

II. Morphonotactics in speech production

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1. INTRODUCTION

The interaction between morphology and phonetics is an area for which a lot of research is still needed (see e.g. Kawahara 2011). Some findings favour the view that morphology does not influence speech production, while others indicate that an interaction between morphology and phonetics exists, i.e. there is an impact of morphology on the phonetic realization of speech.

One way to investigate this topic is to compare consonant combinations across word-internal morpheme boundaries (morphonotactic consonant clusters, e.g. /xt/ in German /max+t/ *macht* ‘(s/he) makes’), with consonant combinations within a single morpheme (phonotactic consonant clusters, e.g. /xt/ in German /maxt/ *Macht* ‘power’). Some consonant combinations only exist across morpheme boundaries (purely morphonotactic clusters, e.g. /xst/ in German /max+st/ *macht* ‘(you) make’), whilst others exist nearly only within morphemes (predominantly phonotactic clusters, e.g. /mpf/ in German /ʃtʁʊmpf/ *Strumpf* ‘sock’). There are, however, several consonant combinations which occur both within morphemes as well as across morpheme boundaries ((mor)phonotactic clusters); these have been studied in the present paper. For purely morphonotactic and predominantly phonotactic clusters, the cluster itself can mark the presence or absence of a morpheme boundary. However, (mor)phonotactic clusters have no boundary-signalling function. Hence, the question arises of whether morpheme boundaries within consonant clusters are marked phonetically. In order to investigate this question, the present study analyses (mor)phonotactic consonant clusters in homophonous word pairs, in word pairs of the same grammatical category, in different positions within the target words (word-final and word-medial clusters) and in languages/varieties with different typological classifications (word language, mixed-type language and quantifying language).²

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² Subsets of the material analysed in this paper have already been analysed for conference contributions and proceedings (Leykum, Moosmüller & Dressler 2015a;

2. STATE OF RESEARCH

2.1. INFLUENCE OF MORPHOLOGY ON SPEECH PRODUCTION

The few studies reporting an impact of morpheme boundaries on the phonetic realization of spoken language show diverging results. Some studies indicate an impact by a morpheme boundary on speech production: several studies (Neu 1980; Guy 1991; Guy 1996; Guy, Hay & Walker 2008; Myers 1995) on word-final /t, d/-deletion in American English (AE) and New Zealand English revealed that there are fewer coronal stop deletions when /d/ represents the regular past ending of conjugated verbs. Equally, for Standard Dutch, Schuppler et al. (2012) found fewer deletions of word-final /t/ when it constitutes a morpheme. Concerning word-final /s, z/ in AE, Seyfarth (2016) spotted longer durations for the stem and suffix of inflected verbs compared to the equivalent durational measurements for uninflected homophonous words (Pluymaekers et al. 2010). The above-mentioned findings, namely fewer reductions and fewer deletions across morpheme boundaries, can be explained by the importance of highlighting the morpheme boundary in order to enhance the comprehensibility. Other studies, however, reported an influence of morphology where the direction of the effect is opposed to the aforementioned findings: Plag (2014) reported shorter durations of word-final /s/ following a morpheme boundary for Dutch. Pluymaekers et al. (2010) found an influence of morphology on the phonetic realization of the Dutch suffix *-igheid* (/əxhɛɪt/): the cluster /xh/ is realized with a longer duration when it consists of only one morpheme; it is realized with a shorter duration when the suffix is bimorphemic (the authors explain this result by the Morphological Informativeness Hypothesis).

Contrary to these findings, other studies revealed no effect of morpheme boundaries on consonant realizations: Zimmerer, Scharinger and Reetz (2011, 2014) showed a large influence of the phonological context on the realization of word-final /t/ in German, but no influence of the morphological status of /t/. Equally, a study investigating realizations and

Leykum, Moosmüller & Dressler 2015b; Leykum & Moosmüller 2015; Leykum & Moosmüller 2016; Leykum & Moosmüller 2017; Leykum & Moosmüller 2018; Leykum & Moosmüller 2019). References concerning the corresponding papers or abstracts will be given at relevant points. However, in the present paper, a broad and detailed analysis of phonotactic and morphonotactic consonant clusters in speech production is conducted, going far beyond a summary of previous studies on subsets of the speech material.

deletions of word-final /t, d/ in British English (BE) found a high impact of the surrounding phonemes on the realizations or deletions of /t, d/, but no influence due to morphology (Tagliamonte & Temple 2005). Seyfarth (2016) investigated AE homophones and found, for stimuli ending in [t, d], no influence of a morpheme boundary prior to the final stop on stem duration or suffix duration.

Some studies investigated articulatory processes during the realization of speech segments across morpheme boundaries. Cho (2001) investigated intergestural timing across morpheme boundaries in Korean by means of electromagnetic articulography (EMA) and electropalatography (EPG). He revealed that articulation is more stable in monomorphemes and more variable across word-internal morpheme boundaries (in non-lexicalized compounds) as well as across word boundaries. However, by using combined acoustic-articulatory investigation methods (EMA, EPG, laryngography), Nakamura (2015) detected only an influence of the phonological context, but no impact of morphology on the realization or deletion of word-final coronal stops in British English.

2.2. AIM OF THE STUDY AND HYPOTHESIS

Until now, acoustic investigations concerning the influence of morpheme boundaries on consonant realizations have been limited to durational measurements in a few languages. The present study not only investigates two languages in which the phonotactic-morphonotactic distinction of consonant clusters has not yet been investigated (apart from our own studies) but also adds the investigation of intensity measurements to the analyses of durational measurements. In addition, contrary to most of the aforementioned studies, which analysed single consonants following morpheme boundaries, our study focuses on phonologically homophonous (mor)phonotactic consonant clusters.

Apart from speech production, other research areas have studied phonotactic and morphonotactic consonant clusters. The processing of morphonotactic clusters is assumed to be facilitated by the morphological function of the consonant clusters (Korecky-Kröll et al. 2014; Celata et al. 2015). In computer simulations, different cognitive representations for the two types of clusters have been revealed (Calderone et al. 2014). Concerning first language acquisition, the findings are mixed. Some studies found that children learn to produce morphonotactic consonant clusters earlier compared to phonotactic consonant clusters (Kamandulytė 2006; Zydorowicz 2007), while others concluded that children learn both types

of clusters at the same time (Freiberger 2007). The aforementioned investigations point out that in speech processing, computer simulations, and language acquisition, differences between the two types of clusters could exist. Therefore, as an extension of the Strong Morphonotactic Hypothesis (Dressler & Dziubalska-Kołaczyk 2006), which is restricted to an interaction between morphology and phonology (not phonetics), the hypothesis of the present study predicts that these differences also exist in speech production, even though the rare findings on speech production are mixed. The hypothesis is as follows:

Consonant clusters across word-internal morpheme boundaries (morphonotactic clusters) are expected to be more robust and more highlighted in speech production than consonant clusters within a morpheme (phonotactic clusters).

Since language-specific differences are possible, three different language types are compared in the present study: a word language (Standard German German (SGG)), a mixed-type language (Standard Austrian German (SAG)) and a quantifying language (Standard French (FR)). These three types were chosen to investigate whether language-type-specific timing characteristics have an influence on the highlighting/reduction of consonant clusters. In quantifying languages, a distinction between homophonous phonotactic and morphonotactic clusters may disturb the temporal pattern of the language (Moosmüller & Brandstätter 2014). Thus, reductions of phonotactic clusters and/or lengthening of phonemes in morphonotactic clusters are expected to be less probable in quantifying languages. Therefore, with regard to the language type, it is hypothesized that durational differences between phonotactic and morphonotactic clusters will be more pronounced in SGG as compared to SAG, and the differences are expected to be greater for both varieties of German than those in FR.

2.3. MATERIAL AND GENERAL METHODS

Stimuli

Comparisons of the acoustic characteristics of consonant clusters within morphemes and across word-internal morpheme boundaries are only conclusive when the clusters are phonologically homophonous. Therefore, for the present study, several (mor)phonotactic consonant clusters were chosen which occur in the same position within words, once as a phonotactic cluster, and once as a morphonotactic cluster (emerging from productive word-formation rules). Since morphonotactic consonant

clusters in the word-initial position are not possible in German, only consonant clusters in a word-medial and word-final position were considered for the present investigation.

The target words were nouns, verbs, and adjectives with a (mor)phonotactic consonant cluster in a word-final or word-medial position. Within each word pair, the phonemes preceding and (for word-medial clusters) following the consonant cluster were kept as constant as possible to minimize the influence of the phonological context on the realization of the consonant cluster. Therefore, the target words with word-final consonant clusters were pairs of homophonous words, which raises the problem that we have to compare nouns and conjugated verbs. For the target words with word-medial consonant clusters, word pairs belonging to the same grammatical category were chosen. The target words are listed in Table 1. Since the word pairs were not matched for word frequency, this variable was controlled for statistically. Word frequency values were extracted from <http://wortschatz.uni-leipzig.de> (Quasthoff, Goldhahn & Heyer 2013).

Participants

Recordings of 16 speakers of Standard Austrian German (SAG) were made. All these SAG speakers were, as defined by Moosmüller (1991), students (younger age group) or university graduates (younger and older age group) who were born and raised in Vienna, with at least one parent fulfilling the same criteria. The speakers can be assigned to two equal age groups: the younger speakers were between 18 and 25 years old; the older speakers were 45–60 years old. In both age groups, the speakers were balanced for gender.

Additionally, recordings of six younger speakers (18–25 years) of Standard French (FR) and eight speakers (18–25 years) of Standard German German (SGG) were conducted. In both groups, the speakers were balanced for gender. The speakers of FR were students or university graduates originating from the region Île-de-France; all speakers of SGG were born and raised in the northern part of Germany (north of the Benrath line). For all participants, the same criteria were fulfilled by at least one parent.

Recordings

The recordings were conducted in a semi-anechoic sound booth (IAC-1202A). In the recording session, after a semi-structured interview, the participants undertook several reading tasks. For one reading task, the

target words were embedded in carrier phrases in a post-focal position. For this, the participants were told that they had to correct a misunderstanding concerning the addressee of an utterance. In the sentences, the pronoun or name was printed in bold, and the participants were asked to stress the pronoun/name when reading the sentences. This type of carrier phrase and the corresponding instructions were chosen to avoid stress on the target word, to enable phonetic reduction processes. The target word was always followed by the word *gesagt* ‘said’ to control the following phonological context for words with a word-final consonant cluster. The sentence finished with *glaube ich* ‘I think’ to avoid a sentence-final lengthening starting already in the target word. The following sentences are two examples of sentences for the first reading task:

*Zu **ihr**? - Ich habe zu **ihm** „die Hast“ gesagt, glaube ich.*

‘To **her**? - I said to **him** “the hurry”, I think.’

*Zu **mir**? - Ich habe zu **Peter** „er macht“ gesagt, glaube ich.*

‘To **me**? - I said to **Peter** “he makes”, I think.’

In a second speaking task, semi-spontaneous speech was elicited. In this task, the speakers had to read a given question (in which the target word was already mentioned) and answer the question by including two given words in their answer. The first given word was the target word, and the second word was given to draw attention away from the target word and to facilitate the task. Only SAG and FR speakers performed the semi-spontaneous task. Here are two examples of the semi-spontaneous speaking task:

<i>Hast, Schlüssel</i>	<i>Was vergisst dein Nachbar oft in der Hast mitzunehmen?</i>
‘hurry, keys’	‘What does your neighbour often forget when he is in a hurry?’

<i>hasst, Katzen</i>	<i>Hasst Herr Müller Hunde?</i>
‘hates, cats’	‘Does Mr. Müller hate dogs?’

Possible answers by the participants for the first question were: *In der Hast vergisst er seine Schlüssel* ‘When he is in a hurry, he forgets his keys’, and for the second example: *Nein, Herr Müller hasst Katzen* ‘No, Mr. Müller hates cats’.

Additionally, some of the target words with word-final consonant clusters were embedded in more natural sentences. In this, for the target words, which were verbs, the subject pronoun and the verb were separated to reduce the redundant coding of the morpheme boundary. In addition, the target word was always followed by a word starting with /g/,

to reduce the impact of the phonological context. These sentences were only read by the speakers of SAG. Two examples of this second reading task are given below:

Die Zeit misst gleich in der nächsten Runde Matthias.

‘The time will be measured in the next round by Matthias.’

Ihr Freund hat gesagt, dass er sie nicht wirklich hasst, glaube ich.

‘Her friend said that he does not really hate her, I think.’

For both reading tasks, the sentences were put in random order and read by the participants twice within the larger recording session. The semi-spontaneous speaking task was conducted only once. After subtracting a few mispronounced and misread items, this resulted in a total of 2,402 analysable target words (SAG + SGG + FR; word-medial + word-final).

In order to conduct the acoustic analyses, the recordings were manually segmented and annotated with STx (Noll et al. 2007) on a sentence, word and phoneme level. The duration and intensity values of the following segments were measured and semi-automatically extracted: target words, surrounding words, consonant clusters, individual consonants of the clusters, and phonemes surrounding the clusters.

The data was statistically analysed with R (R Core Team 2015) by using mixed-effects models (Bates et al. 2015). The variables subject and word were included in the models as random factors. Additionally, the following control variables were included in the models whenever they had an effect on the dependent variables: word frequency, articulation rate, /t/-deletions, stress on the target word, and pauses following the target word.

The mixed-effects models were fitted using a forward approach: effects were added one by one. Based on the p-value, a decision was made on whether to keep the variable or interaction in the model or to exclude it (threshold: $p = 0.1$). Where necessary, Tukey post-hoc tests with p-value adjustment were carried out.

To normalize the data, two different methods were used: on the one hand, the total duration (or mean syllable duration for word-medial clusters) or intensity of the target word were included in the statistical analyses to control statistically for any impact of speaker-specific differences. On the other hand, the relative duration of each cluster or consonant was calculated by dividing the segment duration by the word duration, cluster duration or mean syllable duration (for word-medial clusters). To calculate the relative intensity, the intensity of the segment was divided by the mean word intensity or cluster intensity. The normalization method used for each analysis is indicated in the following section.

Table 1. Target words (translations are provided in Table 2 and Table 4)

Cluster	SAG word-final		SAG word-medial		SGG		French	
	morphono- tactic	phonotactic	morphonotactic	phonotactic	morphonotactic	phonotactic	morphono- tactic	phonotactic
/ʁ/	<i>schafft</i>	<i>Schaft</i>			<i>schaft</i>	<i>Schaft</i>		
/xt/	<i>macht</i>	<i>Macht</i>	<i>Frachter</i>	<i>Fachtagung</i>	<i>macht</i>	<i>Macht</i>		
/pst/	<i>probst</i>	<i>Propst</i>						
/ŋkst/	<i>hängst</i>	<i>Hengst</i>			<i>hängst</i>	<i>Hengst</i>		
/nt/	<i>rinnt</i>	<i>Rind</i>						
/nst/	<i>dienst</i>	<i>Dienst</i>						
/st/	<i>misst</i>	<i>Mist</i>	<i>passte</i>	<i>Paste</i>	<i>misst</i>	<i>Mist</i>		
	<i>hasst</i>	<i>Hast</i>	<i>küsste</i>	<i>Küste</i>	<i>hasst</i>	<i>Hast</i>		
/ŋkt/			<i>Funkturm</i>	<i>Akupunktur</i>				
/sm/			<i>verhältnismäßig</i>	<i>kosmetisch</i>	<i>verhältnismäßig</i>	<i>kosmetisch</i>	<i>transmission</i>	<i>cosmétique</i>
			<i>Missmut</i>	<i>Organismus</i>	<i>Missmut</i>	<i>Organismus</i>		
/sl/			<i>löslich</i>	<i>isländisch</i>	<i>löslich</i>	<i>isländisch</i>	<i>dislocation</i>	<i>islandaise</i>
			<i>häuslich</i>	<i>islamisch</i>	<i>häuslich</i>	<i>islamisch</i>		
/sk/			<i>diskontinuierlich</i>	<i>Diskotheek</i>	<i>diskontinuierlich</i>	<i>Diskotheek</i>	<i>discontinu(e)</i>	<i>discothèque</i>
			<i>Expartner</i>	<i>Experte</i>	<i>Expartner</i>	<i>Experte</i>	<i>expatrier</i>	<i>expert</i>
/ksp/			<i>Fixpunkt</i>	<i>Experiment</i>	<i>Fixpunkt</i>	<i>Experiment</i>		

3. ACOUSTIC ANALYSES

3.1. WORD-FINAL CLUSTERS IN SAG AND SGG

First, word-final consonant clusters in homophonous word pairs realized by speakers of SAG (16 speakers) and SGG (8 young speakers) were compared (see also Leykum & Moosmüller 2015, Leykum et al. 2015a, Leykum & Moosmüller 2016). The target words were realized by all speakers twice within the carrier phrases. Moreover, the speakers of SAG conducted two additional tasks: they read sentences in which the subject pronoun and verb were separated for the bimorphemic target words (twice), and they realized the target word once in the semi-spontaneous speaking task.

The investigated target words were the following:

Table 2. Target words with word-final consonant cluster³

Cluster	SAG		SGG	
	phonotactic	mophonotactic	phonotactic	mophonotactic
/ft/	<i>Schaft</i> 'stem'	<i>schaftt</i> '(s/he) creates'	<i>Schaft</i> 'stem'	<i>schaftt</i> '(s/he) creates'
/xt/	<i>Macht</i> 'power'	<i>macht</i> '(s/he) makes'	<i>Macht</i> 'power'	<i>macht</i> '(s/he) makes'
/pst/	<i>Propst</i> 'provost'	<i>probst</i> '(you) rehearse'		
/ŋkst/	<i>Hengst</i> 'stallion'	<i>hängst</i> '(you) hang'	<i>Hengst</i> 'stallion'	<i>hängst</i> '(you) hang'
/nst/	<i>Dienst</i> 'service'	<i>dienst</i> '(you) serve'		
/nt/ /nd/	<i>Rind</i> 'beef, cow'	<i>rinnt</i> '(it) flows'		
/st/	<i>Mist</i> 'dung, rubbish' <i>Hast</i> 'hurry'	<i>misst</i> '(s/he) measures' <i>hasst</i> '(s/he) hates'	<i>Mist</i> 'dung, rubbish' <i>Hast</i> 'hurry'	<i>misst</i> '(s/he) measures' <i>hasst</i> '(s/he) hates'

³ Even though the orthography differs, for all word pairs, the item with a phonotactic cluster and its counterpart with a mophonotactic cluster are phonemically homophonous.

Results

/t/-deletion

In the word-final position, /t/ was acoustically deleted in several cases. In total, /t/-deletions occurred in 11.18% of the phonotactic clusters, whereas in morphonotactic clusters, 13.64% of word-final /t/ were acoustically deleted. The deletion rates did not significantly differ between the two types of clusters ($z = -0.877$, $p = 0.381$). Since the deletion rate is highly influenced by the phonological context ($z = 3.777$, $p < 0.001$), only the /t/s followed by /g/ were regarded in the next step. Out of these clusters, 11.16% of the phonotactic clusters were realized without the /t/, and 10.38% of the morphonotactic clusters (here again, there is no significant difference between the two types of clusters: $z = -0.220$, $p = 0.826$).

Concerning the segmental context, the deletion rate of /t/ was highest when the preceding phoneme was the homorganic fricative /s/ as compared to the other preceding contexts ($z = -4.139$, $p < 0.001$; /t/-deletions following /s/: 16.09% in phonotactic clusters, 16.23% in morphonotactic clusters; /t/-deletions following other phonemes: 3.36% in phonotactic clusters, 7.66% in morphonotactic clusters, see Figure 1).

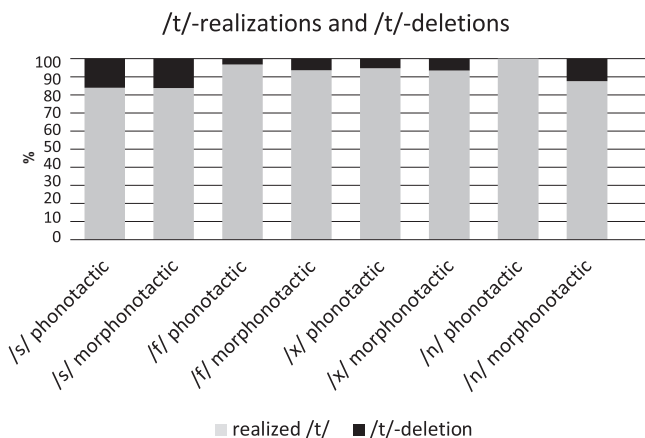


Figure 1. Percentages of /t/-realizations and /t/-deletions

Relative duration of the cluster

The fitted mixed-effects models revealed the following significant effects for the relative duration of the entire cluster (in % of word duration): a type-of-cluster*speaking-task interaction ($F(2,1383) = 20.800$,

$p < 0.001$), a type-of-cluster*/t/-realization interaction ($t(1398) = 3.210$, $p = 0.001$), a gender*variety/age interaction ($F(2,18) = 3.940$, $p = 0.037$), a main effect of articulation rate ($t(1395) = -10.670$, $p < 0.001$), and a main effect of the cluster ($F(6,7) = 47.035$, $p < 0.001$). Post-hoc analyses showed a significant type-of-cluster difference for the type-of-cluster*speaking-task interaction in the additional speaking task only, where subject pronoun and conjugated verb were separated. Here, the phonotactic clusters were shorter compared to the morphonotactic clusters ($t(24) = 3.629$, $p = 0.015$). The type-of-cluster*/t/-realization interaction revealed shorter durations for both types of clusters when the word-final /t/ was deleted. This effect was slightly larger for morphonotactic clusters (phonotactic: $t(1408) = 6.723$, $p < 0.001$; morphonotactic: $t(1411) = 11.539$, $p < 0.001$, see Figure 2). A closer look at the gender*variety/age interaction revealed that the clusters of the elder female SAG-speakers were shorter compared to all other groups of speakers (see Table 3).

Table 3. Gender*variety/age-interaction (post-hoc tests)

contrast	df	t-value	p-value	significance
SAG: elder, female – SAG: elder, male	16.89	-3.752	0.0168	*
SAG: elder, female – SAG: young, female	18.11	-2.950	0.0776	.
SAG: elder, female – SAG: young, male	18.09	-3.184	0.0493	*
SAG: elder, female – SGG: young, female	23.60	-4.320	0.0029	**
SAG: elder, female – SGG: young, male	22.64	-4.687	0.0013	**

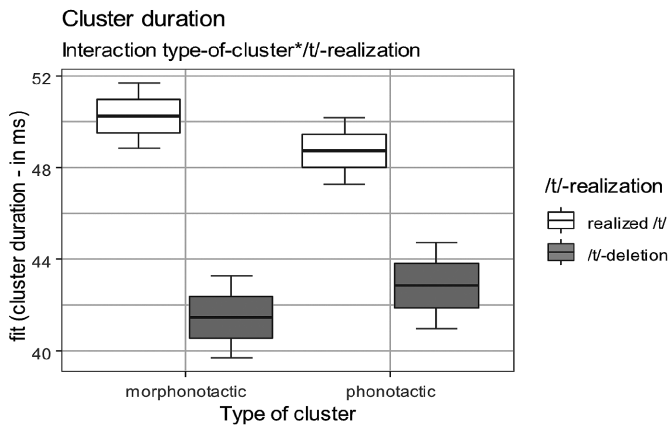


Figure 2. Interaction type-of-cluster*/t/-realization

Relative duration of /t/

Concerning the duration of /t/ in relation to the duration of the entire word (% of word duration), the statistical analyses revealed a significant three-way interaction between the task, the word frequency and the type of cluster ($F(2,1194) = 5.291, p = 0.005$), and main effects of articulation rate ($t(1114) = 2.641, p = 0.008$), variety/age (tendency: $F(2,20) = 2.909, p = 0.077$; elder SAG < younger SAG < SGG speakers), gender (tendency: $t(19) = 1.994, p = 0.061$; female < male speakers), and cluster ($F(6,7) = 17.111, p < 0.001$). Post-hoc analyses showed that only for the speaking task with separated pronoun and verb was it the case that the higher the word frequency, the more the two types of clusters differed in their length; with /t/ being relatively longer in morphonotactic clusters (see Figure 3).

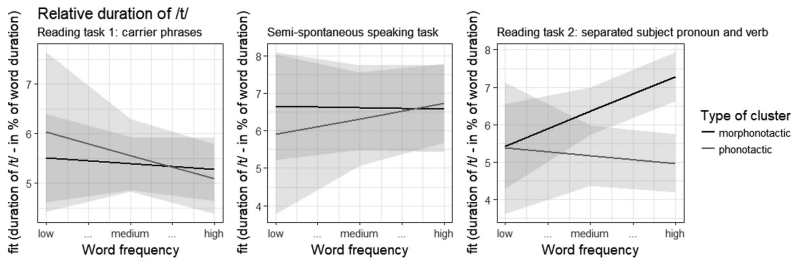


Figure 3. Three-way interaction: task*word-frequency*type-of-cluster

The effect of the articulation rate (longer relative duration of /t/ for higher articulation rates) emerged due to an articulation rate-induced shortening of the entire word (especially the vowel: main effect of articulation rate ($t(1230) = -8.621, p < 0.001$).

Relative intensity of the clusters

The fitted mixed-effects model showed that the relative intensity of the clusters (in % of word intensity) is significantly influenced by an interaction between the task and /t/-realization ($F(2,1406) = 4.114, p = 0.016$), a word-frequency*articulation-rate interaction ($t(1397) = -2.780, p = 0.005$), a main effect of gender ($t(22) = 3.562, p = 0.002$), and a main effect of cluster ($F(6,9) = 130, p < 0.001$). No influence of the type of cluster was found ($p = 0.804$). A post-hoc test concerning the task*/t/-realization interaction revealed significantly lower relative cluster intensities of clusters with realized final /t/ compared to the clusters with

/t/-deletion for both reading tasks (carrier phrases: $t(1409) = -3.215, p = 0.017$; second reading task: $t(1401) = -3.659, p = 0.004$), but not for the semi-spontaneous speaking task ($t(1402) = -0.237, p = 0.999$).

Relative intensity of /t/

The relative intensity of /t/ (in % of word intensity) is influenced by an interaction between the type of cluster and the task ($F(2,1122) = 6.657, p = 0.001$), an interaction of task and gender ($F(2,1204) = 9.462, p < 0.001$), a main effect of articulation rate ($t(1213) = 2.989, p = 0.003$), and a main effect of cluster ($F(6,12) = 13.959, p < 0.001$). Post-hoc analyses revealed that in none of the speaking tasks did phonotactic and morphonotactic clusters differ in their relative intensity of /t/. However, the relative intensity of /t/ was significantly lower in the speaking task with a separated subject pronoun and verb as compared to /t/ in target words embedded in the carrier phrases. This effect was slightly larger for the phonotactic clusters (morphonotactic clusters: $t(1204) = 4.058, p < 0.001$; phonotactic clusters: $t(1147) = 7.607, p < 0.001$, see Figure 4).

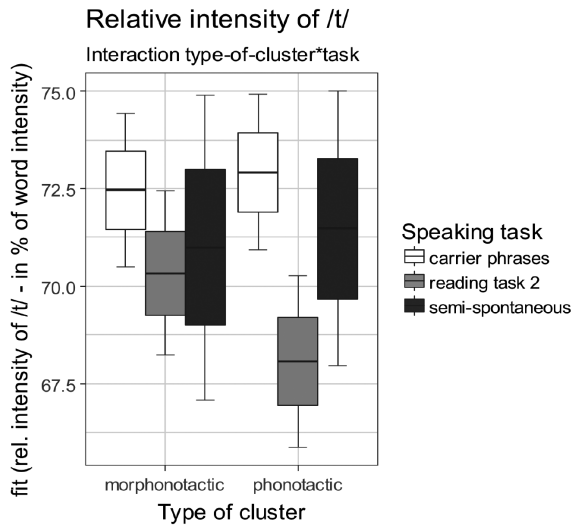


Figure 4. Interaction type-of-cluster*task

Discussion of word-final consonant clusters

Regarding the number of acoustic deletions of /t/ and the relative intensity of the cluster, no significant difference between phonotactic and morphonotactic clusters exists. For the other investigated variables, interactions including an effect of the type of cluster reached significance. However, no main effects of the type of cluster were found. The interactions were, with one exception, all interactions with the speaking task. The additional speaking task was designed to test whether the redundant coding of the information given by the conjugational morpheme reduces the importance of a highlighting of the morpheme boundary, which could result in less highlighting of morphonotactic clusters. Therefore, opposing effects could explain the lack of a difference between the phonetic realization of phonotactic and morphonotactic clusters in the other speaking tasks. However, the effects of the present study could not be interpreted as evidence for this hypothesis, since the additional speaking task involved a highly unnatural wording for some of the sentences, which in itself results in a higher articulation accuracy. The target words containing phonotactic clusters were also embedded in the sentences. For the nouns, however, the context was more natural, possibly resulting in a less accurate articulation. In addition, some of the target words with a morphonotactic cluster were in a phrase-final position, resulting in phrase-final lengthening of the target word.

With regard to the relative duration of the cluster, the type-of-cluster*/t/-realization interaction showing a slightly larger difference between clusters with and without final /t/ for morphonotactic clusters compared to phonotactic clusters seems to be a random result, which possibly emerged due to differences between the clusters themselves and the low number of clusters with /t/-deletion.

The effects of the type of cluster emerging in the analyses can easily be explained by the unnatural wording, and by differences in the positions of the target words within the sentences in the second reading task. However, when investigating word-final consonant clusters in German homophones, the lack of an effect of a cluster-internal morpheme boundary on speech production could not be interpreted as evidence for the non-existence of an influence of the morpheme boundary on the realization of morphonotactic consonant clusters. Within each word pair, the stimuli not only differed in being monomorphemic or bimorphemic, but also in the grammatical category to which the target words belong.

3.2. WORD-MEDIAL CLUSTERS IN SAG, SGG AND FR

In a further step, the (mor)phonotactic clusters in word-medial position were investigated (see Leykum & Moosmüller (2019) for word-medial clusters in SAG; Leykum & Moosmüller (2017) for a comparison of the three languages/varieties). Here, in most cases, the grammatical category was identical for both stimuli within each word pair. The target words are listed in Table 4.

Table 4. Target words with word-medial consonant cluster (p = phonotactic, m = morphonotactic; the word pairs not matched for grammatical category are shaded)

Cluster	SAG word-medial		SGG		French	
	p	m	p	m	p	m
/st/	<i>Paste</i> 'paste'	<i>passte</i> '(it) fitted'				
	<i>Küste</i> 'coast'	<i>küsste</i> '(s/he) kissed'				
/xt/	<i>Frachter</i> 'cargo ship'	<i>Fachta- gung</i> 'sympo- sium'				
/ŋkt/	<i>Akupunk- tur</i> 'acupunc- ture'	<i>Funkturm</i> 'radio tower'				
/sm/	<i>kosmetisch</i> 'cosmetic'	<i>verhält- nismäßig</i> 'relative'	<i>kosmetisch</i> 'cosmetic'	<i>verhält- nismäßig</i> 'relative'	<i>cosmétique</i> 'cosmetic'	<i>transmis- sion</i> 'transmis- sion'
	<i>Organis- mus</i> 'organism'	<i>Missmut</i> 'displea- sure'	<i>Organis- mus</i> 'organism'	<i>Missmut</i> 'displea- sure'		
/sl/	<i>isländisch</i> 'Icelandic'	<i>löslich</i> 'soluble'	<i>isländisch</i> 'Icelandic'	<i>löslich</i> 'soluble'	<i>islandaise</i> 'Icelandic'	<i>dislocation</i> 'disloca- tion'
	<i>islamisch</i> 'Islamic'	<i>häuslich</i> 'domestic'	<i>islamisch</i> 'Islamic'	<i>häuslich</i> 'domestic'		
/sk/	<i>Diskotheek</i> 'disco- theque'	<i>diskon- tinuierlich</i> 'discon- tinuous'	<i>Diskotheek</i> 'disco- theque'	<i>diskontinu- ierlich</i> 'discon- tinuous'	<i>disco- thèque</i> 'disco- theque'	<i>discontinue</i> 'discon- tinuous'

/ksp/	<i>Experte</i> 'expert'	<i>Expartner</i> 'ex-partner'	<i>Experte</i> 'expert'	<i>Expartner</i> 'ex-partner'	<i>expert</i> 'expert'	<i>expatrier</i> 'expatriate'
	<i>Experiment</i> 'experiment'	<i>Fixpunkt</i> 'fixed point'	<i>Experiment</i> 'experiment'	<i>Fixpunkt</i> 'fixed point'		

The target words were realized twice by all 30 speakers (16 SAG, 8 SGG, 6 FR) within the carrier phrases. In addition, the speakers of SAG and FR conducted the semi-spontaneous speaking task.

Results

Absolute cluster duration

The statistical analyses (with relative syllable duration as the control variable) showed a significant interaction between language/variety and articulation rate ($F(3,753)=9.863$, $p<0.001$), an interaction between articulation rate and cluster ($F(6,918) = 11.944$, $p < 0.001$), and a main effect of the speaking task ($t(912) = -3.018$, $p = 0.003$; shorter clusters in the semi-spontaneous speaking task). Concerning the language/variety*articulation-rate interaction, a decrease in the cluster duration with increasing articulation rate was slightly steeper for the speakers of SGG compared to the other groups of speakers. The articulation-rate*cluster interaction emerged because the duration of the clusters /ɲkt/ and /ksp/ was more affected by the articulation rate than the other clusters. The duration of the cluster /sk/ was least influenced by the articulation rate. A morpheme boundary within the clusters had no influence on the duration of the clusters ($p = 0.864$).

Since the material is not well balanced, another mixed-effects model was fitted for a subset of the data. Here, only the stimuli embedded in the carrier phrases were analysed. Furthermore, the French items and the word pairs *Paste-passte* 'paste-fitted', *Küste-küsste* 'coast-kissed' and *Diskotheek-diskontinuierlich* 'discotheque-discontinuous' were excluded so that only word pairs matched for their grammatical category were used, to enhance the comparability. For this subset of data, a three-way interaction between gender, type of cluster and grammatical category emerged ($F(1,463) = 7.398$, $p = 0.007$). Post-hoc analyses showed longer durations of phonotactic clusters for both genders for adjectives. Concerning nouns, no effect occurred for female speakers. For male speakers, however, the phonotactic clusters were shorter compared to

the clusters of female speakers and compared to male speakers producing morphonotactic clusters (see Figure 5). An articulation-rate*cluster interaction ($F(4,470) = 5.970, p < 0.001$) revealed the same effects as the analyses of the entire dataset (see above). In addition, an effect of variety/age ($F(2,12) = 21.320, p < 0.001$) revealed that speakers of SGG produced the clusters with longer durations compared to both age groups of speakers of SAG.

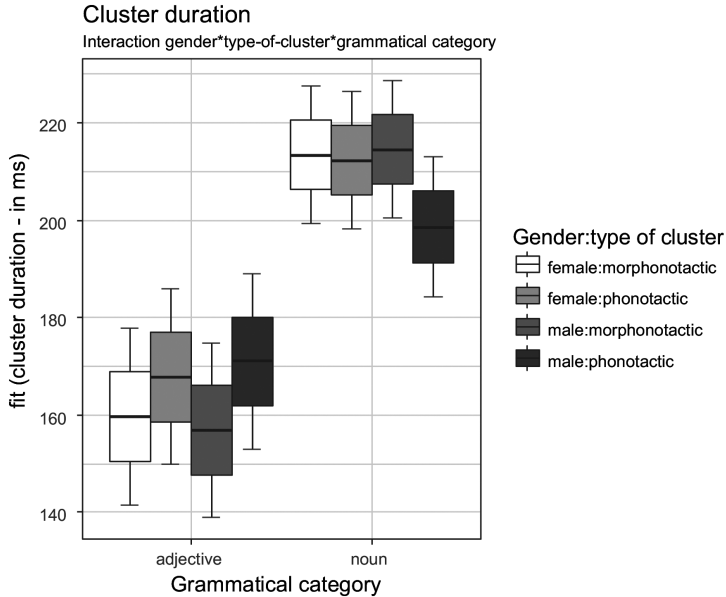


Figure 5. Interaction gender*type-of-cluster*grammatical category

Relative cluster duration (in % of mean syllable duration)

When normalizing the cluster duration by using the mean syllable duration, the fitted mixed-effects model showed the following significant effects: a task*articulation-rate interaction ($F(1,878) = 9.315, p = 0.002$), a main effect of language/variety ($F(3,24) = 7.962, p < 0.001$), and a main effect of cluster ($F(6,21) = 3.210, p = 0.021$). A morpheme boundary within the cluster had no effect on the relative duration of word-medial clusters ($p = 0.461$).

Duration of the cluster-final consonant relative to the cluster duration

When dividing the clusters at the position of the morpheme boundary of the morphonotactic clusters (/xt/ → /x+t/, /ɲkt/ → /ɲk+t/, /sm/ → /s+m/, /sl/ → /s+l/, /sk/ → /s+k/, /ksp/ → /ks+p/) and dividing the duration of the second part of the cluster by the total cluster duration, the relative duration of the cluster-final consonant is calculated. The statistical analyses revealed that the relative duration of the cluster-final consonant is influenced by an interaction between articulation rate, gender and task ($F(1,868) = 4.014$, $p = 0.045$): for target words in carrier phrases, the relative duration of the cluster-final consonant is influenced by the articulation rate only for female speakers. In the semi-spontaneous speaking task, the articulation rate does not influence the duration of the cluster-final consonant. In addition, a main effect of cluster ($F(6,20) = 7.800$, $p < 0.001$) occurred. The type of cluster had no influence on the relative duration of the cluster-final consonant ($p = 0.307$). When reducing the data to a subset of the stimuli which were balanced in terms of the grammatical category, a tendency for an effect of the grammatical category ($F(2,19) = 4.723$, $p = 0.059$) showed longer durations for the cluster-final consonant in adjectives compared to nouns. However, this is not a global effect of differences between nouns and adjectives, but more likely an effect arising due to differences between the different word pairs.

Absolute intensity of the cluster

The absolute intensity of the investigated word-medial consonant clusters is influenced by a main effect of gender ($t(22) = 2.929$, $p = 0.008$), with higher intensity of the clusters realized by male speakers. In addition, a main effect of cluster ($F(6,22) = 20.900$, $p < 0.001$) occurred, and a main effect of speaking task ($t(925) = 3.890$, $p < 0.001$), with higher intensities in the semi-spontaneous speaking task. The type of cluster had no significant influence on the absolute intensity of the clusters ($p = 0.125$).

Relative intensity of the cluster (relative to the intensity of the vowel preceding the cluster)

When normalizing the cluster intensity by calculating the intensity in relation to the intensity of the vowel preceding the cluster, besides an effect of cluster ($F(6,19) = 9.128$, $p < 0.001$), a significant three-way

interaction between word-frequency*articulation-rate*language/variety ($F(3,920) = 5.794, p < 0.001$) occurred. In this, for the speakers of SGG, the relative intensity of the clusters decreased with increasing word frequency for higher articulation rates. The other groups of speakers did not show such an effect. Here again, the type of cluster did not influence the intensity values of the clusters ($p = 0.133$).

Intensity of the cluster-final consonant relative to the cluster intensity

The relative intensity of the cluster-final consonant was calculated by dividing the intensity of the consonant by the intensity of the cluster. The fitted mixed-effects model resulted in a main effect of language/variety ($F(3,24) = 5.039, p = 0.008$), a main effect of cluster ($F(6,21) = 87.051, p < 0.001$), and a main effect of task ($t(938) = 3.727, p < 0.001$). Post-hoc analyses showed that the relative intensity of the cluster-final consonant is lower in FR compared to SAG and SGG. In addition, it is higher in the semi-spontaneous speaking task. The effect of language/variety emerged due to language- and item-specific word-stress differences. The type of cluster had no influence on the relative intensity of the cluster-final consonant ($p = 0.118$).

Discussion of word-medial consonant clusters

One advantage of investigating word-medial clusters is the possibility to compare word pairs of the same grammatical category, as well as to compare French and German consonant clusters, as some consonant clusters exist in both languages, both within morphemes and across morpheme boundaries in a word-medial position. However, there are also several disadvantages: it is not possible to control the phonological context as much as for clusters in homophones; the target words are more diverse, not only in terms of the phonemes surrounding the consonant clusters, but also in terms of the exact position of the consonant clusters within the words, and, most importantly, in terms of the position of the word stress within the German target words.

In order to investigate the impact of the grammatical category of the target words on the realization of the consonant clusters, the dataset was restricted to a subset including only word pairs where both items within each pair belong to an identical grammatical category. These analyses revealed an effect from the grammatical category in only two of the fitted models: concerning the absolute cluster duration and concerning the rela-

tive duration of the cluster-final consonant. With regard to the absolute duration of the cluster, the grammatical category was part of a three-way interaction, revealing a longer duration of phonotactic clusters for adjectives for all speakers and a shorter duration of the phonotactic clusters for nouns when realized by male speakers. Furthermore, the relative duration of the cluster-final consonant was longer in adjectives compared to nouns. Since there were no interactions between the grammatical category and the type of cluster besides the three-way interaction, it could be concluded that for adjectives and nouns, a possible influence of the grammatical category could be ruled out as a factor which could mask effects of a morpheme boundary on the realization of word-medial consonant clusters. In addition, concerning the three-way interaction affecting the absolute cluster duration, the effect on the adjectives is in the opposite direction to the hypothesis: in adjectives, phonotactic clusters were longer than morphonotactic clusters. Concerning nouns, the phonotactic clusters of male speakers were shorter compared to the other clusters, which could be interpreted as less reduction of the morphonotactic clusters by male speakers, compared to a low level of reductions by female speakers, irrespective of the presence or absence of a morpheme boundary.

Concerning all other investigated variables, no effect of a consonant cluster internal morpheme boundary on the realization of the word-medial clusters was detectable.

4. GENERAL DISCUSSION

Previous studies investigating the influence of morpheme boundaries on speech production came to different results. Some studies revealed an effect indicating an acoustic highlighting of the morpheme boundary by lengthening phonemes across morpheme boundaries. Other studies found no effect of a morpheme boundary, or even indicated results with an effect in the opposite direction. Likewise, in the present study, for some variables an effect of the type of cluster emerged, either in the expected direction or in the opposite direction. However, most analyses did not find any effect of the morpheme boundary.

Since the effects of an influence by the morpheme boundary can all be easily explained by other interfering variables, the present study is not able to give any evidence for an impact of morphology on speech production. However, the absence of any effects does not necessarily imply that no influence of morpheme boundaries on the realization of consonant clusters exists.

The possibility that the highly redundant coding of the information of the morpheme boundary in conjugated verbs with word-final morphonotactic consonant clusters leads to a less accurate articulation cannot be ruled out. Opposite effects caused by the morpheme boundary and the high redundancy are still possible. Due to the unnatural wording and the lack of a possibility to match the target words in terms of the position within the sentences, the additional reading task did not provide conclusive findings.

Another factor linked to the redundancy, described by Hanique and Ernestus (2012: 175), is the word-information load: “The less a segment contributes to distinguishing the complete word from other words, the more it may be reduced”. Equally, the degree of morphological decomposability could constitute a factor influencing whether morphonotactic consonant clusters are treated differently from phonotactic clusters in speech production.

The present findings were able to rule out language- and/or variety-specific timing characteristics as a factor inhibiting an acoustic differentiation between phonotactic and morphonotactic clusters (see also Leykum & Moosmüller 2017). However, besides language-specific timing characteristics, other language-specific differences could exist. The investigated languages share a low morphological richness, raising the question of whether the morphological richness of a language determines whether phonotactic and morphonotactic clusters behave the same or not. It is possible that in morphologically richer languages, the information about the morpheme boundary is more important to ensure intelligibility. A fact supporting this hypothesis is research on first language acquisition. It was shown that children acquiring Austrian German learn both types of clusters at the same time (Freiberger 2007), whereas, in the first language acquisition of the morphologically richer languages Polish and Lithuanian, children learn to produce morphonotactic consonant clusters correctly prior to phonotactic consonant clusters (Kamandulytė 2006; Zydorowicz 2007).

5. CONCLUSION

Combining the present findings with analyses of the subsegmental parts of /t/ in word-final clusters (Leykum & Moosmüller 2015; Leykum et al. 2015b; Leykum & Moosmüller 2018), conducted on the same material, none of the analyses could prove that morphonotactic consonant clusters are more highlighted or less susceptible to reduction processes.

Yet, the present analyses do not prove that phonotactic and morphonotactic consonant clusters are identical in their phonetic realization, since statistically insignificant results do not imply that no effect exists. However, the fact that quite a lot of analyses were conducted on a relatively large dataset, all showing no or no stable effect of the morpheme boundary on speech production, leads us to the conclusion that it is very unlikely that speakers realize morphonotactic consonant clusters in German differently because of the morpheme boundary.

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REFERENCES

- Bates, Douglas; Mächler, Martin; Bolker, Ben & Walker, Steve (2015) Fitting linear mixed-effects models using lme4, *Journal of Statistical Software* 67(1), 1–48. doi:10.18637/jss.v067.i01
- Calderone, Basilio; Celata, Chiara; Korecky-Kröll, Katharina & Dressler, Wolfgang U. (2014) A computational approach to morphonotactics. Evidence from German, *Language Sciences* 46, 59–70. doi:10.1016/j.langsci.2014.06.007
- Celata, Chiara; Korecky-Kröll, Katharina; Ricci, Irene & Dressler, Wolfgang U. (2015) Phonotactic processing and morpheme boundaries: word-final /Cst/ clusters in German, *Italian Journal of Linguistics* 27(1), 85–110.
- Cho, Taehong (2001) Effects of morpheme boundaries on intergestural timing. Evidence from Korean, *Phonetica* 58(3), 129–162. doi:10.1159/000056196
- Dressler, Wolfgang U. & Dziubalska-Kołaczyk, Katarzyna (2006) Proposing morphonotactics, *Italian Journal of Linguistics* 18(2), 249–266.
- Freiberger, Eva M. (2007) Morphonotaktik im Erstspracherwerb des Deutschen (Morphonotactics in first language acquisition in German), *Wiener Linguistische Gazette* 74, 1–23.
- Guy, Gregory R. (1991) Contextual conditioning in variable lexical phonology, *Language Variation and Change* 3, 223–239.
- Guy, Gregory R. (1996) Form and function in linguistic variation. In: Guy, Gregory R.; Feagin, Crawford; Schifffrin, Deborah & Baugh, John (eds) *Towards a Social Science of Language. Papers in Honor of William Labov. Volume 1: Variation and Change in Language and Society*. [Current Issues in Linguistic Theory]. Amsterdam/Philadelphia: John Benjamins Publishing Company, 221–252.
- Guy, Gregory R; Hay, Jennifer & Walker, Abby (2008) Phonological, lexical, and frequency factors in coronal stop deletion in early New Zealand English, *Laboratory Phonology* 11, 53–54.

- Hanique, Iris & Ernestus, Mirjam (2012) The role of morphology in acoustic reduction, *Lingue e Linguaggio* 2, 147–164.
- Kamandulytė, Laura (2006) The acquisition of morphonotactics in Lithuanian, *Wiener Linguistische Gazette* 73, 88–96.
- Kawahara, Shigeto (2011) Experimental approaches in theoretical phonology. In: van Oostendorp, Marc; Ewen, Colin J; Hume, Elizabeth & Rice, Keren (eds) *The Blackwell Companion to Phonology. Volume IV: Phonological Interfaces*. Oxford: Wiley-Blackwell, 2283–2303.
- Korecky-Kröll, Katharina; Dressler, Wolfgang U; Freiburger, Eva M.; Reinisch, Eva; Mörrth, Karlheinz & Libben, Gary (2014) Morphonotactic and phonotactic processing in German-speaking adults, *Language Sciences* 46, 48–58. doi:10.1016/j.langsci.2014.06.006
- Leykum, Hannah; Moosmüller, Sylvia & Dressler, Wolfgang U. (2015a) Homophonous phonotactic and morphonotactic consonant clusters in word-final position. *Proceedings of the 16th annual conference of International Speech Communication Association (INTERSPEECH)*, 1685–1689.
- Leykum, Hannah; Moosmüller, Sylvia & Dressler, Wolfgang U. (2015b) Word-final (mor) phonotactic consonant clusters in Standard Austrian German. *Proceedings of the 18th International Congress of Phonetic Sciences (ICPhS)*. <<http://www.internationalphoneticassociation.org/icphs-proceedings/ICPhS2015/Papers/ICPHS0701.pdf>>.
- Leykum, Hannah & Moosmüller, Sylvia (2015) Das (mor)phonotaktische Konsonantencluster /st/ in wortmedialer und wortfinaler Position in homophonen Wortpaaren (The (mor)phonotactic consonant cluster /st/ in word-medial and word-final position in homophonous word pairs). *11. Tagung Phonetik und Phonologie im deutschsprachigen Raum*, Marburg (Poster).
- Leykum, Hannah & Moosmüller, Sylvia (2016) (Mor)phonotactic consonant clusters in Standard Austrian German and Standard German. *Tagungsband der 12. Tagung Phonetik und Phonologie im deutschsprachigen Raum*, 103–106. doi:10.1787/578054332028
- Leykum, Hannah & Moosmüller, Sylvia (2017) Phonotactic and morphonotactic consonant clusters in Standard German German, Standard Austrian German and Standard French, *Phonetics and Phonology in Europe (PaPE 2017)*, Cologne.
- Leykum, Hannah & Moosmüller, Sylvia (2018) Factors influencing the realisation of word-final /t/ in Standard Austrian German and Standard German German. In: *Proceedings of the Conference on Phonetics & Phonology in German-speaking countries (P&P 13)*. Humboldt-Universität zu Berlin, 117–120.
- Leykum, Hannah & Moosmüller, Sylvia (2019) Phonotaktische und morphonotaktische Konsonantencluster in wortmedialer Position in der österreichischen Standardaussprache (Phonotactic and morphonotactic consonant clusters in word-medial position in Standard Austrian German). In: Bülow, Lars; Fischer, Ann K. & Herbert, Kristina (eds) *Dimensions of Linguistic Space: Variation - Multilingualism - Conceptualisations = Dimensionen des sprachlichen Raums: Variation – Mehrsprachigkeit – Konzeptualisierung*. Berlin: Peter Lang, 127–145. doi:10.3726/b15250/16
- Moosmüller, Sylvia (1991) *Hochsprache und Dialekt in Österreich. Soziophonologische Untersuchungen zu ihrer Abgrenzung in Wien, Graz, Salzburg und Innsbruck* (Standard and dialect in Austria. Sociophonetic investigation on their distinction in Vienna, Graz, Salzburg and Innsbruck). [Sprachwissenschaftliche Reihe 1]. Wien: Böhlau.
- Myers, James (1995) *The categorical and gradient phonology of variable t-deletion in*

- English*. International Workshop on Language Variation and Linguistic, Nijmegen.
- Nakamura, Mitsuhiro (2015) Conditioning factors in word-final coronal stop deletion in British English: An articulatory-acoustic analysis. In: Leemann, Adrian; Kolly, Marie-José; Schmid, Stephan & Dellwo, Volker (eds) *Trends in Phonetics and Phonology. Studies from German-speaking Europe*. Bern: Peter Lang Ltd, 241–254.
- Neu, Helene (1980) Ranking of constraints on /t, d/ deletion in American English: a statistical analysis. In: Labov, William (ed.) *Locating Language in Time and Space*. [Quantitative analyses of linguistic structure 1]. New York: Academic Press, 37–54.
- Noll, Anton; White, Jonathan; Balazs, Peter & Deutsch, Werner (2007) *STx - Intelligent Sound Processing, Programmer's Reference*. <<https://www.kfs.oeaw.ac.at/stx>>.
- Plag, Ingo (2014) Phonological and phonetic variability in complex words: An uncharted territory, *Rivista di Linguistica* 26(2), 209–228.
- Pluymaekers, Mark; Ernestus, Mirjam; Baayen, R. Harald & Booij, Geert (2010) Morphological effects on fine phonetic detail: The case of Dutch -igheid. In: Fougeron, Cécile; Kühnert, Barbara; D'Imperio, Mariapaola & Vallée, Nathalie (eds) *Laboratory Phonology 10*. [Phonology and phonetics 4-4]. Berlin/New York: De Gruyter Mouton, 511–532. doi:10.1515/9783110224917.5.511
- Quasthoff, Uwe; Goldhahn, Dirk & Heyer, Gerhard (2013) *Technical Report Series on Corpus Building. Vol. 1. Deutscher Wortschatz 2012* (2013) <<http://asvdoku.informatik.uni-leipzig.de/corpora/data/uploads/corpus-building-vol1-wortschatz-2012.pdf>>.
- R Core Team (2015) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna. <<https://www.R-project.org>>.
- Schuppler, Barbara; van Dommelen, Wim; Koreman, Jacques & Ernestus, Mirjam (2012) How linguistic and probabilistic properties of a word affect the realization of its final /t/: Studies at the phonemic and subphonemic level, *Journal of Phonetics* 40(4), 595–607. doi:10.1016/j.wocn.2012.05.004
- Seyfarth, Scott J. (2016) *Contextual and Morphological Effects in Speech Production*. PhD dissertation, University of California.
- Tagliamonte, Sali & Temple, Rosalind (2005) New perspectives on an ol' variable: (t,d) in British English, *Language Variation and Change* 17(03), 281–302. doi:10.1017/S0954394505050118
- Zimmerer, Frank; Scharinger, Mathias & Reetz, Henning (2011) When BEAT becomes HOUSE. Factors of word final /t/-deletion in German, *Speech Communication* 53(6), 941–954. doi:10.1016/j.specom.2011.03.006
- Zimmerer, Frank; Scharinger, Mathias & Reetz, Henning (2014) Phonological and morphological constraints on German /t/-deletions, *Journal of Phonetics* 45, 64–75. doi:10.1016/j.wocn.2014.03.006
- Zydorowicz, Paulina (2007) Polish morphonotactics in first language acquisition, *Wiener Linguistische Gazette* 74, 24–44.