

On the neutralizing status of Polish word-final devoicing

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Within phonological theory a fundamental distinction is made between rules that are neutralizing and those that are non-neutralizing. Recent experimental research has examined a number of neutralization rules and found that underlying contrasts are, in fact, phonetically preserved. These findings have raised a number of questions about the character of neutralization rules. This paper examines the phonetic effects of word-final devoicing in Polish across different places and manners of articulation, in different phonetic contexts as produced by five different speakers. Fifteen pairs of words (distinguished by underlying voicing of the word-final obstruent) were recorded in two contexts ($_ \# C$ and $_ \# V$). Measurements were obtained for the final consonant closure duration, voicing into closure, and preceding vowel duration. The results demonstrate that the rule of word-final devoicing in Polish is not neutralizing for the group of Polish speakers studied nor for any of the individual speakers. The underlying voice distinction is preserved phonetically. However, the manner in which it is preserved varies depending on phonetic context, place and manner of articulation, and individual speaker. This variation is, nonetheless, systematic and must be accounted for by phonetic implementation rules that are sensitive to abstract phonological distinctions.

1. Introduction

One principal focus of speech science research has been the examination of the phonetic characteristics or implementation of selected phonological contrasts within and across languages. The phonological voice contrast in obstruents, for example, has probably been studied most systematically and extensively in this regard. As a result, a set of acoustic-phonetic parameters has been reliably identified for the implementation of the voice contrast in various contexts. These include vowel duration, voice onset time (VOT), closure duration, voicing into closure and variation in fundamental frequency. These phonetic parameters have been found to vary within limits across the languages of the world and across different contexts within a language (see Keating, 1984, and references therein). While phonological contrasts are fundamental to a sound system and

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are, thus, appropriate as an object of phonetic study, the absence of a contrast is equally fundamental to the characterization of a sound system. For example, while obstruent voicing may in some languages be contrastive in certain contexts within a word (e.g. initially or medially), it may be non-contrastive in certain other specifiable contexts (e.g. word-finally). Typically, when obstruent voicing is non-contrastive in word-final position, only voiceless obstruents occur in that position. Non-contrastive properties of speech are, thus, predictable by rule whereas contrastive properties are not. Interestingly, the bulk of phonetic research has not been concerned with the acoustic effects of such phonological rules. There are in fact very few studies that examine in any detail phonetic properties that could be the result of the application of phonological rules (e.g. see Beckman, 1984 and Dinnsen, 1985, for a general review of phonetic studies associated with phonological rules). The studies that do exist do not permit systematic comparisons since the phonological rules involved are not comparable across languages. Despite the phonological diversity across the various studies, however, one general finding obtains, that is, systematic phonetic differences can be identified in the speech signal that correspond with underlying phonological distinctions. Neutralization rules are one phonological rule type for which this finding obtains. This is surprising since it has always been assumed that neutralization rules have the effect of phonetically merging an underlying contrast. A theoretical dilemma, thus, arises concerning the presumed distinction between neutralization rules and allophonic rules¹.

This paper is offered as one part of a general attempt to systematically study the phenomenon of neutralization by examining the phonetic effects of a specific neutralization rule in Polish that is shared by a number of other languages—word-final devoicing. The rule of word-final devoicing is generally attested in many languages and is a textbook example of a phonological neutralization rule. The phonetic effects of this phenomenon have been studied for two languages other than Polish, i.e. Catalan (Dinnsen & Charles-Luce, 1984) and German (Dinnsen & Garcia-Zamor, 1971; Mitleb, 1981; Fourakis & Iverson, 1984; Port, Mitleb, & O'Dell, 1984; Port & O'Dell, 1984; Charles-Luce, 1985*a*). In both languages, a limited set of temporal parameters were selected for examination including the duration of the vowel preceding the word-final obstruent, the duration of the word-final consonant closure and the duration of glottal pulsing into the word-final consonant closure.

The conclusion that emerges from the phonetic studies on Catalan and German is that the rule of word-final devoicing is non-neutralizing. In general, the underlying voicing distinction is phonetically preserved in terms of one, or some combination, of the temporal intervals noted above. While this is generally the case, the results have been somewhat mixed on this point since some studies have failed to identify phonetic differences corresponding to the underlying voicing distinction for all speakers. For example, Dinnsen & Charles-Luce (1984) found that individual speakers of Catalan vary in their production of final (de)voicing. That is, for some speakers the voice contrast was preserved in terms of differences in closure duration. For other speakers, the voice contrast was preserved in the treatment of vowel durations relative to underlying voicing and phonetic context. The finding in this instance revealed that vowel durations before a final obstruent are affected by certain phonetic properties of the initial segment of the next word (i.e. consonant or vowel) in connected speech, in addition to being affected

¹For a discussion of the theoretical distinction between neutralizing and allophonic rules, see Kiparsky (1976), Fourakis (1984) and Dinnsen (1985).

by the underlying voicing of the final obstruent. As a result of this interaction between underlying voicing and phonetic context, it was observed that vowels shorten to a lesser extent before underlying voiced obstruents if the next word begins with a consonant. Consequently, if phonetic context had not been a variable in that study, the phonetic preservation of the voice contrast might not have been revealed².

In the case of German, some studies have failed to observe phonetic differences corresponding to the underlying voice contrast (e.g. Dinnsen & Garcia-Zamor, 1971; Fourakis & Iverson, 1984). However, in a more detailed analysis of German, Charles-Luce (1985*a*) did find phonetic differences. What emerges from Charles-Luce (1985*a*) is that the voicing distinction is most clearly observed in certain places and manners of articulation in certain phonetic contexts.

Therefore, although the results from these studies are complex, they suggest that, based on acoustic effects, the present characterization of word-final devoicing is inaccurate. We are left with the conclusion that the same rule shows variation across different languages as well as across different speakers and different conditions within the same language. It is thus necessary to observe how the same rule is implemented in different languages and under different conditions (e.g. phonetic context, place and manner of articulation) to determine the range of variation associated with the rule. Furthermore, although Slavic languages are well-known for their (de)voicing rules, the phonetic effects of these rules have not been studied to the same extent as in Romance and Germanic languages.

The rule of word-final devoicing for Polish is motivated by the facts exemplified in Table I and is presumed to be neutralizing. Specifically, word-medial voiced obstruents alternate with word-final voiceless obstruents; word-medial voiceless obstruents do not alternate. While voicing is contrastive in medial position, it is presumed to be non-contrastive in final position since all word-final obstruents appear to be produced as voiceless³. In order to account for the word-medial voice contrast and the morphophonemic alternations, a phonological account requires postulating underlying representations that differ in terms of the [voice] feature of morpheme-final obstruents. At the phonetic level, 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. Whatever the underlying source of the phonetically voiceless obstruents, no phonetic differences in word-final obstruents are expected to correspond with the underlying [voice] distinction.

The rule of word-final devoicing, thus, converts underlying voiced obstruents into

²An analysis of the results for certain other individual speakers failed to identify phonetic differences corresponding to the underlying voice distinction. It cannot, however, be concluded from a null result that neutralization did occur for those speakers. It is possible that the voice contrast was maintained in terms of other parameters not considered in the study. It is evident that there is considerable individual variation which has only just begun to be investigated.

³Polish, like many other languages with word-final devoicing, also exhibits the effects of a regressive voice assimilation rule. Consequently, word-final obstruents are voiceless when phrase-final or when followed by a word beginning with either a vowel or a voiceless consonant. The rule of word-final devoicing is clearly evidenced in those instances where the voiceless character of the final obstruent could not be attributed to assimilation, i.e. when the next word begins with a vowel. With regard to the interaction of Regressive Voice Assimilation and Word-Final Devoicing, it is assumed that a principle such as the Elsewhere Condition (Kiparsky, 1973) will affect disjunctive ordering of Regressive Voice Assimilation and Word-Final Devoicing. For a general discussion of Polish phonology, see Mikos (1977). Furthermore, see Dinnsen (1985) for a discussion of the possible distinction between assimilatory and non-assimilatory neutralization.

TABLE I. Data which motivate a word-final devoicing rule in Polish (from Kenstowicz and Kisseberth, 1979)

Singular	Plural	Gloss	Underlying representation
klup	klubi	'club'	klub
trup	trupi	'corpse'	trup
snop	snopi	'sheaf'	snop
trut	trudi	'labor'	trud
kot	koti	'cat'	kot
grus	gruzi	'rubble'	gruz
nos	nosi	'nose'	nos
wuk	wuji	'lye'	wug
wuk	wuci	'bow'	wuk
sok	soci	'juice'	sok

phonetically voiceless obstruents and accounts for the absence of a voice contrast word-finally. The rule can be formulated as follows:

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

Only one other phonetic study has been reported that examines word-final devoicing in Polish (Giannini & Cinque, 1978). These researchers found that word-final stops that are underlyingly voiceless have a longer closure duration than word-final stops that are underlyingly voiced. Furthermore, their results showed greater voicing into closure for the underlyingly voiced word-final stops. The findings are, however, difficult to interpret given the absence of any details about the experimental design or method of analysis. Moreover, no statistical analyses are reported. The study was in any event limited to an examination of word-final stops.

The present investigation was conducted in order to systematically examine the acoustic effects of word-final devoicing in Polish. Such an examination would provide additional evidence to that obtained for the same phenomenon in German and Catalan. Acoustic data from different languages using the same rule provides evidence regarding the implementation of the rule across languages. In order to address the issue of within-language variation, five speakers recorded minimal pairs of words in which the final obstruent varied in place and manner of articulation. Moreover, the test words were embedded in sentences that provided two different phonetic contexts.

2. Method

2.1. Subjects

One male and four female adult native speakers of Polish served as subjects in this experiment. Each of the speakers was born in Poland. The speakers had no known history of speech or hearing disorders.

2.2. Materials and design

Fifteen pairs of test words were chosen such that the items in a pair constituted an underlying minimal pair. The only contrastive feature between the items in each pair was the underlyingly voice feature of the final consonant. A native Polish speaker (who was not

TABLE II. The 15 minimal pairs used in the experiment listed by phonetic representation (PR), orthographic representation (OR), underlying representation (UR), and the associated gloss. At the right of the table are the inflected forms (IFO), presented orthographically, that motivate the proposed underlying representations.

PR	OR	UR	Gloss	IFO
karp	karp	karp	carp	karpi
karp	karb	karb	notch	karby
grup	grup	grup	group (gen. pl.)	grupi
grup	grób	grub	grave	groby
jot	jot	jot	letter j	joty
jot	jod	jod	iodine	jody
grat	grat	grat	old thing	graty
grat	grad	grad	hail	grady
kot	kot	kot	cat	koty
kot	kod	kod	code	kody
pot	pot	pot	perspiration	poty
pot	pod	pod	under	pod oknem
lok	lok	lok	curl	loki
lok	log	log	logarithm	logi
wuk	łuk	wuk	bow	łuki
wuk	ług	wug	lye	ługi
brik	bryk	brik	coach	bryki
brik	bryg	brig	brig	brygi
paf	paf	paf	flop	pafy
paf	paw	pav	peacock	pawie
vjeɛ	wieś	vjeɛ	village	wsie
vjeɛ	wieź	vjez	carry!	wieziemy
kaɟ	każ	kaɟ	order!	kaz-ę
kaɟ	kasz	kaʒ	cereal (gen. pl.)	kasze
ɲjeɲtɔ	pięć	ɲjeɲtɔ	five	pięciu
ɲjeɲtɔ	piędź	ɲjeɲdz	span	piędzie
xotɔ	choć	xotɔ	although	
xotɔ	chodź	xodz	come	chodzimy
mjeɲtɔ	mieć	mjeɲtɔ	to have	
mjeɲtɔ	miedz	mjedz	copper	miedzie

a subject in this study) verified the pronunciation and meanings of each of the test words. Table II lists the words used in the experiment by their phonetic, underlying, and orthographic representations with the corresponding meanings, as well as the morphophonemically related forms that motivate the claims of underlying voicing. The manner and place of articulation of the final consonant varied, resulting in the following range of final segments across the minimal pairs: two labial stops, four dental stops, three velar stops, one labio-dental fricative, two dental fricatives, and three dental affricates.

Each of the 30 test words was embedded in the two carrier sentences shown in Table III. These two carrier sentences were used to test for an effect of subsequent context on the production of the final segment(s) of the test word. In the first carrier sentence, the test word precedes a word beginning with a voiceless stop. In the second carrier sentence, the test word precedes a word beginning with a vowel. Both contexts should have the effect of devoicing the final obstruent either because of the word-final devoicing rule or because of the regressive voice assimilation rule (when the following word begins with a voiceless obstruent). The 30 test words embedded in two sentence contexts resulted in 60 experimental sentences.

TABLE III. Polish carrier sentences in which test words were embedded

1. Marysia wymawia ---- poprawnie /mariea vimavja ---- popravne/ 'Mary pronounces ---- correctly'
2. Marysia wymawia ---- okropnie /mariea vimavja ---- okropne/ 'Mary pronounces ---- terribly'

The experimental sentences were repeated four times for a total of 240 sentences. The experimental design was therefore a 2 (underlying voicing) by 2 (context) by 15 (minimal pairs) by 4 (repetitions) by 5 (subjects) factorial design.

Thirty-six filler words unrelated to the phenomenon of final devoicing were embedded in each of the sentential contexts resulting in 72 filler sentences to disguise the focus of the experiment. Four typed lists that included the 60 experimental sentences and the 72 filler sentences were prepared for each of five speakers. The order of presentation for each list was fully randomized for each speaker.

2.3. Procedure

Each of the five subjects read four separate randomized lists of the 132 Polish sentences. The sentences were recorded on an AG500 tape deck, using an Electro Voice D054 microphone. The recordings were made in a sound attenuated IAC booth. Prior to recording, the subjects were permitted to read through the sentences to familiarize themselves with the words. Subjects were instructed to read the sentences at a normal speaking tempo and were encouraged to take a break whenever necessary.

The recordings were digitized at a sampling rate of 10 kHz using a 12 bit analog-to-digital converter. The test words were measured using a digital waveform editor (Luce & Carrell, 1981). Three different time intervals were measured for each of the experimental words analyzed for each subject. The measurements obtained were relevant to the final consonant and the preceding vowel for each test word. Measurement criteria varied across final consonant type (stops, fricatives or affricates); therefore, criteria for measurement of the final consonant will be described separately for different consonant types.

2.4. Segmentation criteria

2.4.1. Vowel duration

The interval from the onset of periodicity in the waveform to the end of periodicity associated with the vowel signalled by a drop in amplitude. Whenever a sonorant (e.g. /l, r, w, n, j/) preceded or followed the vowel in the test word, it was included in the measurement of vowel duration. Since inclusion of these segments occurred for both items in a minimal pair and comparisons were made between items in a minimal pair, this procedure does not affect the outcome of the experiment.

2.4.2. Consonant duration

Consonant closure duration (stops). The interval from the offset of the vowel, as described above, to the burst release, typified by a sudden increase in amplitude in the waveform.

Consonant constriction duration (fricatives and affricates). The interval from the end of vowel duration, as described above, to the cessation of aperiodic noise indicating the end of the segment or constriction.

2.4.3. Voicing into consonant closure/frication

(a) *Stops and affricates.* The interval representing glottal pulsing into the closure of the final stop consonant. Measured from the offset of the vowel (see above) to the cessation of periodicity in the waveform.

(b) *Fricatives.* The interval representing periodic information in the waveform concurrent with the noise in the waveform associated with fricatives. Measured from the offset of the vowel (see above) to the cessation of periodicity in the waveform. This interval often included aperiodic noise superimposed on a periodic waveform.

2.5. Measurements

These phonetic parameters were chosen for measurement because other languages with rules of word-final devoicing similar to Polish have evidenced phonetic differences corresponding to underlying distinctions when these parameters were examined, i.e., for replication purposes.

Despite stringent measurement criteria, minor discrepancies in measurement may be expected. Therefore, approximately three months after the original measurements were made, 10% of the test words for each talker were randomly selected and remeasured. An estimate of the measurement error was calculated in the following way. The words selected were remeasured according to the phonetic parameters already described. The values obtained during remeasurement were subtracted from the original measurement values resulting in a difference score. A mean difference score was calculated by averaging the difference scores for each of the three phonetic parameters measured in the experiment for each subject. No individual subject difference score exceeded 4.8 ms for preceding vowel duration, 4.9 ms for consonant duration, and 4.7 ms for voicing into closure/frication duration. The mean difference scores across all subjects were 4.6 ms for preceding vowel duration, 3.4 ms for consonant duration, and 3.8 ms for voicing into closure/frication duration.

The results of each dependent measure are reported separately for all subjects as a group and then for individual subjects.

3. Results: group data

A separate analysis of variance (ANOVA) was computed for the three measurement intervals for each of the five consonant types represented in the experiment (labial stops, dental stops, velar stops, fricatives, and affricates) resulting in 15 separate ANOVAs.

A number of secondary effects were obtained that involved differences between specific words that were analyzed and different repetitions of the test words. These secondary results will not be reported in the text for the following reasons. The aim of this experiment is to examine the effects of underlying representation and phonetic environment on the implementation of phonological rules through a comparison of temporal parameters *within* minimal pairs. However, because of differences in vowel quality and syllable structure across the words used in the experiment, the segmentation criteria for the measurement of parameters across pairs was not always equivalent. Therefore, some

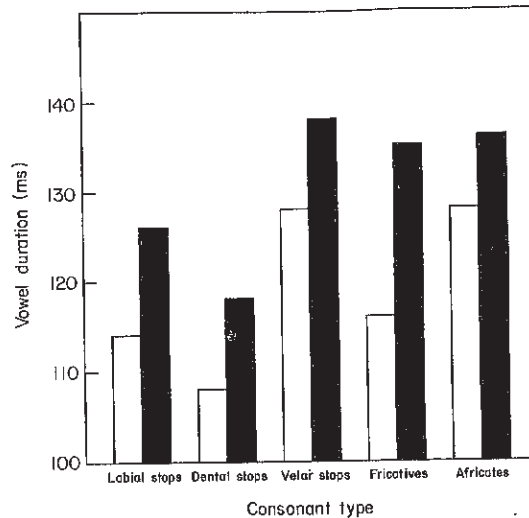


Figure 1. Mean preceding vowel duration for each of the five consonant types when the following obstruent is underlyingly voiceless (□) and when the following obstruent is underlyingly voiced (■) across all subjects.

differences *across* minimal pairs were also obtained as expected. Because these differences are not of interest to the present investigation, they will not be reported here. In addition, repetitions were included in the design to increase the number of observations for statistical purposes; hence, effects involving repetitions are not relevant to the present discussion.

3.1. Vowel duration

A main effect of underlying voicing was found for all five consonant types ($F(1,4) = 8.37, p < 0.04$, for labial stops; $F(1,4) = 14.95, p < 0.02$, for dental stops; $F(1,4) = 33.93, p < 0.004$, for velar stops; $F(1,4) = 11.06, p < 0.03$, for fricatives; and $F(1,4) = 13.43, p < 0.02$, for affricates). This main effect is illustrated in Fig. 1 where the mean duration of the preceding vowel is plotted for the underlyingly voiced and voiceless members of the minimal pairs for all five consonant types. Note that vowel durations are approximately 10% longer before underlyingly voiced obstruents.

In addition, main effects of context were found for test words ending in dental stops ($F(1,4) = 10.19, p < 0.03$) and affricates ($F(1,4) = 7.32, p < 0.05$). For both of these consonant types, the mean duration of vowels preceding the word-final obstruent were longer when the following word began with a vowel than when it began with a consonant (110 vs. 116 ms for dental stops, 128 vs. 135 ms for affricates). An effect of context however was not found for labial stops, velar stops or fricatives ($F < 1.0$, for all three analyses).

3.2. Closure duration

The only significant effect of interest for closure duration was a main effect of context for the closure duration of dental stop consonants ($F(1,4) = 8.16, p < 0.05$). This effect was due to the fact that mean dental stop closure durations were longer (80 ms as

compared with 69 ms) when the segment immediately following the test word was a vowel. No other significant effects of interest were obtained for dental stops or the other four consonant types.

3.3. Voicing into consonant closure/frication

The only significant effect of interest for voicing into consonant closure/frication was a main effect of underlying voicing for labial stops ($F(1,4) = 8.99, p < 0.04$). This effect is due to the fact that the mean voicing into stop closure was significantly longer for underlying voiced labial stops (30 ms) than for underlying voiceless labial stops (17 ms). No other significant effects of interest were obtained for labial stops or for the other four consonant types.

4. Results: individual differences

Separate analyses of variance were computed for each of the five subjects for each of the three phonetic parameters measured (preceding vowel duration, consonant closure/constriction duration, and voicing into closure/frication) by grouping the data for different consonant types.

4.1. Vowel duration

Four of the five subject analyses revealed main effects of underlying voicing ($F(1,10) = 9.20, p < 0.01$, for Subject 1; $F(1,10) = 11.88, p < 0.006$, for Subject 2; $F(1,10) = 8.59, p < 0.01$, for Subject 4; $F(1,10) = 14.91, p < 0.003$, for subject 5). The mean vowel duration values for underlyingly voiceless and voiced items are listed in Table IV for all five subjects. As indicated in Table IV, preceding vowel duration is longer before an underlyingly voiced word-final obstruent than before an underlyingly voiceless obstruent. Furthermore, although underlying voicing was not significant for Subject 3 ($F(1,10) = 3.09, p > 0.1$), it is obvious that the direction of the mean vowel durations are consistent with the data from the other four subjects.

TABLE IV. Mean preceding vowel durations (ms) for five subjects when the following obstruent is underlyingly voiceless (-V) and when the following obstruent is underlyingly voiced (+V)

Subject	-V	+V
1	137	155
2	117	129
3	109	116
4	102	114
5	126	137

Although the data from Subject 3 did not reveal a main effect of underlying voicing, this subject did produce a main effect of context ($F(1,10) = 5.22, p < 0.04$). Specifically, preceding vowel duration was affected by context such that vowels shortened when the segment following the test word was a consonant (110 ms for consonant context; 116 ms for vowel context).

4.2. Closure duration

A main effect of context was observed for Subject 2 ($F(1,10) = 9.23, p < 0.01$), Subject 3 ($F(1,10) = 28.90, p < 0.0003$), Subject 4 ($F(1,10) = 21.73, p < 0.0009$), and Subject 5 ($F(1,10) = 6.99, p < 0.02$). Of greater interest were the significant effects of underlying voicing ($F(1,10) = 11.23, p < 0.007$) and underlying voicing by context ($F(1,10) = 5.78, p < 0.04$) for Subject 5. For this subject, consonant closure duration was 94 ms for underlying voiceless obstruents and 81 ms for underlying voiced obstruents. The voicing by context interaction is due to the fact that in a consonant context mean closure duration was 92 ms, but in a vowel context mean closure duration was 83 ms. Finally, a greater difference between consonant and vowel contexts was revealed for underlying voiced than for underlying voiceless obstruents (a difference between consonant contexts and vowel contexts of 3 ms for underlyingly voiceless obstruents and a difference of 14 ms for underlyingly voiced obstruents).

4.3. Voicing into consonant closure/frication

A significant main effect of underlying voicing was found for Subject 2 ($F(1,10) = 6.83, p < 0.02$), Subject 4 ($F(1,10) = 5.44, p < 0.04$), and Subject 5 ($F(1,10) = 22.96, p < 0.0007$). For each of these three subjects, voicing into closure/frication was longer for underlyingly voiced obstruents than for underlyingly voiceless obstruents (voiceless vs. voiced: for Subject 2, 17 ms vs. 24 ms; for Subject 4, 20 ms vs. 28 ms; and for Subject 5, 12 ms vs. 27 ms). In addition, a significant two-way interaction of underlying voicing and context was observed for Subject 3 ($F(1,10) = 7.15, p < 0.02$) and Subject 4 ($F(1,10) = 6.88, p < 0.03$). For both of these subjects there was a greater difference between the mean consonant and vowel contexts for the underlyingly voiced obstruents than for the underlyingly voiceless obstruents.

5. Discussion

The central question addressed in this paper is whether the phonological rule of word-final devoicing in Polish is neutralizing as has been assumed. If the rule is truly neutralizing, there should be no systematic acoustic differences between otherwise identical words with devoiced and voiceless final obstruents. However, the results from this study require that the phenomenon of devoicing be characterized as non-neutralizing. Thus, while there is a voice alternation in final obstruents, various temporal properties in the signal preserve the underlying voice distinction such that voicing remains contrastive in word-final position. Specifically, at least two phonetic parameters relevant to the final voice contrast have been identified for the group of Polish speakers in this experiment as a whole, i.e. vowel duration and voicing into the closure of labial stops.

The analyses of the vowel duration measurements show that vowels are approximately 10% longer before final obstruents that are underlyingly voiced compared with those that are underlyingly voiceless (cf. Fig. 1). The phonetic implementation of a voice contrast in terms of preceding vowel duration is relatively unremarkable in terms of how other languages implement the voice contrast (N.B. English; also cf. Chen, 1970; Maddieson, 1977; Mack, 1982). In this instance, however, implementing the final voice contrast in terms of vowel duration is noteworthy for two reasons. First, the vowel duration differences in Polish are not correlated with a [voice] feature at the phonetic

level (cf. Keating, 1984, for a discussion of this issue). Second, vowel duration does not appear to be a relevant parameter for the word-medial voice contrast in Polish (Keating, 1979). More specifically, a particular phonetic parameter (vowel duration) is used to implement the voice contrast in final position while a different phonetic parameter is used to implement the contrast in other positions within a word. This type of contextual variation in the implementation of the voice contrast is not unlike what is found in other languages (see Keating (1984) and references therein). These results, thus, support the independence of phonetic implementation rules across different contexts.

While the parameter of vowel duration differentiated underlying voiced and voiceless word-final obstruents across all places and manners of articulation, labial stops were in addition differentiated by yet another phonetic parameter, namely voicing into closure of the final consonant. Specifically, underlying voiced labial stops evidenced more voicing into the consonant closure as compared to underlying voiceless labial stops. The fact that a language would exhibit such a place and manner effect for voicing into closure may be attributable to aerodynamic factors (Ohala, 1983). That is, sustaining vocal cord vibration requires a differential in air pressure above and below the glottis. A larger supraglottal cavity behind a labial obstruction may inhibit vocal cord vibration less (due to the latent build-up of air pressure) than smaller supraglottal cavities associated with other consonant types. Consequently, the other consonant types may have failed to exhibit the voice contrast in terms of this phonetic parameter because of aerodynamic constraints. Whatever the explanation for the particular effect, in the case of labial stops at least, the underlying voice distinction is manifested in terms of multiple acoustic cues, i.e. vowel duration and voicing into closure. For other consonant types, the final voice contrast is maintained in terms of, at least, vowel duration.

The group results for this study demonstrate that the rule of word-final devoicing in Polish is non-neutralizing. From the phonetic studies of this phenomenon in languages such as German and Catalan, it appears that languages do not vary with regard to the neutralizing status of the rule. In other words, some constraints appear to operate across languages to ensure the non-neutralizing status of this rule. While languages may not vary in terms of the status of the neutralization rule, there does appear to be variation across languages, as well as within a specific language, on how to preserve the voice contrast associated with this rule. On the one hand, German and Polish are similar in that both languages employ vowel duration and voicing into closure as phonetic parameters for the final voice contrast⁴. On the other hand, Catalan and Polish differ in two ways. First, no main effect of underlying voicing was observed for Catalan in the group results for the parameters measured. Although an examination of individual speakers' results for Catalan did reveal that some speakers do maintain the voice contrast in terms of either closure duration or vowel duration (as conditioned by context), the considerable amount of individual variation across speakers may have prevented any significant group results. Thus, Catalan speakers as a group differed from German and Polish speakers. Second, the phonetic parameters used in the treatment of the final voice contrast for Catalan varied for different individual speakers of Catalan and differed from those parameters used in other languages. In order to draw firm

⁴Comparisons between German and Polish are somewhat problematic with regard to voicing into closure since some of the German studies (e.g. Port, Mitleb & O'Dell, 1984; Port & O'Dell, 1984) collapsed across place of articulation. Also, while Charles-Luce (1985a) did analyse the results by place of articulation for German, no words ended in labial stops (a crucial consonant type in Polish). Charles-Luce did find, however, that voicing into closure differentiated underlying voiced and voiceless dentals.

conclusions about differences across languages, however, it will be necessary to replicate these studies.

An examination of the individual differences across Polish speakers reveals a similar range of variation to that obtained in Catalan. Specifically, while each individual Polish speaker maintained a final voice contrast, speakers did vary in the details of their implementation of that contrast. In general, speakers varied in the number, type, and combination of phonetic parameters used. More specifically, four of the five subjects maintained the voice contrast in terms of vowel duration such that vowels were longer before underlying voiced obstruents. While Subject 3 failed to show a statistically significant difference, his vowel duration values were at least in the same direction as the other subjects. In addition, Subject 3 maintained the voice contrast in terms of another phonetic parameter, namely voicing into closure. That is, Subject 3 (as well as Subject 4) showed a significant interaction between underlying voicing and context. Consequently, context affected the voicing into closure interval more in underlying voiced obstruents than it did in underlying voiceless obstruents.

While all speakers maintained the contrast in terms of at least one temporal parameter, some speakers used multiple acoustic parameters to maintain the contrast. Subject 5, for example, exhibited (in addition to the vowel duration differences) a main effect of underlying voicing for closure duration along with an interaction of underlying voicing and context. It was found in this instance that closure duration was longer for underlying voiceless obstruents than for underlying voiced obstruents. This finding is consistent with the Polish implementation of the voice contrast in word-medial position (Keating, 1979). Closure duration was also one of the parameters employed in Catalan as an acoustic cue to the final voice contrast.

The interaction of underlying voicing and context evidenced by Subject 5 is probably best understood in relation to the general context effect observed in Subjects 2, 3, 4, and 5. That is, it was found that final closure durations are shortened when the next word begins with a vowel. A similar effect was observed in Catalan. The interaction of underlying voicing and context for Subject 5 reveals that the closure durations of underlying voiced obstruents are shortened more than underlying voiceless obstruents in the same context, i.e. before a word beginning with a vowel.

In addition to vowel duration and closure duration differences, Subject 5 also maintained the final voice distinction in terms of voicing into closure. Underlying voiced obstruents exhibited longer glottal pulsing intervals than underlying voiceless obstruents. Voicing into closure was a significant parameter for Subjects 2 and 4 as well.

Subject 5 thus preserved the final voice contrast in terms of all three parameters examined here. Subjects 2 and 4 maintained the contrast in terms of vowel duration and voicing into closure. Subjects 1 and 3 maintained the contrast in terms of one phonetic parameter each, vowel duration and voicing into closure, respectively. A summary of the significant findings relevant to underlying voicing for individual subjects is presented in Table V. This table illustrates the variation of the implementation of the final voice contrast across different speakers.

Thus, as in the group results, the results for individual differences show that the underlying voice distinction is phonetically preserved. Moreover, we found variation in the implementation of the voice contrast for individual subjects. These results illustrate the range of variability in the implementation of a phonological rule. This variability, however, is highly constrained and purposeful, such that individual speakers of different

TABLE V. Summary of the significant effects relevant to underlying voicing (UV) for individual subjects for each of the three parameters measured.

Subject	Vowel duration	Closure duration	Voicing into closure
1	UV	—	—
2	UV	—	UV
3	—	—	UV × context
4	UV	—	UV
5	UV	UV	UV × context
		UV × context	UV

languages exhibit the same range of variation, and the unifying result is the preservation of a phonological contrast.

A few words concerning the linguistic character of these production results is necessary. It might be argued that the phonetic differences obtained in this study are the result of non-linguistic factors such as spelling pronunciations. In the case of Polish, the orthography does correspond with the underlying voicing distinction such that devoiced final obstruents are represented with voiceless-type graphemes and voiced final obstruents are represented with voiced-type graphemes. Speakers may attempt to produce phonetic differences where corresponding orthographic differences occur. It is difficult to tell in such cases whether the orthography is the way it is because of pronunciation differences or vice versa. However, it should be noted that the phonetic effects observed for Polish are very similar to those observed for Catalan, a language where there is no orthographic distinction corresponding to the underlying voicing distinction. The Catalan results provide evidence that phonetic differences of this type can occur independent of orthography.

It might be argued by some (as it was by Fourakis & Iverson, 1984, for the case of devoicing in German) that the results of this experimental study are unnatural. Specifically, neutralization does not obtain because the experimental situation is unnatural. The presumption is that neutralization would obtain in more natural speech situations such as in fast or casual speech. It is interesting to note, however, that a recent experimental and instrumental study of fast/casual speech (Dalby, 1984) has acknowledged that there is probably very little homophony or neutralization that is the result of such style shifting. Although Dalby's conclusions are contrary to others' claims about fast/casual speech (e.g. Zwicky, 1972*a,b*; Bolozsky, 1977; Donegan & Stampe, 1979; Stampe, 1979), it must be noted that these other studies of casual speech (and incidentally many other studies of putative neutralization) are based solely on 'impressionistic' phonetics and are not otherwise supported by instrumental analyses. It is not surprising that impressionistic phonetic studies could misrepresent the facts of putative neutralizations. After all, phonetic transcription is admittedly an abstraction that, by necessity, (over)simplifies. Also, the phonetic transcriptions are based at best on highly filtered and biased perceptual judgments of the transcriber. The problem arises in taking the phonetic transcriptions as an objective representation of the 'facts'. In other words, the claim that neutralization does occur in natural speech is, thus far, without empirical support⁵.

⁵Fourakis (1984) acknowledges these and other problems with the concept of neutralization and suggests that neutralization may be a viable construct if the domain of neutralization is extended to include the (phonological) word. Such a proposal still fails to address the problem of interpreting the null result as support for the construct of neutralization.

The findings reported here have numerous consequences for phonological theory. First, the validity of the construct 'neutralization rule' is seriously challenged by the demise of the neutralizing status of the word-final devoicing rule in Polish (as well as in the other languages examined). This rule has been taken as the prototypic neutralization rule. Second, given the range of inter- and intra-language variation associated with the phonological phenomenon of devoicing, phonological theory must allow for different descriptions of the same language as well as different descriptions of the same phenomenon in different languages. Finally, the relationship between phonological rules (such as devoicing) and phonetic implementation rules (such as those that adjust timing intervals like vowel duration, closure duration and voicing into closure) is further elucidated in the present study. That is, it has generally been assumed that phonetic implementation rules are low-level and apply after phonological rules. Given, however, that the phonetic implementation rules discussed here (and in Catalan, cf. Dinnsen & Charles-Luce, 1984) are sensitive to underlying voicing, they must be permitted to apply before the phonological rule that devoices final obstruents.

To illustrate this interaction between phonetic implementation rules and the rule of final devoicing consider, for example, the facts of consonant closure duration for Subject 5. Recall that the closure duration of the final obstruents was shortened when the next word began with a vowel. The important point, however, is that the amount of shortening obtained in this context depends on the underlying voicing. Specifically, underlying voiceless obstruents shorten very little (resulting in a 3 ms difference) while underlying voiced obstruents shorten to a greater extent (resulting in a 14 ms difference). The following rule presents a first approximation of the phonetic implementation rule accounting for these facts⁶:

$$\left[\begin{array}{l} - \text{sonorant} \\ \langle + \text{voice} \rangle \end{array} \right] \longrightarrow [\text{shorten } n \langle + 1 \rangle] / \text{ ______ } \# V$$

This rule expresses the claim that all word-final obstruents shorten (in closure duration) when the next word begins with a vowel; but if the final obstruent is [+voice] (underlyingly), closure duration is shortened even more. The interaction of this phonetic implementation rule is crucial relative to final devoicing. Specifically, if final devoicing is applied before the shortening rule, there would be no [+voice] obstruents to serve as inputs to the expansion of the rule that results, in the greatest shortening effect. The order 'Devoicing before Shortening' would predict incorrectly that all final obstruents should shorten equally when the next word begins with a vowel. The opposite order 'Shortening before Devoicing' would permit underlying voiced obstruents to shorten the greater requisite amount while still specified [+voice]; underlying voiceless obstruents would shorten (to a lesser extent) by the other expansion of the rule. After the Shortening rule has adjusted differentially the closure durations, the final devoicing rule can specify all word-final obstruents to be [-voice]. By applying Shortening first, the distinction in closure duration (and thus underlying voicing) is preserved even though voiced and voiceless obstruents may be [-voice] phonetically in word-final position. Essentially, the same account would be required for Subjects 3 and 4 regarding the implementation of the voice contrast by means of the parameter of voicing into closure in different contexts.

⁶No specific proposal is intended by the particular formalism employed in the statement of the rule. The angle bracket notation '<...>' can be interpreted as abbreviating two disjunctively ordered rules as in standard Generative phonology.

A very similar account (i.e. phonetic implementation rules applying before other phonological rules) was required for the facts of Catalan as presented in Dinnsen and Charles-Luce (1984). While such accounts do not conform to conventional conceptions of the relationship between phonology and phonetics, there is nothing in principle which excludes the possibility of phonetic implementation rules applying before phonological rules. There is, however, one interesting exception. That is, within lexical phonology (cf. Kiparsky, 1982), there is a principled basis for distinguishing rule types and assigning them to different layers or levels with associated constraints on rule interactions. The basic distinction is between 'lexical' and 'post-lexical' rules. The rule of word-final devoicing, for example, is a lexical rule; moreover, the phonetic implementation rule of (consonant closure) Shortening is a post-lexical rule as would be any rule applying across word boundaries. A principle of lexical phonology is that no post-lexical rule can apply before any lexical rule. Given that Polish (and Catalan) requires the application of a post-lexical rule before a lexical rule, lexical phonology would be incapable of accounting for such facts.

There are conceivably other accounts of these facts that would not involve crucial rule orderings, for example a global rule solution. For a critical review of global rules, see Dinnsen (1974). The inclusion of global rules in phonological theory would permit a rule to have access to distinctions from earlier points of a derivation. Thus, the Shortening rule could apply after devoicing and still shorten voiced and voiceless obstruents differentially since all (underlying) distinctions are carried throughout the derivation. While this may be a theoretical possibility, it must be noted that global rules constitute an extremely powerful and *ad hoc* descriptive device. It is, moreover, not at all clear that lexical phonology could admit global rules and maintain any internal consistency.

There is, of course another possibility. That is, it might be argued that there is no rule (neutralizing or otherwise) of word-final devoicing. All the facts in this case could be accounted for by phonetic implementation rules—much like allophonic rules such as aspiration. Such an account would, however, require incorporating the structural conditions of the devoicing rule in each of the phonetic implementation rules, resulting in considerable duplication and loss of generalization. It would also miss the generalization that there is a voice alternation in final obstruents independent of context.

One other possibility which partially avoids the issue of neutralization is to posit an additional abstract feature specification for final obstruents such as [tense] or *n*-ary valued features. In this approach, a feature specification such as [tense] could be carried through the derivation to guarantee the correct application of the phonetic implementation rules. Specifically, obstruents could be differentiated in terms of [+/- voice] and [+/- tense]. The devoicing rule could change [+voice] obstruents to [-voice] without modifying the feature specification of [+/- tense]. The phonetic implementation rule would be formulated in terms of [+/- tense] which would correlate with the underlying voicing. It would be possible, then, to argue that the devoicing rule (needed independently to account for the observed voice alternation) is neutralizing, but the tensivity of obstruents is not neutralized as evidenced by the phonetic implementation rules that would be sensitive to that distinction. The obvious difficulty with such a proposal is that there is no other independent support for an additional feature specification. Moreover, any correlations between voicing and tensivity must be regarded as accidental under such an approach.

The results reported in this study are concerned with facts of production. It remains to be seen whether the acoustic measures identified here are functional in perception.

While speakers of Polish produce systematic phonetic differences corresponding to the underlying voicing distinction, they may or may not be able to use those differences in perception. It seems likely, however, that these differences are perceptually salient in Polish given the results from similar studies on German and Catalan. Specifically, Port and O'Dell (1984) found that native speakers of German were able to correctly identify better than chance naturally spoken words differing in underlying voicing. In addition, Charles-Luce (1985*b*) found for Catalan that listeners were able to differentiate the rather more subtle production differences reported in Dinnsen and Charles-Luce (1984). In any event, if perception tests revealed that the Polish production differences were in fact perceptually salient, then both production and perception results would converge on the non-neutralizing character of this phenomenon.

On the other hand, there are several possible interpretations if subjects are unable to differentiate these production differences. First, the absence of a significant finding in a perception study may indicate that the experimental task was not sensitive to the perceptual differences. Second, although there are linguistically significant differences in production of allophones of a given phoneme, those production differences are generally *not* perceived by listeners. Therefore, Polish listeners may not perceive the production differences as linguistically relevant, although it may be possible to train them to detect such differences. Moreover, if the production differences are not found to be perceptually salient, can the production results be ignored as linguistically non-significant? To ignore the production results would suggest that grammars are more properly descriptions of perceptual phenomena and not production. The standard assumption has been, however, that grammars are neutral with respect to speaker and hearer. Dinnsen (1985) entertains an alternative view whereby linguistic theory admits both production-based and perception-based grammars. Under such a view, it would be possible to maintain the possibility of a rule as neutralizing, if only as a perceptual phenomenon.

In conclusion, the facts reported here demonstrate that the rule of word-final devoicing in Polish is not neutralizing for the group of Polish speakers studied, nor for any individual speaker. The so-called 'devoiced' word-final obstruents are phonetically distinguishable from word-final voiceless obstruents. Thus, the underlying voice distinction is preserved phonetically. However, the manner in which it is preserved varies depending on context, place and manner of articulation, and the individual speaker. This variation is, nonetheless, systematic and must be accounted for by phonetic implementation rules that are sensitive to abstract phonological distinctions.

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