Duration differences in the articulation and acoustics of Swiss German word-initial geminate and singleton stops[a]

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Stops in Swiss German contrast only in quantity in all word positions; aspiration and voicing play no role. As in most languages with consonant quantity contrast, geminate stops are produced with significantly longer closure duration (CD) than singletons in an intersonorant context. This holds word medially as well as phrase medially, e.g., [on**i** **tt**oːsə] "without roar" versus [on**i** **t**oːsə] "without can." Since the stops are voiceless, no CD cue distinguishes geminates from singletons phrase initially. Nevertheless, do speakers utilize articulatory means to maintain the contrast? By using electropalatography, the articulatory and acoustic properties of word-initial alveolar stops were investigated in phrase-initial and phrase-medial contexts. The results are threefold. First, as expected, CD and contact duration of the articulators mirror each other within a phrase: Geminates are longer than singletons. Second, phrase initially, the contact data unequivocally establish a quantity distinction. This means that—even without acoustic CD cues for perception—geminates are articulated with substantially longer oral closure than singletons. Third, stops are longer in phrase-initial than phrase-medial position, indicating articulatory strengthening. Nevertheless, the difference between geminates and singletons phrase initially is proportionately less than in phrase-medial position. © *2008 Acoustical Society of America.* [DOI: 10.1121/1.2916699]

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I. INTRODUCTION

In this investigation, we focus on the articulatory properties of word-initial voiceless geminate and singleton stops in Swiss German, contrasting them in two phrase-medial contexts and one phrase-initial context. We raise three related questions. First, although no acoustic information regarding closure duration (CD) is available for listeners phrase initially, do speakers still make an articulatory distinction between geminates and singletons in natural speech? Second, if the consonantal quantity contrast is indeed maintained, is there any additive effect distinguishing the contrasting sounds phrase initially as compared to phrase medially? Third, phrase medially, are geminates and singletons articulated differently in different contexts, namely, after vowel-final words versus after obstruent-final words?

A number of earlier acoustic studies revealed that stops in Swiss German contrast in the duration of their closure phase (CD), i.e., not in closure voicing or the duration of the closure release or voice onset time (VOT) or any combination of the two. This has variously been called a phonological distinction in terms of fortis versus lenis (e.g., Dieth and Brunner, 1943; Fulop, 1994; Willi, 1996), voicing (e.g., Ham, 1998), and quantity (e.g., Kraehenmann, 2001, 2003), the latter of which we will adopt. It roughly corresponds to the standard German contrast variously analyzed as a fortis-lenis (cf. Kohler, 1984), a [spread glottis] (cf. Iverson and Salmons, 1995; Jessen and Ringen, 2002), or a voicing contrast (cf. Wiese, 1996), which, however, is primarily realized in phonetic terms as difference in VOT, not CD. The Swiss German quantity contrast occurs in all word positions (Table I).

On purely acoustic grounds, Kraehenmann (2001, 2003) showed that word-initial geminate CDs were about twice the length of singletons when in an intersonorant context. However, when a preceding word ended in an obstruent consonant, the contrast was neutralized by geminates having become shorter and singletons longer. Based on these results, we expect in the present study, where we combine articulatory and acoustic facts, that, within a phrase, the articulatory electropalatography (EPG) measures go hand in hand with the acoustic CD measures. That is, in phrase-medial position after a vowel, geminate durations should be longer than those of singletons, while geminate and singleton durations should be indistinguishable after an obstruent. Our expectations concerning neutralization and maintenance of the long-short contrast in this phrase-medial position rest on the syllabification of these consonants. We briefly sketch our assumptions in Fig. 1.

According to standard assumption, geminates are part of two syllables. Word medially, they close one syllable and build the onset of the following syllable (d.i.), while single-

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TABLE I. Swiss German quantity contrast in three places of articulation and three word positions.

	Labial		Alveolar		Velar	
Initial	/**pp**a:ʀ/	"couple"	/**tt**ipp/	"tip"	/**kk**a:ʀ/	"tour bus"
	/**p**a:ʀ/	"bar"	/**t**ipp/	"dip"	/**k**a:ʀ/	"cooked"
Medial	/su**pp**əʀ/	"great"	/ma**tt**ə/	"mat"	/ma**kk**ə/	"tic"
	/su**p**əʀ/	"clean"	/ma**t**ə/	"maggot"	/ma**k**ə/	"stomach"
Final	/al**pp**/	"alp"	/vɛl**tt**/	"world"	/ʃnɛ**kk**/	"snail"
	/xal**p**/	"calf"	/fɛl**t**/	"field"	/vɛ:**k**/	"way"

tons only build the onset (d.ii.). Similarly, word initially—provided there is room—geminates close the final syllable of a preceding word (c.i.) and, thus, are part not only of two syllables but also of two words. The phonological quantity contrast is then realized both word medially and word initially in a vocalic context by significantly longer phonetic duration of geminates as compared to singletons. If, however, the final syllable of a preceding word is already closed by an obstruent consonant (b.i.), the first part of geminates cannot be syllabified, remains unassociated, and subsequently deletes. As a result, the phonological distinction between geminates and singletons disappears, as does the phonetic length difference, leading to contrast neutralization.

In phrase-/utterance-initial position, the syllabification of geminates is a moot point. It would be possible that neutralization similar to the consonantal context occurs since there is no preceding syllable available. However, following Kraehenmann (2001), we assume that the first part of initial geminates is prosodically associated (a.i.), although at the word rather than the syllable level. This representation would allow both for phonological and articulatory/acoustic maintenance of the contrast in this position. We hypothesize that

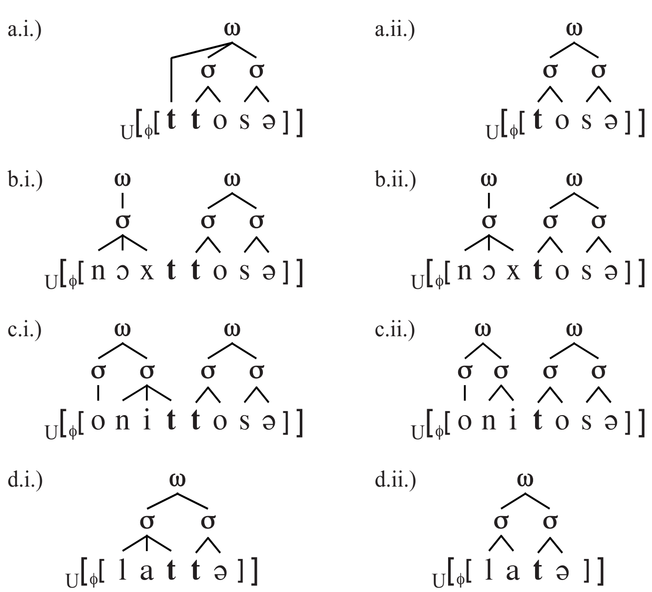

FIG. 1. Sample syllabifications and phrasings of word-medial (d) and word-initial geminates and singletons phrase/utterance initially (a) and phrase medially (b) and (c). (U=utterance phrase; ϕ=phonological phrase; ω=phonological word; σ=syllable): (a.i.) /**tt**o:sə/ "roar," (a.ii.) /**t**o:sə/ "can," (b.i.) /nɔ**x** **tt**o:sə/ "after roar," (b.ii.) /nɔ**x** **t**o:sə/ "after can," (c.i.) /on**i** **tt**o:sə/ "without roar," (c.ii.) /on**i** **t**o:sə/ "without can," (d.i.) /la**tt**ə/ "crossbar," and (d.ii.) /la**t**ə/ "shop."

geminates have a longer linguopalatal contact than singletons—in spite of the fact that in this position, CD information is missing.

Continuing on issues involving phrase-/utterance-initial contexts, in more recent literature, investigations have heavily focused on what influence the edges of prosodic domains—such as the syllable, the phonological word, the phonological phrase, etc.—have on the articulation of speech sounds. Consistent durational effects, which are of most relevance to our study, are primarily reported at the beginning of prosodic domains and seem to increase in force as the height of the domain in the prosodic hierarchy increases (e.g., Fujimura, 1990; Byrd *et al.*, 2005). For example, Fougeron and Keating (1997) found initial strengthening, i.e., longer and more extreme lingual articulation of initial consonants in English CV syllables with a cumulative effect. Likewise, a boundary effect on domain-initial segments (alveolar stops and fricatives) in Dutch was found by Cho and McQueen (2005). Also, Jun (1993), Cho and Keating (2001), and Keating *et al.* (2003) report that VOT measures in Korean stops are longest phrase initially, somewhat shorter word initially within a phrase, and shortest word medially within a phrase. While all these studies investigated the phonetic effects of different prosodic contexts for individual word-initial segments, the present study will take this one step further by examining not only absolute differences but also differences in the way a phonological contrast is realized.

In literature focusing specifically on word-initial voiceless geminates and singletons, Abramson (1986, 1987, 1991, 1999) established in a series of studies on Pattani Malay that CD was the primary acoustic cue. In its absence, i.e., phrase initially, listeners relied on two combined secondary cues, namely, rms amplitude of the first syllable and fundamental frequency ($F0$) of the vowel following the word-initial consonant, to successfully recover the phonemic difference. Similarly, by following up on work by Tserdanelis and Arvaniti (2001) on the word-medial quantity contrast in Cypriot Greek, Muller (2003) also found consistent CD and VOT differences in word-initial stops. She found geminates to have both longer CDs and longer VOTs phrase medially and that phrase initially the longer VOTs were sufficient secondary cues for native listeners to perceive the phonological difference. Ridouane's (2007) comprehensive study on the consonant system of Tashlhiyt Berber revealed two sets of results for word-initial stops. First, in terms of acoustics, release duration (i.e., positive VOT) did not significantly differ for geminates and singletons, and there was only a tendency for geminates to show greater rms amplitude during the release phase. The CD information could not be determined because the word-initial consonants only occurred phrase initially in the acoustic study. Second, in terms of articulation, an independent EPG study found that word-initial geminates were systematically articulated longer than their singleton counterparts, both phrase initially and medially. Moreover, phrase-initial stops were longer than phrase-medial ones, which Ridouane (2007) interpreted as prosodic lengthening.

While the studies on domain-initial prosodic strengthening only considered languages without a consonantal quantity contrast and had their primary focus on articulation, the studies on languages with a quantity contrast primarily focused on the acoustics. There are only few studies that combine the two (e.g., Lehiste *et al.*, 1973; Farnetani, 1990; Dunn, 1993; Löfqvist, 2005, 2007; Payne, 2006), and only Ridouane (2007) who discusses the articulation results with reference to prosodic strengthening issues. However, unfortunately, he had separate data sets for his articulatory and acoustic analyses. He investigated, on the one hand, the articulation of word-initial geminate and singleton stops in phrase-initial and phrase-medial position, and on the other hand, the acoustics of word-initial, word-medial, and word-final consonants. In our study, we intend to establish both the articulation and the acoustics of word-initial geminates and singletons, as they appear at different domain edges, i.e., phrase/utterance initially and phrase medially. Based on the existing literature mentioned, we expect to find phrase-initial articulatory strengthening as compared to the phrase-medial context. That is, we anticipate to ascertain longer articulations for geminates and singletons alike, possibly both in terms of the stop closure and the release phase.

In sum, by comparing Swiss German word-initial voiceless geminate versus singleton stops in differing phrasal positions, we expect (a) contrast maintenance phrase medially after a vowel and phrase/utterance initially, (b) contrast neutralization phrase medially after an obstruent, and (c) articulatory strengthening phrase initially as compared to phrase medially.

II. METHOD

A pilot EPG study reported by Kraehenmann and Jaeger (2003) had shown (a) that in phrase-initial position Swiss German geminates were distinguished from singletons and (b) that phrase medially there was neutralization in an obstruent context as opposed to contrast maintenance in a sonorant context. However, the pilot study only reported on data from a single speaker, and the carrier sentences used proved not to be ideal because they could potentially have had a phrase break at the crucial point of interest ([i ha elf_ksaitt] "I said eleven_;" [i ha t͡svai_ksaitt] "I said two_"). Our study avoided this by embedding the target words with initial geminates and singletons inside a prepositional phrase where the connection to the preceding preposition was prosodically fairly tight. In normal speech, a prepositional phrase always constitutes a single phonological phrase (ϕ).

TABLE II. Prosodic and segmental contexts.

Phrase-initial environment		
∅/**tt**o:sə/	"roar"	Isolation context
∅/**t**o:sə/	"can"	
Phrase-medial environment		
/nɔ**x**/ /**tt**o:sə/	"after roar"	C-context
/nɔ**x**/ /**t**o:sə/	"after can"	
/on**i**/ /**tt**o:sə/	"without roar"	V-context
/on**i**/ /**t**o:sə/	"without can"	

A. Recording material and procedure

Although Swiss German distinguishes geminate and singleton stops at three places of articulation (see Table I), we restrict our investigation to the alveolar stops /tt t/ in order to get the clearest results possible, particularly for the articulatory investigation. We chose 61 minimal and near-minimal pairs of words, of which 52 were proper names and 70 were common nouns (see Appendix A for a list of the individual names and nouns). We included proper names because they have been known to display special linguistic characteristics. Specifically, they are associated with processing difficulties (e.g., Brédart, 1993; Izaute, *et al.*, 2002) and language impairments (Evrard, 2002) and also show phonological peculiarities. For example, in Greek, proper names derived from common nouns show recessive word stress (Kurylowicz, 1966): *karpós* "fruit" versus *Kárpos* person name. Since there is evidence for the differential access and representation properties of proper names, it is feasible that speakers either overemphasize the quantity differences in proper names, or choose to disregard the contrast—either way distinguishing proper names from other common nouns.

We had two different prosodic environments: (a) phrase initial (henceforth *isolation context*) and (b) phrase medial. The phrase-medial condition had two segmental contexts: In the first, the preceding word ended in an obstruent (henceforth *C-context*), while in the second the preceding word ended in a vowel (henceforth *V-context*). Thus, each noun and name occurred in three distinct contexts: isolation, consonantal, and vocalic (Table II).

In order to be able to compare whatever effect we would get within the word-initial contrast with the typologically more common word-medial contrast, we recorded 42 additional nouns. These nouns contained the alveolar stops /tt t/ in the word-medial position between vowels (e.g., /k͡xø:**tt**əʀ/ "mutt,"/k͡xø:**t**əʀ/ "lure," see Appendix B for full list). The full set of items presented to the speakers consisted of two-thirds target words and one-third fillers. All target and filler items consisted of two syllables and carried main stress on the first.

Our subjects were given custom-fitted EPG palates a few weeks before the day of the recording to give them a chance to get accustomed to talking as uninhibitedly and naturally as possible with the palates in place. They also had at least 15 min warm-up time before the recording began.

We recorded four female Swiss German speakers, ranging in age between 27 and 42. The subjects read the test

TABLE III. Number of tokens used in each category.

	Names	Nouns		
	Initial	Initial	Medial	
Singletons	537	692	140	
Geminates	462	693	146	
	999	1385	286	2670

items in the three different contexts as they appeared in a random order on a computer screen. After a short break, the sets were read a second time. The EPG and audio signals were directly recorded onto the computer.

For all subsequent duration measures, we had a total of 2670 tokens—122 word-initial stops, 4 speakers, 2 repetitions, 3 contexts; 42 word-medial stops, 4 speakers, 2 repetitions, 1 context. The distribution is as listed in Table III below.

Since we needed both the EPG and the acoustic data combined, we discarded tokens in which, due to various factors, either one or the other was not usable. For example, for the sets in the isolation context, the subjects were asked to start with their mouth slightly open and the tongue not touching the palate to ensure that the first contact of the articulators corresponded to the beginning of the word. In quite a number of cases, this instruction was not followed, and thus the EPG could not be considered. Tokens were also discarded if there were hesitations, pauses, and/or noise interferences at the crucial points of interest. The distribution of tokens by context is given in Table IV.

B. Electropalatography

The articulatory goal of the study was to ascertain how articulation of word-initial long and short voiceless stops changes as a function of their preceding context. The measure we used was the duration of contact during the constriction of the consonants between the two main articulators, namely, the tip of the tongue and the anterior portion of the hard palate. To obtain these contact duration measures, we used the EPG system WINEPG (Articulate Instruments Ltd., Edinburgh, UK). In this system, 62 electrodes, embedded in a thin custom-fitted acrylic palate, are scanned for tongue-to-palate information at a sampling interval of 10 ms. Simultaneously, the audio signal was recorded at a sampling rate of 48 kHz via a Sennheiser MKH20P48 microphone. Data analysis of the articulatory duration measure was done with the ARTICULATE ASSISTANT software (Version 1.12), while analysis of the acoustic duration measures was done with the MULTI SPEECH software (Kay Elemetrics, Version 2.2).

C. Measurement

We annotated the EPG and speech files of our test items such that the articulatory and acoustic duration measures could be extracted and statistically analyzed.

1. Articulatory parameter

The articulatory annotations were done with the ARTICULATE ASSISTANT software. The annotation marked the interval between the first and last EPG frames in which 100% of the electrodes in the first row or at least 80% in the two front rows combined indicated contact of the articulators. We call this measure the *duration of maximum contact* (DMC) (cf. Kraehenmann and Jaeger, 2003). We give an illustration of this in Fig. 2 below.

2. Acoustic parameters

From the audio signal, two measures were annotated by using the MULTI SPEECH software. The first was CD. With the help of spectrograms and wave forms, tag 1 was set in the C-context data at the offset of the random noise, particularly in the higher frequencies, of the preceding velar fricative [x]. In the data for the V-context and the tokens with medial contrast, the offset of the vowel was taken to be the point at which there was sudden drop in amplitude along with the disappearance of higher harmonics in the wave form. In the isolation context, tag 1 could not be set because there was no preceding sound. Tag 2 designated the point of closure release in all data. The second acoustic measure, VOT,[1] designated the interval between the stop release (tag 2) and the beginning of the regular wave form pattern (i.e., voicing) of the following vowel (tag 3). Although CD is the most relevant cue also cross-linguistically, we include VOT as a measure because it has been shown to play a role in some languages with a quantity contrast, for example, in Cypriot Greek by Tserdanelis and Arvaniti (2001) and Muller (2003) or in Turkish by Lahiri and Hankamer (1988). Furthermore, there could be phrase-initial strengthening of this measure similar to the Korean VOT measures by Jun (1993), Cho and Keating (2001), and Keating *et al.* (2003).

D. Statistical analysis

An ANOVA was separately performed for the words with initial and medial contrast (using the statistical software suite JMP; SAS Institute, 2003; MAC version 5.0.1.2) with the following independent factors: *speaker* (as random factor),

TABLE IV. Distribution of used tokens by context.

	Names initial		Nouns initial		Nouns medial		
	Sing	Gem	Sing	Gem	Sing	Gem	
C-	202	160	242	236			
V-	186	171	231	232	140	146	
Iso	149	131	219	225			
	537	462	692	693	140	146	2670

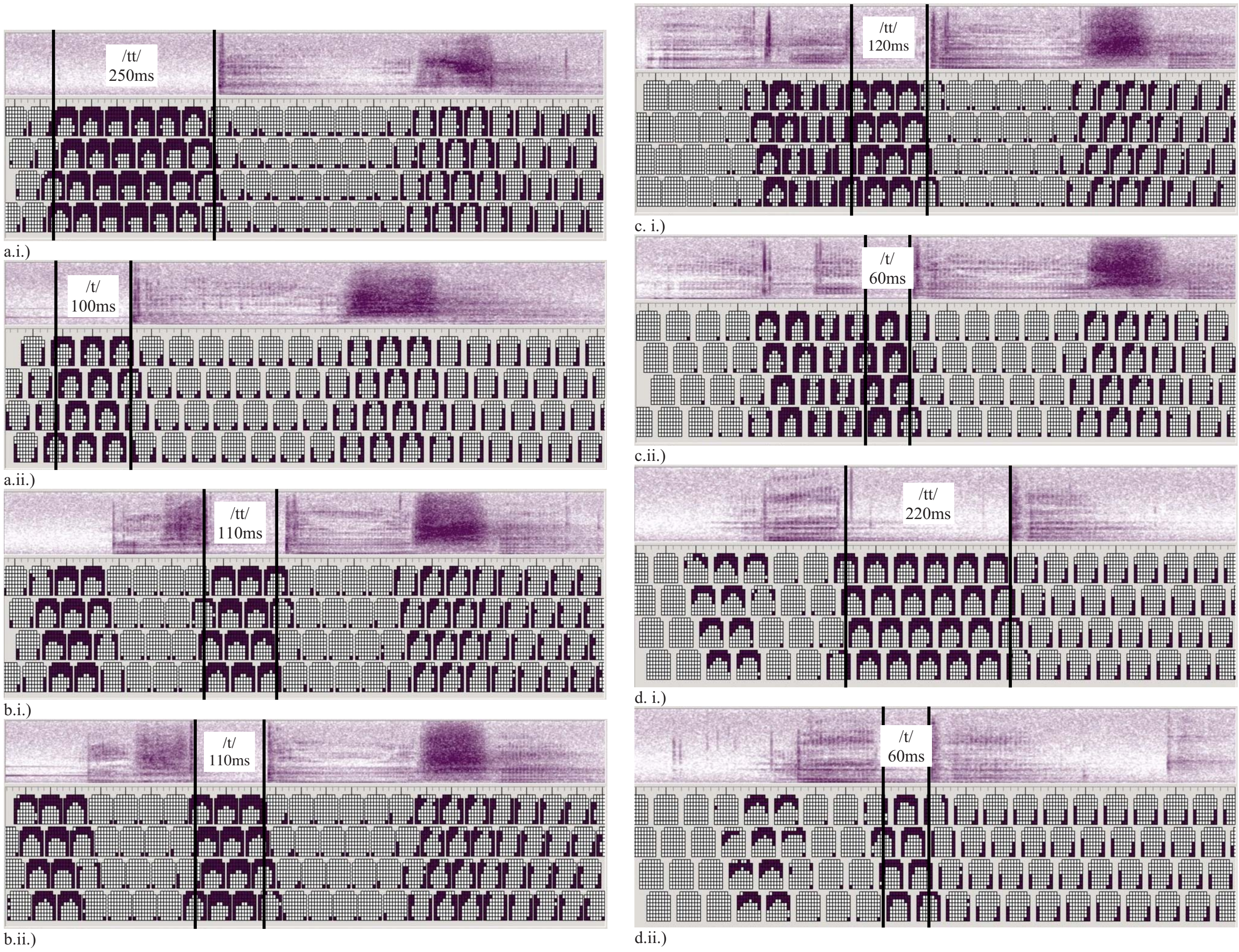

FIG. 2. (Color online) EPG illustration of quantity contrast in (a) isolation, (b) consonantal, (c) vocalic context, and (d) in word-medial context. The duration can be calculated as follows: (number of frames within lines—1) multiplied by 10 ms: (a.i.) /**tt**oːsə/ "roar," speaker 3, (a.ii.) /**t**oːsə/ "can," speaker 3, (b.i.) /nɔ**x** **tt**oːsə/ "after roar," speaker 2, (b.ii.) /nɔ**x** **t**oːsə/ "after can," speaker 2, (c. i.) /on**i** **tt**oːsə/ "without roar," speaker 2, (c.ii.) /on**i** **t**oːsə/ "without can," speaker 2, (d.i.) /la**tt**ə/ "crossbar," speaker 2, and (d.ii.) /la**t**ə/ "shop," speaker 2.

quantity (singleton, geminate), *condition* (isolation, consonantal, vocalic), and *noun type* (common noun or proper name) in a standard least squares design by using the restricted maximum likelihood (REML) estimation. The dependent variables were DMC, CD, and VOT. Significance was computed at the 5% level, and asterisks in the graphs and after the probability values indicate significant value differences.

III. RESULTS

A. Articulatory parameter: DMC

For the DMC measure there was no main effect for noun type [$F(1,2376)=2.47$, $p=0.7344$]. We found main effects for quantity, $F(1,2376)=1155.01$, $p=0.0002$*, and for condition, $F(2,2376)=1597.17$, $p=0.0009$*. Articulator contact was on average 55 ms longer for geminates (167 ms) than for singletons (112 ms). It was longest in the isolation context (207 ms), shorter in the C-context (109 ms), and shortest in the V-context (102 ms).

A *post hoc* test revealed that geminate contact was significantly longer in all three contexts (Fig. 3; Table V).

However, an additional *post hoc* test showed that the difference in DMC between geminates and singletons was significantly smaller in the C-context as compared to both the V- and the isolation context ($p<0.0001$*).

In comparison with the DMC values for word-medial geminates and singletons, the word-initial contrast in the V-context spanned a smaller range: The ratio of geminates to singletons was roughly 2:1 in the latter, as opposed to 3:1 for

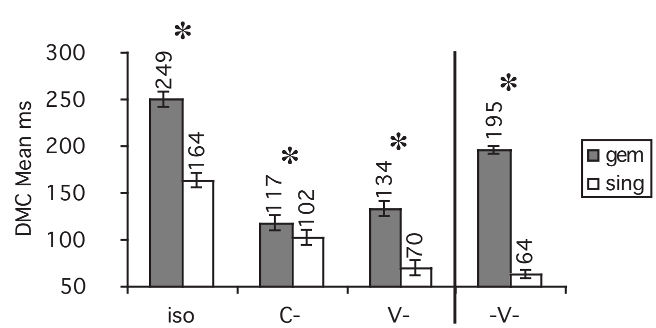

FIG. 3. DMC least squares means (ms) for *quantity* within *context*. Error bars: ±1 standard deviation(s).

TABLE V. DMC least squares means (ms), standard error (ms), difference (ms), and probability values for geminates and singletons in the three word-initial contexts (iso, *C*-, *V*-) and one word-medial context (-*V*-).

			LSM	Std error	*diff*	*p*
Initial	iso	Gem	249	16.6	85	<0.0001*
		Sing	164	16.6		
	C-	Gem	117	16.6	15	<0.0001*
		Sing	102	16.6		
	V-	Gem	134	16.6	64	<0.0001*
		Sing	70	16.6		
Medial	-*V*-	Gem	195	8.6	131	<0.0001*
		Sing	64	8.7		

the former. However, the difference displayed the same high level of statistical significance for both value sets.

B. Acoustic parameters: CD and VOT

As with DMC, there was a main effect for the CD measure for quantity, $F(1,1653)=1278.35$, $p=0.0022$*. CD was on average 42 ms longer for geminates (132 ms) than for singletons (90 ms). There was no main effect for condition, $F(1,1653)=78.27$, $p=0.0776$, nor for noun type, $F(1,1653)=2.45$, $p=0.1181$.

The factors quantity and condition significantly interacted. Geminates had longer CDs than singletons both in the C- and the V-context (Fig. 4; Table VI).

Here, too, the difference in CD between geminates and singletons was significantly smaller in the C-context as compared to the V-context ($p<0.0001$*).

The comparison to the CD values of medial geminates and singletons was virtually the same as in the articulatory data.

For VOT, there was no main effect for quantity, $F(1,2376)=34.57$, $p=0.4398$, nor for noun type, $F(1,2376)=4.73$, $p=0.3917$. However, there was an effect for condition, $F(2,2376)=4323.15$, $p=0.0209$* (Fig. 5, Table VII). Similar to the two other length measures, we found the shortest average duration in the C-context. The VOT values were significantly smaller in the C-context as compared to both the V-context ($p=0.0133$*) and the isolation context ($p=0.0147$*). There was no significant difference between the vocalic and the isolation context ($p=0.9782$).

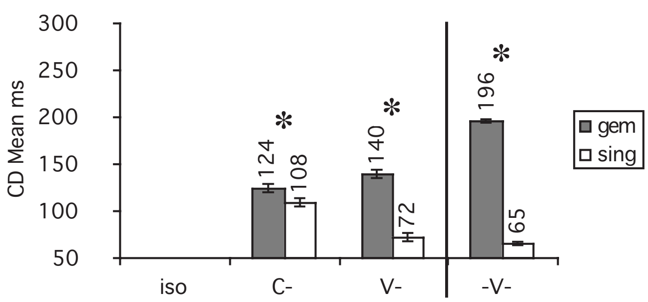

FIG. 4. CD least squares means (ms) for *quantity* within *context*. Error bars: ±1 standard deviation(s).

IV. DISCUSSION

We investigated Swiss German alveolar geminate and singleton stops in the word-initial position with respect to their articulatory and acoustic duration properties. Our main interest was directed toward finding out how the quantity distinction is manifested in articulator contact, closure duration, and release duration and how they vary as a function of different phrasal contexts.

The one variable which played the most minor role in our study was noun type: The speakers treated the word-initial geminates and singletons of proper names just like those in common nouns in all three conditions tested. Geminates, therefore, seem to be just as different and distinguished from singletons in proper names as they are in common nouns.

Regarding the other variables in our data, the three hypotheses we entertained were the following: (a) phrase-initial geminates would maintain longer contact than singletons although the acoustic correlate of closure duration was unavailable, (b) both phrase-initial geminates and singletons are produced longer than phrase-medial ones, and (c) the contrast between phrase-medial geminates and singletons in the consonantal context is neutralized while it is maintained in the vocalic context. We discuss each in turn.

(a) Our first hypothesis is confirmed, i.e., the contrast between word-initial geminates and singletons is maintained in phrase-/utterance-initial position in articulation. The average DMC measure is 249 ms for geminates and is 164 ms for singletons. This result may seem surprising if viewed with acoustics only in mind, because the quantity contrast is between voiceless stops and thus there is no acoustic cue of closure duration in this position.

(b) Second, there is a marked increase in the duration of linguopalatal contact for both geminates and singletons in phrase initial as compared to the phrase-medial contexts (see Fig. 3 and Table V). This finding confirms the pilot results by Kraehenmann and Jaeger (2003) and is similar to Tashlhiyt Berber, as discussed by Ridouane (2007). In *absolute* measures, geminates as well as singletons are articulated roughly 100 ms longer than in the phrase-medial vocalic context. These results replicate previous findings of articulatory strengthening at the beginning of a higher prosodic domain for a range of other languages (e.g., Fougeron and Keating, 1997; Keating *et*

TABLE VI. CD least squares means (ms), standard error (ms), difference (ms), and probability values for geminates and singletons in two of the three word-initial contexts (iso, *C*-, *V*-) and one word-medial context (-*V*-).

			LSM	Std error	*Diff*	*p*
Initial	*C*-	Gem	124	9.1	16	0.0002*
		Sing	108	9.1		
	V-	Gem	140	9.1	68	<0.0001*
		Sing	72	9.1		
Medial	-*V*-	Gem	196	3.7	131	<0.0001*
		Sing	65	3.7		

al., 2003; Byrd *et al.*, 2005; Cho and McQueen, 2005; Ridouane, 2007).

However, other than the absolute differences, we are also interested in the realization of the phonological contrast. In *proportional* terms, the highly significant difference between geminate and singleton articulations has become considerably smaller in the phrase-initial isolation context as opposed to the phrase-medial vocalic context: 1.5:1 versus 2:1. Thus, for the articulatory measure, the difference between geminates and singletons decreases rather than increases in phrase-initial position. This means that, although the articulation is heightened within both categories, the contrast between the categories is not.

(c) Turning now to the comparison between the two phrase-medial conditions, articulation and the acoustic measure CD parallel each other (cf. Figs. 3 and 4) as was established in earlier studies (Dieth and Brunner, 1943; Kraehenmann and Jaeger, 2003). As expected, geminates and singletons are clearly distinguished in the V-context.

Contrary to our expectations, however, the contrast also seems to be realized in the C-context. Kraehenmann (2001) and Kraehenmann and Jaeger (2003) did not find any articulatory or acoustic length differences for geminates and singletons in this condition. In other words, the contrast was neutralized in their data. While the difference of about 16 ms between geminates and singletons is statistically significant in this study, it is highly questionable—and subject to further study—whether it is also linguistically significant, i.e., whether it is sufficient for the phonological contrast to be recoverable in perception. At any rate, as mentioned above, the difference in articulatory and acoustic length is significantly smaller in the C-context than in the V-context. In terms of proportion, there is a 2:1 ratio in the V-context as compared to a 1.1:1 ratio in the C-context. The shortening of the geminate was expected based on the assumption that a syllable position is lost [cf. Fig. 1(b.i.)]. What the syllabification account cannot explain is the fact that singletons also lengthen in the C-context, which means that they strengthen although the prosodic structures are identical in both contexts [cf. Fig. 1(b.ii.) versus Fig. 1(c.ii.)]: The singletons begin the same word-initial syllable. This lengthening suggests that speakers are attempting to approach similar duration values which are within the ambiguous range of geminates and singletons, namely, around the 90–110 ms mark in this data set. Kraehenmann (2003) reports in her investigation that the CD values of geminates and singletons in the C-context (77.6 ms versus 70.5 ms) are comparable to the CD values of stops in word-medial consonant clusters, such as /nix**t**ə/ "niece" (78.1 ms). Our data unfortunately do not contain word-medial clusters and thus we cannot verify whether our values are comparable.

Note that the DMC measures for word-medial stops are three times as long for the geminates as for the singletons, confirming results of earlier acoustic work (Kraehenmann, 2001, 2003). The word-medial contrast, however, was only used as a control to establish that the DMC measures would be parallel to the acoustic measures established in earlier research. We did not vary the words with medial contrast in different phrasal contexts and, hence, there is no phrasal articulatory strengthening issue. Within a word, one could vary the prosodic environment in terms of the number of syllables, such as [kʀavá**tt**ə] "tie" versus [má**tt**ine] "matinee," but that would be another study.

A final comment concerns the acoustic measure VOT (Fig. 5). Our results are as anticipated, considering that there

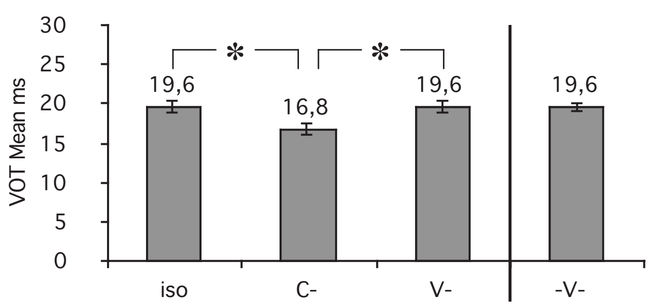

FIG. 5. VOT least squares means (ms) for *context*. Error bars: ±1 standard deviation(s).

TABLE VII. VOT least squares means (ms) and standard error (ms) across the three word-initial contexts (iso, *C*-, *V*-) and in one word-medial context (-*V*-).

		LSM	Std error
Initial	iso	19.6	1.5
	C-	16.8	1.5
	V-	19.6	1.5
Medial	-*V*-	19.6	0.7

was no main effect for quantity. This means that there was no statistical difference in the duration of the closure release for geminates and singletons, which is consistent with findings in earlier work (cf. Kraehenmann, 2001; 2003; Kraehenmann and Jaeger, 2003; Staeheli, 2005) and was also found for the voiceless stops of Tashlhiyt Berber by Ridouane (2007). Therefore, VOT can be ruled out as attributing to the phonological quantity contrast. What is surprising is the way VOT measures differ across—rather than within—contexts. If VOT patterned like the measures by Jun (1993), Cho and Keating (2001), and Keating *et al.* (2003), we would expect longer values in the phrase-initial context as opposed to the phrase-medial ones. While they are indeed significantly longer than in the C-context ($p=0.0147^{*}$), they are indistinguishable from the ones in the V-context ($p=0.9782$). Thus, what we found is not an instance of language-specific enhancement of a phonetic feature (cf. Cho and McQueen, 2005), since it does not make a phonological contrast (i.e., quantity) more pronounced. Rather, it seems that it marks a certain phonetic context, the context in which stops are shortest in their primary correlate, namely, the duration of the articulatory and acoustic closure: After an obstruent-final word, word-initial stops have the shortest closure as well as the shortest VOT. With a difference of barely 3 ms, it appears very unlikely that it is more than a mechanical effect of the shorter closure gesture. The fact that VOT does not lengthen phrase initially [where we have the longest closures (cf. Fig. 3)] in comparison to phrase medially in the vocalic context leads us to conclude that release duration of any sort is phonologically as well as phonetically absolutely inert in this language.

V. CONCLUSIONS

Our study showed that a contrast in word-initial voiceless geminate and singleton stops is clearly maintained phrase initially where the main acoustic cue, closure duration, is missing. There is no articulatory neutralization of the word-initial quantity contrast. Whether this articulatory difference can be exploited in perception is subject to further investigations. In the phrase-medial position, the quantity contrast of the word-initial stops is considerably reduced in absolute terms, both regarding the acoustic CD and articulatory contact. Moreover, the difference is sensitive in the segmental context. When the preceding word ends with a vowel (V-context), the duration measures are much longer for geminates than for singletons (approximately 70 ms, 2:1 for DMC and CD). In comparison when the preceding word ends in an obstruent consonant, the differences—although significant—are marginal (approximately 15 ms.; 1.1:1 for CD and DMC). One could, therefore, claim that the word-initial contrast is enhanced phrase initially and that Swiss German shows the same domain-initial articulatory strengthening as found in other languages (e.g., Fougeron and Keating, 1997; Keating *et al.*, 2003; Byrd *et al.*, 2005; Cho and McQueen, 2005; Ridouane, 2007). Nevertheless, in proportional terms, the results are ambiguous. Although both DMC and CD are much greater for both geminates and singletons in phrase-/utterance-initial position (e.g., DMC geminates 249 ms, singletons 164 ms), the difference between them is 1.5:1, as compared to either the phrase-medial vocalic context, where the difference is 2:1, or the word-medial context, where the difference is 3:1. Thus, the quantity contrast itself is not enhanced phrase initially, although an overall strengthening effect at a prosodic boundary is undoubtedly there.

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APPENDIX A: NAMES AND NOUNS WITH WORD-INITIAL CONTRAST

Names /tt/		Names /t/	
Tahar	Timon	Dagi	Dimo
Taina	Tinette	Dagmar	Dina
Taleb	Tito	Dagon	Dino
Tamar	Titus	Daina	Dogan
Tamra	Tobi	Dani	Domi
Tanja	Tomi	Daphne	Donald
Tara	Toni	Dara	Donat
Tatian	Tonya	David	Doris
Tela	Toris	Delfons	Dorit
Telka	Tory	Delma	Dunja
Telmo	Tunja	Denja	Durgun
Tero	Tünde	Derik	Dylan
Tessa	Türkkan	Deta	Dürke
Nouns /tt/		Nouns /t/	
Taler	"old coin"	Dame	"lady"
Tate	"deeds"	Datum	"date"
Tackel	"dachshund"	Daune	"down"
Taucher	"diver"	Delle	"dent"
Teller	"plate"	Delta	"delta"
Tecki	"cover"	Denker	"thinker"
Teflon	"Teflon"	Deppe	"dorks"
Tempel	"temple"	Dessin	"pattern"
Tesseer	"dessert"	Detail	"detail"
Ticki	"thickness"	Dichter	"poet"
Tiger	"tiger"	Dichti	"density"
Tili	"ceiling"	Dichtig	"seal"

Tinte	"ink"	Dinar	"denar"
Tipex	"Tipex"	Diner	"dinner"
Tischler	"carpenter"	Dischtle	"thistle"
Tischli	"table (DIM)"	Disel	"diesel"
Toggel	"pawn"	Diwan	"divan"
Toner	"toner"	Dogge	"mastiff"
Tonner	"thunder"	Doole	"jack-daw"
Totzet	"dozen"	Dooping	"doping"
Toose	"roar"	Doppel	"dupli-cate"
Tuume	"thumb"	Dose	"can"
Tuure	"tours"	Dosis	"dosage"
Tunell	"tunnel"	Dossier	"file"
Tuusig	"thousand"	Double	"double"
Tuusis	"Thusis"	Duden	"dictio-nary"
Tääler	"valleys"	Dumping	"dump-ing"
Töönig	"tinge"	Duuma	"Duma"
Töörli	"gate (DIM)"	Dääne	"Danes"
Tüle	"pie"	Dööner	"kebab"
Tümpel	"pool"	Döösli	"can (DIM)"
Tüüfi	"depth"	Dübel	"peg"
Tüürig	"inflation"	Dünger	"fertil-izer"
Tüüschig	"deception"	Düse	"nozzle"
		Düüter	"inter-preter"
		Düütig	"inter-preta-tion"

APPENDIX B: NOUNS WITH WORD-MEDIAL CONTRAST

Medial /tt/		Medial /t/	
Butter	"butter"	Adel	"nobility"
Chette	"chain"	Badi	"bath"
Chittel	"frock"	Bode	"floor"
Chlette	"barnacle"	Flider	"lilac"
Chutte	"cowl"	Jodel	"yodel"
Flotte	"fleet"	Liide	"affliction"
Foti	"photograph"	Luuder	"hussy"
Hütte	"hut"	Moode	"fashion"
Jute	"jute"	Pudel	"poodle"
Leiter	"leader"	Sooda	"soda"
Motte	"moth"	Model	"model"
Latte	"bar"	Lade	"store"
Kööter	"mutt"	Kööder	"lure"
Vatter	"father"	Fade	"thread"
Matte	"mat"	Made	"maggot"
Fuetter	"feed"	Fueder	"cart load"
Lette	"mud"	Leder	"leather"
Patte	"flap"	Paddel	"paddle"
Ruete	"rod"	Rueder	"oar"
Schatte	"shadow"	Schade	"damage"
Wetter	"weather"	Wedel	"frond"

[1]The combined use of *after closure time* (ACT), *superimposed aspiration* (SA), and CD has been established as a more accurate means of quantifying the difference between voiced and voiceless consonants (Mikuteit and Reetz, 2007; cf. also Clements and Khatiwada, 2007), lessening the confusion between CD definitions overlapping with lead VOT or negative VOT, positive VOT overlapping with aspiration, and so on. However, we chose to continue by using the term VOT for ACT since we are not dealing with a voicing contrast. The consonants are all voiceless and neither prevoicing nor aspiration play any role in the quantity distinction. Consequently, VOT essentially means *positive VOT*, i.e., consists of the duration of the burst release, and is interchangeable with ACT.

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