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Production and perception of vowels: does the density of the system play a role?

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ABSTRACT

The objective of the present paper is to understand whether the "density" of the vowel system of a language, in other words the large or small number of vowels in the language, plays a significant role in the production and perception of vowels. Three languages (French, English and Spanish) are analysed. This work rests upon the comparison between speech production and the cognitive processing of linguistic units. Two different methodologies were employed in this aim : observation of phonetic productions and analyses of behavioural measures. First results lead us to hypothesise that perception units can be larger than production units. In other words, the density of a vowel system seems to influence vowel perception but not vowel production.

1. INTRODUCTION

Each language has its own more or less fixed inventory of phonemic units (vowels and consonants). Given this, each language differs as concerns the number of phonemes in its inventory. The study performed by Manuel and Krakow [1] showed that the tolerance for variation in the *production* of a vowel is lesser in a language with a filled vocalic system. Hence, the density of the vocalic system apparently has an impact upon vowel perception. This hypothesis is weakened, however, by the results obtained by Manuel [2] in a comparative study of three languages which varied little between each other as concerns their vocalic space. As concerns perception, the majority of studies have dealt with the more global problem of perceptual assimilation rather than with the specific issue of density. On the other hand, Flege and Munro [3] argue in favor of a universal perceptual process, based upon a purely auditory component which is independent of any given phonological system.

The specificity of the organisation of vowels within each language is directly related to questions concerning the

cognitive processing of linguistic sounds : do the listeners of languages which possess only a few vowels perceive larger phonetic categories than listeners of languages with a dense vocalic system? Moreover, is the phonetic production of a vowel affected by the density of the system? Last, is there a relationship between the acoustic space associated with the production of a vowel and the perceptual space that is representative of its vocalic category?

In the present work, we plan to compare the processing of vowels by speakers of French, Spanish and English. In English, there are between 13 and 15 oral vowels while French distinguishes some 10 or 12. The density of these two systems is therefore similar, but the specific vowels in each differ considerably. In contrast, Spanish has a relatively sparse inventory, with only 5 vowels, but within this inventory we find the same vowels as in French and English (/a/, /e/, /i/, /o/ and /u/). These three languages thus offer the opportunity to distinguish the effects of density, without a concomitant difference in the phonological nature of the vowels present in the two systems (French and Spanish), from the effect of differing inventories of vowels within comparably dense systems (French and English).

This work rests upon the comparison between speech production and the cognitive processing of linguistic units. Two different methodologies were employed in this aim : observation of phonetic production and analyses of behavioural measures.

2. HYPOTHESES

Whether the question is production or perception, various hypotheses can be envisaged. The vowel space may be a function of the density of the system, in which case the space covered by a phoneme of language A takes up the space of two vowels in language B (Hyp. 1). The vowel space may be constant, independent of the density of the vowel system, in which case the acoustic-articulatory space between two vowels is unexploited (Hyp. 2). Last, the vowel space may be fixed, but the production and/or perception of vowels which are phonologically similar may differ, in which case the /a/ in Spanish may differ from the /a/ in French (Hyp. 3). These three hypotheses will be

evaluated both in the production and in the perception of speech.

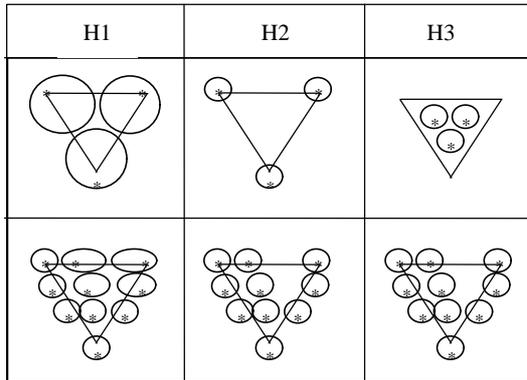


Figure 1: Three hypotheses representing the possible phonetic realizations of vowels regarding to the density of the systems (here two systems with 3 or 10 vowels).

3. LINGUISTIC MATERIAL

For each vowel two lists were created, each having three-word groups that contained the vowel of interest. To avoid ambiguity (the pronunciation of certain vowels in isolation in French and English is rather artificial), speakers were requested to produce vowels after having repeated all three words.

Examples :

English : "he, me, be ... i/"

French: "si, lit, nid ... /i/"

Spanish: "si, mi, ti ... /i/"

Three speakers (2 women, 1 man) of each language were recorded. Each speaker repeated the lists corresponding to his/her language 5 times (3 speakers * 5 repetitions * 2 lists = 30 exemplars per vowel et per language).

This corpus allowed us to evaluate the variability of vowel production in the absence of context. The controlled nature of the situation should considerably reduce variation. Moreover, the present corpus of isolated vowels provided us with the necessary materials for the preparation of acoustic stimuli for later behavioural experiments.

The two corpuses were manually marked to identify each vowel. Thereafter, an automatic procedure enabled the analysis of F1 and F2 formants of each vowel (the measurement was taken at one-third of the duration of each vowel, due to English speakers tendency to produce diphthongs).

The formant measurements were then normalised to attenuate inter-individual differences, which were not considered in the present project.

4. ACOUSTIC RESULTS

English and Spanish systems occupy approximately the same space as concerns F1/F2 (see figure 2). The French system, however, was slightly different : it appears to be more closed and more posterior than the other two systems. The size of the system is comparable for the three languages : *hypothesis 3 can be refuted as concerns production; Spanish system is not reduced or centralized.*

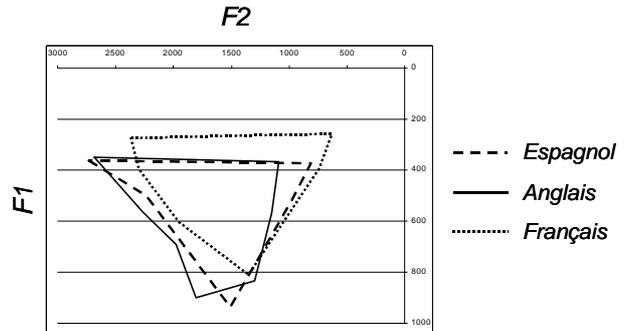


Figure 2: Acoustic position and surface of the three languages.

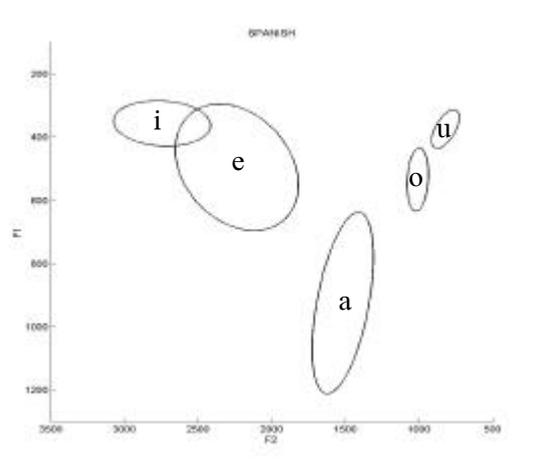


Figure 3: Spanish vocalic spaces.

The Spanish and French speakers produced distinct vowels which showed little to no overlap between categories, quite unlike the English speakers (figures 3, 4 and 5)

Nonetheless, the size of the production spaces appeared relatively similar for the three languages, although the vowel spaces allocated for French and Spanish were somewhat more restricted than those for English (figure 5). It can be further noted that the production space of back vowels /u/ et /o/ was highly restricted for all three languages. In opposition, low front vowels were given a relatively large space. In English, certain vowel categories were completely contained within the space of other vowels (/ɪ/ is contained within /e/).

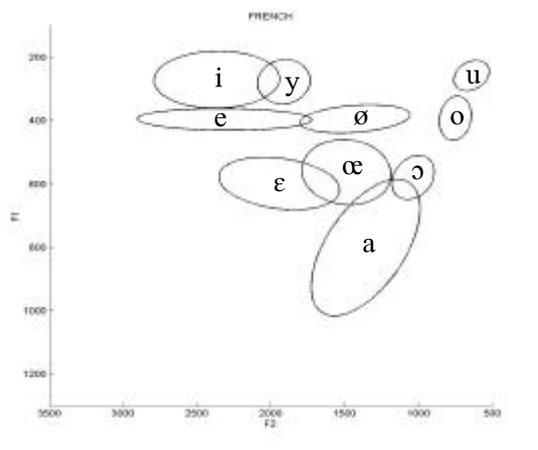


Figure 4: French vocalic spaces.

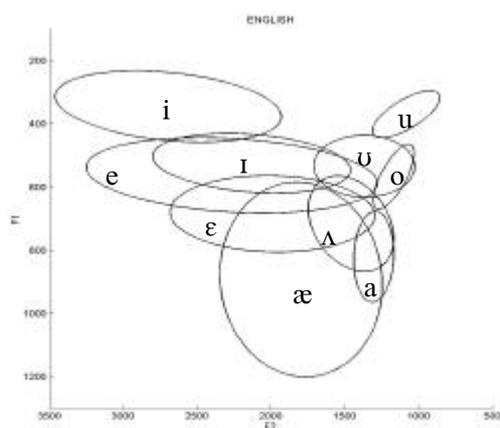


Figure 5: English vocalic spaces.

For Spanish speakers, there was basically no overlap between vowels as their number is lesser within the same global space : *the density of the vowel system does not appear to have an impact upon the production of vowels.* This observation goes against hypothesis 1, which predicted a larger production area for systems with fewer vowels.

5. IDENTIFICATION EXPERIMENT

In this experiment, the listeners from each language group were asked to transcribe both vowels which are foreign to their system and those of their own language. Subjects were requested to provide an obligatory response (transcribed), even for vowels which are absent from their vocalic system. The results of this experiment provide information concerning the assimilation of vowels which are absent in a system

Three groups of subjects (20 Spanish, 22 English and 22 French) participated in the experiment. The listeners of each language were requested to identify auditorily presented isolated vowels (listeners were first presented the vowels of their own system, as a control, then those of the

two foreign languages), and to mark their choice on designated response sheets. The stimuli were taken from the corpus used for acoustic analyses. Each vowel was produced 5 times by 2 different speakers (1 male and 1 female) for each language.

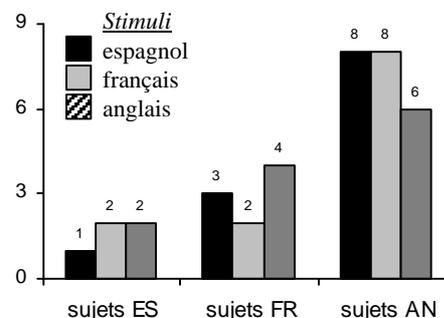


Figure 6: Mean number of identified vowels for each stimulus.

Spanish subjects :

Spanish listeners identified the vowels of their native language without ambiguity. Their perception of French stimuli corresponded perfectly to the obtained acoustic results : French vowels were perceived as globally higher and more posterior, with the exception of the vowel /a/, which did not produce a change in category. The central vowels that are absent from Spanish (/y/ /ø/ /œ/) were most often assimilated to back vowels for /y/ and /ø/, which corresponds to the acoustic re-positioning described above. The vowel /œ/ was predominantly assimilated to /a/. The English vowels corresponding to Spanish ones (/a/ /e/ /i/ /o/ /u/) were correctly identified. This is in line with our acoustic results inasmuch as the area covered by the two languages was similar. As concerns the English vowels absent from Spanish, their assimilation appeared to pose little difficulty, except for the vowel /ε/ which Spanish subjects categorized equally as /a/ and /e/. Spanish subjects experienced little difficulty with the categorisation task, even for vowels outside of their own system. They seldom proposed different vowels for a same stimulus (figure 6), and do not hesitate when they choose a category (figure 7).

French subjects:

The French subjects categorized vowels from their own system without ambiguity, with the exception of the vowels /ε/ /œ/ and /ɔ/ whose presence is generally contextual. The Spanish vowels were globally perceived as lower, which corresponds to the acoustic results for Spanish subjects as concerns French stimuli. The English vowels were perceived as lower in some cases, which also corresponds to our acoustic results although not as closely as in the case of Spanish. Indeed, given that the English system is as full as the French one, with a slightly different distribution, categorization is rather complex for vowels that are absent

from French. In particular, the vowel /ɪ/ posed considerable difficulty and was categorized across three or even four vowels. The vowels /ʊ/ and /ʌ/ were principally assimilated to interior French vowels, /ø/ and /œ/ respectively. The French subjects did not appear to have difficulties identifying the English stimuli, which is hardly surprising as those vowels that are specifically English are both similar to each other and distinct from French vowels (/ɪ/, /æ/, etc.). The number of categories proposed for each stimulus was globally rather small (figures 6 and 7).

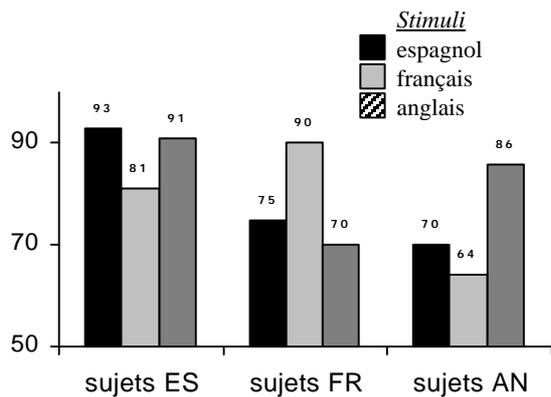


Figure 7: Mean percentage of the best identified vowels.

English subjects:

The results of the present experiment reveal English subjects difficulty in accomplishing the task, as indeed did the self-reports by the subjects following the session. For each stimulus, English subjects demonstrated considerable variability as concerns their categorisations. This was true not only for French and Spanish stimuli but for stimuli for their own language as well. Spanish vowels were globally perceived as lower, which is quite surprising given our acoustic results. French vowels produced a large degree of uncertainty. However, the vowels /ʊ/ - /ø/ and /ʌ/ - /œ/ produced good overlap, as was the case for French subjects.

In Figure 6 we can see that for each stimulus English subjects proposed a large number of different vowels, reflecting the difficulty these subjects had with the task. In like manner, the best identified vowel obtained a relatively low score in relation to those obtained by French subjects, and even more so in relation to Spanish subjects (figure 7).

5. DISCUSSION

The first hypothesis was that subjects would adapt their productions as a function of the number of vowels in their system, to occupy the entire space (H1, figure 1). Our results do not support this hypothesis. We find, rather, that the space occupied by different vowels is fairly constant across systems, i.e. not affected by the density of the system.

These observations tend to confirm the second hypothesis. As concerns the position of vowels within the system, we found a displacement of the French system (higher and farther back). This variation as concerns position cannot, however, be considered as a centralizing and thus is not to be taken as evidence of an impact of density. *The third hypothesis is not then supported.*

On the other hand, our behavioral experiment tends to show that Spanish subjects are able, without hesitation, to categorize stimuli which do not form part of their space of production. Thus, space perception seem to be larger than production ones. *This suggests that the first hypothesis would be more appropriate for perception process.* Nevertheless, these results should be confirm with another experiment.

We observed a great coherence between acoustical and perceptual results: Spanish and French produce distinct vowel categories and did not find difficulty to categorize vowel stimuli even if they do not form part of their vowel phonological system. On the other hand, the production of English speakers show a very broad overlapping between the categories and their experimental results show a very great difficulty in the task of categorization. Some works [4] show that, beyond nine vowels, the vowel systems profit from secondary systems of features. This is the case of English: duration makes it possible English listeners to distinguish some vowels. Thus, in our experiment, English subjects misses indices to achieve the task correctly. In the same way, their production is confused because our results only represent F1/F2 values.

In conclusion, our results tend to show that density 1/ may not play a role on vowel production (but this should be confirmed with larger and different linguistic material) and 2/ may play a role on perception but only for languages whose formant values are the only distinctive features between vowels.

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