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Phonological neutralization, phonetic implementation and individual differences

Daniel A. Dinnsen and Jan Charles-Luce

Bell Laboratories, Murray Hill, New Jersey, U.S.A. and
Department of Linguistics, Indiana University, Bloomington, Indiana, U.S.A.

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Abstract: This paper is an experimental study of the phonetic consequences of the phonological devoicing of word-final obstruents in Catalan. The results bear on two presumably distinct rule types, namely phonological neutralization rules and phonetic implementation rules. It was found, contrary to all phonological accounts, that individual speakers vary in their treatment of word-final devoicing such that there is no neutralization for, at least, some speakers. It was also found that a phonetic implementation rule is needed to account for this non-neutralization, and that the phonetic implementation rule must apply before the phonological rule devoicing obstruents.

Introduction

A fundamental distinction is made in phonology between neutralizing and non-neutralizing rules, and all theories of phonology have appealed to the distinction in the statement of grammatical principles, phonological descriptions and/or the explanation of substantive properties of rules. The assumption has always been that neutralization rules phonetically merge or obliterate the differences between segments which are phonologically contrastive in other contexts and other levels of representation. Surprisingly, little or no empirical evidence has been offered in support of neutralization rules, despite the availability of instrumental techniques of analysis. In fact, where the phonetics of putative neutralizations have been analyzed, it has been found that there are phonetic differences corresponding to the underlying distinctions. That is, the putative neutralization rules are non-neutralizing. For a review of the general issues surrounding neutralization and the associated experimental phonetic studies, see Dinnsen (1982*a*, *b*, 1983) and references therein.

The phonological rule of word-final devoicing is one putative neutralization rule that is non-controversial as a rule of grammar and is widely attested in the languages of the world. Experimental findings on the phonetic consequences of this rule from German (Port, Mitleb & O'Dell, 1981; O'Dell & Port, 1983), Polish (Giannini & Cinque, 1978) and Russian (Chen, 1970), however, suggest that its neutralizing effect may not be so indisputable. For each of these languages, it was found, contrary to all phonological accounts, that the underlying voice distinction was not neutralized. Phonetic distinctions were observed in any one or some combination of the following parameters: (1) the vowel duration before word-final obstruents, (2) the closure duration of the final obstruent, and (3) the voicing into the beginning of the closure of the final obstruent.

While the experimental studies on word-final devoicing in various languages have yielded

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findings that would seem to compromise seriously the construct "neutralization", it is at least possible that those results are an artifact of orthography. The problem is that even though word-final obstruents are supposed to be phonetically voiceless due to the devoicing rule, in the languages cited above the underlying voice distinction is also represented in the orthography. It could be argued, then, that speakers produce phonetic distinctions that are intended to correspond with orthographic distinctions since the orthography corresponds with phonological distinctions in positions other than word-finally. Of course, it could also be argued the other way. That is, because speakers produce phonetic distinctions, the orthography is set up to reflect those differences. In any event, these concerns are obviated by a language with a rule of word-final devoicing and no orthographic distinctions in that context corresponding with underlying phonological voice distinctions. Catalan presents such a situation.

This paper is an experimental study of the phonetics of the putative neutralization rule of word-final devoicing in Catalan. For a discussion of Catalan phonology, see Wheeler (1979), DeCesaris (1980), Dinnsen (1979, 1980), Mascaro (1978), and Walsh (1977). The results derived from the present study should contribute to the accumulation of empirical evidence on neutralization phenomena and serve as a basis for cross-language comparisons of similar or related phonological processes. The specific questions asked in this study are: Is the rule of word-final devoicing neutralizing, and do all speakers treat the phenomenon the same?

The rule of word-final devoicing is motivated by alternating and non-alternating pairs of words exemplified in Table I. Word-medial voiced obstruents alternate with word-final voiceless obstruents; word-medial voiceless obstruents do not alternate. The usual observation is that all obstruent stops are voiceless word-finally when phrase-final or when followed by a word beginning with either a vowel or a voiceless consonant.[1] Such forms require postulating underlying representations which differ in terms of the [voice] feature of morpheme-final obstruents such that some word-final voiceless obstruents are derived from underlying voiced obstruents by the rule of word-final devoicing and others are derived from underlying voiceless obstruents.

The rule of word-final devoicing has been formulated as follows:

$$[-\text{sonorant}] \rightarrow [-\text{voice}] / \_ \#$$

Table I Examples of alternating and non-alternating pairs of words from Catalan motivating the phonological rule of word-final devoicing

[ʎóp]	wolf (m)
[ʎóβə]	wolf (f)
[əmik]	friend (m)
[əmiɣə]	friend (f)
[sɛ́k]	dry (m)
[sɛ́kə]	dry (f)
[frɛ́t]	cold (m)
[frɛ́ðə]	cold (f)
[tót]	all (m)
[tótə]	all (f)

[1] Word-final obstruent stops agree in [voice] with a following consonant. A rule of regressive voice assimilation is motivated (see references above). Regressive voice assimilation cannot in any case account for the voicelessness of stops word-finally when the next word begins with a vowel.

Table II Experimental test words from Catalan specified in phonetic, underlying and orthographic representations along with associated meanings

Phonetic	Underlying representations	Orthographic	Gloss
1. [kap]	/kap/	cap	no(ne)
2. [kap]	/kap/	cap	toward
3. [kap]	/kab/	cap	head
4. [kap]	/kab/	cap	he fits
5. [fat]	/fat/	fat	fate
6. [fat]	/fad/	fat	silly
7. [sek]	/sek/	séc	furrow
8. [sek]	/seg/	cec	blind
9. [sɛk]	/sɛk/	sec	dry (masc. sg.)
10. [sɛk]	/sɛg/	sec	I sit down

Method

Design and materials

Ten test words were selected and are shown in Table II in their phonetic, underlying and orthographic representations with the corresponding meaning. These items constitute underlying minimal pairs. Each member of a pair differed only in the underlying [voice] feature of the final consonant. The underlying voicing of obstruents was determined based on morphophonemic evidence. Across pairs, the place of articulation of the final consonant was varied. Note that the first four items are said to be homonyms and end in a labial stop. Items 5 and 6 are presumed to be homonyms and end in a dental stop. Items 7–10 end in a velar stop, but 7 and 8 differ from 9 and 10 in vowel quality. Note, however, that 7 and 8 differ from one another in underlying voicing just as 9 and 10 do.

Each test word was embedded in the two carrier sentences shown in Table III. The carrier sentences were constructed so that only the word following the test word differed, but in a specific way. In one sentence the test word occurred before a word beginning with a voiceless consonant and in the other sentence the test word occurred before a word beginning with a vowel. For the test words in which the final obstruent was underlyingly voiced, the final obstruent should, then, be phonetically voiceless due either to the rule of word-final devoicing or the rule of regressive voice assimilation. The ten test words in the two sentence contexts resulted in 20 experimental sentences.

Table III Catalan carrier sentences in which test words were embedded

Maria va dir —— clarament.
[mariə va ði —— klarɔmen]
"Mary said —— clearly."
Maria va dir —— aixi.
[mariə va ði —— əši]
"Mary said —— thus."

Five repetitions of each experimental sentence were presented for a total of 100 experimental sentences. The experiment was therefore a 2 (underlying voicing: voiced/voiceless) × 2 (environment: − #C and − #V) × 5 (minimal pairs) × 5 (repetitions) × 5 (subjects) factorial design.

A total of 560 filler sentences were constructed for use in other experiments and to disguise the focus of this experiment. A separate typed list of the 660 sentences was prepared for each subject with the order of presentation fully randomized.

Subjects

Three male and two female adult native speakers of standard (Barcelona) Catalan served as subjects in this experiment.

Procedure

The five subjects were asked to read the list of 660 Catalan sentences. It is important to note that the orthography of Catalan, unlike the orthography in the other languages examined in this regard (e.g. German), does not distinguish the underlying voicing of word pairs; for example, /fad/ and /fat/ are represented orthographically as *fat*. Underlying representations are thus not uniquely recoverable from the orthography. Consequently, in order to cue the subjects as they read as to which meaning (and thus which underlying representation) was intended, a Spanish gloss was provided in parentheses immediately after the test word in the carrier sentence. This glossing was done for all 660 sentences in order not to assign any special status to the test words of the experimental sentences.

Each subject recorded a different randomization of the 660 sentences. Four of the subjects were recorded in an anechoic chamber in the Phonetics Laboratory of the Department of Linguistics at Indiana University using a Revox A-700 tape recorder. One subject was recorded in an anechoic chamber at Bell Laboratories at Murray Hill using a Crown studio tape recorder. Prior to recording, subjects were permitted to read over the entire list of sentences to familiarize themselves with the words and the task. Subjects were instructed to read the sentences at a normal speaking tempo during the recording phase.

Two of the recordings were digitized at Bell Laboratories and the remaining three recordings were digitized at the Speech Research Laboratory in the Psychology Department at Indiana University. All recordings were digitized at a sampling rate of 10kHz, and the test words were measured using digital waveform editors (Nakatani, 1977; Luce & Carrell, 1981). Three different time intervals were measured for all 100 test words for all subjects. The measurements obtained were relevant to the final consonant of each test word and the preceding vowel. Time intervals measured and criteria for measurement were as follows.

(1) Vowel duration. The interval from onset of periodicity in the waveform to sudden drop in amplitude.

(2) Consonant closure duration. The interval from offset of vowel and onset of consonant constriction (see above) to burst, typified by a distinct perturbation in the waveform or a sudden increase in amplitude.

(3) Voicing into consonant closure. The interval representing glottal pulsing into the beginning of the final consonant from the offset of vowel duration (see above) until energy was no longer detected.

These particular phonetic parameters were chosen for measurement because they have been found in other languages to evidence phonetic differences corresponding to underlying distinctions involving a rule of word-final devoicing.

Although the experimenters applied the above measurement criteria stringently, discrepancies in measurement may be expected. Thus, approximately three months after the original measurements were made, one of the experimenters randomly redigitized and remeasured 20% of the test words per talker in order to obtain an estimate of measurement error. Mean

measurement errors were calculated for vowel durations and consonant closure durations.[2] The results indicated that no single mean measurement error exceeded ± 3 ms for vowel durations or ± 9 ms for closure durations. The total mean measurement errors for all five talkers did not exceed 1 ms for vowel duration or 4 ms for closure duration.

The results of each dependent measure are reported separately, first, for all subjects as a group and then individually. All statistical analyses for the group results and individual differences are based on four of the five repetitions per test word because of a mispronunciation by a subject and extraneous noise in the recording of a subject. Where it was not necessary to discard any tokens, one repetition was pseudo-randomly discarded to obtain an equal number of repetitions for all test cells.

Results: group data

Vowel duration

Figure 1 presents mean values of vowel duration for the four conditions derived by underlying voicing and environment for all subjects as a group. The results of ANOVA showed a significant main effect of environment, $F(1, 4) = 19.59$, $p < 0.01$; but there was no main effect of underlying voicing nor a significant interaction between environment and underlying voicing.

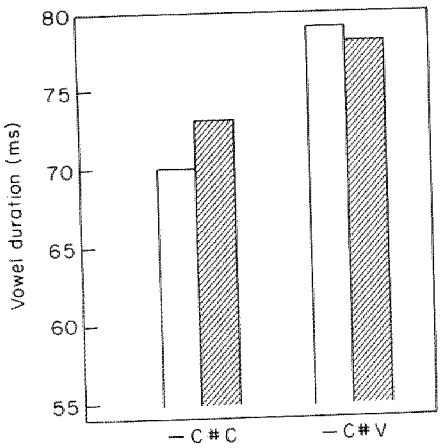

Figure 1 Mean vowel durations collapsed across all subjects for the four conditions defined by underlying voicing and environment. Significant main effect of environment, $p < 0.01$, by ANOVA. □ UR voiceless; ▤ UR voiced.

The main effect of environment shows that vowels shorten by approximately 9% before word-final obstruents followed by a word-initial consonant, i.e. in the environment –C#C.

Closure duration

Figure 2 presents mean values for closure duration for the four conditions defined by underlying voicing and environment. The results of ANOVA showed no significant main effects or interactions.

[2] Voicing into closure was not remeasured since no significant differences were observed in either the group data or the individual differences data. See the results section below.

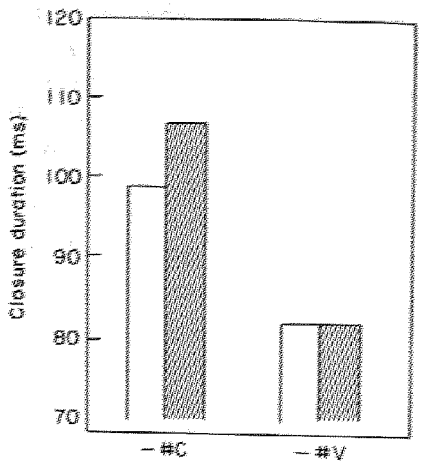

Figure 2 Mean closure durations collapsed across all subjects for the four conditions defined by underlying voicing and environment. □ UR voiceless; ▤ UR voiced.

It can be seen, however, that word-final obstruents tend to be shorter in closure duration when the next word begins with a vowel, i.e. in the environment −#V.

Voicing into closure

Figure 3 presents mean values for voicing into closure for the four conditions defined by underlying voicing and environment. The results of ANOVA showed no significant main effects or interactions.

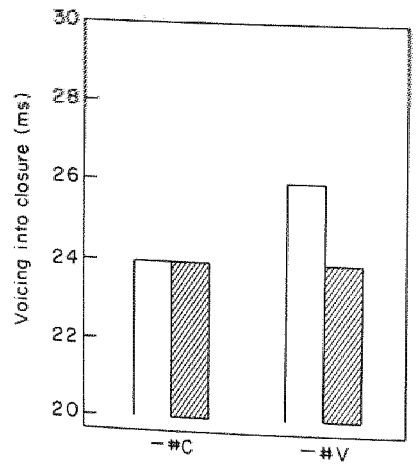

Figure 3 Mean voicing into closure collapsed across all subjects for the four conditions defined by underlying voicing and environment. □ UR voiceless; ▤ UR voiced.

Results: individual differences

Table IV presents the mean values from each subject for each of the dependent measures (vowel duration, closure duration, and voicing into closure) for the four conditions defined by underlying voicing and environment.

The results of ANOVA showed no significant main effects or interactions for any subject for the variable of voicing into closure.

Table IV Mean values (ms) from each subject for each dependent measure for the four conditions defined by underlying voicing and environment

Subject	Underlying voicing	Vowel duration		Closure duration		Voicing into closure	
1	−voice	62	77	99	84	18	20
	+voice	67	74	100	91	18	20
2	−voice	60	68	83	76	29	27
	+voice	63	69	104	83	26	27
3	−voice	68	71	111	75	26	23
	+voice	64	69	106	68	25	23
4	−voice	66	70	105	60	25	27
	+voice	72	73	111	61	27	25
5	−voice	93	106	88	117	22	31
	+voice	97	103	100	108	25	28
Environment		−C#C	−C#V	−#C	−#V	−#C	−#V

Two of the subjects (3 and 5) showed no significant main effects or interactions for any of the variables. Subject 4 showed a significant main effect of environment for closure duration, $F(1, 1) = 157.22$, $p < 0.05$. In the case of Subject 4, then, word-final obstruent closure durations are shorter before a word beginning with a vowel, i.e. in the environment −#V.

Subjects 1 and 2, however, did show some interesting and significant main effects and interactions. For instance, Subject 1 showed a significant main effect of environment for both vowel duration, $F(1, 1) = 4325.14$, $p < 0.01$, and closure duration, $F(1, 1) = 149.35$, $p < 0.05$, and a significant interaction between environment and underlying voicing for vowel duration, $F(1, 1) = 2023.00$, $p < 0.02$. Consequently, in the environment −C#C, vowels shorten; but they shorten significantly more (by 20%) before an underlying voiceless obstruent compared with only 10% shortening before an underlying voiced obstruent. Also, final obstruent closure durations are shortened by 12% (statistically significant) in the environment −#V.[3] The shortening of consonant closure durations for this subject is almost identical to that observed for Subject 4.

The results for Subject 2 are strikingly different (with some notable exceptions). There were no main effects or interaction for vowel duration. However, there were main effects of both environment, $F(1, 1) = 4784.14$, $p < 0.01$, and underlying voicing, $F(1, 1) = 273.59$, $p < 0.04$, for closure duration. It is the main effect of underlying voicing that constitutes the most striking difference. The similarity arises in the main effect of environment, which we found with Subjects 1 and 4. These results show that closure durations are shortened by 15% (statistically significant) in the environment −#V. This is similar to the shortening effect seen in Subjects 1 and 4 and in the group results, although it was not statistically significant for the group data. More importantly, however, for this subject underlying voiced obstruents are approximately 15% longer in closure duration than

[3] The results for Subject 1 have been reported elsewhere (Dinnsen 1982*a*, *b*) but are slightly different from the results reported here. In the earlier studies, there was also a significant interaction between environment and underlying voicing for closure duration. The loss of that interaction in this study is likely due to the statistical analysis and the reduced number of repetitions. See the Procedure section in this paper for an explanation.

underlying voiceless obstruents, independent of environment. No other subject evidenced this main effect of underlying voicing.

Discussion

The results from this study bear on three general issues: (1) the empirical assessment of a putative neutralization of the word-final voice contrast, (2) the characterization of non-neutralization, and (3) the description of individual speaker differences.

Neutralization and individual differences

In order to maintain that word-final devoicing is non-neutralizing in Catalan, it would be sufficient to find in the results of ANOVA a significant main effect of underlying voicing in any one of the three variables examined or a significant interaction between underlying voicing and environment in any of those variables. A main effect of underlying voicing would show that phonetically a distinction is being maintained between word-final underlying voiced and voiceless obstruents. A significant interaction would mean that underlying voiced and voiceless obstruents are treated differently in different environments. The group results failed to yield such findings. This does not mean, however, that word-final devoicing is neutralizing. All that can be concluded based on the group results is that no differences corresponding to the underlying voice distinction were observed in the parameters examined. It is possible that an examination of other phonetic parameters (e.g. fundamental frequency, burst characteristics, etc.) would reveal the appropriate distinctions. There is, moreover, a general problem in the empirical substantiation of neutralizations. The problem is that in order to establish a case of neutralization, it would be necessary to show that all phonetic parameters that could possibly be influenced by the underlying distinction have been identified and have failed to yield any phonetic differences. We are, unfortunately, far from having identified all the relevant parameters.

While the group results failed to yield findings that established the non-neutralization of the voice contrast, the individual subject data showed considerable differences across subjects and non-neutralization for some subjects. In particular, Subjects 1 and 2 did not neutralize the voice contrast, although their strategies for maintaining the contrast were different. Subject 1, for example, exhibited a statistically significant interaction between underlying voicing and environment for vowel duration. The interpretation of this finding is that vowels shorten before a word-final obstruent if the next word begins with a consonant, but they shorten significantly less if the word-final obstruent is underlyingly voiced. That is, vowels shorten by 20% before underlying voiceless obstruents but only by 10% before underlying voiced obstruents. While this difference is small in magnitude, it is nonetheless statistically significant and supports the claim that the voice contrast is not neutralized. The magnitude of these phonetic differences no doubt raises questions about the perceptual salience of certain production differences. The relationship between perception and production facts in such matters and the implications of the two for phonological theory are considered in Dinnsen (1983). The mere fact that a production difference may not be discriminated by a speaker does not mean that the production difference is linguistically non-significant. Dinnsen reviews a number of experimental studies establishing the independence of production and perception. In any event, there are important questions to be raised concerning the goals of phonological description, i.e. are they production-based or perception-based? For a discussion of how this contextual shortening is implemented, see the section below on phonetic implementation.

Subject 2 used a different strategy for not neutralizing the voice contrast. For this subject,

there was a significant main effect of underlying voicing for closure duration. Specifically, underlying voiced and voiceless obstruents were overall kept distinct phonetically by a difference of 15% in the closure duration of final obstruents.

One point which emerges from this study is the richness of individual speaker variation in the treatment of one phonological phenomenon, namely word-final devoicing. An examination of the group data alone would have failed to reveal linguistic distinctions that were being used by individual speakers and would also have attributed to some speakers distinctions that those speakers were not using. The strategies for maintaining the underlying voice distinction can vary across speakers. In this study, one speaker maintained the voice distinction by means of a contextual shortening of vowels. Another speaker maintained the distinction in terms of closure duration. Even with regard to those phonetic effects where underlying voice may not have been involved, it can be seen that there is considerable speaker variation. For example, three subjects showed main effects of environment for closure duration while the other two did not. Similarly, only one subject showed a main effect of environment for vowel duration while the other four did not. The fact that three speakers from this study failed to exhibit phonetic differences corresponding to the underlying voice distinction is less surprising given the range of variation that is apparently possible and the limited set of phonetic variables examined in this experiment.

Non-neutralization and phonetic implementation

The fact that the word-final voice contrast is not always neutralized (despite the operation of the devoicing rule) requires a characterization that departs from standard conceptions of phonology. Under the standard view, the rule of word-final devoicing would be neutralizing if no other rules interacted with it. Apparently, however, some other process which appeals to the underlying voice distinction is interacting with the phonological devoicing rule. The evidence for this is that the voice distinction is preserved, although in masked terms. For example, in our study, the underlying voicing of word-final obstruents can be determined from a speaker's differential shortening of vowels (e.g. Subject 1). This is not unlike what Kaye (1974, 1975) has termed "recoverability" of underlying distinctions as a result of certain phonological rule interactions. The observation in phonological terms is that a rule appears to have applied despite the lack of any apparent phonetic conditioning. It is thus claimed that phonological rules can apply in such a way as to allow underlying distinctions that would otherwise be obliterated (neutralized) to be recovered or preserved. It is as if a rule or rule interaction is motivated in order to avoid or compensate for a potential neutralization.

The rule and the rule interaction motivated for this study are different than what is expected phonologically because it appears that a phonetic implementation rule is crucially involved and that it must apply before the phonological devoicing rule.

Given the group results for vowel duration, it is evident that vowels are systematically affected by their local phonetic environments (even across word boundaries) and must, therefore, be adjusted by rule. Such an adjustment is relatively small (9% shortening – yet statistically significant) and may even be subphonemic, characteristic of phonetic implementation rules. Figure 4(a) presents a first approximation of the rule(s) needed to account for this adjustment.[4]

[4] The formalism and features used in the statement of these rules are not intended as a proposal for the characterization of phonetic implentation rules. They are a matter of convenience. The angle bracket notation may be interpreted as in generative phonology.

(a) Group results

$$V \rightarrow [\text{shorten N}] / - [-\text{son}] * C$$

(b) Subject 1

$$V \rightarrow [\text{shorten N} < -1 >] / - \left[\begin{matrix} -\text{son} \\ < +\text{voice} > \end{matrix}\right] * C$$

Figure 4

Phonetic implementation rules. (a) This characterize the group results and specifies that vowels are shortened before a word-final obstruent if the next word begins with a consonant. (b) This characterizes the results from Subject 1 and specifies that vowels are shortened before a word-final obstruent if the next word begins with a consonant, but they are shortened to a lesser extent if the final obstruent is voiced.

The rule specifies that vowels are shortened before a word-final obstruent if the next word begins with a consonant. The claim embodied in this rule is consistent with phonetic and phonological expectations that vowels shorten before a consonant cluster.

The facts of vowel duration for Subject 1 require a somewhat different formulation of the phonetic implementation rule and is reformulated in Fig. 4(b). Subject 1 exhibits the same general contextual vowel shortening; but given the significant interaction of environment and underlying voicing, the rule must also be sensitive to the feature [voice]. The rule for Subject 1 thus specifies that vowels are shortened before a word-final obstruent if the next word begins with a consonant, but they are shortened to a lesser extent if the final obstruent is voiced. This would account (roughly) for the statistically significant difference of shortening 20% before underlying voiceless obstruents but only 10% before underlying voiced obstruents.

According to the conditions specified in the contextual vowel shortening rule (Fig. 4(b)), the word-final obstruent must be voiced if the rule is to apply properly. It should be noted, however, that word-final obstruents are not voiced phonetically; they are voiceless due to the phonological rule of word-final devoicing. The contextual shortening rule cannot, then, apply after the phonological rule devoicing final obstruents since the phonological rule would bleed (i.e. remove representations from the domain of) the shortening rule. It is only prior to the application of the phonological rule that the structural description of the shortening rule can be satisfied. We leave open the issue of whether the shortening rule applies before or simultaneously with the phonological rule. In either case, the point remains that the shortening rule cannot apply after the phonological rule.

These findings refute the generally accepted contention (e.g. Anderson, 1975; Chomsky & Halle, 1968; King, 1973; Klatt, 1976) that there is a separate phonological rule component ordered before a phonetic rule component. They also refute the weaker claim that phonological rules must apply before phonetic implementation rules.

It could be argued, however, that the shortening rule is not a phonetic implementation rule, but rather a *bona fide* phonological rule. While these findings would not bear, then, on the issue of the interaction of phonological rules and phonetic implementation rules, such an argument would have significant consequences for phonological theory and the conduct of research in the field. The most obvious consequence would be that phonological representations and rules would have to incorporate time as a parameter. Any distinction between phonological rules and phonetic implementation rules would be diminished. On the methodological side, phonologists would be required to take account of the additional facts

previously left to the concern of phoneticians. We know of no *a priori* objections to any of the consequences considered here, but all require modifications of standard phonological theory. Either phonetic implementation rules must be permitted to apply freely among phonological rules, or phonological rules and phonetic implementation rules cannot be differentiated.

Conclusion

Evidence has been presented that for at least some speakers the word-final voice contrast is not neutralized in Catalan. Individual speakers vary in their production strategies for maintaining the voice contrast as well as in their treatment of other phonetic effects (e.g. contextual shortening of closure durations). In certain instances, a phonetic implementation rule (or a rule accounting for relative timing) must be permitted to apply before the phonological devoicing rule in order to account for the non-neutralization of the word-final voice contrast. The results from this study provide little or no support for the construct "neutralization", at least, in the case of the widely attested rule of word-final devoicing.

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References

Anderson, S. R. (1975). On the interaction of phonological rules of various types. *Journal of Linguistics*, 11, 39–62.

Chen, M. (1970). Vowel length variation as a function of the voicing of the consonant environment. *Phonetica*, 22, 129–159.

Chomsky, N. & Halle, M. (1968). *The Sound Pattern of English*. New York: Harper & Row.

DeCesaris, J. (1980). Consonant alternations in Catalan. *Innovations in Linguistics Education*, 1, 65–84.

Dinnsen, D. A. (1979). Atomic phonology. In: *Current Approaches to Phonological Theory*. (Dinnsen, D. A. ed.) pp. 31–49. Bloomington: Indiana University Press.

Dinnsen, D. A. (1980). Phonological rules and phonetic explanation. *Journal of Linguistics*, 16, 171–191.

Dinnsen, D. A. (1982*a*). *On the Phonetics of Phonological Neutralization*. Paper presented at the Working Group on Language/Speech Behavior, XIII International Congress of Linguists, Tokyo.

Dinnsen, D. A. (1982*b*). *Abstract Phonetic Implementation Rules and Word-final Devoicing in Catalan*. Paper presented at the annual meeting of the Linguistic Society of America, San Diego.

Dinnsen, D. A. (1983). On the characterization of phonological neutralization. *Research in Phonetics*, Vol. 3.

Giannini, A. & Cinque, U. (1978). Phonetic status and phonemic function of the final devoiced stops in Polish. *Speech Laboratory Report*. Napoli: Istituto Universitario Orientale.

Kaye, J. D. (1974). Opacity and recoverability in phonology. *The Canadian Journal of Linguistics*, 19, 134–149.

Kaye, J. D. (1975). A functional explanation for rule ordering in phonology. In: *Functionalism*. pp. 244–252. Chicago: Chicago Linguistic Society.

King, R. D. (1973). Rule insertion. *Language*, 49, 551–578.

Klatt, D. H. (1976). Linguistic uses of segmental duration in English: Acoustic and perceptual evidence. *Journal of the Acoustical Society of America*, 59, 1208–1221.

Luce, P. A. & Carrell, T. D. (1981). Creating and editing waveforms using WAVES. *Research on Speech Perception*. No. 7: 287–297. Bloomington: Indiana University.

Mascaro, J. (1978). *Catalan Phonology and the Transformational Cycle*. MIT Doctoral Dissertation. (Also Indiana University Linguistics Club, Bloomington.)

Nakatani, L. (1977). Computer-aided signal handling for speech research. *Journal of the Acoustical Society of America*, 61, 1056–1062.

O'Dell, M. & Port, R. (1983). *Discrimination of Word-final Voicing in German*. Paper presented at the Acoustical Society of America, Cincinnati.

Port, R., Mitleb, F. and O'Dell, M. (1981). *Neutralization of Obstruent Voicing in German is Incomplete*. Paper presented at the Acoustical Society of America, Miami.
Walsh, T. (1977). *On the Necessity of Rule Ordering in Natural Generative Phonology*. Presented at the VIIth Linguistic Symposium of Romance Languages, Cornell University, Ithica.
Wheeler, M. (1979). *Phonology of Catalan*. Oxford: Blackwell.