theory of vowel systems presented in a companion paper (Schwartz *et al.,* this issue).

The various "predictions" of vowel systems by quantitative substance-based models (see e.g., Liljencrants & Lindblom, 1972; Stevens, 1972, 1989; Lindblom, 1986, forthcoming; Schwartz, Boë, Perrier, Guérin & Escudier, 1989; Wildgen, 1990; ten Bosch, 1991; Vallée, Boë & Schwartz, 1991; Boë, Schwartz & Vallée, 1994; Carré & Mrayati, 1995) aim at exploiting auditory or articulatory arguments to derive the most likely individual positions or systemic configurations of vowels in the articulatory-acoustic space. The major question for these theories concerns the *economy* of vowel systems, namely the way a system of vowels functions as a whole, and the way vowels interact within a given system. This general question can be most easily explained in terms of vowel positions in the acoustic space (e.g., formant frequencies), and developed into the following questions:

1. For a given number of vowels in a system, what is the global occupation of the acoustic space in terms of peripheral (front unrounded or back rounded) *vs.* non-peripheral vowels?
2. Concerning peripheral vowels, how are the left and right "boundaries" of the acoustic space occupied, specifically what can be said exactly in terms of front *vs.* back occupation, front *vs.* back symmetry, and gaps or holes in the peripheral system?
3. Concerning non-peripheral vowels, how is the "interior" of the acoustic space occupied, namely what is the relation among the different interior series (front rounded, central rounded or unrounded, back unrounded), what is the vertical organization in these series, and what is the exact status of schwa?

All of these questions are critical for testing quantitative theories of vowel systems and attempting to clearly delimit the boundary between what is understandable in terms of substance-based principles and what is not. Previous typological studies have already addressed some of these questions (see e.g., the model-oriented work by Crothers, 1978; and the study of "holes" in peripheral systems by Disner, 1984). However, we felt that more could be said on these questions by a careful reinspection of UPSID, using an original methodology for defining an adequate taxonomy defined in Section 2. The database analyzed according to this taxonomy is studied in Section 3, and the main facts extracted from this study are summarized in Section 4.

2. Elaboration of a taxonomy

2.1. *The UPSID database*

The UPSID database contains a representative sample of 317 languages, drawn from the 20 families of languages defined in the Stanford classification: Khoisan, Niger-Kordofanian, Nilo-Saharan, Afro-Asiatic, Dravidian, Burushaski, Caucasian, Indo-European, Basque, Ural-Altaic, Ainu, Paleo-Siberian, Eskimo-Aleut, Sino-Tibetan, Austro-Tai, Austro-Asiatic, Indo-Pacific, Australian, Northern and Southern Ameridian. At least one language from each group of languages (sub-family) is present in the basis, with a criterion of genetic distance of at least 1500 years for the separation of languages, "*a long enough period for substantial independent developments to occur in the phonological patterns of any two languages belonging to the same larger family*" (Maddieson, 1991, p. 348). This database has already provided the substance for several cross-linguistic analyzes (see e.g., Crothers, 1978, on a subset of 209 languages; Maddieson, 1984; Disner, 1984; Vallée, Boë & Schwartz, 1990). It has been implemented in our laboratory in a Macintosh/Hypercard environment, for a number of statistical exploitations (Vallée, 1994). In this environment, vowels are represented by their localization in a phonetic grid with 37 symbols (Fig. 1), with, if necessary, a number of added diacritics. In this classic representation, the vertical dimension displays the seven possible opening degrees, and the horizontal dimension displays the three possible backness degrees (front, central, back) and for each of them the unrounded articulation on the left and its rounded counterpart on the right.

It is important to note that a given "system" in UPSID is in fact a set of *phonologically contrastive* segments, their phonetic representation being what

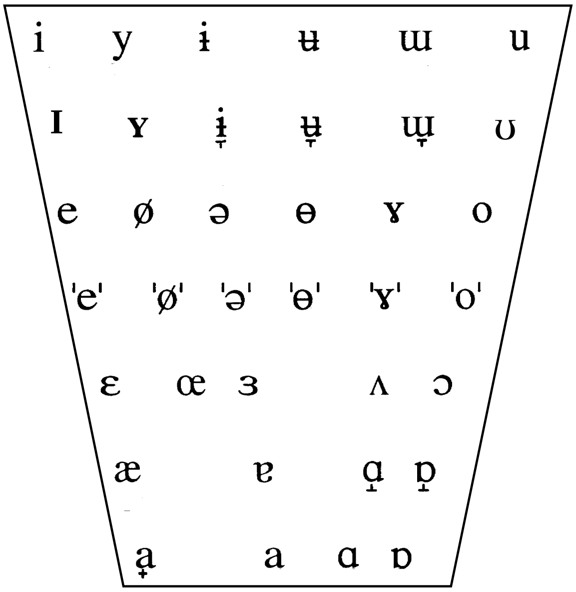

Figure 1. The grid for representing the 37 vowel symbols in UPSID. The horizontal dimension represents the front-back and rounding dimensions and the vertical dimension represents the close-open (or high-low) dimension.

Maddieson considered its "most representative" allophone. The very content of vowel systems can be (and has been) criticized for a number of reasons, such as:

• Problems of phonological description (e.g., vocalic harmony in various African languages in relation to the feature [±ATR]);
• Problems of auditory transcription in the phonetic content of a system (see e.g., Ringgard, 1965; Kingston, 1991);
• Problems in the choice of the "most basic allophone" (Maddieson, 1991, p. 13), which may be in a number of cases the "mean" of a family of neighboring sounds rather than a sound precisely defined in auditory terms. This is typically the case of the mid vowel symbols enclosed in ' ', such as /'e'/ or /'o'/, which were often used by Maddieson as a kind of "cover symbol" for mid vowels whose quality was only described as "mid" by the sources consulted (Maddieson, 1984). This finds some confirmation in the fact that contrasts between these mid vowels and corresponding higher-mid (/e/ or /o/) or lower-mid (/ɛ/ or /ɔ/) neighbors are infrequent in the database.

2.2. *Preliminary considerations on secondary articulations*

The position of a vowel on the grid displayed in Fig. 1 is intended to define the primary articulation, while diacritics indicate secondary articulations, namely lengthening, shortening, breathy or creaky voice, voicelessness, nasality, retroflexion, retraction and advancement of the tongue root, velarization, pharyngealization, and laryngealization.

The first decision one must make before undertaking a description of the economy of vowel systems is what to do with secondary articulations. These articulations might be simply discarded, as in the study by Crothers (1978) in which only vowels with no secondary articulation were considered in the typology. This, however, results in loss of a considerable amount of data, which must have some significance for a theory of vowel systems. Alternatively, if one wants to retain secondary articulations, two extreme positions might be suggested: either consider all vowels at the same time, ignoring their secondary characteristics, or consider all vowels with a given secondary articulation as a single subsystem which must be studied independently of the others.

The first position—include all vowels but treat vowels differing only in secondary characteristics as the same—is probably quite arguable, and has in fact never been adopted. A major problem would be, for example, the nasal feature, which obviously leads to significant changes in the formant space, and is likely to be processed on another dimension than the oral one (see e.g., Feng & Castelli, 1996).

The second position—look at several "parallel" subsystems, one for each secondary articulation—is more popular (see e.g., Hockett, 1955). It might, however, lead one to ignore some important interactions between such subsystems as long *vs.* "normal" (i.e., neither short nor long) *vs.* short vowels. Indeed, it is clear that vowel quantity oppositions may be accompanied by systematic modifications of primary articulations (see e.g., the study of vowel quantity in Franco-Provençal by Abry, Bo4e & Cheikh-Rouhou, 1995) which may even become the major perceptual „Abry, Boë & Cheikh-Rouhou, 1995) which may even become the major perceptual correlate of a given phonetic opposition (as in the study of the /o/ *vs.* /ɔ/ contrast in French by Gottfried & Beddor, 1988).

As an illustration of the difference between an "independent" dimension, such as nasality, and a "non-independent" dimension, such as quantity, consider the repartition of nasal *vs.* oral vowels and long *vs.* normal vowels in the UPSID database. Notice first that nasal (normal or long) vowels and long oral vowels respectively represent about 15% and 10% of the UPSID database, while primary vowels (no secondary articulation) represent 72% of the database—hence secondary articulations other than nasality and length constitute only 3% of the database. Now, when we consider the repartition of nasal vowels, we notice that in 94% of the cases for a nasal vowel in a given system there is a corresponding oral vowel with exactly the same primary articulation. This suggests that nasal vowels quite likely constitute an independent subsystem. In contrast, a long oral vowel occupies the same position as a primary non-long vowel in a given system in only 58% of the cases. In fact, it is clear from the UPSID database that in a number of cases we cannot consider a primary system with primary vowels, and an independent secondary system with long oral vowels. Indeed, one can notice three kinds of arrangements of long and normal oral vowels:

Systems in which normal vowels provide "the basis" and long ones provide a smaller "parallel" subsystem, as in:
Hupa system: /ɪ 'e' a 'o' 'e'ː aː 'o'ː/

Systems in which long vowels provide "the basis" and normal ones provide a smaller "parallel" subsystem, as in:
Dagomba system: /i a u iː 'e'ː aː 'o'ː uː/

Systems in which there is a global arrangement of normal and long vowels in order to exploit optimally the acoustic space, as in:

Arabic system: /ɪ a ʊ iː eː æː oː uː/ or in:
Wichita system: /i ɛ ɑ u eː ɛː aː oː/
Such cases as the last two are not rare, and it is clear that in these cases one would probably lose important characteristics of global arrangements of vowel articulations by separately considering long and normal vowels in two different subsystems.

Therefore, based on both intrinsic considerations of such features as nasality and quantity, and the different patterning of these features in the UPSID database, we suggest that vowels with different *quantity* diacritics should be grouped together, while other secondary articulations such as nasality should imply different subsystems that should be considered independently.

2.3. *Methodological choices*

We shall now attempt to describe the entire database using a three-step method: first, extract from a given system what we call its "primary" and, if they exist, its "secondary" constituents; second, describe each system (be it primary or secondary) in terms of its "peripheral" structure; and third, describe its non-peripheral additional components. This results in a rather compact description of the database, useful for further analyzes which explore the structural trends in vowel systems. Let us be more precise about these three steps.

2.3.1. *Primary vs. secondary system*

We consider first primary vowels or vowels with only duration diacritics (i.e., primary vowels, plus long oral vowels and short oral vowels if any). Within this set, if two vowels have the same position in the vowel space, but different diacritics, we consider one as being part of the "primary" system (S1) and the other as part of a "secondary" system (S2). However, if two vowels have different diacritics and different timbres, we consider them both as part of the "primary" system. In all cases, both systems (S1 and S2) are described only in terms of vowel position in the chart of Fig. 1. This results in the following kind of description:

Dagomba system: /i a u iː 'e'ː aː 'o'ː uː/ → /i 'e' a 'o' u/ (S1) + /i a u/ (S2)
Wichita system: /i ɛ ɑ u eː ɛː ɑː oː/ → /i e ɛ ɑ o u/ (S1) + /ɛ ɑ/ (S2)

Moreover, if the system has another set of vowels with another diacritic (e.g., nasal, be they normal or long), we also consider it to be a "secondary" system, and describe this subset in terms of positions of the vowels in the chart:

Bribri system: /i 'e' a 'o' u ĩ 'ẽ' ã 'õ' ũ/ → /i 'e' a 'o' u/ (S1) + /i 'e' a 'o' u/ (S2)

Finally, if there are two or more of these "secondary" systems, we assign the label S2 (secondary) to the subsystem with the greatest number of vowels:

Karok system: /i ɛ a ʊ iː eː aː oː ʊː ĩ ã/ → /i e ɛ a o ʊ/ (S1) + /i a ʊ/ (S2) + /i a/ (S3)

In the following, we shall consider only the primary and, if it exists, the secondary system, since higher-order systems are rare and cannot lead to firm statistics in the framework of the UPSID database. The primary system S1 and, if it exists, the secondary system S2, are then described according to two criteria, the structure at the periphery and the nature of non-peripheral vowels.

2.3.2. *Peripheral structure of a given system*

It is classic to attribute the label "peripheral" to front unrounded and back rounded vowels. We respect this convention, with some adaptations, and define three groups of peripheral vowels.

Front peripheral vowels: All front unrounded vowels from /i/ to /æ/, namely: /i ɪ e 'e' ɛ æ/.

Back peripheral vowels: All back rounded vowels from /u/ to /ɒ̞/, namely: /u ʊ o 'o' ɔɒ̞/. We also use the label "peripheral" for back unrounded vowels, when their rounded counterpart is lacking. Hence, if we consider the following example:

Ocaina system: /i ɛ a o ɯ ĩ ã õ ɯ̃/ → /i ɛ a o ɯ/ (SI) + /i a o ɯ/ (S2)

the vowel /ɯ/ is considered as peripheral in both S1 and S2. However, an unrounded back vowel is considered as non-peripheral if accompanied by its rounded counterpart, as in the following example:

Ao system: /i ɛ a o ɯ u/ → /i ɛ a o ɯ u/ (S1)

Notice that, in contrast to back unrounded vowels, front rounded vowels can never be considered as "peripheral". It is well-known that a rounded front vowel of a given height never exists without its unrounded counterpart (Vallée *et al.,* 1991).

Low peripheral vowels: We define a broad low-peripheral region including all vowels in the set /ɐ a̟ a ɑ ɒ/ (i.e., vowels lower than those belonging to the front or back peripheral sets).

Having at our disposal the peripheral structure of a given system (i.e., the list of "peripheral" vowels), we consider two potentially important characteristics of this peripheral structure: symmetry and holes.

Symmetry—Does a peripheral structure have the same number of front and back vowels (symmetry) or, if not, are there more front vowels or back vowels? We consider three situations:

- More peripheral front vowels: the peripheral structure is labelled "left";
- More peripheral back vowels: the peripheral structure is labelled "right";
- Equal number of front and back peripheral vowels. This can be realized either with an odd number of peripheral vowels with one "low" one (i.e., belonging to the /ɐ a̟ ɑ ɒ a/ set), which is the "classic" case; or, in the case of an even number

of peripheral vowels, by using zero or two "low" vowels. In case there is more than one "low" vowel, we attribute to the peripheral structure the label "bottom"; in case there is none, we attribute the label "up".

Holes—We consider here only holes at the top of the periphery, and we do not consider "small" holes. Indeed, in case the highest vowel within a given series is lacking, and the second highest vowel is present, we systematically attribute it the highest category, for example:

Haida system: /i a ʊ/ → /i a u/ (S1)

However, in the case of "large" holes, which occur when one of the extreme vowels /i/ (or its "equivalent" /ɪ/) or /u/ (or one of its "equivalents" /ɯ ɯ̞ ʊ/) is missing, we attribute to the peripheral structure the label "with hole".

2.3.3. *Non-peripheral vowels*

We then complete the description of a given system by giving *in extenso* the complementary non-peripheral vowels, with the following simplifications.

Vertical series—We consider only three non-peripheral series, by grouping the unrounded and rounded central vowels within the same unrounded label, unless both series are present. This is exemplified in the following case:
Somali system: /i ɪ 'e' ɛ æ a ɔ ʊ ʉ̞ 'ɵ'/ → /i ɪ 'e' ɛ æ a ɔ u ɨ 'ə'/ (S1)
Opening degrees—For the series /y ʏ/, /ø 'ø' œ/, /ɨ ɨ̞ ʉ ʉ̞/, /ə 'ə' ɵ 'ɵ' ɜ/, /ɯ ɯ̞/, and /ɤ 'ɤ' ʌ/, if there is only one vowel in a particular series, consider it to be the first vowel listed for that series.

2.3.4. *Terminology*

The preceding classifications result in attributing to a given system, be it primary or secondary, the following label:

$$(X \ldots Y)^{(h)}\pi_{p(a)}$$

with:
p the number of peripheral vowels; (a) unmarked for a symmetrical peripheral system with one low peripheral vowel; (a) = l for a "left" peripheral system; (a) = r for a "right" peripheral system; (a) = b for a "bottom" peripheral system; (a) = u for an "up" peripheral system; (h) = h for a peripheral system "with hole"; (X . . . Y) = non-peripheral vowels.
For example, our classification scheme assigns the following labels:
Javanese system: /i e ɛ a ɔ o u ə/ = əπ_7
Noutka system: /i ɛ a ɔ o/ = $^{h}\pi_5$
Bandjalang system: /i 'e' a u/ = π_{4l}
Kirghiz system: /ɪ y ø ɛ a a̟ ɔ ʊ ɨ̞/ = yøɨπ_{6b}

TABLE I. Classification of the 317 primary UPSID vowel systems in terms of their number (n) of vowels, their peripheral structure, and non-peripheral complementary vowels

n = 3 (total lang. = 19)

system label	lang.
π_{3}	14
$^{h}\pi_{3}$	3
π_{3l}	1
ə π_{2u}	1

n = 4 (total lang. = 25)

system label	lang.
π_{4l}	8
π_{4r}	4
$^{h}\pi_{4l}$	6
ɨ π_{3}	2
ɨ $^{h}\pi_{3}$	1
ə π_{3}	1
ə $^{h}\pi_{3}$	1
ɯ π_{3}	2

n = 5 (total lang. = 109)

system label	lang.
π_{5}	95
$^{h}\pi_{5}$	2
π_{5l}	1
ɨ π_{4l}	1
ɨ π_{4r}	1
ɨ $^{h}\pi_{4l}$	2
ə π_{4l}	1
ə π_{4r}	1
ɤ π_{4r}	2
y π_{4r}	1
ø $^{h}\pi_{4l}$	1
ɨə $^{h}\pi_{3}$	1

n = 6 (total lang. = 60)

system label	lang.
π_{6l}	12
π_{6r}	4
π_{6b}	3
ɨ π_{5}	8
ə π_{5}	26
ɯ π_{5}	4
ɤ π_{5}	1
ø π_{5}	2

n = 7 (total lang. = 44)

system label	lang.
π_{7}	23
ɨ π_{6l}	3
ə π_{6l}	5
ɨə π_{5}	6
yə π_{5}	3
yø π_{5}	1
yø π_{5r}	1
əɜ π_{5}	1
ɯʌ π_{5}	1

n = 8 (total lang. = 19)

system label	lang.
π_{8l}	3
π_{8r}	2
ɨ π_{7}	1
ə π_{7}	6
ø π_{7}	1
əɯ π_{6l}	1
ɨəy π_{5}	1
ɨyø π_{5}	1
ɯyø π_{5}	2
əyø π_{5r}	1

n = 9 (total lang. = 24)

system label	lang.
π_{9}	7
ə π_{8l}	1
ə π_{8b}	1
ɨə π_{7}	7
ɨə π_{7l}	1
yø π_{7l}	3
ɨyø π_{6b}	1
ɤyø π_{6b}	1
ɯyø π_{6r}	1
ɨɤyø π_{5}	1

n = 10 (total lang. = 8)

system label	lang.
π_{10b}	1
ə π_{9}	2
ə π_{9l}	1
ɨə π_{8l}	1
ɨə π_{8b}	1
ɯɤʌ π_{7}	1
ɯɤyø π_{6l}	1

n = 11 (total lang. = 4)

system label	lang.
ɨə'ə' π_{8r}	1
ɯɤʌ π_{8l}	1
yøœ π_{8b}	1
yøə π_{8l}	1

n = 12 (total lang. = 2)

system label	lang
əɜ π_{10b}	1
ɨ'ə'ɐʉ'ɵ' π_{7}	1

n ≥ 13 (total lang. = 3)

system label	lang.
ɨə'ə' π_{10b}	1
'ə'ɐyɤøœ π_{8l}	1
ʉ'ə'yɤøœ π_{9l}	1

3. The structure of vowel systems in UPSID: main results

The methodology described in the previous section leads to the data provided in Tables I and II, which respectively summarize the classification of all 317 UPSID primary systems and of the 121 secondary systems according to our conventions. We examine the main structural characteristics of these systems relative to the questions asked in the introduction concerning global repartition, occupation at the periphery, and occupation of the interior.

TABLE II. Classification of the 121 secondary UPSID vowel systems in terms of their number (n) of vowels, their peripheral structure, and non-peripheral complementary vowels

n = 1 (total lang. = 11)

system label	lang.
π_{1b}	6
π_{1l}	3
π_{1r}	2

n = 2 (total lang. = 10)

system label	lang.
π_{2u}	6
π_{2l}	2
əπ_{1b}	1
yπ_{1l}	1

n = 3 (total lang. = 16)

system label	lang.
π_3	12
$^h\pi_3$	2
π_{3l}	1
$^h\pi_{3l}$	1

n = 4 (total lang. = 22)

system label	lang.
π_{4l}	4
$^h\pi_{4l}$	2
π_{4r}	4
$^h\pi_{4r}$	2
π_{4u}	1
ɨ π_3	1
ɨ $^h\pi_3$	2
ə $^h\pi_3$	1
ɯ π_3	3
œ $^h\pi_3$	1
yøπ_{2u}	1

n = 5 (total lang. = 32)

system label	lang.
π_5	25
$^h\pi_5$	1
π_{5l}	2
$^h\pi_{5l}$	1
ɨ π_{4r}	1
ə π_{4l}	1
ɤ π_{4r}	1

n = 6 (total lang. = 12)

system label	lang.
π_{6l}	2
π_{6r}	2
ɨ π_5	1
ə π_5	4
ɤ π_5	1
ø π_5	1
yø π_{4r}	1

n = 7 (total lang. = 12)

system label	lang.
π_7	4
π_{7l}	1
ə π_{6l}	1
ə π_{6r}	1
ə π_{6b}	1
ɨə π_5	1
ɯɤ π_5	1
yø π_5	1
øœ π_5	1

n = 8 (total lang. = 4)

system label	lang.
π_{8r}	2
əπ_7	1
ɯɤ π_{6l}	1

n ≥ 9 (total lang. = 2)

system label	lang.
ə π_{8b}	1
ə π_{9l}	1

3.1. *Global repartition of vowels in primary and secondary systems*

First, Table I confirms a classic fact, namely that the preferred number of vowels in a primary system is 5, and that systems mainly use between 3 and 9 different vowels. This leads to a response to an important question, namely "when" (or "why") do vowel systems develop a secondary system. The classic answer is provided by Lindblom & Maddieson (1988), who show that secondary articulations appear when the number of vowels within a system becomes large and, hence, too large to be managed only in terms of acoustic distances in the formant space. We have ourselves suggested (Vallée, 1994) that the highest limit for a viable primary system is 9 (see also Crothers, 1978), and noticed that above this limit there was a trend for using a number of timbres equal to the number of vowels less five, which means a secondary system with 5 vowels, as in the following examples:

Bribri system: /i 'e' a 'o' u ĩ 'ẽ' ã 'õ' ũ/ → /i 'e' a 'o' u/ (S1) + /i 'e' a 'o' u/ (S2)
Bariba system: /i e ɛ a ɔ o u ĩ ɛ̃ ã ɔ̃ ũ/ → /i e ɛ a ɔ o u/ (S1) + /i ɛ a o u/ (S2)

The original contribution of the present paper is to present a systematic description of the acoustic structure of these "secondary" systems (Table II). It appears that the repartition of vowels in these systems closely mimics their repartition in primary systems (Vallée, 1994). In structural terms, we still observe a peak of 5 vowels in a secondary system, but with of course a strong trend towards smaller systems than found for primary systems. Two thirds of the primary systems have between 5 and 7 vowels, while two thirds of the secondary systems have between 2 and 5 vowels, the mean number of vowels in a system being 6.2 in the first case and 4.4 in the second one. Notice finally that of the 121 secondary systems, 45 come from durational contrasts, and 76 from secondary articulations, of which 67 are nasal.

3.2. *Peripheral structures*

3.2.1. *Holes*

It is well-known that, among peripheral vowels, /i/, /a/, and /u/ are preferred, and occur more than 90% of the time in UPSID primary vowel systems (Vallée, 1994). Table I shows that in structural terms, systems "with hole" (i.e., lacking either /i/ and /ɪ/, or /u/, /ʊ/, /ɯ/, and /ɯ̞/) or "up" systems (lacking /ɐ a̟ ɑ ɒ a/) occur in a large proportion of primary systems with 3 or 4 vowels (more than 25% of the time), marginally for 5-vowel systems (around 6% of the time) and never with more than 5 vowels in the system.

The trend is the same for secondary systems (see Table II). In more than 80% of the cases, there is one vowel in the left corner (i.e., /i/ or /ɪ/), one in the right corner (/u/, /ʊ/, /ɯ/, or /ɯ̞/) and one in the bottom (/ɐ/, /a̟/, /ɑ/, /ɒ/, or /a/). Systems "with hole" or "up" systems (which are, of course, the only classifications for 1- and 2-vowel secondary systems) occur about 30% of the time for 3- and 4-vowel systems, marginally for 5-vowel systems (about 6% of the time), and never for more than 5 vowels.

3.2.2. *Symmetry and front vs. back occupation at the periphery*

A peripheral vowel system, be it with or without hole, may be "left", "right", or "symmetrical"; if symmetrical, it may be "bottom", "up", or unmarked. Tables III and IV summarize these characteristics for primary and secondary systems, respectively.

The data in these tables confirm two classic facts. First, symmetry is highly preferred, for both primary and secondary systems. This conclusion is reinforced by the fact that there is a tendency, mainly for primary systems, to prefer an odd number of peripheral vowels (hence, one "low" and an equal number of front and back ones) whatever the overall number of vowels in a system. This pattern is evident in the number of non-peripheral vowels, which is more likely to be even when the overall number of vowels is odd and vice-versa (see Tables V and VI). Notice however that, when symmetry is more strictly defined, the contrast is less strong. Indeed, if we define a symmetric peripheral system as one in which any front peripheral vowel has a back peripheral counterpart with exactly the same degree of height, then we obtain the results displayed in Tables VII and VIII, where the difference between symmetrical and asymmetrical systems is strongly reduced in primary systems, and disappears in secondary systems. The second classic fact confirmed by these data is that, when there is an asymmetry, it is more likely to be left (i.e., front) than right (i.e., back): three times more in primary systems and two times more in secondary systems, according to Tables III and IV.

TABLE III. Structure of the primary peripheral systems according to their number (p) of vowels. numb. "symmetrical" = numb. (π_p) + numb. (π_{pb}) + numb. (π_{pu}) + numb. (${}^h\pi_p$); numb. "left" = numb. (π_{pl}) + numb. (${}^h\pi_{pl}$); numb. "right" = numb. (π_{pr}) + numb. (${}^h\pi_{pr}$); numb. is the number of languages of a given structure in UPSID

Number (p) of vowels	Number of languages		
	symmetrical	left	right
3	17	1	0
4	0	14	4
5	97	1	0
6	3	12	4
7	23	0	0
8	0	3	2
9	7	0	0
10	1	0	0
Total	148	31	10

3.3. *Structure of the interior of the vowel space*

Tables IX and X give the repartition of non-peripheral vowels in primary and secondary systems, respectively. In these tables, central unrounded and rounded vowels are merged, such as first and second height levels and third and fourth height levels in Fig. 1. Number of occurrences of back unrounded vowels are separated into cases where the back unrounded vowel is accompanied by a back rounded counterpart with equal height, and cases where it is "alone".

TABLE IV. Structure of the secondary peripheral systems according to their number (p) of vowels. numb. "symmetrical" = numb. (π_p) + numb. (π_{pb}) + numb. (π_{pu}) + numb. (${}^h\pi_p$); numb. "left" = numb. (π_{pl}) + numb. (${}^h\pi_{pl}$); numb. "right" = numb. (π_{pr}) + numb. (${}^h\pi_{pr}$)

Number (p) of vowels	Number of languages		
	symmetrical	left	right
1	6	3	2
2	6	2	0
3	14	2	0
4	1	6	6
5	26	3	0
6	0	2	2
7	4	1	0
8	0	0	2
9	0	0	0
Total	57	19	12

Table V. Number (i) of non-peripheral vowels in primary systems according to their number (n) of vowels. Each (i, n) value represents the number of UPSID languages of the corresponding structure

Number (n) of vowels	Number of languages							
	i = 0	i = 1	i = 2	i = 3	i = 4	i ≥ 5	i odd	i even
3	18	1					1	18
4	18	7					7	18
5	98	10	1				10	99
6	19	41					41	19
7	23	8	13				8	36
8	5	8	1	5			13	6
9	7	2	11	3	1		5	19
10	1	3	2	1	1		4	4
11				4			4	0
12			1			1	1	1
≥13				1		2	1	2

Table VI. Number (i) of non-peripheral vowels in secondary systems according to their number (n) of vowels. Each (i, n) value represents the number of UPSID languages of the corresponding structure

Number (n) of vowels	Number of languages				
	i = 0	i = 1	i = 2	i odd	i even
1	11			0	11
2	8	2		2	8
3	16			0	16
4	13	8	1	8	14
5	29	3		3	29
6	4	7	1	7	5
7	5	3	4	3	9
8	2	1	1	1	3
≥9		2		2	0

Table VII. "Strict" symmetry of the primary peripheral systems according to their number (p) of vowels

Number (p) of vowels	Number of languages	
	strictly symmetrical	asymmetrical
3	15	3
4	0	18
5	75	23
6	3	15
7	19	4
8	0	6
9	5	2
10	1	0
Total	118	71

Table VIII. "Strict" symmetry of the secondary peripheral systems according to their number (p) of vowels

Number (p) of vowels	Number of languages	
	strictly symmetrical	asymmetrical
1	7	5
2	4	4
3	10	6
4	1	12
5	21	8
6	0	5
7	3	2
8	0	1
Total	46	43

Table IX. Number of languages with non-peripheral vowels in a primary system, according to vowel backness and height

Front rounded	Number of languages	Central	Number of languages	Back unrounded	Number of languages
/y/	25	/ɨ/	45	/ɯ/	23 (14 with /u/, 9 alone)
/ø/	22	/ə/	77	/ɤ/	14 (8 with /o/, 6 alone)
/œ/	3	/ɜ/	3	/ʌ/	4 (3 with /ɔ/, 1 alone)

3.3.1. *Primary systems*

The trend in primary systems is the following. First, let us concentrate on the vowels occupying the top of the vowel space, namely the high vowels. We observe from Table IX that high non-peripheral vowels are nicely balanced, with a vowel at the middle of the space (i.e., central /ɨ/) about 50% of the time, and the remaining 50% being equally distributed between front rounded /y/ and back unrounded /ɯ/.

As we consider non-high vowels, we observe that the number of vowels in the front rounded and back unrounded cases decreases from higher to lower, first slowly (compare the number of occurrences of higher-mid /ø/ and /ɤ/ with those of high /y/ and /ɯ/) and then much more quickly (lower-mid /œ/ and /ʌ/ being rather marginal). The trend of a roughly equal number of occurrences in the

Table X. Number of languages with non-peripheral vowels in a secondary system, according to vowel backness and height

Front rounded	Number of languages	Central	Number of languages	Back unrounded	Number of languages
/y/	4	/ɨ/	6	/ɯ/	7 (5 with /u/, 2 alone)
/ø/	5	/ə/	14	/ɤ/	7 (4 with /o/, 3 alone)
/œ/	2	/ɜ/	0	/ʌ/	1 (0 with /ɔ/, 1 alone)

front rounded and back unrounded series remains, although languages are slightly more likely to have front rounded vowels. Vallée (1994) notes that the trend is more towards organization of front rounded vowels in series, while it is rather towards organization of back unrounded vowels as individual occurrences in a given system.

A surprise is the large number of languages with /ə/, almost twice as high as the number of languages with /ɨ/, which contradicts the trend of a smaller number of mid vowels than of the corresponding high vowel in a given series (a trend which also holds for peripheral vowels). This provides a first indication of a "special" status for schwa, to which we shall return later.

A second interesting point emerging from the data in Table IX is that while front rounded vowels are always truly "interior", back unrounded vowels are "peripheral" 40% of the time because they replace a missing back rounded vowel of equal height. If one considers the remaining 60% of the back unrounded vowels as the only "true interior" ones, there are two times fewer back unrounded than front rounded vowels at the interior of primary systems. Therefore, the apparently "balanced" repartition of vowels in the vowel space is in fact strongly biased towards "left" interior vowels, that is, front rounded ones. Notice that this is not a simple replication of the trend towards "left" peripheral systems, because altogether there are only 6% more front unrounded vowels than back rounded ones in primary systems.

Finally, if we look at the possible repartition of interior high vowels in UPSID primary systems (Table XI), we observe that after the much preferred /i ɨ u/ series, the most likely candidate is the /iyu/ series, which is slightly more frequent than the /i ɯ u/ series.

3.3.2. *Secondary systems*

The structure of the interior of secondary systems is rather different than for primary systems (see Table X), with an almost equal number of "interior" front rounded and back unrounded vowels, although the low overall number of interior

Table XI. Number of languages with at least one non-peripheral high vowel in a primary system, according to set of high vowels

High vowel system	Number of languages
/iɨu/	38
/iyu/	14[a]
/iɯu/	10
/iyɨu/	5[a]
/iyɯu/	4[a]
/iɨʉu/	1

[a] There are two languages with both /y/ and /ʏ/ in the database, which explains why the total number of series with /y/ is 23 in Table XI instead of the value 25 given in Table IX.

vowels in secondary systems makes any conclusion more risky. However, we have a confirmation of the high number of /ə/ occurrences in secondary systems.

3.4. *The case of schwa*

As we have already observed, it is clear that /ə/ (or more precisely, if we return to a fine-grained description, /ˈəˈ/) is the most frequent non-peripheral vowel in both primary and secondary systems, and that its proportion of occurrences in UPSID is unexpectedly high. Moreover, it is striking to observe that this vowel is difficult to predict in isolation with a peripheral system within the framework of the substance-based theories. Indeed, this vowel is difficult to stabilize in the Dispersion-Focalization Theory (Boë, Schwartz & Vallée, 1994), and in any case it is less favored than /ɨ/ in terms of acoustic dispersion (Dispersion Theory, Lindblom, 1986).

Consequently, we were driven to wonder whether this vowel does not in some sense "escape" from the traditional vowel space. Our assumption is that schwa, when it does exist in a given system, might be produced by a kind of systematic "relaxation" procedure based on vowel reduction (see van Bergem, 1994), just as in a chemical equilibrium two structures can coexist in a certain proportion, thanks to systematic exchange procedures. In other words, we suggest that schwa should be considered as constituting a "parallel" system linked to a kind of "reduction" feature. If this were the case, the consequence is that the presence or absence of schwa should not modify the structure of a vowel system, while any other vowel should do so because of relational interactions patterning vowel systems. This seems compatible with the view expressed by van Bergem (1994), according to which schwa is a vowel "*without target*" (pp. 99) able to systematically coexist with full vowels in the mental lexicon, within style-dependent variant forms (Solé & Ohala, 1991).

This view is confirmed in Fig. 2, which shows for primary systems that the distribution of the 186 peripheral systems ${}^{(h)}\pi_{p(a)}$ in terms of the number of peripheral vowels (p) from 3 to 9 is basically the same as the distribution of the 48 (peripheral + schwa) systems ə${}^{(h)}\pi_{p(a)}$. This holds roughly true for secondary systems as well, though the correspondence is less good because of the small number of systems (Fig. 3). The test-case for a given vowel should therefore be that the distribution of systems without this vowel is the same as the distribution of systems with this vowel: we can call this the "*transparency rule*". Obviously, this is not the case for most other vowels, which do play a part in determining the overall pattern of the vowel system. To take a classic example, if /i/ is lacking in a given system, /y/ will also be missing, showing that the presence or absence of /i/ influences the whole structure. The only other case where one might wonder whether the transparency rule holds is the high central category. In fact, the distributions of peripheral systems and systems with a high central vowel (be it /ɨ/, /ʉ/ or even /ɯ/, which is acoustically close) are not so different for primary systems (Fig. 4). However, for systems with a single non-peripheral high vowel, there is a trend for a too large proportion of small systems ($n \leq 5$) and an absence of large systems: in this last case, the high central vowel is accompanied by at least one other non-peripheral vowel, generally around /ə/. This trend is dramatically increased for secondary systems, for which the repartitions completely diverge (Fig. 5): single interior high

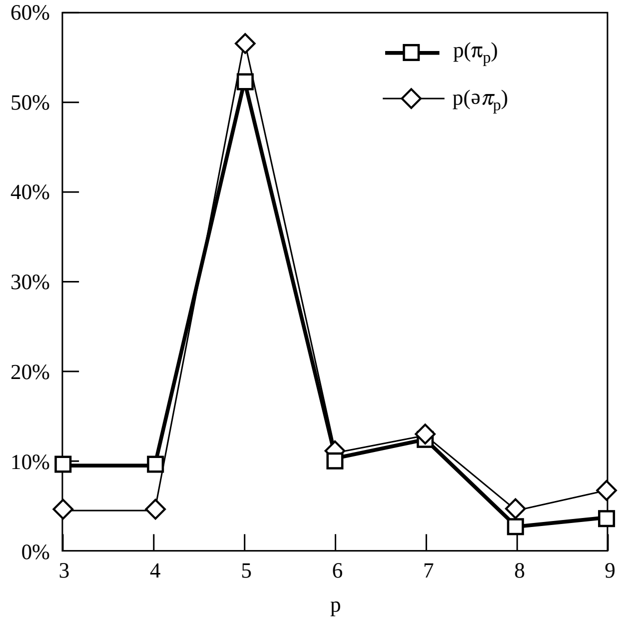

Figure 2. Compared repartitions of π_p and $ə\pi_p$ primary systems in UPSID. For each value of p (number of peripheral vowels in system) on the abscissa, the figure plots the percentage of π_p and $ə\pi_p$ primary systems in the UPSID database with respect to the overall number of π and $ə\pi$ primary systems in the database.

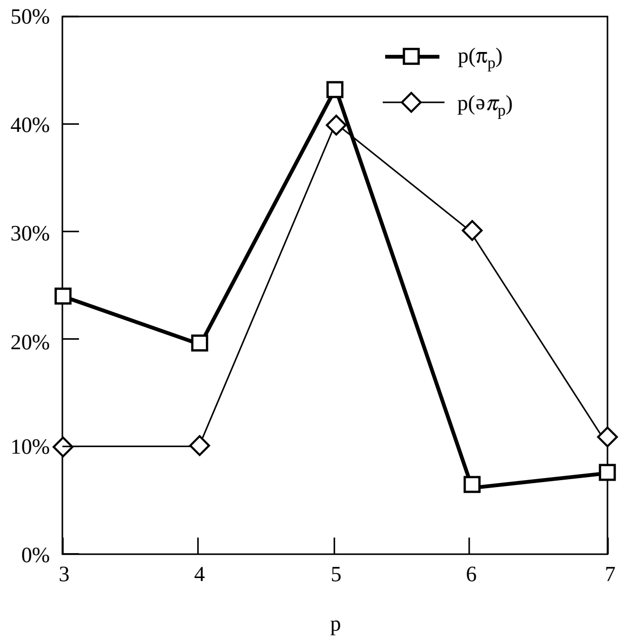

Figure 3. Compared repartitions of π_p and $ə\pi_p$ secondary systems in UPSID. Same presentation as in Fig. 2.

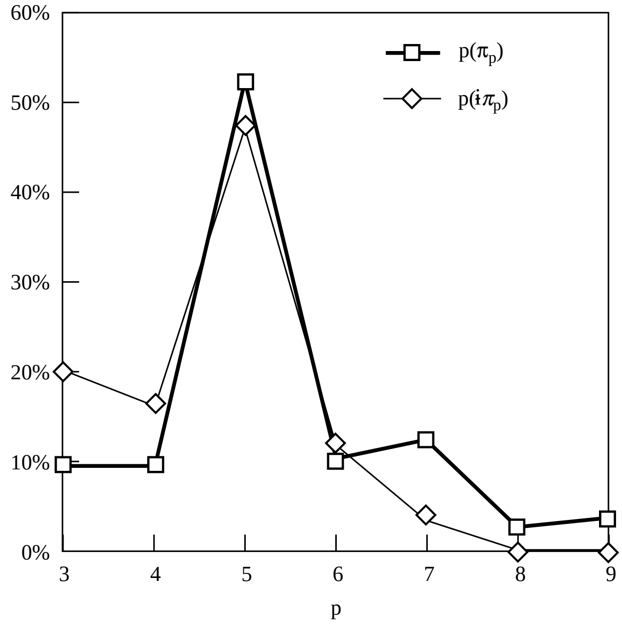

Figure 4. Compared repartitions of π_p and ɨπ_p primary systems in UPSID. Same presentation as in Fig. 2. ɨ refers here to one of the vowels /ɨ/, /ʉ/, or /ɯ/ (see text).

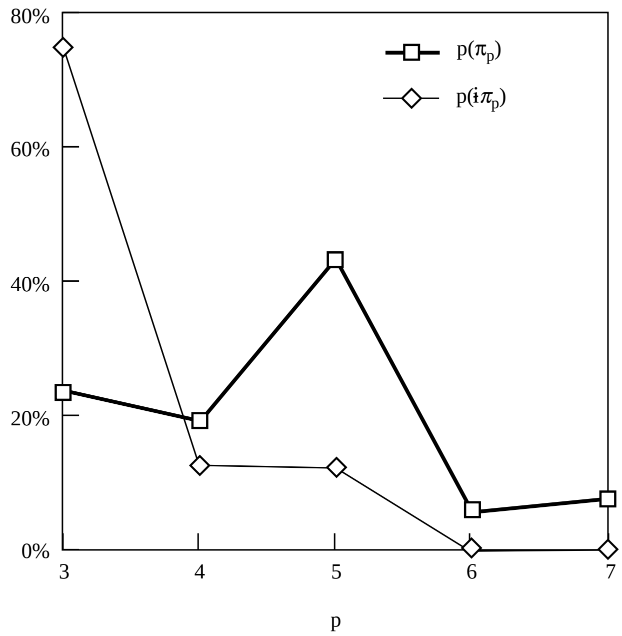

Figure 5. Compared repartitions of π_p and ɨπ_p secondary systems in UPSID. Same presentation as in Fig. 2. ɨ refers here to one of the vowels /ɨ/, /ʉ/, or /ɯ/ (see text).

vowels mainly appear with π_3, while peripheral structures, alone or with /ə/, are mainly of the type π_5.

In summary, we have introduced a "transparency rule" which specifies whether a vowel interferes or not with the overall structure of the vowel system, we have shown that schwa is the only vowel which respects this transparency rule, and we argue that this reinforces our assumption that schwa is a "parallel" vowel which exists because of intrinsic principles (probably based on vowel reduction) different from those of other vowels.

4. Conclusion

The present set of results comes as a confirmation or a refinement of a number of already known trends of vowel inventories. More than most previous studies, however, it focuses on "structural" trends of the occupation of the acoustic space by vowels. The method enables one to derive from the UPSID inventory the following picture.

1. Vowel systems first exploit a "primary" system of sounds, and then, with more than 9 sounds, there is a clear trend for exploiting at least one new dimension ("secondary systems").
2. Primary systems mainly consist of 3 to 9 vowels, with a strong preference for 5 vowels, two thirds of the systems having between 5 and 7 different vowels.
3. Secondary systems mainly consist of 1 to 7 vowels, with a preference for 5 vowels, two thirds of the systems having between 2 and 5 different vowels.
4. In both primary and secondary systems, the sounds are mainly concentrated at the periphery. Holes at the corners are limited to small systems (with less than 5 vowels). Symmetry is the rule, in the sense that there is a strong trend for having the same number of front and back vowels in a peripheral system. However, the trend for having exactly the same height levels on the front and the back peripheral sides is less clear. Finally, if there is an asymmetry (around 30% of the cases), the number of front vowels is likely to be greater than the number of back vowels (3 times more likely in primary systems, 2 times more in secondary systems).
5. For "interior" vowels, the trend in primary systems is that a high interior vowel is more likely to be central (about 55% of the high interior occurrences); if it is not central, the vowel is more likely to be front rounded (30%) than back unrounded (15%). Probability of occurrence decreases from high to low vowels, with the clear exception of schwa, which is the preferred non-peripheral vowel. In secondary systems, the trends are blurred by the small number of occurrences, but schwa remains the preferred candidate.
6. Finally, a "transparency" rule applied to both primary and secondary systems shows that schwa does not seem to interact with other vowels within the system, which leads us to propose that it is a "parallel" vowel which exists because of intrinsic principles (probably based on vowel reduction) different from those of other vowels.

These basic rules set the requirements to be applied to any theory of vowel systems—be it formal or substance-based—and it should provide in the future a canvas for delimiting within the various proposals what is necessary for understanding the structure of vowel systems in human languages.

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