Phonetic Variation and Phonological Theory: German Fricative Voicing*

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1. Introduction

This paper reports on the result of an experiment that was designed to test the different predictions of two phonological analyses of German fricative voicing, one that actively bans voicing in coda position, and one that preferentially preserves voicing in presonorant position. In spite of the fact that there is considerable variation in the data, we argue that the results support only one of the analyses. Specifically, we argue that the positional faithfulness account that preserves voicing in presonorant position, but not the coda devoicing account, is consistent with the experimental results.

Jessen & Ringen (2002) argue that the contrast in German *stops* is one of [spread glottis] (sg) vs. no laryngeal specification. Hence, there *is* no syllable-final devoicing of stops: all stops are voiceless unless (variably) voiced by passive voicing when between sonorants. However, their analysis says nothing about fricatives. Unlike stops, German fricatives *do* contrast for voicing in word-initial position and there is a clear voice contrast in intervocalic position as well, as illustrated by the examples in (1). Hence, it might be suggested that although there is no coda devoicing of stops in German, there *is* coda devoicing of fricatives.

(1a) *Word-Initial* (data from Jessen 1998) [1]

***w**ir*	[v]	'we'	***v**ier*	[f]	'four'
***W**ahl*	[v]	'election'	***f**ahl*	[f]	'pale'
***S**iel*	[z]	'sluice'	***S**eal*	[s]	'seal'
***S**aat*	[z]	'seed'	***S**ade*	[s]	(name)

(1b) *Intervocalic*

*Grä**s**-er*	[z]	'grass PL'	*Gra**s***	[s]	'grass SG'
*akti**v**-e*	[v]	'active FEM, NOM SG'	*akti**v***	[f]	'active'
*Fü**ß**-e*	[s]	'foot PL'	*Fu**ß***	[s]	'foot SG'
*Hö**f**-e*	[f]	'courtyard PL'	*Ho**f***	[f]	'courtyard SG'

An analysis that bans [voice] on obstruents in coda position and one that preserves [voice] only in presonorant position make similar predictions about devoicing of fricatives. For example, both accounts predict the devoicing of fricatives in the examples in (4b). Specifically, the underlyingly voiced fricative is devoiced by the coda devoicing analysis because it is in a coda, and by the positional faithfulness account because it is not in presonorant position, as illustrated in (5).

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[1] In word-initial position, [s] is only found in unassimilated loan words (Wiese 1996:12).

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(2) *Key Constraint, Coda Devoicing Analysis*

VoiCoda** (VoiObs&*Coda**) (Ito & Mester 1998)
"Voiced obstruents are prohibited in codas."

(3) *Key Constraint, Positional Faithfulness Analysis*

Id-Presonorant Voice (Id-preson voi) (Steriade 1997, Padgett 1995, Lombardi 1999, Beckman 1998, Petrova et al. 2000, 2006)

"An obstruent in presonorant position must be faithful to the input specification for [voice]."

(4a) *Intervocalic voiced fricatives*

*kur**v**en*	[v]	'curve INF'
*verlo**s**en*	[z]	'raffle INF'
*rei**s**en*	[z]	'travel INF'

(4b) *Devoicing of coda fricatives*

*kur**v**te*	[f]	1SG & 3SG PAST
*verlo**s**te*	[s]	1SG & 3SG PAST
*rei**s**te*	[s]	1SG & 3SG PAST

(5) *Coda Devoicing Analysis*

kur/v/+te	*VoiCoda	Id[voi]	*VoiObs
☞kur[f].te		*	
kur[v].te	*!		*

Positional Faithfulness Analysis

kur/v/+te	Id-Preson voi	*VoiObs	Id[voi]
☞kur[f].te			*
kur[v].te		*!	

However, the two accounts differ in crucial cases where an underlying voiced fricative occurs before a sonorant consonant, as in the forms in (6a),

(6)	(a)	gruseln	[z]	'to spook'	gruslig	[z] or [s]?	'spooky'
		Faser	[z]	'fiber'	fasrig	[z] or [s]?	'fibrous; stringy'
	(b)	Schlüssel	[s]	'key'	Verschlüsslung	[s]	'encryption'
		Wasser	[s]	'water'	wässrig	[s]	'full of water'

where [zl] and [zr] are not possible onsets. Here, if speakers produce [z] rather than [s], we have evidence that there is no coda devoicing because the syllabification must be *gru*[z.l]*ig*, *fa*[z.r]*ig*. In contrast, the voiced pronunciation is predicted by an analysis with faithfulness to voicing in presonorant position.

(7) *Coda Devoicing Analysis*

gru/z/l+ig	*VoiCoda	Id[voi]	*VoiObs
☞gru[s].lig		*	
gru[z].lig	*!		*

Positional Faithfulness Analysis[2]

gru/z/l+ig	Id-Preson voi	*VoiObs	Id[voi]
gru[s].lig	*!		*
☞gru[z].lig		*	

Although the coda devoicing and positional faithfulness analyses provide similar empirical coverage for most aspects of German fricative voicing, they differ crucially in the treatment of problematic fricative-sonorant onset cluster, as we see in (7). In order to decide which of the two approaches is correct, we must first determine what the voicing facts for such clusters are.

2. Experimental Evidence

32[3] native speakers of Standard German, 17 male and 15 female students, were recorded in a sound-treated recording studio at the University of Bielefeld, Germany. The students' ages ranged from

[2] Note that the ranking of Id[voi] and *VoiObs necessarily differs in the two analyses.

[3] 36 speakers were recorded, but for the first four speakers that were recorded, slight echoes occurred; these echoes were not present in the remaining recordings because the recording location was changed. Although the general voicing patterns for these four speakers could be seen, the accuracy of the measurements would have been reduced had these data been included. For this reason, only the data from the remaining 32 speakers were

19 to 31, with an average of 23 years. All had been raised in Bielefeld or the larger area around Bielefeld.

The list read by the subjects consisted of 75 sentences, some of which contained words with the linguistic structures crucial to the present study (*fasrig*, etc.). This list was read three times and the results for all three readings were evaluated. The target words are given in (8):

(8) Target words analyzed in the experiment

a.

Word	Gloss
knau**s**rig	'stingy'
kräu**s**lig	'curly'
fa**s**rig	'fibrous'
Berie**s**lung	'constant stream'
gru**s**lig	'spooky'
fu**ss**lig[4]	'fuzzy'
du**ss**lig	'foolish'

b.

Word	Gloss
wä**ss**rig [s]	'full of water' cf. Wasser [s] 'water'
Verschlü**ss**lung [s]	'encryption' cf. Schlüssel [s] 'key'
gra**s**reich [s]	'full of grass' cf. *Gräs-er* [z] 'grass PL'
lö**s**lich [s]	'soluble' cf. *lös-en* [z] 'to (dis)solve'

All words in (8a) are single prosodic words, consisting of a stem followed by the derivational suffix –*ig* or –*ung*. The alveolar fricative highlighted in boldface, which is the target of the present investigation, has an input [voice] specification, which is apparent from pairs of words such as *gruslig* [z] 'spooky' ~ *gruseln* [z] 'to spook' (see 6a above).

In (8b), the alveolar fricatives highlighted in boldface fall into two groups (separated by an empty line). The first two words do not have input [voice]. This can be inferred from the lack of alternations in pairs such as *Verschlüsslung* [s] 'encryption' ~ *Schlüssel* [s] 'key' (see 6b). The second two words have underlyingly voiced fricatives (cf. *lös-en* 'to (dis)solve' and *Gräs-er* 'grass PL' with [z]) that occur at the right edge of a prosodic word (before the derivational suffix -*reich* or -*lich*). In this position the fricatives are predicted to be voiceless by assignment of [sg] at the right margin of prosodic words, a process which affects all obstruents. These four examples in column (b) were included as voiceless control items for the crucial voiced items in column (a). In order to distinguish the alveolar fricatives in column (a) from those in (b), the ones in (a) will be called "predicted voiced" and the ones in (b) "predicted voiceless" – bearing in mind that predicted voiceless can either mean that they are not input [voice] or that they are input [voice] but phonetically voiceless due to PW-final [sg].

One striking aspect of the results is that the sonorant that follows the alveolar fricative in question was sometimes produced syllabically and sometimes non-syllabically. For example, in some tokens the sonorant /l/ in *gruslig* was non-syllabic, in others it was syllabic. This variation was mainly due to speaker differences but also occurred between words and repetitions. In the most extreme case, a schwa was inserted between the fricative and the sonorant, which however occurred much less frequently than a syllabic sonorant without schwa. 15 speakers used schwa as one of the possible variants of type of words listed in (8a). For 3 of these 15 speakers this was their most frequent variant for these words. For the others it was a much rarer variant and for 4 of the 15 speakers schwa only occurred in one token out of all words in (8a).[5] Cases with schwa are not listed separately in (9) but are counted together with syllabic sonorants under the category "syllabic".

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measured. As the voicing and syllabicity patterns of these first four speakers reflected most of the variation that occurred in the entire set of speakers, no bias was introduced by removing these speakers from the analysis.

[4] The input specification in column (a) for *fusslig* 'fuzzy' and *dusslig* 'stupid' might be questioned. Voiced /z/ after a lax vowel in items such as *Fusseln* 'fuzz PL' is a marked structure in German (cf. the "Puzzle constraint" introduced in Jessen 1998); thus, one might expect a voiceless [s] in such items. However, when testing the pronunciation of the word *Fusseln* among the 36 speakers of this study, only 5 produced the alveolar fricative in this word as voiceless or mostly voiceless. It can therefore be assumed that in the cognition of the vast majority of our speakers, the crucial fricatives in these two words are input [voice].

[5] In some cases the presence of schwa was difficult to distinguish from a syllabic sonorant with strong or varying amplitude (when the earlier part was louder than the latter). Giegerich (1989: 51) mentions that this variation between syllabic sonorant and schwa followed by non-syllabic sonorant in German is a "gradient phenomenon".

Phonologically, in tokens where the following sonorant is syllabic or where schwa is inserted, the alveolar fricative constitutes the onset of the following syllable, whereas in tokens where the sonorant is non-syllabic the alveolar fricative occurs in the syllable coda. Since this distinction has an influence on the phonological analysis, it was decided to classify each token in the experiment into the categories non-syllabic or syllabic, whereby syllabic included the case where a schwa was inserted. This classification had to be performed primarily on auditory grounds because no single acoustic criterion on syllabicity seemed to be available.

Measurements of the following acoustic events were performed: *beginning of fricative*, as defined by the onset of turbulence in the frequency regions which are characteristic for an alveolar fricative, *end of fricative*, as defined by the offset of alveolar frication turbulence, and *end of voicing*, which is defined as the point in time where voicing periodicity ends during the fricative. From these three events two durations were calculated: ***voicing duration***, as defined by the time interval from beginning of fricative to end of voicing, and ***voicing percentage***, as defined by the percentage of voicing duration relative to the total duration of the fricative (i.e. end of fricative minus beginning of fricative).[6] This set of measurements was performed on all tokens that were classified as non-syllabic. For the syllabic cases an abbreviated format was used, where only voicing percentage was determined (i.e. fully voiced tokens, which occurred frequently with syllabic sonorants, were not measured for fricative duration). A first impression of the results is given in Figure 1 below.

Figure 1 shows a histogram of the voicing percentage values in all non-syllabic tokens pooled across the 32 speakers and the 3 readings. Separate results are presented across all the words with predicted voiced fricatives (black columns), as listed in (8a), and across all the words with predicted voiceless fricatives (white columns), as listed in (8b). The x-axis shows different intervals of voicing percentage values. How many predicted voiced and how many predicted voiceless tokens have voicing percentage values that fall within each interval.is shown at the top of each column.

As can be seen in Figure 1, the vast majority of predicted voiceless tokens have a voicing percentage from zero to 25 percent – with a peak occurrence between 5 and 10 percent. Predicted voiced tokens also have many tokens in the range from 0 to 25%, although it should be noted that voicing percentage among predicted voiced fricatives is rarely lower than 5%. Furthermore, predicted voiced fricatives also have many tokens with voicing percentages larger than 25%, which is extremely rare among predicted voiceless fricatives. Very strikingly, a large number of predicted voiced tokens are fully voiced, which can be seen with the high column in the 95-100% interval.

In addition to pooling the data in the manner shown in Fig. 1, the results were also evaluated separately for each target word and separately for tokens with syllabic and non-syllabic sonorants. These results are presented in (9a) for predicted voiced fricatives and in (9b) for predicted voiceless fricatives.

As mentioned above, the tokens were classified into those produced with syllabic sonorant (or schwa) and those with non-syllabic sonorant, which is reflected in the top line of the tables. For each of these categories, the numbers of tokens that were produced with different voicing percentages are listed. Voicing percentage was divided into three classes. The first category, "100%", shows how many fricative tokens were fully voiced. The second and third categories show how many fricatives had voicing percentages lower than 25% and higher than (or equal to) 25%, but lower than 100%. The choice of this 25% boundary was made because the predicted voiceless fricatives rarely have voicing percentages greater than 25%. Hence, this dividing line shows how many predicted voiced fricatives have voicing percentages so small that they fall into the range of predicted voiceless fricatives, and how many predicted voiced tokens have voicing percentages that are clearly higher than those found in predicted voiceless fricatives.

He says "schwa can be reduced/shortened, and the question of whether or not it is present in such contexts is often hard to answer". This is an observation that can be confirmed from the present results. Giegerich (1991) again mentions this gradiency ("nonbinary nature"; p. 164) and also points out that the variation is style-and tempo-dependent. Based on these observations Giegerich (1991) classifies this variation between a syllabic sonorant and a schwa-nonsyllabic-sonorant sequence as a postlexical phenomenon. Due to the gradient nature involved, we classify this variation as phonetic and see no need to model it in the phonology.

[6] Compare this with the F2-oriented method in Jessen (1998).

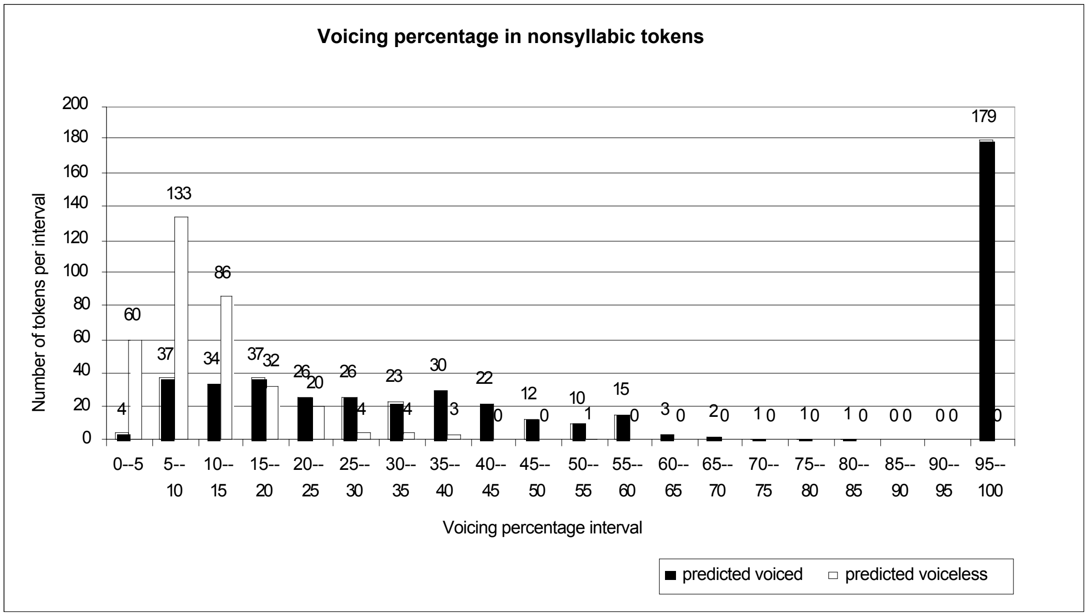

Fig 1: Voicing percentage in tokens classified non-syllabic, pooled across words, repetitions and speakers.

(9a) Detailed results for predicted voiced fricatives

	non-syllabic			syllabic		
voicing pct.	100%	≥25%	<25%	100%	≥25%	<25%
knau**s**rig	38	27	15	11	5	0
kräu**s**lig	24	12	23	34	3	0
fa**s**rig	28	28	21	12	6	1
Berie**s**lung	26	16	15	35	3	1
gru**s**lig	22	21	17	34	0	0
fu**ss**lig	21	23	21	28	2	0
du**ss**lig	21	18	25	27	1	1
SUM	180	145	137	181	20	3

(9b) Detailed results for predicted voiceless fricatives

	non-syllabic			syllabic		
voicing pct.	100%	≥25%	<25%	100%	≥25%	<25%
grasreich	0	0	96	0	0	0
Verschlüsslung	0	5	53	0	3	34
wässrig	0	0	93	0	0	3
löslich	0	8	88	0	0	0
SUM	0	13	330	0	3	37

A number of observations can be made about the data presented in (9). Beginning with the syllabic tokens in (9a), we can see that the vast majority of predicted voiced fricatives before a syllabic sonorant are fully voiced. Partially voiced tokens with voicing percentages above 25% are much less common and those below 25% are close to zero. It seems from this result that the position before a syllabic sonorant (or schwa), and hence the position in the syllable onset, is favorable to the occurrence of voicing.

One might hypothesize from this finding that the speakers who produced a syllabic sonorant did so in order to preserve fricative voicing. This could be construed as an argument in favor of a coda devoicing analysis: speakers avoid coda position for an underlyingly voiced fricative because in that position the voicing feature cannot be implemented faithfully. However, that this cannot be the correct explanation for syllabic sonorant production is shown by the results for the word *Verschlüsslung* in

(9b). In this word, the fricative is not input [voice], but otherwise has the same status (PW-internal position) as the words in (9a). This word has a considerable number of tokens (37) that were produced with syllabic sonorant. If voicing preservation were the cause for syllabic sonorant production, there would not be any reason for syllabic sonorants to be produced in words which have no input [voice] specification that needs to be preserved.[7]

Turning to the non-syllabic cases, the predicted voiced fricatives with <25% voicing are most supportive of the coda devoicing analysis, whereas those with 100% voicing are most supportive of the positional faithfulness analysis. This would only give a slight advantage to the positional faithfulness analysis, since the number of tokens in the 100% category is only slightly larger than those in the <25% voicing category. What about the cases with more than 25% and less than 100% voicing, which amount to about one third of the tokens? We will argue that these tokens support the positional faithfulness analysis—the only way these tokens with partial but long voicing can be accounted for is by assuming that they are voiced candidates according to OT analysis, but are partially devoiced for phonetic reasons. If both the 100% and the ≥25% cases support positional faithfulness, the numerical support for the positional faithfulness account is clearly stronger than the alternative. But, we will argue, even if the number of <25% cases were equal to or greater than the sum of the 100% and the ≥25% cases, positional faithfulness would still be the better option because with the positional faithfulness approach, <25% voicing in phonologically voiced fricatives can be derived phonetically, whereas there is no way within the coda devoicing approach to derive ≥25% to 100% voicing. Any such procedure would also affect phonologically voiceless fricatives, and these almost never have voicing percentages larger than 25%.

3. The Positional Faithfulness Account of Fricative Voicing

We turn now to the full positional faithfulness account of fricative voicing in German. As we noted in the introduction, German fricatives, unlike stops, contrast for voice in initial position and between sonorants (cf. (1) above.). Thus, it would appear that although there are no underlying German stops specified for [voice], there are fricatives specified underlyingly as [voice].

In their analysis of the German stops, Jessen & Ringen (2002) motivate the constraint in (10) requiring that input and output correspondents have the same specification for [spread] and the constraint in (11) prohibiting voiced spread glottis stops. (This is in addition to the familiar markedness constraints banning aspirates (*SG) and voiced obstruents (*VOIOBS).) According to this analysis, all German stops are voiceless; the actual contrast is between stops that are specified as [spread] and those that are not. The only voiced stops arise by (phonetic) passive voicing, which accounts for the (variable) voicing of inter-sonorant non-[sg] segments.

(10)	**ID[sg]**	"An input segment and its output correspondent must have the same specifications for [spread]."
(11)	***VOI/SG**	"Voiced spread glottis segments are prohibited."

While Jessen & Ringen's analysis will account for some of the attested German fricative facts, it does not account for the behavior of all coda fricatives in German (illustrated in the second column of (1b) and (4b) above and in second column in (12)), nor does it connect with independent claims about the [spread] status of German voiceless fricatives (Jessen 1998; c.f. Vaux 1998).

(12a)	*pre**ss**en*	[s]	'press INF'	*pre**ss**te*	[s]	1SG & 3SG PAST
	*ha**ss**en*	[s]	'hate INF'	*ha**ss**te*	[s]	1SG & 3SG PAST
	*sur**f**en*	[f]	'surf INF'	*sur**f**te*	[f]	1SG & 3SG PAST

[7] Syllabic sonorant production is much rarer in the word *wässrig* than in *Verschlüsslung* (all the other words in (9b) are structurally different). However, this is part of another general pattern, by which the sonorant /l/ is more frequently syllabic than the sonorant /r/. This pattern also occurs with the input [voice] items and hence is independent of the voicing issue (see the lower number of syllabic sonorants in *knausrig* and *fasrig* compared with the other words in (9a)).

(12b) *kur**v**en*	[v]	'curve INF'	*kur**v**te*	[f]	1SG & 3SG PAST
*verlo**s**en*	[z]	'raffle INF'	*verlo**s**te*	[s]	1SG & 3SG PAST
*rei**s**en*	[z]	'travel INF'	*rei**s**te*	[s]	1SG & 3SG PAST
(12c) *gruseln*	[z]	'to spook'	*gruslig*	[z]	'spooky'
Faser	[z]	'fiber'	*fasrig*	[z]	'fibrous; stringy'
Schlüssel	[s]	'key'	*Verschlüsslung*	[s]	'encryption'
Wasser	[s]	'water'	*wässrig*	[s]	'full of water'

The data in (1)/(4) and (12) can be accounted for with Jessen & Ringen's constraints with the addition of two independently motivated constraints. These are given in (13) and (14). ID-PRESON-f requires that presonorant fricatives retain their input voice specification on output correspondents, while FRIC-SG requires that (voiceless) fricatives be [sg]:

(13) **ID-PRESON-f** "An input fricative and its output correspondent must have the same specifications for [voice] in pre-sonorant position." (c.f. Padgett 1995, Lombardi 1999, Beckman 1998, Petrova et al. 2000, 2006 for variations on presonorant faithfulness, and Jun 1995 for manner-sensitive faithfulness)

(14) **FRIC-SG** "Fricatives are [spread]." (Vaux 1998)

The interaction of these constraints will produce the full array of fricative behavior attested in German. First, it accounts for the uniformly voiceless character of word-final fricatives. This is illustrated in (15a) for an input voiced fricative, and in (15b) for a voiceless fricative.

(15) Uniform results in word-final position

(a)

Gra/z/	*VOI/SG	ID-PRESON-f	FRIC-SG	ID[sg]	*VOIOBS	ID[voi]	*SG
☞ Gra[s^{sg}]				*		*	*
Gra[z]			*!		*		
Gra[z^{sg}]	*!			*	*		*
Gra[s]			*!			*	

(b)

Fu/s^{sg}/	*VOI/SG	ID-PRESON-f	FRIC-SG	ID[sg]	*VOIOBS	ID[voi]	*SG
☞ Fu[s^{sg}]							*
Fu[z]			*!	*	*	*	
Fu[s]			*!	*			

(16) Underlyingly [voice] fricative

(a)

kur/v+t^{sg}/+e	*VOI/SG	ID-PRESON-f	FRIC-SG	ID[sg]	*VOIOBS	ID[voi]	*SG
☞ *kur*[f^{sg}t^{sg}]*e*				*		*	**
kur[ft^{sg}]*e*			*!			*	*
kur[vt^{sg}]*e*			*!		*		*
kur[v^{sg}t^{sg}]*e*	*!			*	*		**

(b)

kur/v/+en	*VOI/SG	ID-PRESON-f	FRIC-SG	ID[sg]	*VOIOBS	ID[voi]	*SG
kur[f^{sg}]*en*		*!		*		*	*
☞ *kur*[v]*en*			*		*		
kur[f]*en*		*!	*			*	
kur[v^{sg}]*en*	*!			*	*		*

(c)

gru/z/l+ig	*VOI/SG	ID-PRESON-f	FRIC-SG	ID[sg]	*VOIOBS	ID[voi]	*SG
gru[s^{sg}].*lig*		*!		*		*	*
☞ *gru*[z].*lig*			*		*		
gru[s].*lig*		*!	*			*	
gru[z^{sg}].*lig*	*!			*	*		*

As shown in (16a), the optimal output for an input voiced fricative followed by a (voiceless) stop is voiceless—though there is no coda devoicing constraint in the grammar. This is because only fricatives in presonorant position retain their input voice specifications. Voiced fricatives are simply not possible here, because fricatives that are not in presonorant position are forced to be voiceless by high-ranking FRIC-[sg]. In contrast, the input voiced fricatives in (16b) and (16c) surface with voicing because they are in presonorant position. Of particular note is the case in (16c), where the alveolar fricative is necessarily syllabified as a coda, due to the prohibition on *zl* and *zr* onsets—yet surfaces with voicing, because it is nonetheless in presonorant position. This is exactly the case that the **coda devoicing** account predicts should **not** exist; yet, as the experimental evidence in section 2 illustrates, voicing is robustly attested in this environment.

4. Some Remarks on Variation

4.1 Variation in Sonorant Syllabicity

There are two distinct types of variation documented in our experimental data: variation in the syllabicity of the liquid in the target fricative+liquid clusters, and variation in the duration/percentage of voicing produced in the predicted voiced fricatives. The first type of variation, we argue, can be accounted for by means of unranked constraints in the phonology. The variation in voicing production, however, we attribute to the difficulty of producing voicing in fricatives. We will first illustrate the key aspects of the syllabification analysis, and then turn our attention to the treatment of the variable fricative voicing.

As noted above, the experimental data showed variation between a coda-onset pronunciation of the target fricative+liquid clusters (e.g. gruz.lig) and a pronunciation in which the fricative appeared in the onset of a syllable with a syllabic sonorant nucleus (e.g. gru.zl̩.lig). This variation can be captured in Optimality Theory with crucially unranked constraints. If two constraints are crucially unranked, either ranking results in a possible output. In the case at hand, the unranked constraints are *PEAK/LIQUID and NOCODA.

(17) ***PEAK/LIQUID** (cf. Prince & Smolensky 1993/2002)
"No liquid in syllable peak."

Also essential to the analysis is an undominated phonotactic constraint, shown in (18). Note that *COMPLEX is not sufficient to rule out these onset clusters—complex onsets are entirely legal word-initially, but *zl* and *zr* are banned even in that position.

(18) ***ZL/ZR** "No [zl] or [zr] clusters in onset position."

The interaction of the unranked *PEAK/LIQUID and NOCODA with the constraint in (18) (and the other constraints motivated above) yields two different optimal outputs—both of which are attested in our data. This is illustrated in (20) and (21).

(19) *ZL/ZR » *PEAK/LIQ, NOCODA

(20) *Peak/Liq » NoCoda

/gruzl+ig/	*zl/zr	*Peak/Liq	NoCoda	Id-preson-f
gru.zlig	*!		*	
☞ gruz.lig			**	
grus.lig			**	*!
gru.zl̩.lig		*!	*	

(21) NoCoda » *Peak/Liq

/gruzl+ig/	*zl/zr	NoCoda	*Peak/Liq	Id-preson-f
gru.zlig	*!	*		
gruz.lig		**!		
grus.lig		**!		*
☞ gru.zl̩.lig		*	*	

4.2 Variation in Fricative Voicing

Our analysis based on presonorant faithfulness still leaves open the question of why it is so often the case that the fricative /z/ in words like *gruslig* is phonetically voiceless instead of voiced. That is, though our experimental finding confirm that the fricative retains its voicing in coda position in many utterances, devoicing does also occur. We suggest that phonetic factors are responsible for the devoicing of /z/ in the presonorant context studied here.

First of all, voiced fricatives are difficult to produce in general (Ohala 1983). This difficulty has to do with an inherent conflict between the production of voicing and the generation of turbulence that is essential for the identification of a fricative and its place of articulation. For the generation of strong frication turbulence, high intra-oral air pressure is necessary, but if intraoral air pressure is raised too much, it becomes too similar in magnitude to subglottal air pressure and voice production will cease. This problem is particularly urgent in the production of strident fricatives such as /z/. In order to distinguish strident from non-strident fricatives, strident fricatives need to be produced with a large amplitude of frication turbulence. But simultaneous voice production inevitably leads to a reduction of frication amplitude. This has the consequence that the difference in frication amplitude between voiced strident and voiced nonstrident fricatives is much smaller than the amplitude difference between voiceless strident and voiceless nonstrident fricatives, so that the perception of the feature [strident] is challenged for voiced fricatives (Balise & Diehl 1994). When a strident fricative such as /z/ is devoiced, it means that the speaker was not able to maintain this balance between the goals of voice production and the generation of strong frication turbulence. This does not necessarily have the consequence that the distinction between /s/ and /z/ is lost for the listener, because the distinction is also cued by other means such as a difference in duration between voiceless (longer) and voiced (shorter) fricatives (Jessen, 1998 for overview and German data). Perhaps because of this and other cues to the voiced/voiceless distinction among fricatives, the speaker often gives in to the articulatory difficulty of voiced strident fricative production and devoicing occurs.

5. Is There a Viable Coda Devoicing Alternative?

Conceivably, proponents of the coda devoicing analysis could object to our conclusions. They would predict that, in words like *gruslig,* the feature [voice] should not surface because the fricative occurs in coda position. However, they could claim that the coda fricative might still be voiced, as it is in our data, due to variable voicing of fricatives between vowels or sonorants, which occurs in the phonetics. They could support their view by pointing out that in roughly one third of the time in words like *gruslig* this kind of phonetic re-voicing does not apply, hence supporting the variable nature of such a phonetic re-voicing process. But such an alternative account would not work for the following reason. When the control items *Verschlüsslung* and *wässrig* were examined acoustically, it turned out that the fricatives /s/ in these words were almost always mostly or fully voiceless (as illustrated in (9b) where all but 13 of 343 tokens were less than 25% voiced). If a phonetic process of fricative voicing between vowels or sonorants occurred in the language, why would words like *wässrig* be systematically excluded from such a process? The different phonological category in words like *gruslig* on the one hand (phonologically voiced) and words like *wässrig* on the other hand (phonologically voiceless) cannot be responsible, since due to coda devoicing the alveolar fricatives in both words would be left without a [voice] specification.

For example, as illustrated in (22), in the case of *gruslig*, the coda devoicing account produces a voiceless non-[spread] coda fricative which could reasonably be subject to phonetic passive voicing.

(22) *Coda Devoicing; voiced input gruslig*

gru/z/l+ig	*VOI/SG	*VOICODA	*VOIOBS	*SG
gru[s^{sg}].*lig*				*
gru[z].*lig*		*!	*	
☞ *gru*[s].*lig*				
gru[z^{sg}].*lig*	*!	*	*	*

In the phonetics, PASSIVE VOICE yields gru[z]lig, with variable voicing

But with a voiceless input, if the input fricative has no laryngeal specification, the output would be expected to undergo passive voice, as illustrated in (23):

(23) *Coda Devoicing Analysis; unspecified input*

pre/s/*en*	*VOI/SG	*VOICODA	*VOIOBS	*SG
pre[s^{sg}]*en*				*
pre[z]*en*			*	
☞ *pre*[s]*en*				
pre[z^{sg}]*en*	*!		*	*

*In the phonetics, PASSIVE VOICE yields *pre[z]en, with variable voicing*

The result is exactly parallel to that obtained in (22): an unspecified fricative which can be the target of phonetic passive voicing in intersonorant position. **But there are no underlyingly voiceless fricatives which undergo variable voicing in intervocalic position!**

It might appear that the coda devoicing analysis must assume the constraint FRIC-SG, in order to prevent the non-alternating voiceless fricatives in cases such as (23) from being subject to passive voicing.

(24) Coda Devoicing, assuming FRIC-SG; unspecified input fricative

pre/s/*en*	*VOI/SG	*VOICODA	FRIC-SG	ID[sg]	*VOIOBS	*SG
☞ *pre*[s^{sg}]*en*				*		*
pre[z]*en*			*!		*	
pre[s]*en*			*!			
pre[z^{sg}]*en*	*!			*	*	*

This analysis derives a [spread] fricative in (24) which is immune to passive voicing, as desired. However, consider the results with a voiced input in (25):

(25) Coda Devoicing, assuming FRIC-SG; voiced input fricative

gru/z/l+ig	*VOI/SG	*VOICODA	FRIC-SG	ID[sg]	*VOIOBS	*SG
☞*gru*[s^{sg}].*lig*				*		*
gru[z].*lig*		*!	*		*	
gru[s].*lig*			*!			
gru[z^{sg}].*lig*	*!	*		*	*	*

Here, since the output fricative is [spread], no passive voice is possible and the voiced variant cannot be accounted for.

6. Conclusion

In this paper we have presented new experimental data showing that German voiced fricatives, regardless of their syllabification, can and do retain their underlying voicing when followed by a sonorant segment. This pattern of behavior is explained by the positional faithfulness account we argued for above, but is problematic for an analysis of German which employs a coda devoicing constraint. Interestingly, even though there is substantial variation in both fricative voicing and sonorant syllabicity, both types of variation are consistent with the positional faithfulness analysis. The variation in syllabicity of sonorants results from the existence of unranked constraints in the (phonological) grammar: *PEAK/LIQUID and NOCODA are unranked, allowing either [gru.zl̩.lig] or [gruz.lig] to occur as a viable surface output. The variation in fricative voicing, on the other hand, can be understood in the Positional Faithfulness analysis as variable (phonetic) failure to achieve voicing in segments in which voicing is difficult. There is no comparable explanation available for this variation in the Coda Devoicing analysis.

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