'VOICING' IN ENGLISH CONSONANTS

INDICE

Juan A. Alvarez González
I.N.B. Lugones (Oviedo)

1. Introduction

Every Spanish speaker when learning English has to use a pronouncing dictionary again and again, but it will be of little use if he or she cannot interpret correctly the phonetic symbols and their precise realizations. Usually, as in Daniel Jones' "English Pronouncing Dictionary", the transcription is a broad phonetic one which is similar to, if not the same as, a phonological transcription. Accordingly the correct interpretation of those symbols is a necessity. The wrong application of the phonological rules when realizing the so called "voiced" and "voiceless" consonantal phonemes is the origin of many problems when pronouncing English.

2. "Voiced"-"voiceless"

The research carried out during the last thirty years has shed a lot of light on the characteristics which form the opposition between voiced and voiceless consonants.

One controversial issue in phonetics, in relation to English, has been which is the feature that differentiates pairs of consonants having the same place and manner of articulation. Traditionally this feature was allocated to voice and the adjectives "voiced" and "voiceless" were used to indicate the opposition. Voice as marker of the phonological opposition was taken from the phonetic level, indicating vocal fold vibration. So, when Daniel Jones deals with the voiced phonemes he tells us, for instance, that "the principal English b is formed like the principal English p except that the force of exhalation is weaker and the vocal cords are made to vibrate so that 'voice' is produced during the articulation of the sound. The formation of the principal English b may therefore be expressed shortly by defining it as a VOICED BILABIAL PLOSIVE consonant". (number 504). Below (n. 506) Jones (1962) repeats that the "chief members of the b phoneme are wholly or partially voiced".

He defines the other voiced plosives and affricate in a similar manner, giving prominence to voice as the marker of the opposition, although in n. 573 he states that "in English when b, d, and g (and in 615 also dz) occur initially ... they are partially devoiced in the pronunciation of most people, that is to say, voice is not heard during the whole of the stop but only during part of it, generally the latter part". And he continues: "With some speakers the voice disappears altogether so that the sounds are replaced by b, d, g".

In final position, especially when another consonant precedes, as in 'bulb', "the stop itself is partially or even completely devoiced in these circumstances" with many speakers" (ns. 575 and 576).

As far as fricatives are concerned we read that in initial and final positions partially voiced sounds are generally used and in the cases when the phoneme is final and preceded by another consonant, a completely voiceless sound is generally used (ns. 788-794).

In summary, according to Daniel Jones, it is voice what differentiates the cognate plosives, affricates and fricatives, and the voiced plosives, affricate and fricatives are fully voiced when in medial position, while in initial position partially devoiced sounds are used by most people, and in final position they are voiced, though in both initial and final positions some speakers use completely devoiced consonants.

From what has been said the question immediately arises: What is it that differentiates a completely devoiced consonant from a voiceless consonant? Daniel Jones states that completely devoiced consonants are weak or very weak voiceless consonants (ns. 576 and 789). From a strictly phonetic point of view completely devoiced consonants do not exist since there is not vocal fold vibration and in these cases they are voiceless consonants. The acoustic cues which differentiate weak from strong voiceless consonants are not mentioned. We shall elaborate on these terms later.

If we make a spectrographic analysis of the so called voiced plosives, affricate and fricatives, we shall find that not only in initial and final position are these consonants partially or completely devoiced, but even in medial position some speakers produce a partially or almost completely devoiced consonant, especially plosives and affricate. In words such as 'rubber', 'udder', 'aboard', 'ago', the medial plosive may be devoiced. We can appreciate what I have just said in figure 1. Medial fricatives, on the other hand, are less likely to be devoiced.

3. Lenis-fortis (lax-tense)

It was noted that in English, and in other languages too, vocal fold vibration is not a necessary cue to differentiate voiced from voiceless consonants, since it may not be present, at least in some positions, and the opposition continues to be operating, so the use of voiced and voiceless to mark such oppositions was questioned. Since the two adjectives voiced and voiceless were taken literally as indicating vocal fold vibration they were eventually dropped and replaced by 'fortis-lenis', or 'tense-lax', which indicated that the main opposition consisted in the force of articulation. Thus Stetson (1951) said that the "difference in pressure, expressed by the terms "fortis" and "lenis", is more fundamental than the voicing of consonants".

Malecot (1955, 1956, 1958, 1966, 1968, 1969) has shown experimentally that 'voiceless' consonants have much higher average mouth pressures than the 'voiced' ones. He divides the consonants into 'strong' consonants, which are the 'voiceless' stops and fricatives, and 'weak' consonants, which include all the rest. He does not mention the affricates.

In his work (1955) he made the recordings in a kymograph using a tube placed through the nostrils into the faringeal cavity. The mouth pressures obtained for the 'voiceless' stops were around 100% higher than the 'voiced' ones. For instance, in intervocalic position the pressure for 'p' was 81 while for 'b' it was 42.8 and in final position it was 71 for 'p' and 25.5 for 'b'. He forms a ranking order in the three positions—intervocalic, initial and final—, and in all positions the 'voiceless' consonants are at the top followed by the 'voiced' consonants, the nasals being last in the three positions, their pressure ranging from 9.9 to 12.2.

Harris et al. (1965) studied the electromyographic output of the lip muscles during the production of 'p, b, mp, mb' to see if there was a difference in the amount of patterning of activity between sounds usually described as 'tense' and 'lax'. They placed several electrodes mainly in different parts of the orbicularis oris muscle of five subjects, and asked them to pronounce certain words. They analysed the readings obtained and concluded that overall there is a slight average tendency for 'tense' sounds to be produced more forcefully than 'lax' ones, but this tendency is present only for some subjects and when large numbers of responses are averaged. They claim that the difference is not large enough to serve as the basis for a phonemic distinction based on muscular effort, so that the essential difference between /p/ and /b/ lies elsewhere, namely in the relative timing of events at the glottis and at the place of oral occlusion.

Lisker and Abramson (1964) had arrived at this conclusion when studying the difference in glottal behaviour of these consonants, though in initial position. They said that "it would seem that such features of voicing, aspiration and force of articulation, are predictable consequences of differences in the relative timing of events at the glottis and at the place of oral occlusion.

Fromkin (1966), in her electromyographic studies, arrived at a similar conclusion when she stated that "there is so much overlap between /b/ and /p/ in terms of peak amplitudes, that one may conclude that the gestures at the lips were virtually identical, so that the differences between /p/ and /b/, based on muscular tenseness or laxness, could not serve as a basis for a workable phonemic distinction.

Jakobson and Halle (1964) contend that the most stable cue for the distinction of 'tense' and 'lax' phonemes remains the greater duration of the former.

If the opposition based on voice was questioned, the opposition based on force of articulation was questioned too.

4. 'Short-long'

Research continued. The acoustic cues for the discrimination of initial plosives, both voiced and voiceless, were studied extensively. Cooper et al. (1952), Halle et al. (1956, 1957), Schatz (1954), Delattre et al. (1955, 1962), Hoffman (1958), Cooper (1958), Liberman et al. (1958), Winitz et al. (1972) are some of the studies.

Acoustic cues for the identification of final plosives were studied too, as the work of Wang (1959), Malecot (1958) shows. In a similar way fricatives (Harris, 1954, 1956, 1958) were studied.

In one way or another these works concerned themselves almost exclusively with the role played by the formant transitions, the frequencies of the burst and acoustic loci, or resonant structure of the noise, as in the fricatives.

4.1. Duration in medial position

One problem still open to investigation was what were the the cues for the differentiation of medial unstressed plosives. Lisker (1957) using real speech and Liberman et al. (1961) using synthetic speech, have shown that the difference between medial unstressed cognate plosives is precisely the different duration of the closure.

By means of a tape splicing technique, Lisker increased or reduced the duration of the closure at will. The experiment was conducted in three stages. In the first place, an utterance of 'rupee' was manipulated in such a way that the closure duration of the plosive ranged from 40 to 150 msecs., in steps of 10 msecs. An utterance of 'ruby' was also manipulated in a similar manner. Blank tape was added to the duration of the plosive in order to produce different items in which its duration also ranged from 40 to 150 msecs., also in stops of 10 msecs. Using the first part of the utterance of 'rupee' (plosive excluded) and the second part of the utterance of 'ruby' (plosive excluded, too) closure durations ranging from 40 to 150 msecs were added. In a similar way ten more items were obtained using the first part of the utterance of 'ruby' (plosive excluded) and the second part of the utterance of 'rupee' (plosive excluded, too). All the items thus obtained were put to a listening test and the conclusion at which he arrived was that, in the context studied, closure durational differences play a major role in the voiced-voiceless stop distinction. A closure duration of less than 70 msecs. was interpreted as the voiced plosive and from 100 msecs. onwards it was interpreted as the voiceless plosive.

The fact that duration is a consistent and systematic feature which differentiates voiced and voiceless consonants, was shown by Alvarez González (1974). In a thorough and systematic

study of the durational behaviour of English consonants I demonstrated that voiceless consonants were longer than their voiced counterparts.

In order to keep under control, as much as possible, all the variables so that their influence on the final output were reduced to the minimum, we devised a system of tempo and rhythm markers. Also, the phonological structure in which the different consonants were inserted was identical for all of them. We used three phonological structures, /'ʌCə/, /ə'Ca:/ and /'pʌC/ where /C/ is each one of the English consonants. Every word produced in this way was uttered by five informants at least twice. Spectrographical analyses of all the items were made and the durations of the consonants were measured. The mean value of each consonant in each structure for the five informants is given in table 1.

In the results obtained we noticed a regularity of patterns. This prompted us to make a closer study of the relationships between some voiced and voiceless consonants which are in opposition only in this feature. The consonants studied are /tʂ, ʂ, s, f, k, t, p/ and their voiced counterparts /dʒ, ʒ, z, v, g, d, b/. /Θ/ and /ð/ were excluded because the latter had only appeared in two of the informants, but they seem to fall in line with the other pairs of consonants. We are going to concentrate our attention only on structures /'—C—/ and /'C—/, since in structure /'—C/ the durational differences are more widely scattered, due, we think, to the inconsistent drawling factor affecting the duration of the final sounds.

The durational differences between the 'voiced' and 'voiceless' consonants in the two structures, together with their standard deviation, are given in table 2.

	/'—C—/(5)	/'C—/(5)	/'—C/(5)
tʂ	176(85+91)	204(96+108)	356(141+215)
ʂ	159	187	289
s	153	186	298
Θ	137	176	256
f	142	182	250
h	126(2)	149(2)	—
k	144(92+52)	190(112+78)	246(146+100)
t	137(76+61)	189(114+75)	228(127+101)
p	131(103+28)	185(118+67)	222(137+85)
dʒ	136(76×60)	166(98+68)	269(115+154)
ʒ	106	143	198
z	95	135	185
ð	66(2)	123(2)	159(2)
v	89	117	192
g	91(70+21)	133(108+25)	172(90+82)
d	78(64+14)	141(121+20)	171(97+73)
b	88	131(120+11)	186(114+72)
ŋ	98(2)	131(2)	—
n	82	118	215
m	94	131	232
l	79	118	189
w	—	134(2)	—
j	—	130(2)	—
r	70(2)	131(2)	—

Table 1.—Total average durational values in the three structures. The values are expressed msecs.

	Structure /'—C—/	Structure /'C—/
tʂ/dʒ	40	38
ʂ/ʒ	53	44
s/z	58	51
f/v	53	65
k/g	53	57
t/d	59	48
p/b	43	54
Mean value	51 σ 7.18	51 σ 8.83

Table 2.—Durational differences, in msecs. between the cognate 'voiced'-'voiceless' consonants. 'Voiceless' are longer than 'voiced' consonants by the amount expressed.

The main feature which is present in the results is the great consistency which occurs in the differentiation between the cognate voiced-voiceless consonants. This consistency is shown very clearly by the small standard deviations. This consistent differentiation can be more easily observed in figures 2 and 3.

That those consistent differences play a major role in the voiced-voiceless differentiation was shown also by Alvarez González (1974, 1978) when investigating the effect produced by the durational closure of the medial plosive in "gambling". I used synthetic speech. To produce the synthetic stimuli I used a parallel terminal analog synthesizer controlled by a PDP-12 laboratory computer. The time during which a given sound, or part of it, was performed was done by the computer following the information given. This information could be altered at will and the changes produced gave rise to different stimuli. The durations of the different segments were as follows: /ae/ 190 msecs. including 60 msecs. of transition at the beginning to mark the velar plosive; /m/ 50 msecs.; the closure of the plosive ranged from 40 to 240 msecs., in steps of 10 msecs.; /l/ 50 msecs.; and /n/ 220 msecs. No voice bar was given to either of the 'voiced' plosives.

Our aim in this experiment was to see the effect that the duration of the medial plosive had on the differentiation between /p/ and /b/ on the one hand, and between /p/ and /pp/ on the other. As our interest in this paper is to focus our attention on the first differentiation only, we shall leave aside the other aspect.

In figure 4 we show the percentages of listeners' judgements of the stimuli as being "gambling" or "gampling" as a function of the duration of the medial plosive. We include only the stimuli from 40 to 140 msecs. since in those from 140 msecs. onwards the opposition was between /p/ and /pp/.

The results show that a voiceless closure of relatively short duration, from 40 to 70 msecs., is interpreted as the 'voiced' plosivz, /b/, while a closure duration from 90 to 140 msecs. is interpreted as /p/. These results give support to the conclusion that, in the context studied here, durational differences play a major role in the 'voiced'-'voiceless' stop distinction.

4.2. Duration in final position

The importance of duration as the cue to differentiate final 'voiced' and 'voiceless' consonants was shown by Denes (1955). Tape recordings were made of utterances of /ju:z/ (to use) and /ju:s/ (the use), and the final consonants were interchanged after making adjustements to their durations. In the first place, the /s/, long sound, was cut off and shortened by using only

its central third portion. The sound thus obtained was spliced to the /ju:/ section taken from /ju:z/, after the original /z/ had been removed. In the same manner the /z/ of /ju:z/ was cut off and rerecorded three times and these three sections were spliced together and then spliced to the /ju:/ section of /ju:s/, after the original /s/ had been removed. His results showed that it was not so much the presence or absence of vocal fold vibration during the final sound what determines the listener to hear /ju:z/ or /ju:s/ but the sound duration; a short duration was interpreted as the 'voiced' consonant and a long duration was interpreted as the 'voiceless' consonant.

But the problem under investigation is more complex still and he performed asecond experiment in which another factor was studied, namely the duration of the previous sound, the vowel. In this second experiment the variables were both the duration of the vowel and the duration of the final consonant. Every vowel duration occurred in combination with every fricative duration, which made a total of 20 items. The conclusions at which he arrived were that the duration of the vowel and that of the final consonant have a definite and consistent influence on the perception of 'voicing'. He concluded that the duration of the vowel in the perception of 'voicing' is not independent of that of the consonant and viceversa. The perception of 'voicing' of the final consonant increases as the ratio of the durations of final consonants to preceding vowel decreases.

Raphael (1972) found in a study similar to the one we have just mentioned that the preceding vowel duration is a sufficient cue to the perception of the voicing feature of a word-final stop, fricative or cluster, even though the presence of voicing during the closure period of a final consonant, or cluster, does have some cue value, though minor compared to that of vowel duration. He found that the cue of preceding vowel duration is more effective before stops and clusters than before fricatives, which is to a certain extent obvious since the final stop might not be exploded.

If the perception of 'voicing' of the final consonant depends mainly on the duration of the preceding vowel, what happens when the final but one sound is another consonant has been studied by Alvarez González (1974). These, I analysed spectrographically different pairs of words in which the opposition of the final consonants was a matter of 'voice', minimal pairs of the type "send-sent", "fens-fence", "felled-felt", etc. Due to the phonotactic possibilities of the language only the nasal and lateral phonemes appear in front of both final voiced and voiceless consonants. We used two informants in this experiment, who uttered the different words. The results obtained showed that the penultimate consonants, /l, m, n/, are cosistently longer when followed by a voiced plosive or fricative than when followed by a voiceless one. This difference of duration ranged in one of the informants from 70% to 280% and in the other from 120% to 220%. The durational difference between the final consonants was also important, in the plosives especially that between the closed phases. The closed phases of /t/ and /p/ were longer than that of /d/ and the difference ranged from 100% to 340%. The voiceless fricative was also longer than the voiced one by 100%. We also found out that the first segments of the words do not seem to be affected by the lengthening phenomenon present in the rest of the word.

From the results obtained in the analysis it was not clear which durational cue is more important for the differentiation of the two members of each pair. The duration of the penultimate consonants seems to be most important, because, as in pairs like those analysed, had the plosives been unexploded, practically all the load on the differentiation would have been on them.

To study the effect that the duration of both the penultimate and final consonant had on the differentiation of minimal pairs of the type we are dealing with, in other words, to study the cause of the perception of 'voicing' in final consonants, a new experiment was designed. This time synthetic speech was used. Full details will be given in a forthcoming article. The pair studied was "fens-fence". The aim of the experiment was to determine the relative significance of the durations of the nasal and fricative in differentiating the pair. The experiment was similar to those of Denes (1955) and Raphael (1972), the difference being that instead of the penultimate sound being a vowel it is a nasal consonant.

The duration of the [n] ranged from 120 to 280 msecs. in steps of 40 msecs., i.e. five different durations, and that of the fricative, which we synthesized without a voice bar, ranged from 120 to 290 msecs., in steps of 30 msecs., i.e. seven different durations. Every nasal duration occurred in combination with every fricative duration, making a total of 35 stimuli or items. The conclusions at which we arrived were that the role played by the durational characteristics of sounds is of major importance in differentiating 'voiced' and 'voiceless' final consonants and that the durations of both final consonants have a definite and consistent influence on the perception of 'voicing' and both durations are interrelated. Neither duration is a sufficient cue. As the ratio of the durations of final consonant to preceding consonant decreases, the perception of 'voicing' of the final consonant increases.

5. Miscellany of cues

In spite of all the research done, Malecot (1970) insists on the advantages of force of articulation over the other oppositions to distinguish consonantal phonemes with the same place and manner of articulation. He objects to consonantal duration since in absolute initial plosives it is not operative and in final plosives not necessarily so. In terminal positions "the role of force in communication appears to be most important for consonants" he says, and here "it provides an acoustic cue in the form of the duration of the preceding vowel" and closure duration is not necessarily available here as a cue, since its perception depends on the presence of an audible release.

Lisker (1963), on the other hand, questions the validity of the 'fortis-lenis' description "whose wide currency" he says, "cannot be explained on the grounds that it has been adequately tested.

The controversial issue discussed has been one of priorities, namely which feature is the most important in the opposition. There is a common ground which is shared by all, and everybody agrees that the opposition is a complex one and that the feature that distinguishes it, which we may variously call voiced-voiceless, lenis-fortis, tense-lax, long-short, etc., can be conveyed by several means, presence-absence of voice bar (vocal fold vibration) contrastive vowel and closure durations, presence-absence of aspiration in stops, contrastive noise amplitudes for fricatives, etc. All this is recognized by Malecot (1970) when he says that we should not expect force of articulation to provide cues for the oppositions in all contexts, and the same can be said of duration, voice, aspiration, etc.

Similarly Lisker (1963), Jakobson and Halle (1964), Fant (1960) share this view that the opposition can be effected in several ways. We shall see which are the several ways but now lets go back to the starting point of this paper.

6. Phonetic and phonological levels. Realization rules

As we said before the terms voiced-voiceless were taken from the phonetic level indicating vocal fold vibration. It is necessary, in order to avoid all confusion, to differentiate clearly the phonetic level and the phonological one. Thus on strictly phonetic grounds a voiced consonant, or a voiced contoid if we prefer to use Pike's terminology, is always produced with vocal fold vibration while a voiceless consonant, or contoid, is determined by the absence of vocal fold vibration.

To use the same terms, voiced and voiceless, at the phonological level is feasible provided that we know the connotations of those terms at this level. It is inmaterial whether we use voiced-voiceless, lax-tense, lenis-fortis, short-long, or white-black if we prefer, to mark the opposition.

What is really important is to know the realization rules of those phonological units which are the following:

1) Plosives:

a) Initially in accented syllables /p, t, k/ are distinguished from /b, d, g/ mainly through the presence or absence of aspiration. /b, d, g/ in initial position may be partially voiced or completely voiceless.

b) In medial position /b, d, g/ may have full voice especially when they occur between vowels and in unstressed syllables. They are relatively short compared to /p, t, k/.

c) In final position /p, t, k/ and /b, d, g/ are distinguished mainly by the duration of the previous sound, especially when they are not audibly released.

Gimson (1970) advises foreign students to pay particular attention to the aspiration of /p, t, k/ when these phonemes occur initially in an accented syllable, since there is the danger that the English listener hears /b, d, g/. So we Spaniards should be aware since for us the opposition between stop cognates relies purely upon the presence or absence of voice. Another useful hint by Gimson is to "avoid excessive voicing of /b, d, g/, especially in final positions.

What has been said about the plosives can be applied with minor adjustements to the affricates.

2) Fricatives:

a) Initial position: /v, ð , z, ʒ/ may be partially voiced or completely voiceless. Duration and tenseness is what differentiates them from their 'voiceless' counterparts; they are shorter and lenis.

b) Medial position: When /v, ð , z, ʒ/ occur between voiced sounds they tend to be fully voiced. The devoincing characteristic we notice in stops in this position is much less marked in fricatives so that the tendency is to have full voice, and they are shorter and lenis.

c) In final position /v, ð , z, ʒ/ are practically voiceless. They are differentiated from their voiceless (phonological level) counterparts by their duration and especially by the duration of the preceding sound, relatively short when they are followed by a 'voiceless' fricative and relatively long when followed by a 'voiced' one.

These are the realization rules of the 'voiced' English plosives, affricates, and fricatives. In order to make ourselves understood and to have a reasonably acceptable English pronunciation, we have to put into practice those realizations and if we are teachers we have to teach them.

Whenever we have to use a pronouncing dictionary it is necessary to interpret correctly the symbols used and I hope to have thrown some light on the correct interpretation as to the realization of the 'voiced' and 'voiceless' English consonants.

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INDICE