

A comparison of vowel devoicing/deletion phenomena in English laboratory speech and German spontaneous speech^{*}

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1 Introduction

This paper continues the examination of deletion, reduction, and reorganization phenomena in spontaneous German speech¹ and adduces data from English laboratory speech to establish cross-linguistic similarities between vowel deletion in German and vowel devoicing in English. We describe how two sets of data were gathered: one of Standard Southern British English (S.S.B.E.) that establishes the ground-rules of devoicing in that accent; and one of spontaneous German speech gathered in the framework of the *Verbmobil* project, which mirror the English findings. A further aim of the paper is to show how the corpus can be exploited using relatively simple search techniques.

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¹see Kohler (1994), Helgason and Kohler (1996), Helgason (1996), Rodgers (1996), Rodgers et al. (1997), Rodgers (1997)

2 Method

2.1 Material

English

The S.S.B.E. experiments aim to establish the extent to which vowel devoicing in English is a phonetic process predictable from the aerodynamic constraints of the vocal tract. The experiments apply aerodynamic principles supported by observations from languages that devoice segments allophonically, to examine the phonetic context in which vowel devoicing is most likely to occur. Properties of the critical syllable — stress, onset, vowel, coda — are systematically varied to test hypotheses about their effect on the aerodynamics of voicing.

The hierarchy of vowel devoiceability that the experiment aims to establish is based on the following hypotheses:

1. Unstressed vowels are more likely to devoice than stressed vowels.
2. Aspirated voiceless stops will allow less devoicing of the following vowel the further they are articulated from the glottis.
3. Close vowels are more likely to devoice than open vowels.
4. A voiceless coda will allow devoicing, while a voiced coda of any manner of articulation will preclude devoicing of the preceding vowel.

A set of critical syllables was chosen that varies in:

1. stress of the critical syllable;
2. place of articulation, voicing and aspiration of the onset of the critical syllable;
3. height of the vowel in the critical syllable;
4. voicing and manner of articulation of the coda of the critical syllable.

For example:

1. /t'it tit/ contrast in stress;
2. /pit spit bit tit kit/ contrast in place of articulation, voicing and aspiration of onset;
3. /tit tæt tɒt/ contrast in vowel height, rounding, and backness;
4. /tit tid tis tɪz/ contrast in manner of articulation and voicing of coda.

Balanced sets of polysyllabic words containing each critical syllable type in an identical phonetic context were built into a fictional passage of 1000 words which when read aloud in a sufficiently casual style elicited the desired effects.

The passage was recorded in a sound-treated room onto professional-quality digital audio-tape using a Sony DTC 750 digital audio-tape deck, Symetrix SX202 pre-amplifier, and Sennheiser MKH 40 P48 condenser microphone with cardioid response, placed 45 cm from the speaker. Subjects familiarized themselves with the task such that they produced “normal informal casual speech”. Four subjects aged between 24 and 27 took part in the tests: a woman and three men who were all graduate students at the University of Cambridge. One male spoke “educated Northern” (i.e. near RP, but with [æ] not [ɑ:] in *bath*) and the remaining three were speakers of Standard Southern British English; three had received training in practical phonetics.

German

This survey is based on the *Kiel Corpus of Spontaneous Speech* (Kohler, Pätzold, and Simpson 1995), and comprises the 31 labelled dialogues of CD-ROM#2 (IPDS 1995) together with a further 56 dialogues which have since been released on CD-ROMs#3–4 (IPDS 1996, 1997). A list of the dialogues is provided in Appendix A on page 213.

The labelling of the data base ensures a high degree of uniformity between different segmenters; it relies on an inventory of phonetic symbols which is, with a few exceptions, limited to the phonemic notations that are used to transcribe canonical representations. This, unlike narrow phonetic transcription, limits the inventory of symbols available to the segmenter.

Another characteristic of the labelling adopted in the *Kiel Corpus* is its linear nature, i.e. symbols are placed in succession on a time scale with no overlap (although certain symbols have no time extension), so the labelling of the corpus is basically linear, segmental and phonemic.

The symbolic representation of the speech signal provides the basis for easy data access and for retrieval of phonetic types from the data base for acoustic analysis and articulatory interpretation. The conventions regarding the marking of segmental deletions and modifications refer to canonical forms of words, which are always reconstructable from the actually transcribed realizations. For example, if a pronunciation of the word *natürlich* (canonical form nat'y:6lIC) without the l, and with f instead of C were to be represented, nat'y:6l-:IC-f would be transcribed, retaining the information that the l and the C are part of the canonical transcription.

The data base was searched for the same segmental patterns as had been examined in the English survey.

2.2 Measurement and analysis

Both the English and German speech signals (sampled at 16 kHz with 16 bit amplitude resolution) were analysed on a *Silicon Graphics Iris Indigo* using *xwaves+* and *ESPS*.

The duration of the voiceless and voiced portions of the vowel in the critical syllables of all tokens was measured using waveforms and wide-band spectrograms.

For English, repeated measures multivariate analysis of variance was then carried out on the mean durations of voicelessness and of voicing, and on the proportion of voicelessness, to establish whether the effects observed were statistically significant. A Greenhouse-Geisser epsilon factor (G-G) is applied to adjust for inherent correlations in repeated measures design.

For German, means only were calculated. Despite their narrowly defined task, the speakers of the *Kiel Corpus of Spontaneous Speech* produce *spontaneous* speech, which *ipso facto* does not have the same balanced sets of items as the English experiments had been painstakingly designed to elicit. The numbers of items represented are so different as to make statistical evaluation and support of findings impossible by tests like analysis of variance. For some types of syllable there are no examples in the German corpus, whilst the minimum n is 1, the maximum is 120. Standard deviations are not appropriate where $n < 30$ (Ott and Mendenhall 1994), yet the data do not lend themselves to non-parametric tests like the Wilcoxon signed ranks test (Siegel and Castellan 1988) which allow for unbalanced samples. In the absence of an appropriate test, Appendix B on page 214 shows means for each syllable type.

2.3 Measures of voicing and voicelessness

The absolute durations of the voiceless and voiced portions of each vowel were measured, their sum giving the duration of the whole vowel. In the presentation and discussion of results, there are no cases where the patterns for proportion of voicelessness contrast with the patterns of absolute durations of voicelessness, voicing, or the vowel, so the duration of voicelessness expressed as a proportion of the duration of the entire vowel is used exclusively.

Proportional values are needed to confirm patterns that may occur naturally in absolute durations of voicelessness or voicing². Use of absolute durations alone could

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- Apparent differences in duration of voicelessness caused by stress could be attributed to the fact that stressed vowels are typically longer than unstressed: the average duration for a stressed vowel in General American is about 130 ms in a connected discourse, that of unstressed vowels, including schwa, is about 70 ms (Klatt 1975). Klatt (1973) suggests that if a stressed vowel is followed by a voiceless consonant in a monosyllable the vowel will be 25% shorter than if it were followed by a voiced consonant; but a stressed vowel that is the first syllable of a disyllable is 30% shorter than in a monosyllable. The interaction is complex and Klatt invokes a notion of incompressibility to express it.
- Apparent differences in duration of voicelessness caused by place of articulation of onsets could be attributed to differences in aspiration and VOT values ($p < t \leq k$).
- Apparent differences in duration of voicelessness caused by different vowel types could be attributed to the fact that vowels have different inherent durations, e.g. / $\text{ɛ} \text{æ} \text{ʊ}$ / are shorter than other English vowels, open vowels are longer than close ones (Peterson and Lehiste 1960).

invite the criticism that the differences were artifactual and not due to devoicing. Expressing the voiceless portion as a proportion of the whole vowel is the only way of substantiating the proposal that differences in duration of voicelessness in critical syllables are greater than should be expected from straightforward differences in VOT due to onset, stress, vowel quality, and coda voicing.

3 Results

3.1 Stress and syllable onset

Figures 1 and 2 show the mean proportions of voicelessness in the vowel of syllables with voiceless stop coda that contrast in stress and onset; Table 1 shows the results of the MANOVA performed on the English data in the figure.

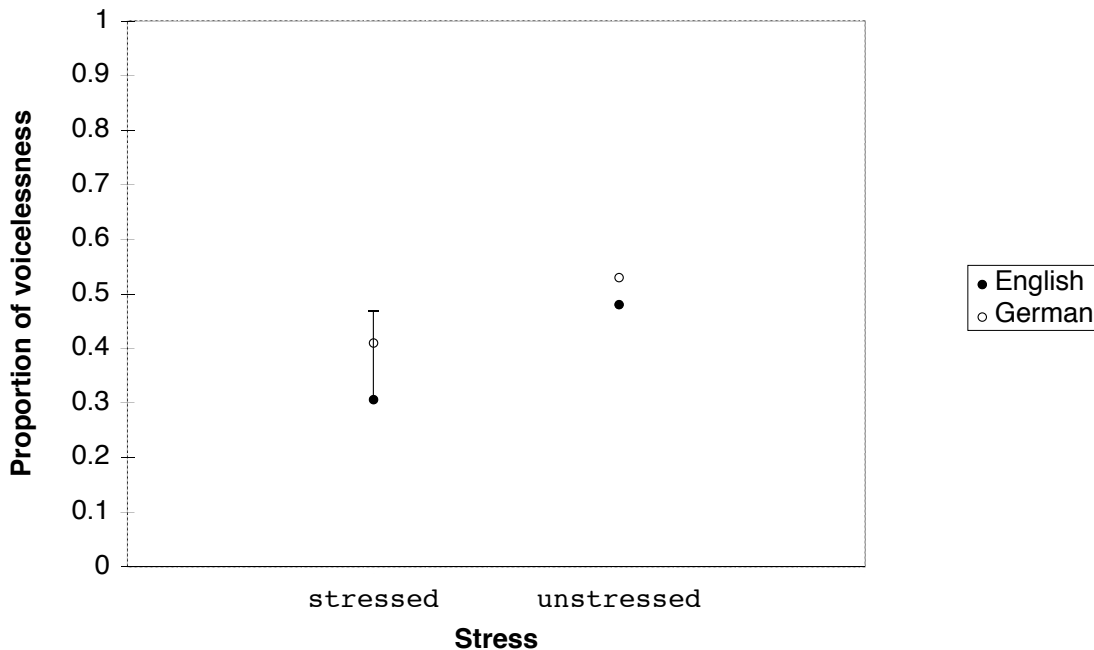


Figure 1: Mean of duration of voicelessness expressed as percentage of duration of whole vowel in syllables with voiceless stop coda contrasting in stress. Standard deviation is also shown for English.

- Apparent differences in duration of voicelessness caused by voicing of the coda could be attributed to the fact that vowels with voiced coda are longer than those with voiceless coda (Delattre 1962; Summers 1987): this probably results from a slightly early glottal opening gesture for a post-vocalic voiceless consonant in order to ensure that no low-frequency voicing cue is generated during the obstruent.

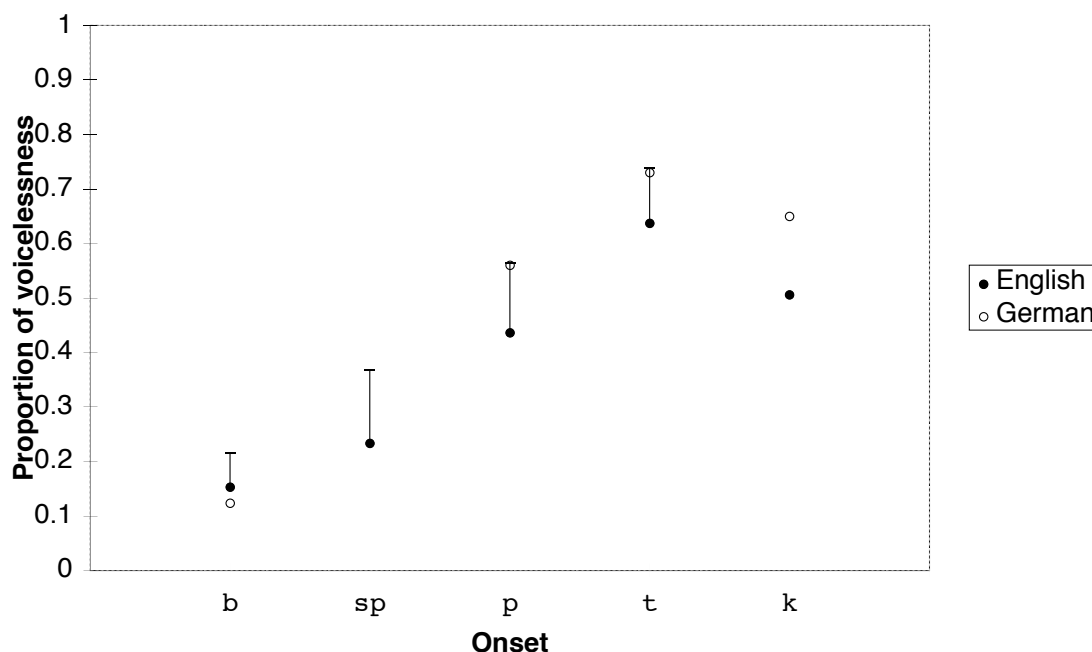


Figure 2: Mean of duration of voicelessness expressed as percentage of duration of whole vowel in syllables with voiceless stop coda contrasting in onset. Standard deviation is also shown for English.

As hypothesized, the differences in voicelessness due to stress and onset are significant for English, with the German data showing the same trend albeit with a greater degree of devoicing.

3.2 Vowel height

Figure 3 shows the mean proportions of voicelessness in the vowel of SVS³ syllables that contrast in vowel type; Table 2 shows the results of the MANOVA performed on the English data in the figure.

As predicted, there is greater voicelessness in close vowels than in open; voicelessness in open vowels is also greater where lips are rounded — Eng. /ɒ/, Ger. /ɔ/ — rather than spread — Eng. /æ/, Ger. /a/. For German, high vowels seem to devoice more than English, and low vowels less, so that the contrast between voiced and devoiced is greater.

3.3 Coda voicing

Greater voicelessness was predicted before a voiceless coda than a voiced. Although there is greater voicelessness in a vowel with a voiceless than a voiced coda, as can

³where S is a voiceless stop and V a vowel

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	.708	.236				
onset	4	6.288	1.572	30.630	.0001	.0008	.0001
onset * Subject	12	.616	.051				
stress	1	1.517	1.517	13.704	.0342	.0342	.0342
stress * Subject	3	.332	.111				
repetition	4	.145	.036	1.206	.3582	.3632	.3582
repetition * Subject	12	.362	.030				
onset * stress	4	.356	.089	2.396	.1082	.1745	.1082
onset * stress * Subject	12	.445	.037				
onset * repetition	16	.319	.020	.910	.5632	.4659	.5632
onset * repetition * Subject	48	1.050	.022				
stress * repetition	4	.274	.069	2.158	.1359	.1878	.1359
stress * repetition * Subject	12	.381	.032				
onset * stress * repetition	16	.616	.039	1.612	.1019	.2571	.1019
onset * stress * repetition...	48	1.147	.024				

Dependent: Proportion of voicelessness

Table of Epsilon Factors for df Adjustment
Dependent: Proportion of voicelessness

	G-G Epsilon	H-F Epsilon
onset	.487	1.380
stress	1.000	1.000
repetition	.550	2.121
onset * stress	.484	1.353
onset * repetition	.162	1.256
stress * repetition	.561	2.298
onset * stress * repetition	.178	4.089

NOTE: Probabilities are not corrected for values of epsilon greater than 1.

Table 1: Manova on duration of voicelessness expressed as percentage of duration of whole vowel in English syllables with voiceless stop coda contrasting in onset and stress.

be seen from Figure 4 and Table 3, the difference is not significant. The difference is about the same for German.

Figure 5 shows the mean proportions of voicelessness in the vowel of /tɪC/ syllables where C is one of /tɔdz/, i.e. there is a contrast in manner of articulation and voicing of the coda⁴; Table 4 shows the results of the MANOVA on coda performed on the English data in the figure.

4 Summary and discussion

The experiments on English aimed to establish a hierarchy of probability of devoicing based on stress, place of articulation of preceding stop, vowel height, and voicing of coda. The hypotheses about stress and place of articulation of the preceding stop were confirmed: the predicted order of devoicing (p<kt) was observed in stressed and

⁴in German [ʃ] instead of [s] before [p].

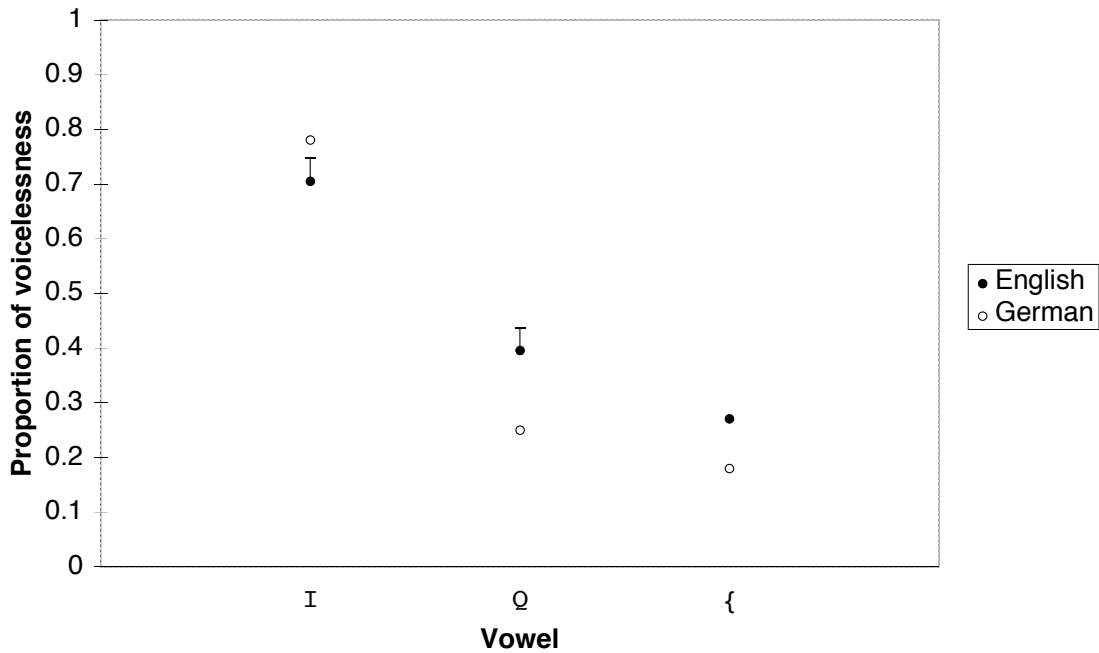


Figure 3: Mean of duration of voicelessness expressed as proportion of duration of whole vowel in SVS syllables contrasting in vowel type. I is Eng./Ger. /ɪ/, Q is Eng. /ɒ/ and Ger. /ɔ/, { is Eng. /æ/ and Ger. /a/. Standard deviation is also shown for English.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	.280	.093				
vowel	2	7.194	3.597	92.254	.0001	.0020	.0016
vowel * Subject	6	.234	.039				
repetition	17	1.101	.065	4.854	.0001	.0501	.0014
repetition * Subject	51	.681	.013				
vowel * repetition	34	1.454	.043	3.159	.0001	.1070	.0117
vowel * repetition * Subject	102	1.381	.014				

Dependent: proportion of voicelessness

Table of Epsilon Factors for df Adjustment
 Dependent: proportion of voicelessness

	G-G Epsilon	H-F Epsilon
vowel	.518	.546
repetition	.127	.459
vowel * repetition	.065	.249

Table 2: Manova on duration of voicelessness expressed as proportion of duration of whole vowel in English SVS syllables contrasting in vowel type.

unstressed syllables. There was confirmation of the hypothesis about vowel height. Data from spontaneous German speech support these findings, which can be explained in terms of aerodynamics. Voicing of the coda does not uniquely govern duration of

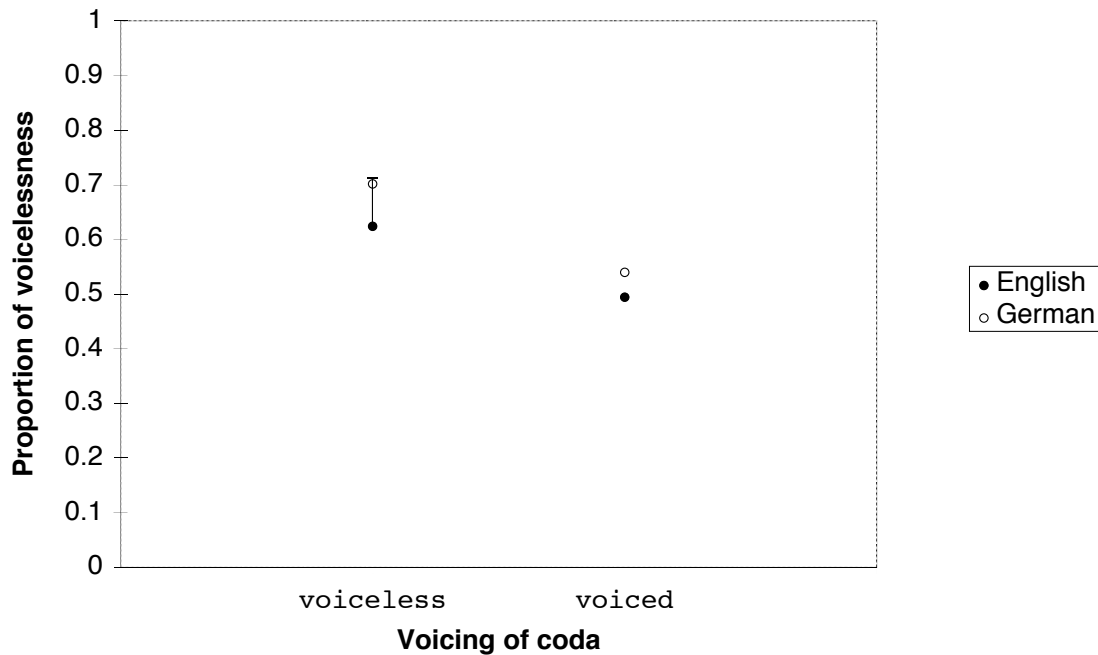


Figure 4: Mean of duration of voicelessness expressed as proportion of duration of whole vowel in unstressed /tɪC/ syllables contrasting in voicing of coda. Standard deviation is also shown for English.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	.653	.218				
voicing	1	.338	.338	9.112	.0568	.0568	.0568
voicing * Subject	3	.111	.037				
repetition	9	1.226	.136	2.928	.0147	.1438	.0729
repetition * Subject	27	1.256	.047				
voicing * repetition	9	.290	.032	1.365	.2519	.3249	.2847
voicing * repetition * Subj...	27	.638	.024				

Dependent: proportion of voicelessness

Table of Epsilon Factors for df Adjustment

Dependent: proportion of voicelessness

	G-G Epsilon	H-F Epsilon
voicing	1.000	1.000
repetition	.189	.413
voicing * repetition	.218	.628

Table 3: Manova on duration of voicelessness expressed as proportion of duration of whole vowel in unstressed English /tɪC/ syllables contrasting in voicing of coda.

voicing in the preceding vowel in either language.

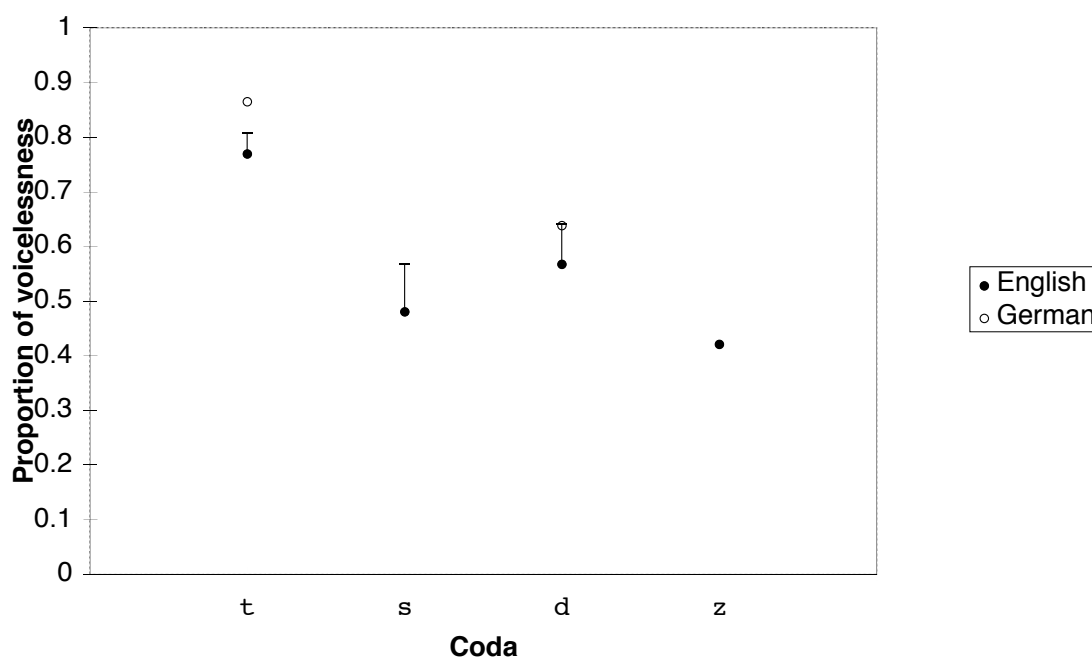


Figure 5: Mean of duration of voicelessness expressed as proportion of duration of whole vowel in unstressed syllables with /tI/ onset and voiced or voiceless obstruent coda. Standard deviation is also shown for English.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	3	.653	.218				
coda	3	1.388	.463	12.238	.0016	.0278	.0150
coda * Subject	9	.340	.038				
repetition	4	.123	.031	.680	.6187	.5132	.5780
repetition * Subject	12	.543	.045				
coda * repetition	12	.344	.029	.919	.5387	.4528	.5176
coda * repetition * Subject	36	1.123	.031				

Dependent: proportion of voicelessness

Table of Epsilon Factors for df Adjustment Dependent: proportion of voicelessness

	G-G Epsilon	H-F Epsilon
coda	.403	.528
repetition	.382	.699
coda * repetition	.180	.657

Table 4: Manova on duration of voicelessness expressed as proportion of duration of whole vowel in unstressed English /tIc/ syllables contrasting in coda.

4.1 Stress and place of articulation of preceding stop

It was hypothesized that the vocal folds would vibrate sooner after the release of a /p/ than a /t/ or /k/, as oral pressure should drop more rapidly the further the constriction

from the glottis. In the set of English data on stress and onset place of articulation the predicted trend of less devoicing after a /p/ than a /t/ or /k/ was statistically significant in both stress conditions; the same pattern is found in German.

Of course transglottal pressure drop is only one factor affecting vowel devoicing: vocal fold thickness, the damping coefficient of vocal fold tissue, the velocity of the mucosal wave, and glottal width are also important (Titze 1980 cited in Löfqvist 1992). But it is assumed that these factors are the same across places of articulation. However there may be differences across places of articulation in duration of consonantal occlusion and tension of vocal folds which affect the devoiceability of the vowel.

In unstressed syllables some relaxation of precision in the placement of articulators may occur, and this relaxation may occur to different degrees at different places of articulation: these differences of degree could underlie the non-significance of the trend. Stevens (1990) argues that for acoustic/perceptual reasons there is greater freedom in the articulation of /p/ and /k/ than in /t/, pointing out that coronal articulations require more precise control than velars (and presumably, bilabials, though Stevens is addressing articulations made with the tongue). The tongue position for a velar stop consonant can vary significantly without influencing appreciably the acoustic requirement for a velar of a prominent mid-frequency peak in the burst spectrum. Variation in the position of the point of contact between the tongue and hard or soft palate of 1–2 cm will give rise to bursts with a range of frequencies, but the relevant compactness property of the burst remains the same. In the case of a stop consonant produced with the tongue tip or blade however, the position of the point of contact of the tongue with the hard palate must be adjusted to within a few millimetres of the alveolar ridge to produce the appropriate acoustic property for a coronal articulation, viz. high frequency prominence⁵.

This argument for sloppier articulation of /k/ than /t/ is appealing, although it ignores sensory feedback — which may be important, if velar articulations (i.e. between the tongue blade/body and soft palate) make different use of such feedback from coronal articulations (i.e. between the tongue tip and teeth or alveolar ridge). By concentrating on the activity of individual articulators such an argument also fails fully to acknowledge the fact that in speech — as in any skilled motor behaviour — groups of muscles and articulators act synergistically to achieve phonetic goals, not dissimilarly to the notion discussed in 4.2 to account for the fact that high front vowels increase longitudinal tension of the vocal folds

Even without making specific claims about differences in degree of freedom of articulation amongst different articulators, it is clear that there is greater articulatory freedom in the production of unstressed than stressed syllables, which mirrors our findings on consonant deletions in Rodgers et al. (1997).

⁵The traditional view on assimilation of alveolars and velars holds that alveolars tend to be more subject to assimilation. In the light of Stevens' remarks, it may be that in practice alveolars vary as much as velars in their actual place of articulation, and it is simply that the greater modification of their acoustic properties than those of velars by the change in place of articulation, for the reasons outlined above, causes them to be perceived as more assimilated than velars.

4.2 Vowel height

The differences in devoicing due to vowel height can be explained in terms of aerodynamics. The data are consistent with the theory that the transglottal pressure drop that is one of the requirements for voicing is achieved sooner during the production of an open vowel than a close one (Berg 1958; Stevens 1977; Titze 1980; Titze 1986; Ohala 1983). Presumably, the difference in proportion of voicelessness between rounded and spread open vowels of similar height (i.e. Eng. /ɒ/ vs. /æ/, Ger. /ɔ/ vs. /a/) is also due to aerodynamics: the greater resistance at the lips due to rounding should have the same effect as a raised tongue body, slowing the achievement of a transglottal pressure-drop by constricting the vocal tract. A further reason why high (especially front) vowels should be more prone to devoicing is that unless the speaker actively controls the two articulators such that they behave independently, the forward shift of the tongue root for the production of a high vowel affects the glottis by increasing longitudinal tension in the vocal folds, making it more difficult to set them into vibration (Honda 1983)⁶.

4.3 Coda

Given appropriate stress, onset and vowel for devoicing it was hypothesized that a voiceless stop or fricative coda would be preceded by a devoiced vowel and that a voiced coda would preclude devoicing. This was not borne out by the data for English (or German), which suggest that voicing of the coda does not uniquely govern the proportion of voicelessness in the preceding vowel, and that manner of articulation also seems to play a role: stop codas favour devoicing more than fricatives.

There is some evidence that voiceless fricative codas should in fact favour devoicing. Fibre-optic video shows that the vocal folds typically widen before a voiceless fricative to be wider than for normal breathing, presumably in order to generate greater glottal volume velocity: friction will occur over a wider range of cross-sectional areas at the oral constriction when glottal volume velocity is high. Voicing requires both a transglottal pressure drop and adducted vocal folds: in an unstressed /tɪs/ syllable the voiceless aspirated onset and unstressed high front vowel would provide the environment for devoicing by delaying the achievement of a pressure drop, and with the folds abducted for the production of an upcoming voiceless fricative, the potential to devoice should be greater than in a stop, where there will be an adduction gesture.

Why then are voiceless fricative codas preceded by a smaller proportion of voicelessness than voiceless and even voiced stops? An explanation of the unexpected pattern could be found in interarticulator timing. The formation of a voiceless consonant

⁶The notion of the intrinsic pitch of the vowel (e.g. Lehiste 1970) acknowledges the consistent relation between vowel quality and average fundamental frequency: high vowels have higher F₀ than low. As well as for reasons of aerodynamics, low vowels (with low F₀) should be harder to devoice than high vowels (with high F₀), where vocal fold tension is high, and the folds are harder to set into vibration.

involves the coordination of the placement of the relevant articulator with a laryngeal abduction-adduction gesture. Multiple articulators are interdependently modulated such that timing variation in one articulator is accompanied by proportional changes in the timing of all the active articulators. Munhall et al. (1994) used a perturbation paradigm to study the coordination of spatially remote articulators, namely the lips and larynx, and established that although there are some limitations on the ability of the articulators to compensate for mechanical perturbations so as to maintain interarticulator timing, the timing of the activity of the lips and larynx is tightly coupled in the production of voiceless consonants. The Munhall study focused on stressed syllables, yet this coupling of articulators is presumably maintained in unstressed syllables in spite of relaxation of articulatory precision. Löfqvist (1992) suggests that interarticulator timing is used to control overall (rather than fine-tuned) properties of voice onset time and mode of phonation at vowel onset. Gracco and Löfqvist (1994) suggest that there is a different degree of temporal coupling in closing and opening gestures, with one possible explanation for this being that closing — generally associated with consonant production — and opening — generally associated with vowel production — are two distinct classes of speech motor actions with different principles underlying their coordination and control. Within these two broad classes of closing and opening movements, there may be differences between coordination for stops and fricatives which would account for the differences in devoicing preceding a stop and fricative coda that are found in the data. Not only may the movement into the consonantal occlusion for a fricative be slower and longer, but also the smaller proportion of voicelessness before fricative than stop codas may be due to the fact that time is taken to generate friction, and because fricative production may rely on time-consuming auditory feedback more than stop production. This is supported by Butcher (1977), who found that stop articulations can be made with less articulatory precision than fricatives.

Voiced fricatives are probably preceded by the smallest proportion of voicelessness since they have more exacting requirements than voiceless fricatives and voiced and voiceless stops. For the sake of continued voicing the oral pressure should be low, but for the sake of friction the oral pressure should be high, that is, the difference between oral and atmospheric pressure should be great enough to cause high air velocity through the consonantal occlusion. Meeting both of these requirements simultaneously may be difficult, and establishing them initially may be time-consuming. If the segment retains voicing it may be a poor fricative, and if it is a good fricative it risks being devoiced. The noise component for voiced fricatives is much less than that for voiceless fricatives Pickett (1980) and in nonsibilant voiced fricatives ([βvð]) may be barely detectable.

5 Conclusions

In summary, the patterns for proportions of voicelessness before fricative and stop codas may be explained in terms of different kinematic characteristics of fricative and

stop production, which override the natural potential of fricatives, especially voiceless, to allow devoicing.

This experiment examined variables within the syllable, and by doing so established the influence of stress, onset and vowel. A hypothesis about coda voicing was refuted by data on fricative codas: an explanation is sought in terms of the kinematics of the formation of the consonantal occlusion for stops and fricatives, and the effect of this movement on interarticulator timing.

The advantages of finding similarities between the two sets of data are clear: similar devoicing/deletion phenomena occur in different (stress-timed) languages and in two different contexts — experimental and spontaneous. The spontaneous speech corpus especially lends itself to further analysis of phenomena on which necessarily narrow experimental examination has imposed some investigative framework: further work may involve aspects of rhythm, speaker differences, articulation rate, and even phonatory differences, which may all have some influence.

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A Dialogues

g071a–g077a	g251a–g257a
g081a–g087a	g274a
g091a–g097a	g287a
g111a–g117a	g297a
g121a–g127a	g306a
g141a–g147a	g311a–g317a
g191a–g197a (excl. g193a)	g361a–g364a
g202a	g366a–g367a
g211a–g217a	g421a–g427a

Table 5: The dialogues from the *Kiel Corpus of Spontaneous Speech* used in this survey.

B Means for German syllable types

Contrast	Mean
Vowel height	
i	.781
ɒ	.25
æ	.18
Onset	
b	.123
sp	n/a
p	.56
t	.73
k	.65
Stress	
Stressed	.41
Unstressed	.53
Coda voicing	
Voiced	.702
Voiceless	.54
Coda	
t	.865
s	n/a
d	.64
z	n/a

Table 6: Means for measurements of proportional voicelessness made on German corpus data for comparison with English data.