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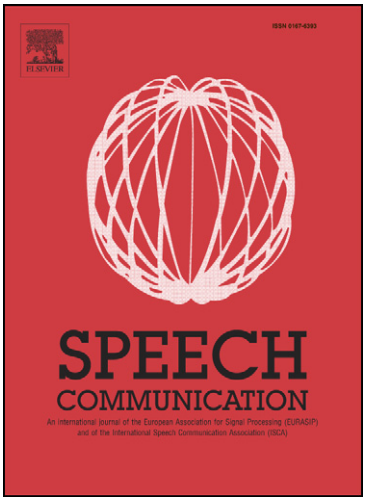

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When BEAT becomes HOUSE:

Factors of word final /t/-deletion in German

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Abstract

The deletion and reduction of alveolar /t/ is a phenomenon that has been given considerable attention in the research on speech production and perception. Data have mainly be drawn from spoken language corpora, where a tight control over contributing factors of /t/-deletion is hardly possible. Here, we present a new way of creating a spoken language corpus adhering to some crucial factors we wanted to hold constant for the investigation of word-final /t/-deletion in German. German is especially interesting with regard to /t/ deletion due to its rich suffixal morphology, attributing morphological status to word-final /t/ in many paradigms. We focused on verb inflection and employed a verb form production task for creating a concise corpus of naturally spoken language in which we could control for factors previously established to affect /t/-deletion. We then determined the best estimators for /t/-productions (i.e. canonical, deleted, or reduced) in our corpus. The influence of extra-linguistic factors was comparable to previous studies. We suggest that our method of constructing a natural language corpus with carefully selected characteristics is a viable way for the examination of deletions and reductions during speech production. Furthermore, we found that the best predictor for non-canonical productions and deletions was the following phonological context.

Keywords: Segment deletion, segment reduction, natural speech, production, phonology

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1. Introduction

Typos set aside, printed language in books or newspapers can be considered "perfect input" for word recognition. Words are separated by visible spaces and are always "produced" canonically. In contrast, the input from spoken language is far from being as clear and canonical as the input from written language: The speech stream is not easily separable into single words – let alone segments – and their canonical production is the exception rather than the rule. For instance, single segments can show considerable variation in the output, arguably hampering the recognition process (cf. Pickett & Pollack, 1963; Pollack & Pickett, 1963). On the extreme end of reduction (i.e. shortening) and lenition (i.e. weakening) processes, segments or even syllables are completely omitted (deleted) in natural speech. One of the most studied phenomena in this respect is alveolar /t/-deletion (e.g. Guy, 1980; Mitterer & Ernestus, 2006; Mitterer, Yoneama, & Ernestus, 2008; Neu, 1980; Raymond, Dautricourt, & Hume, 2006; Sumner & Samuel, 2005).

Despite segment deletions in general and /t/ deletions in particular, listeners usually understand what speakers say and are assumed to compensate for imperfect realizations (Mitterer & Ernestus, 2006; Mitterer et al., 2008; Pollack & Pickett, 1963). While this would suggest a rule-based (undoing) mechanism for /t/-deletion in natural speech, it is not completely regular in a traditional, rule-based phonological sense, because it does not occur in 100% of the cases (contrary to, e.g. Turkish vowel harmony). However, /t/-deletion is not completely random, either (cf. Raymond et al., 2006, and references therein). There are several factors that influence deletion rates and can therefore be considered "deletion predictors". These might be based on linguistic factors (e.g. phonological context) or reflect extra-linguistic factors like properties of the speaker (e.g. gender).

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In this article, we report /t/ deletion and reduction rates in German verb forms, stemming from a production task, which provides a highly controlled way of spoken language corpus construction. German is of special interest in this regard, not only because it is understudied with respect to deletions in natural language production, but also because of its rich morphology, attributing morphological content to the alveolar stop, especially in suffix position. We focus on few linguistic deletion factors and analyze them together with extra-linguistic factors using a novel statistical methodology (Baayen, 2008), which allows for the determination of the best predictors for non-canonical productions and deletions. At the same time, a comparison of linguistic and extra-linguistic factors between our study and previous studies allows us to validate the method of construction a spoken language corpus in a controlled way. We also show that /t/ deletions are promoted in contexts that allow for compensations by lengthening the (constant) preceding segment.

2. Relevant factors of /t/-deletion

We distinguish between factors directly reflecting linguistic properties (preceding and following segments, morphological function of /t/) and properties relevant to the speaker (gender) or the speaking style (fluent, dysfluent). We subsume the latter factors under the label "extra-linguistic".

As for *extra-linguistic* factors, a common finding is that deletion rates in general are higher for men than for women (cf. Byrd, 1994; Neu, 1980; Wolfram, 1969),[1] while Guy (1992) found that older speakers deleted /t/ and /d/ less often than younger speakers in Standard American English. Differences in social class and dialect have also been found to influence /t, d/-deletion (e.g. Labov, 1967; Wolfram, 1969). Another factor effecting segment deletion is speaking rate. A number of researchers found higher deletion rates for fast speech than for slow speech (cf. Byrd & Tan, 1996; Fosler-Lussier & Morgan, 1999; Guy, 1980; all

[1]However, Raymond et al. (2006) did not find a gender difference in the rate of medial /t, d/-deletion.

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investigating English).[2] Related to this is the finding that dysfluent production (e.g. characterized by hesitational pauses) may have an impact on the probability of deletions, in that segments are strengthened when occurring in dysfluent contexts (e.g. Fougeron & Keating, 1997; Fox Tree & Clark, 1997; Kingston, 2006; Shriberg, 1999).

As for linguistic factors, previous research established that word category, frequency, and predictability influence deletion and reduction rates (Jurafsky, Bell, Gregory, & Raymond, 2001; Lieberman, 1963; Neu, 1980; Raymond et al., 2006). Relevant to our study are findings that show positional and context effects on deletions as well as studies revealing dependencies of deletions on the morphological status of a particular segment (e.g. /t/). Greenberg (1999) showed that deletions were less likely in syllable onset than in syllable coda positions. Additionally, deletion rates differed according to whether syllables were stressed or not. For stressed syllables in English, deletion rates were generally lower than for unstressed syllables (Greenberg, Carvey, Hitchcock, & Chang, 2002; Turk & Shattuck-Hufnagel, 2007; Turk & White, 1999; Zue & Laferriere, 1979). Moreover, segments flanking alveolar stops decisively influence their deletion rate, depending on syllable position. For instance, Mitterer & Ernestus (2006) showed that in Dutch, the likelihood of /t/-deletion in word final position was highest if preceded by /s/ or followed by bilabials. Other studies found higher deletion rates for /t/s in positions followed by consonants than when followed by vowels (Guy, 1980; Labov, 1967; Neu, 1980; Wolfram, 1969). The same studies indicated that the preceding context similarly caused more deletions if it was consonantal than if it was vocalic. Besides the manner of articulation of the following segments, it has been shown that the place of articulation of these segments also influenced alveolar stop deletion rates. For Afro-American English, Fasold (1972) found more deletions of alveolar stops if these were followed by consonants with the same place of articulation than if they were followed by consonants with a different place of articulation.

[2]Byrd & Tan (1996) investigated segment reduction, not deletion *per se*. However, since we assume deletion to be at the "endpoint" of reduction processes, their results are applicable to deletion data as well.

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Finally, it has been shown that the morphological status of /t/ determines its likelihood of being deleted. If it carried morphological function as in the case of the English past tense (e.g. *deal-t*), deletion was less likely to occur (Guy, 1980, 1992; Neu, 1980; Raymond et al., 2006). On the other hand, if the stop did not carry morphological function (e.g. *mist*), deletions were more likely to occur[3].

The majority of findings on /t/-deletion and reduction is based on naturally spoken language corpora (e.g. Buckeye for English, Pitt et al., 2007; and Kiel Corpus for German, IPDS, 1994). A natural shortcoming of existing corpora is that the multitude of factors affecting /t/ deletion cannot be assessed in a way that would allow for comparisons of controlled sample sizes. For this reason, we wanted to construct a specific spoken language corpus where we can restrict the deletion factors to a minimum and control for comparable phonological and morphological contexts. We thereby can look at the most prominent linguistic factors without potential confounds resulting from peculiarities of the corpora. For our purposes, we employed a verb form production task for the investigation of /t/-deletions in German verb suffixes.

3. Properties of the German verb form corpus

For the purpose of investigating /t/-deletions in German, we created a new corpus. In the following section we explain how the corpus was created and what method has been used. Because we opted for a verb production paradigm, we first present a short overview over the verbal paradigms in German.

[3] Note that another quantitative morphological measure with predictions for /t/-deletion is relative frequency of morphemes at whose edges /t/ may be deleted (Hay, 2001). A more detailed examination of this issue is however beyond the scope of this paper.

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3.1. Verb-final /t/ in German

We decided to investigate 2nd person singular forms of German regular and irregular verbs in the present tense for several reasons. Firstly, this form uses solely the unique *–st* suffix in its German inflection. Besides, within the verbs' paradigm, omitted final /t/ usually does not cause ambiguities, while ambiguities outside the paradigm are still possible (e.g. /t/-deletion in *hau-st* 'you beat' results in *hau-s* 'house' or *hau's*, a reduced form of *hau es* 'beat-IMP it'). The alveolar fricative is sufficient to distinguish the 2nd person from all other person/number combinations if the stem does not end in /s/. This is important regarding the findings of Guy (1980, 1992) and Neu (1980), who found differences in /t/-deletion depending on the morphological function of the alveolar plosive. Next, the 2nd person forms provide a constant preceding context (i.e. /s/),[4] in which /t/-deletions are to be expected for *a priori* reasons (cf. Mitterer & Ernestus, 2006, for Dutch), allowing for a closer investigation of the upcoming context. Furthermore, the preceding /s/ can be either part of the stem or part of the suffix. In the verb form *hau-st* from the infinitive *hauen* ('beat'), [s] surfaces as part of the suffix, while in the form *haus-(s)t* from *hausen* ('house, dwell'), [s] surfaces either as part of the stem, the suffix, or is possibly "ambimorphemic". Finally, the -/st/ suffix is attached independently of whether the verb stem is regular or not.[5].

[4] We transcribe the alveolar fricative consistently as unvoiced, although Standard German differentiates between /z/ and /s/. However, this contrast is neutralized in Southern German varieties from which we drew our speakers.
[5] Irregularity is in fact defined in terms of past tense formation: The verb *graben* ('dig') is irregular since its past tense is not formed with the regular past tense suffix *–te*, but expressed by a stem vowel change (**grab-te-st* vs. *grub-st* 'you dug'). On the other hand, the past tense of the regular verb *baden* ('bath') involves the regular past tense suffix without a vowel change (*bade-te-st* 'you bathed'). There are dialects which allow the alternative form *grabst* ('you dig') in the present tense. However, in Standard German, this form is not grammatical. Irregular verbs may also show a stem vowel alternation in the present tense. For *graben*, the 2nd person singular is *gräbst*, not **grabst*, while the present tense of regular verbs never shows such alternations (*bad(e)-st,* not **bäd(e)-st*).

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3.2. Methodological considerations

Regarding a controlled data set with regular and irregular verbs with inflected 2nd singular forms, we were faced with the problem that no existing corpus of spoken language could provide us with the necessary data. For German, the corpus that is comparable to the ones used in the most recent studies (e.g. Mitterer & Ernestus, 2006; Raymond et al., 2006) is the Kiel corpus of spontaneous speech (IPDS, 1994). It consists of about 4 hours of phonetically labeled speech from 42 Northern German speakers. However, there are hardly any 2nd person singular forms in this corpus, since the spontaneous conversations were based on the usage of honorable 2nd person forms which are equivalent to the 3rd person plural with an *–en* suffix (e.g. *Sie hau-en* 'you beat'). Secondly, the corpus is based on a restricted vocabulary, since the conversations are exclusively about appointment making. Another natural result of the corpus structure is that any control over the following context of the forms of interest is hard to achieve, if not impossible. Finally, the rather random conversational samples make it very difficult to control for extra-linguistic variables such as gender, age, and dialect. For these reasons, we created a corpus conforming to our needs, which will be described in the next section.

3.3. Corpus construction

The rate of /t/-deletion crucially depends on the task subjects have to perform, or more precisely, the speech register they use (e.g. Mitterer & Ernestus, 2006; Raymond et al., 2006 and references therein: Fosler-Lussier & Morgan, 1999; Guy, 1980; Jurafsky et al., 2001; Wolfram, 1969). In read speech, subjects reduce words less drastically and delete segments less often compared to (fast) natural, conversational speech. Yet, at the same time, we wanted to be able to control what subjects produced in which (phonological) context. In order to achieve a natural way of speech production, while simultaneously being able to control for specific verbs and the context in which they occur, we opted for a verb paradigm production

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task. In such a task, subjects have to produce inflected forms of a verb's paradigm. For each production trial, subjects are given the infinitive of the respective verb as well as the personal pronouns for each inflected form, but not the form itself. Thus, subjects have to provide the correct word forms by themselves. Therefore, the task is not a simple reading task and it increases the probability of a natural way of speaking. Furthermore, producing verbs in a fast way is not a very complex task for native speakers.

Material

For the corpus, 50 verbs (25 irregular, 25 regular) were chosen. A complete list of the verbs is given in the appendix. All verbs were disyllabic. Care was taken to match the log mean lemma frequencies for the regular and irregular verbs (cf. Table 1).

Table 1: Average log-frequencies (standard deviations in parentheses) for each verb class of the test stimuli (based on 'per million' count from Mannheim frequencies as given in CELEX, Baayen, Piepenbrook, & Gullikers, 1995).

Frequency Type	Frequency Regular	Frequency Irregular	*t* value[6]	p
log (Lemma)	1.00 (0.34)	1.15 (0.34)	1.62	<0.11
log (Infinitive)	0.57 (0.31)	0.60 (0.32)	0.37	<0.71
log (2nd person)	0.03 (0.01)	0.21 (0.40)	2.55	<0.05

Note while infinitive and lemma frequencies are very similar across verb classes, the 2nd person singular forms of regular verbs have a lower frequency than the 2nd singular

[6] Two-tailed Student *t* test comparing the log-frequencies of regular and irregular forms.

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forms of the irregular verbs. This difference is significant. Note, however, there is more variation in the 2nd person frequencies than in the lemma or infinitive frequencies.

Table 2: Paradigm of the verb *hauen* 'to beat' and the cells of the paradigm that had to be produced for the verbs in the respective conditions, indicated by "×". Column 1 indicates the pronouns for the respective verb form.

Pronoun Person/Number		**Verb stem + Suffix e.g. *hau-en* 'to beat'**	CONDITION I	CONDITION II	CONDITION III
Ich	'I – 1st sg'	*hau-e*	×	×	
Du	'you – 2nd sg'	*hau-st*	×	×	×
Er/Sie	's/he – 3rd sg'	*hau-t*	× **(he)**		× **(she)**
Wir	'we – 1st pl.'	*hau-en*	×	×	
Ihr	'you – 2nd pl.'	*hau-t*	×	×	×
Sie	'they – 3rd pl.'	*hau-en*	×		×

Subjects were asked to produce the full or partial range of the verbs' paradigm in the present tense. Every subject had to produce each verb in three different conditions. Table 2 gives an overview of the complete paradigm for the verb *hauen* ('to beat') and the three production conditions. In CONDITION I, the complete paradigm of the present tense had to be produced (e.g. *"ich haue, du haust, er haut, wir hauen, ihr haut, sie hauen*"). In this condition, the 2nd person singular form of the verb is followed by a vowel [ə□] of the pronoun *er* (he, [ə□□]), as indicated by the underlined segments. In CONDITION II (cf. column

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4 in Table 2), four inflected verb forms were required. In this condition, the crucial verb form was preceding the pronoun *wir* (we [vi□□]) with a voiced labiodental fricative [v] as initial segment (i.e. "… *du haust, wir hauen* …"). Finally, in CONDITION III, the verb form we were interested in was followed by the singular feminine pronoun *sie* (she [z/si□]) (i.e. "… *du haust, sie haut, wir hauen* …"). Canonically, this pronoun would be produced with an initial [z]. However, in the Southern German dialects of our speakers as well as in fast and conversational speech, this fricative is realized as a voiceless [s]. We therefore transcribe the voiceless fricative for this condition.

Thus, each subject had to produce the 2nd person singular in three different phonological contexts (i.e. [ɐ□], [v], [s]) for each of the 50 verbs. This allowed for a good control over the contexts in which the final /t/ occurred. In total, every subject provided us with 150 verb productions. The production conditions I-III of each verb were pseudo-randomized.

Method

Overall, 10 subjects from the Universities of Frankfurt and Konstanz (6 female, 4 male) participated in the production task. They received monetary compensation for their participation and were not told the purpose of the study beforehand. Subjects were given the infinitive of each verb in the center of a screen located approximately 50 cm in front of them (e.g. *hassen* 'to hate', font type Arial, font size 24 points). Underneath each form, the relevant personal pronouns according to the conditions illustrated in Table 2 indicated which forms had to be produced (e.g. *ich, du, wir, sie* pl. 'I, you, we, they'). Hence, subjects had to create the paradigm forms for themselves and thought they were involved in a morphological task. As a consequence, they did not perform a pure reading task. Subjects could determine the speed of presentation for themselves. When they pressed a mouse button, the next trial was

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presented on the screen. During the session, no feedback was given as to the accuracy of their production. Additionally, emphatic orders as “do not slow down” or to “speed up a little” were presented on the screen. These orders were given randomly and did not correlate with the subjects’ performances. The purpose of these instructions was to keep the speaking rate at a relatively high level.

Subjects were asked to produce the verb forms as quickly as possible. We instructed subjects not to worry about mistakes. At the same time, we wanted to ensure that each form was produced correctly at least once. If subjects realized they made a mistake, they could repeat the word in question. A pretest had shown that the instruction to avoid mistakes altogether, resulted in productions that were much less natural and much slower.

Subjects received written instructions before the experiment. Before the main task, a training session with different verbs than in the test session ensured that the subjects got familiarized with the task. Overall, the production task lasted approximately 25 minutes, including instructions and the training session.

3.4. Method of labeling

In German, a canonically produced final /t/ roughly consists of three physical events: The closure of the articulators, their release and a subsequent phase of aspiration. The process of final /t/-deletion does not occur in an “either-or” fashion. Rather, there are gradual differences. The canonically produced /t/ is on one end of the scale, whereas the deleted /t/ lies on the other. A dichotomous decision of either “/t/ produced” or “/t/ deleted” is not always easy to make. However, following Mitterer & Ernestus (2006), we think that this simplistic categorization is more reliable than classification schemes of more elaboration. In determining our dichotomous factors, we decided for the following criteria:

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Final /t/ counted as "deleted", when there was none of the three characteristic events – closure, release, aspiration – to be found in the speech signal (cf. Figure 1).

If all three physical events occurred in the signal, /t/ was assumed to be present and produced canonically (cf. Figure 3).

FIGURES 1, 2, 3, 4 ABOUT HERE

Besides a complete omission of the final /t/, there was another pattern that occurred regularly in the data. Subjects produced an audible and visible closure and vowel onset, but abstained from producing a release burst and aspiration. These cases were treated as /t/-reductions (cf. Figure 4).

Theoretically, a fourth possibility could have arisen: The omission of a closure with a simultaneous production of a release/aspiration. However, we did not find this production pattern in our data. If the /t/-deletion occurred in the /s/ context, the result of the deletion was a /ss/ segment. The length of the two segments in these cases was determined by halving its complete length if there were no cues for segment boundaries, as, for example, indicated by a drop in the signals' amplitude (cf. Figure 2) as it showed up in few cases. In these cases, the boundaries of the two segments were aligned with the amplitude minima (cf. Figure 1).

The labeling of the corpus in the phonetic sound application PRAAT (Boersma & Weenink, 2007) was carried out by a phonetically trained graduate student who was unaware of the purpose of the study. For our subsequent analyses, 54 cases had to be excluded (3.6% of the overall data). In these cases, subjects produced an incorrect verb or verb form, or they did not produce the desired verb form at all.

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4. Analyses of deletion and reduction rates

4.1. Factors of interest

The construction of the corpus via the verb form construction task allowed us to hold constant the preceding context for alveolar /t/, which was always /s/. As suggested by previous results regarding compensatory effects in deletions (Mitterer & Ernestus, 2006; Mitterer et al., 2008; Pollack & Pickett, 1963), a crucial factor of interest was the duration of preceding /s/. Next, due to the sequence of productions, the following context was restricted to the first segments /v/, /e□/, and /s/ of the respective pronouns (see *Material* section). This constituted our phonological context. Further, we distinguished between regular and irregular verbs, and verbs ending in /s/ and verbs ending in any other segment. Another factor of interest was the verb form frequency. We assessed dysfluency by whether or not /t/ was followed by a (hesitational) pause. Finally, we were interested in potential gender differences regarding deletion and reduction rates.

4.2. Analyses

The categorical dependent measures *deletion rate* (deleted vs. not deleted), */t/-production* (canonical vs. non-canonical, i.e. deleted or reduced) and non-canonical */t/-realization* (deleted vs. reduced, all as log-odds) were analyzed in Mixed Logit Models, i.e. Generalized Linear Mixed Models for binomially distributed outcomes (cf. Agresti, 2002; Breslow & Clayton, 1993), using the lme4 package (Bates & Maechler, 2010) in R (R Development Core Team, 2010). Note that we used treatment coding for our contrasts, with the following reference values: 0=not deleted for *deletion rate*, 0=non-canonical for */t/-production*, and 0=reduced for */t/-realization*. For illustration purposes, deletion rates were calculated by dividing the observations for one of the categories by the overall number of observations. Furthermore, we analyzed the duration of the preceding /s/ in a Linear Mixed Model (Baayen,

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2008; Pinheiro & Bates, 2000). For all models, we paralleled multiple regression analyses by determining the best-fit Mixed Model from an initial set of predictor variables as described in Baayen (2008). Only the best-fit models are reported. They have significantly lower Aikaike and Bayesian Information Criteria (AIC, BIC) compared to alternative models. Our model comparisons also included random subject and item effects as well as random slopes. They occur in reported models if their inclusion significantly improved the model fit. Predictor variables comprised the across-subject effect GENDER (male, female), the across-item effects S-STEM (i.e. whether the verb stem ended in /s/ or not, e.g. haus-en 'house' vs. hau-en 'beat'), VERB CLASS (regular, irregular), FREQUENCY (log-frequency of item), and CONTEXT (following segment, /e□/, /v/, or /s/), as well as the co-variates /s/-LENGTH (duration of preceding /s/) and PAUSE (presence of silence after /t/).

The best-fit model for deletion rates (see Table 3 for details and Table 7 for an assessment of the goodness-of-fit) included the random factors SUBJECT and ITEM, the random slopes for /s/-LENGTH, PAUSE, and GENDER, and the fixed effects PAUSE, GENDER, CONTEXT, and /s/-LENGTH, as well as the interaction of CONTEXT and /s/-LENGTH. Note that we also calculated by-item slopes for GENDER and by-subject slopes for /s/-LENGTH. However, the inclusion of neither of the one improved our model fits.

Overall, /t/ was deleted in 20% of all the productions. Deletion rates significantly differed between productions followed by a pause (3.7%) and productions not followed by a pause (24.3%). Further, deletion rates were lower in stems ending in /s/ (16.8%) than in stems ending in another segment (21.5%) (e.g. haus-en vs. hau-en), while males deleted /t/ more often than females (30.4% vs. 13.1%). The best across-item predictor was the (phonological) context. Significantly more deletions occurred before /s/ (45.5%) or /v/ (11.5%) than before /e□/ (3.3%). Finally, the strongest co-variate of /t/-deletion was the length of the preceding /s/, with which it was positively correlated. The interactions between /s/-length and context indicate that this correlation differed across contexts. Random and fixed effects together with

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Wald *z* and *p* values are summarized in Table 3, the goodness-of-fit is assessed by Somers' Dxy Rank Correlation as described in Baayen (2008) and shown in Table 7.

Table 3: Random and fixed effects for the Mixed Logit Model on /t/-deletion (deleted vs. not deleted).
Significance levels are as follows: *** p > 0.001; ** p > 0.01; * p > 0.05.

Random Effects	**Variance**		**Correlation**		
ITEM *(Intercept)*	3.52				
/s/-LENGTH	260.29		-0.952		
SUBJECT *(Intercept)*	2.07				
GENDER: male	8.04		-0.829		
PAUSE: pause	11.90		-1.000	0.829	
Fixed Effects	**Estimate**	**Std. Err.**	**Wald z**	**Prob>|z|**	**Sign.**
(*Intercept*)	-13.34	1.39	-9.63	< 2e-16	***
PAUSE: pause	-5.59	1.41	-3.97	7.30E-05	***
/s/-STEM: /s/-stem	-0.81	0.29	-2.80	0.00518	**
GENDER: male	2.69	1.12	2.40	0.01658	*
CONTEXT: /s/	10.37	1.30	7.99	1.34E-15	***
CONTEXT: /v/	5.13	1.27	4.04	5.39E-05	***
/s/-LENGTH	83.34	10.30	8.09	5.88E-16	***
CONTEXT: /s/ X /s/-LENGTH	-59.15	10.57	-5.60	2.20E-08	***
CONTEXT: /v/ X /s/-LENGTH	-33.86	10.95	-3.09	0.00199	**

The best-fit reduction model for /t/-productions (i.e. canonical vs. non-canonical) comprised the random factors SUBJECT and ITEM, the random slopes for PAUSE and GENDER, and the fixed effects FREQUENCY, VERB CLASS, PAUSE, /S/STEM, GENDER, CONTEXT as well as the interaction CONTEXT X /S/-LENGTH. Random and fixed effects are summarized in Table 4, the goodness-of-fit is given in Table 7. Deletion rates and rates of canonical productions are illustrated for each significant effect in Figure 5. Again, we additionally calculated by-item slopes for GENDER and by-subject slopes for /s/-LENGTH, the inclusion of which did not improve the model fit.

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FIGURE 5 ABOUT HERE

Table 4: Random and fixed effects for the Mixed Logit Model on /t/-productions (canonical vs. non-canonical).
Significance levels are as follows: *** p > 0.001; ** p > 0.01; * p > 0.05.

Random Effects	**Variance**	**Correlation**
ITEM *(Intercept)*	0.08	
SUBJECT *(Intercept)*	6.42	
GENDER: male	4.80	1.000
PAUSE: pause	0.53	-0.930

Fixed Effects	**Estimate**	**Std. Err.**	**Wald z**	**Prob>|z|**	**Sign.**
(*Intercept*)	3.44	1.16	2.97	0.00303	**
LOG-FREQUENCY	0.01	0.01	0.91	0.36448	
VERB CLASS: regular	0.30	0.18	1.63	0.1041	
PAUSE: pause	3.18	0.39	8.24	2.00E-16	***
/s/-STEM: /s/-stem	0.50	0.19	2.58	0.01001	*
GENDER: male	-0.23	1.15	-0.20	0.83919	
CONTEXT: /s/	-5.12	0.66	-7.78	7.26E-15	***
CONTEXT: /v/	-1.69	0.56	-3.02	0.00256	**
/s/-LENGTH	-36.32	4.91	-7.40	1.32E-13	***
CONTEXT: /s/ X /s/-LENGTH	26.87	6.05	4.44	9.02E-06	***
CONTEXT: /v/ X /s/-LENGTH	11.50	5.80	1.98	0.04744	*

There were more canonical /t/-productions if there was a following pause (77%) than if there was no pause (46%). Further, /t/-productions were more canonical in /s/-stems (57%) than in non-/s/-stems (50%) (e.g. haus-en vs. hau-en). The significant context effect revealed that /t/ was most often realized canonically if the following context started in /e□/ (70%),

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while /t/ was most often realized non-canonically if the following context started in /s/. This effect depended on the length of the preceding /s/: The longer the preceding /s/, the more likely was a non-canonical realization in the /s/ context.

Finally, the best-fit reduction model for non-canonical /t/-realizations comprised the random effects ITEM and SUBJECT, the fixed effects FREQUENCY, VERB CLASS, PAUSE, GENDER, CONTEXT, /s/-LENGTH as well as the interaction CONTEXT X /s/-LENGTH. Random and fixed effects are summarized in Table 5. The goodness-of-fit is shown in Table 7. Deletion and reduction rates for non-canonical /t/-productions are summarized in Figure 6.

Table 5: Random and fixed effects for the Mixed Logit Model on non-canonical /t/-realizations (deleted vs. reduced).
Significance levels are as follows: *** p > 0.001; ** p > 0.01; * p > 0.05.

Random Effects	**Variance**				
ITEM *(Intercept)*	0.40				
SUBJECT *(Intercept)*	1.15				
Fixed Effects	**Estimate**	**Std. err.**	**Wald z**	**Prob>|z|**	**Sign.**
(*Intercept*)	-9.89	1.40	-7.06	1.65E-12	***
LOG-FREQUENCY	-0.01	0.01	-0.51	0.61311	
VERB CLASS: regular	-0.09	0.28	-0.33	0.74252	
PAUSE: pause	-2.63	0.82	-3.21	0.00131	**
GENDER: male	1.67	0.74	2.25	0.02462	*
CONTEXT: /s/	8.30	1.33	6.22	4.98E-10	***
CONTEXT: /v/	3.51	1.37	2.57	0.01013	*
/S/-LENGTH	66.05	10.74	6.15	7.66E-10	***
CONTEXT: /s/ X /s/-LENGTH	-50.56	11.30	-4.48	7.61E-06	***
CONTEXT: /v/ X /s/-LENGTH	-23.03	12.08	-1.91	0.05664	.

FIGURE 6 ABOUT HERE

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Interestingly, reductions occurred more often than deletions if /t/ was followed by a pause (84% reductions, 16% deletions; for effect sizes, cf. Table 5). While males deleted /t/ slightly more often than they reduced it (56% vs. 44%), females deleted only rarely (30%) but reduced more frequently (70%). Finally, reductions occurred more often than deletions if /e/ followed (89% vs. 11%), while reductions occurred less often than deletions if /s/ followed (37% vs. 63% deletions). This effect, however, could be driven by the fact that /t/-deletions already accounted for a large number of occurrences in the /s/-context.

Since the deletion rate analysis revealed a strong correlation between /t/-deletion and /s/-length, we wanted to investigate whether an increased /s/-length is in fact a compensatory process for /t/-deletion, or whether /s/-length also depends on factors other than /t/-deletion. For that purpose, we determined the best-fit Mixed Model for the dependent variable /s/-LENGTH (i.e. duration of preceding /s/) according to the same procedure as described above. The set of predictors was the same as before, except that we now grouped the levels of /t/-realization in the effect /t/-GRADE (deleted, reduced, canonical). The model comprised the random factors SUBJECT and ITEM, the fixed effects PAUSE, /t/-GRADE, CONTEXT, VERB CLASS, FREQUENCY, /s/-STEM as well as all possible interactions between CONTEXT and /t/-GRADE, and VERB CLASS, FREQUENCY and /s/-STEM. For all effects, *p* values were calculated with 10 000 Markov Chain Monte Carlo samplings (cf. Baayen, 2008, Table 6).

As can be seen in Table 6, the best predictor for /s/-length is the /t/-GRADE level *deleted*, i.e. if /t/ was deleted. In this condition, /s/ was longer (112 ms) than if /t/ was reduced (98 ms) or produced canonically (97 ms). The best across-item predictor is the phonological context. In particular, /s/ was longer in the /s/ context (113 ms) than in the /v/ (96 ms) or /e/ (91 ms) context. Finally, /s/ was longer when there was a pause after /t/ (119 ms) than if there was no pause (95 ms).

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Table 6: Random and fixed effects of the best-fit Mixed Model on /s/-length. Significance levels are as follows: *** p > 0.001; ** p > 0.01; * p > 0.05.

Random Effects	Name	Variance	MCMCmean
ITEM	*(Intercept)*	3.66E-05	5.70E-03
SUBJECT	*(Intercept)*	2.36E-04	1.40E-02
RESIDUAL		6.62E-04	2.58E-02

Fixed Effects	Estimate	MCMCmean	t value	p(>|t|)	Sign.
(*Intercept*)	7.60E-02	7.60E-02	13.23	0.000	***
FREQUENCY	2.10E-05	0.0000	0.219	0.8265	
VERB CLASS: regular	4.18E-03	4.20E-03	1.857	0.0635	
/s/-STEM: /s/-stem	1.22E-02	1.21E-02	5.126	0.000	***
CONTEXT: /s/	9.45E-03	9.50E-03	4.871	0.000	***
CONTEXT: /v/	2.12E-03	2.20E-03	1.27	0.2044	
/t/-GRADE: deleted	3.04E-02	3.03E-02	12.774	0.0000	***
/t/-GRADE: reduced	9.02E-03	8.90E-03	4.869	0.0000	***
PAUSE: pause	2.43E-02	2.44E-02	10.134	0.0000	***

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Table 7: Somers' Dxy Rank Correlations for the three comparisons deleted/non-deleted, canonical/non-canonical, and deleted/reduced.

Comparison	C	Dxy	n	missing
deleted/non-deleted	0.8983	0.7966	1446	0.00
canonical/non-canonical	0.9001	0.8011	1446	0.00
deleted/reduced	0.9027	0.8054	687	0.00

5. General discussion

The objective of our production study was to investigate potential factors for word final alveolar /t/-deletion in German verb forms. We were furthermore interested to what degree the verb form production task would provide us with corpus data comparable to larger data collections (e.g. the Kiel corpus, IPDS, 1994).

Regarding the latter issue, we could replicate most of the findings on word final /t/-deletion in other Germanic languages such as Dutch and English, both for linguistic and extra-linguistic factors. For instance, we found that canonical /t/-productions and /t/-deletions depended on the gender of the speaker. Deletion rates were higher for men than for women (cf. Byrd, 1994; Neu, 1980; Wolfram, 1969), while among non-canonical productions, it was the women who reduced more than the men. We are aware that the result of gender differences in our study must be viewed critically, since we investigated a small population size.

As for linguistic factors, on the other hand, we found that /t/-deletions and non-canonical /t/-productions were consistently affected by the following phonological context (cf. Guy, 1980; Labov, 1967; Mitterer & Ernestus, 2006; Neu, 1980; Wolfram, 1969). We could thus show that /t/ deletion in German does not follow entirely random patterns, but is constrained in rather systematic ways. The most important constraint, in this respect, has been the phonological context.

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Overall, final /t/ was deleted in 289 cases (of 1446 possible /t/ realizations, 20.0%). This deletion rate is almost identical to the overall /t/-deletion rate of 21.4% in the Kiel Corpus of Spontaneous Speech (IPDS, 1994, cf. Zimmerer, 2009). The fact that the overall deletion rate of final /t/ as part of a suffix was almost identical to the Kiel corpus, indicates that the way we constructed our corpus provided us with data that is comparable to data from conversational speech (see also Zimmerer, 2009).

Concerning extra-linguistic factors, we found that hesitational pauses promoted canonical productions of /t/. Within non-canonical productions, hesitational pauses correlated with fewer /t/-deletions, but with more /t/-reductions. This result might be taken as a first indication of the difference between reduction and deletion processes. If one parallels hesitational pauses with (dys)fluency, our results conform to previous studies showing less deletions in dysfluent speech or at prosodic breaks, which are also indicated by pauses (e.g. Fougeron & Keating, 1997; Fox Tree & Clark, 1997; Kingston, 2006; Shriberg, 1999).[7] On the other hand, pauses could also be indicative of more careful speech. In this respect, the lack of pauses should reflect faster speaking rates. Again, this would be in line with previous findings, showing that deletion rates were larger in fast speech compared to slower or more careful speech (cf. Byrd & Tan, 1996; Fosler-Lussier & Morgan, 1999; Guy, 1980).

As for phonological factors, the corpus was constructed in a way that allowed only for an examination of the following context. Our results once more conformed to previous investigations that showed a strong influence of this following context. In particular, the vocalic context demoted the deletion rate, while a following coronal fricative (/s/-context) led to a deletion rate of almost 50%. The labio-dental fricative /v/ produced an intermediate amount of deletion. Altogether, the /s/-context showed the least amount of canonical /t/-productions, the highest rate of /t/-deletions, and a much lower reduction rate compared to the /e/- or /v/-context, the latter could also be due to the already large number of deletions. Our

[7] There does not exist a clear definition of how speech rate, or fluency are defined (see, e.g., Koreman, 2006)

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context findings are somewhat different from Mitterer & Ernestus (2006), who found the highest amount of deletion in front of a (bi)labial consonant. However, this difference is likely to result from differences in the data sets. In our corpus, the /s/ context allowed for cluster simplification since our preceding context was consistently the coronal fricative /s/ (cf. Kohler, 1995:209). Other phonological factors were kept constant across the different conditions and are not investigated here any further.

As indicated above, complete /t/-deletion can be considered as the extreme end on a reduction scale. We therefore also investigated the amount of final /t/s that were reduced. The analysis of /t/-reduction showed that the results were not identical to the ones obtained for /t/-deletion. Overall, 398 words had the final /t/ reduced (out of 1446, i.e. 27.5%).

As in the deletion analysis, pauses led to fewer final /t/-reductions. This is in line with lenition accounts that show that (prosodic) boundaries are indicated by more canonical productions of segments (e.g. Kingston, 2006).

As for further linguistic factors, the emerging reduction patterns rather differed from the deletion patterns. Crucially, the phonological context was not a significant determiner for /t/-reduction.

Furthermore, we found that stems ending in /s/ showed more canonical productions of /t/. One rather speculative interpretation of this result could be that the ambimorphemic status of the preceding /s/ in verb form like *hau(s)t* ('you dwell') renders the /t/ of the suffix into a somewhat more information-carrying position, in contrast to a case like *hau-st* ('you beat'). However, the effect is rather small and the effect has to be shown in other environments as well before far reaching interpretations of this result should be made.

Finally, we analyzed the duration of /s/ in order to see whether deletion of /t/ resulted in different /t/ realizations. Previous research suggested that in a final /st/ cluster, the /s/ is shorter than a single final /s/. This difference obviously even holds after /t/-deletion and can be interpreted as a cue for an underlying /t/ (Mitterer & Ernestus, 2006). In our corpus,

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subjects seemed to compensate for /t/-deletion in that /s/ was produced longer if /t/ was deleted, but not when it was reduced. This result is opposite to findings by Mitterer and Ernestus (2006) where subjects did not compensate for /t/-deletion. They showed also that in perception studies the short [s] was taken as cue for a /st/ cluster, regardless of the presence of the plosive in the signal. Our data suggest that, at least for German, this strategy is not always viable, since speakers lengthen the /s/ when the /t/ is deleted.

If we compare /t/-reduction and /t/-deletion in our corpus, we can conclude that reduction is a more general process which takes place irrespective of context. It is mainly driven by speed of articulation, that is, if hesitational pauses co-occur. For the complete deletion of /t/, on the other hand, phonological context becomes more crucial.

To summarize, the construction of our corpus by means of a verb production paradigm seems to be a promising and viable one. The task prevented subjects to pay too much attention on *how* they produced the paradigm; their main focus was on *what* they produced. This resulted in naturally spoken data despite the tightly controlled stimulus set and laboratory setting. The method enabled us to mimic data from conversational speech, as can be seen in the replication of several factors for /t/-deletion and reduction.

Second, we found that /t/-deletion in German 2nd person singular suffixes occurs as frequently as elsewhere. This might not be surprising, since from a morphological point of view, 2nd person singular forms are still unambiguous even in the absence of final /t/. Third, /t/-deletion was promoted in phonological contexts allowing for cluster simplification, i.e. if /s/ followed. This had also repercussions for the duration of the alveolar fricative, which was either part of the stem and the suffix or the suffix alone.

Third, the results of our corpus analysis adds further potentially interesting data to the discussion centered around the question of the interface between phonology and phonetics. Reduction processes have attracted a lot of interest from both phonological and phonetic points of view (e.g. Johnston, 2004; Kingston, 2006; Nolan, 1992; Pycha, 2010; Zimmerer,

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2009; Zimmerer, Reetz & Lahiri, 2009). Since their resemblance is quite strong, some accounts have argued that reduction and deletion are only different with respect to the gradient nature of the process.

Our findings suggest, however, that this interpretation should be made very cautiously. While on first sight, it is attractive to assume only one general process of reduction, the results also allow for an alternative interpretation where phonology and phonetics are important to be kept apart (see, among others Arvaniti, 2007; Kingston, 2006; Lahiri, 2007; Pycha, 2010). This possible interpretation treats (mere) reduction as a rather gradual (phonetic) process, while deletion seems to be more categorical (phonological) in nature. Partial evidence for this claim comes from our /s/-length analysis. The effect of /s/-lengthening is stronger in cases /t/ is deleted than in cases /t/ is reduced.

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Appendix

List of verbs used for the corpus construction. The log lemma frequency is normalized to 1 ppm (part per million, based on Mannheim frequencies, taken from CELEX, Baayen, Piepenbrook, & Gullikers, 1995)

INFINITIVE	LOG LEMMA FREQUENCY	STEM	VERB CLASS	GLOSS
bergen	1.44	non-s	irregular	*rescue*
braten	0.50	non-s	irregular	*fry*
fliehen	1.37	non-s	irregular	*flee*
frieren	1.06	non-s	irregular	*freeze*
graben	0.99	non-s	irregular	*dig*
hauen	1.01	non-s	irregular	*hew*
kneifen	0.62	non-s	irregular	*pinch*
kriechen	1.12	non-s	irregular	*crawl*
pfeifen	1.34	non-s	irregular	*whistle*
quellen	0.60	non-s	irregular	*well*
raten	1.63	non-s	irregular	*guess*
reiben	1.14	non-s	irregular	*rub*
speien	0.67	non-s	irregular	*spit*
spinnen	0.87	non-s	irregular	*spin*

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INFINITIVE	LOG LEMMA FREQUENCY	STEM	VERB CLASS	GLOSS
stechen	1.12	non-s	irregular	*stab*
waschen	1.32	non-s	irregular	*wash*
werben	1.28	non-s	irregular	*advertize*
beißen	1.35	s	irregular	*bite*
blasen	1.18	s	irregular	*blow*
fließen	1.52	s	irregular	*flow*
fressen	1.25	s	irregular	*feed/fretting*
gießen	1.07	s	irregular	*pour*
preisen	0.86	s	irregular	*praise*
reißen	1.86	s	irregular	*rip*
wachsen	1.65	s	irregular	*grow/wax*
baden	1.06	non-s	regular	*bath*
bannen	1.14	non-s	regular	*ban*
blähen	0.40	non-s	regular	*swell*
buchen	0.78	non-s	regular	*book*
kauen	0.88	non-s	regular	*chew*
kleben	1.16	non-s	regular	*glue*
knallen	1.03	non-s	regular	*bang*

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INFINITIVE	LOG LEMMA FREQUENCY	STEM	VERB CLASS	GLOSS
kochen	1.23	non-s	regular	*cook*
loben	1.34	non-s	regular	*praise*
mieten	0.98	non-s	regular	*rent*
raffen	0.65	non-s	regular	*grub*
rauben	1.06	non-s	regular	*rob*
reihen	0.86	non-s	regular	*rank*
ruhen	1.44	non-s	regular	*rest*
sperren	1.29	non-s	regular	*bar*
streifen	1.08	non-s	regular	*streak*
tilgen	0.98	non-s	regular	*amortize*
büßen	1.03	s	regular	*atone*
hassen	1.21	s	regular	*hate*
hausen	0.97	s	regular	*dwell*
missen	0.65	s	regular	*miss*
pressen	1.14	s	regular	*press*
reisen	1.70	s	regular	*travel*
rußen	0.00	s	regular	*smut*
speisen	0.85	s	regular	*dine*

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Zimmerer, F., Reetz, H., & Lahiri, A. (2009). Place assimilation across words in running speech: Corpus analysis and perception. *The Journal of the Acoustical Society of America, 125*. 2307-2322.

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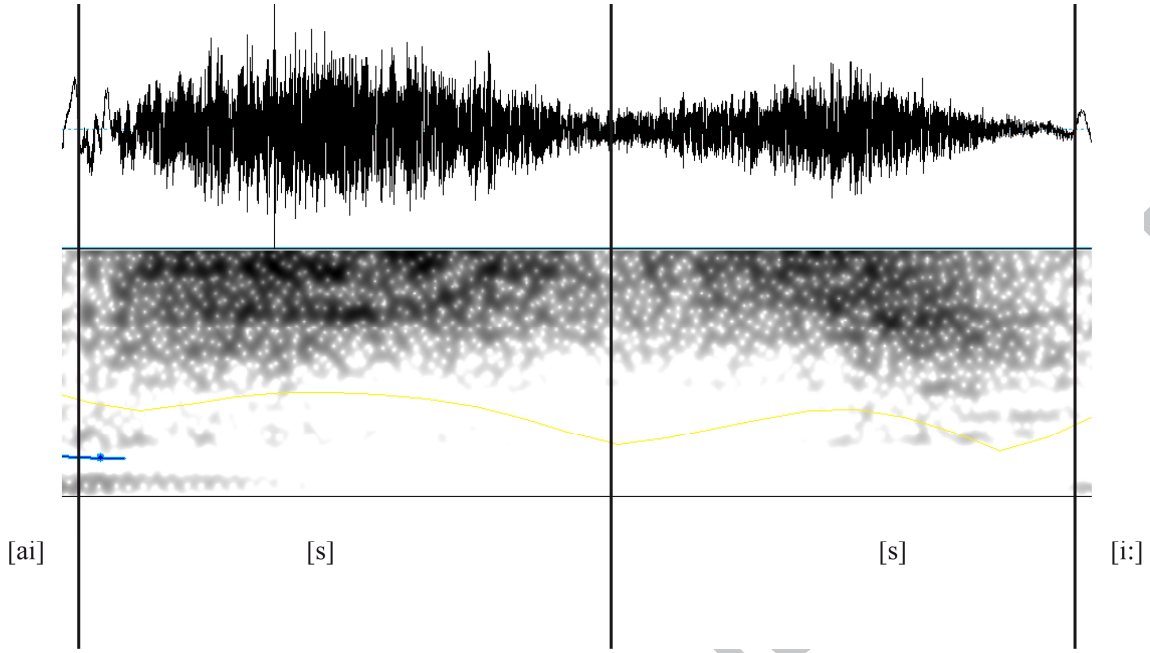

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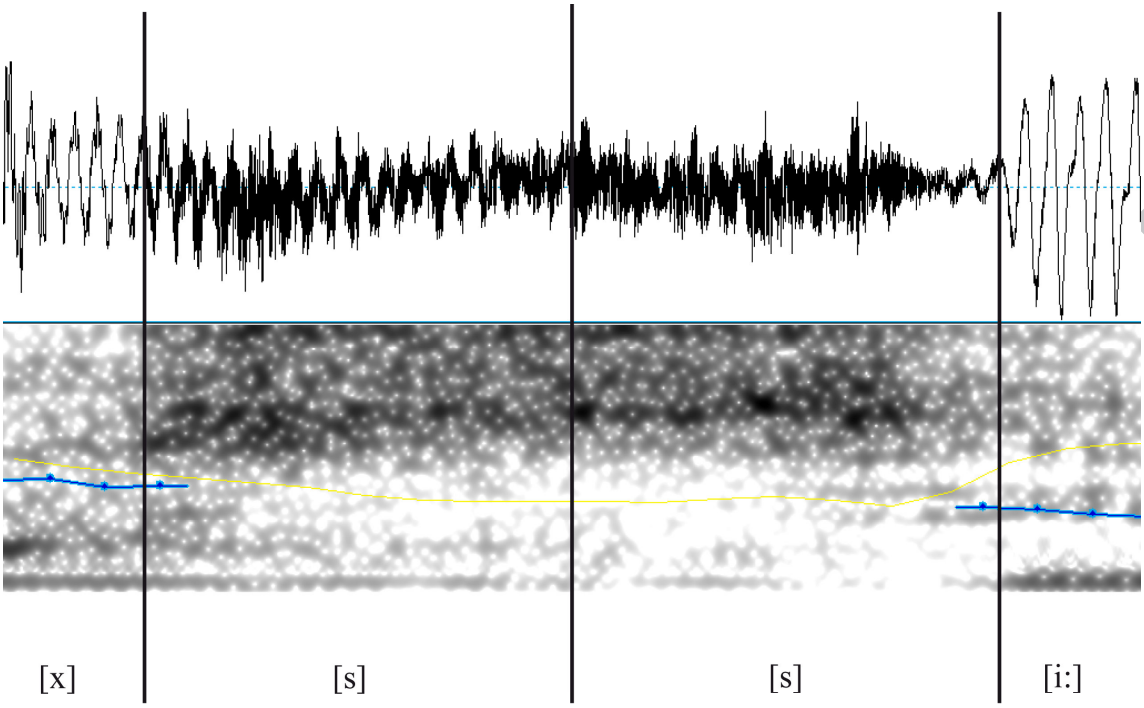

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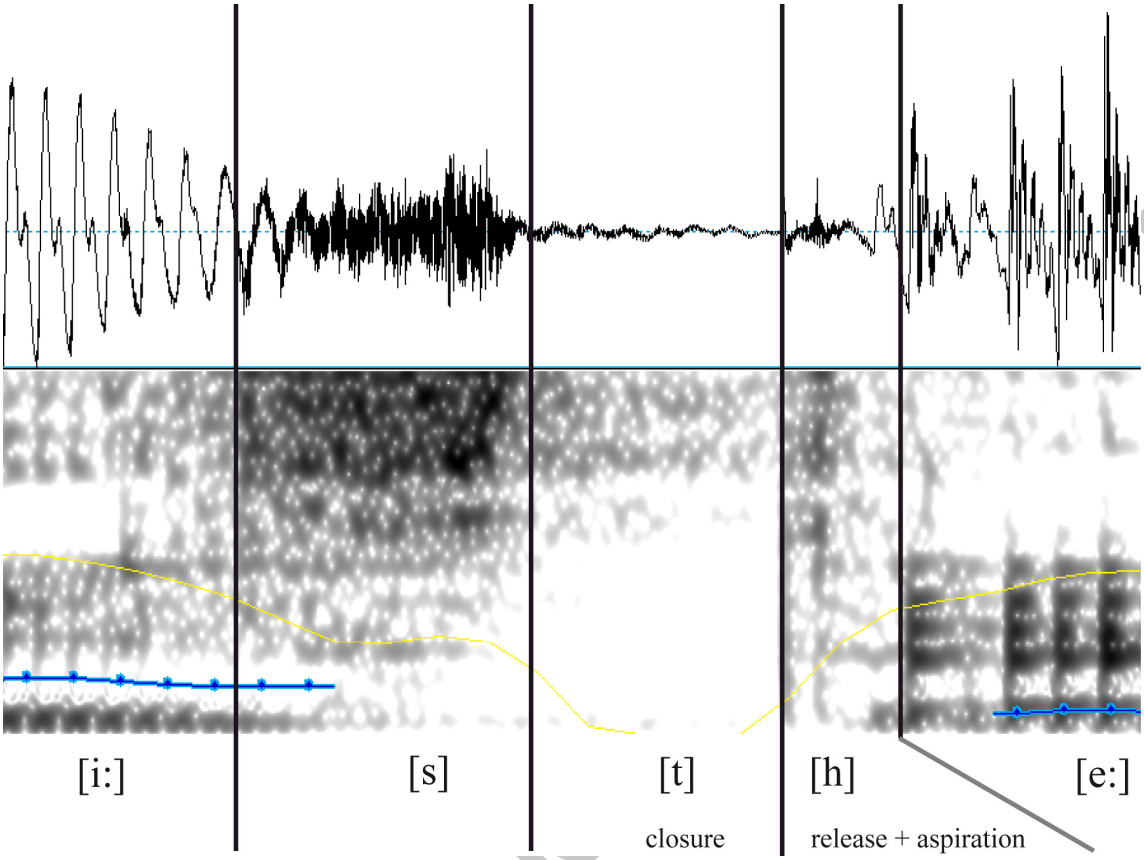

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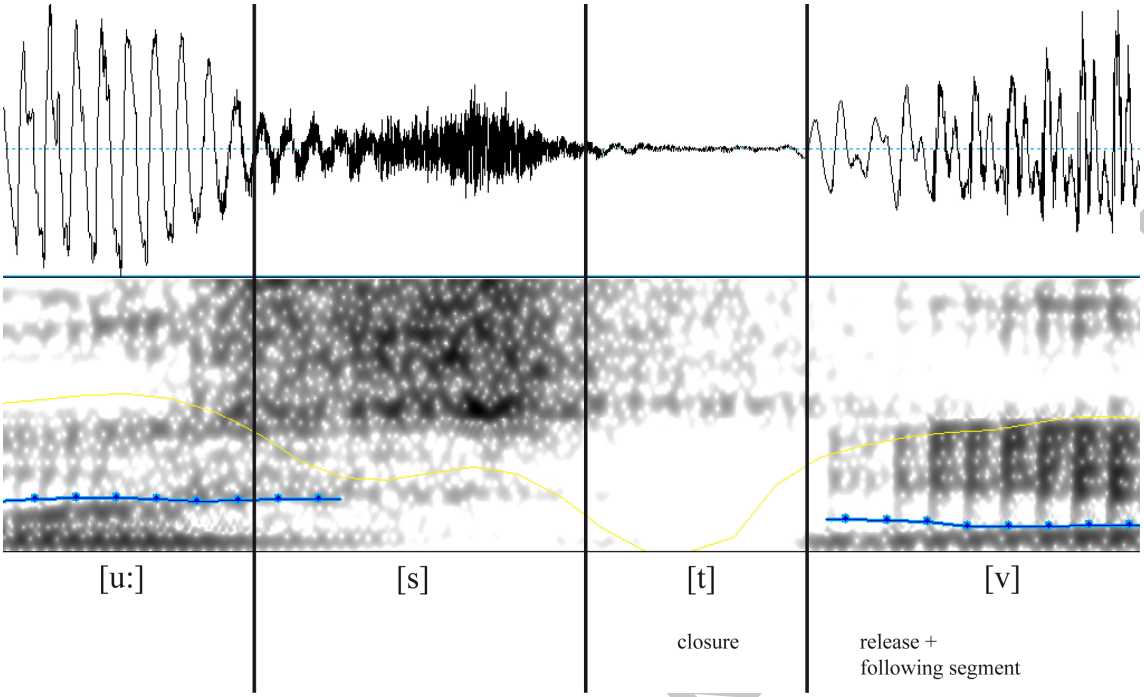

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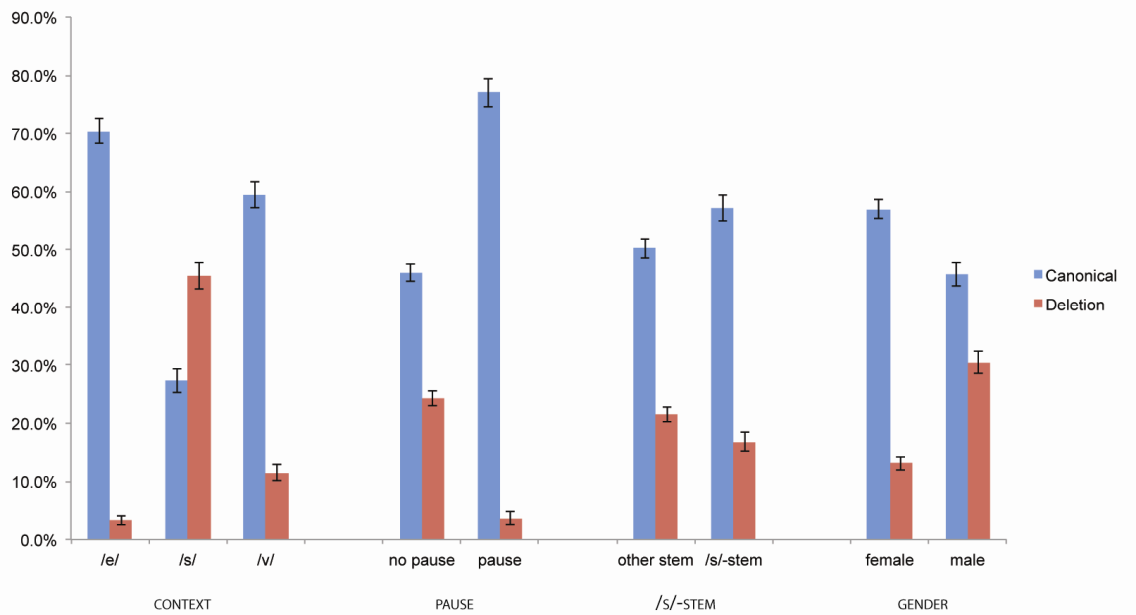

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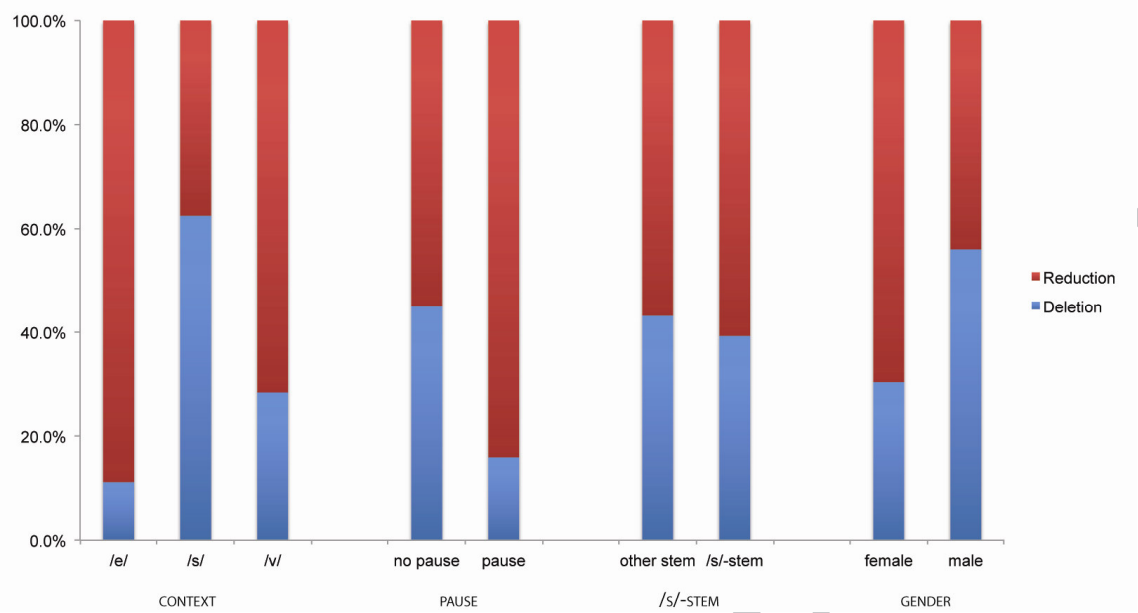

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Figure Captions

Figure 1: Example for deleted /t/ in the sequence '*du hau[s(t) s]ie haut*' (you beat, she beats). There is no indication for any of the three physical events closure, release, and aspiration, in the speech wave form and in the spectrogram. Note that the context of preceding /s/ can lead to a sequence of two alveolar fricatives.

Figure 2: Example for deleted /t/, where the deletion lead to a long /ss/ with no visible phoneme boundary, and the segment was cut into two /s/ of equal length for further analysis.

Figure 3: Example for canonical /t/. Closure, release and aspiration phases are clearly visible in the signal. We marked the closure of the alveolar stop with the corresponding IPA symbol and the release and aspiration phase additionally.

Figure 4: Example for reduced /t/. There is a visible closure period, marked by the IPA symbol for the alveolar stop in our transcription, but a clear aspiration is missing. The release is marked by the onset of the following vowel in this example.

Figure 5: Overview of reduction and canonical production rates for each significant predictor based on the Mixed Logit Models.

Figure 6: Overview of deletion vs. reduction rates for the non-canonical /t/-productions for each significant predictor based on the Mixed Logit Models.

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