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Is a Stop Consonant Released when Followed by Another Stop Consonant?

JANETTE B. HENDERSON, BRUNO H. REPP

Haskins Laboratories, New Haven, Conn., USA

Abstract. Many phonetics textbooks state that, in sequences of two stop consonants in English, the first stop is commonly unreleased. For nonhomorganic stop consonant sequences, this statement may be taken to imply that the (necessary) articulatory release of the first stop has no observable acoustic consequences. To examine this claim, we recorded sentences, produced by several native speakers of American English at a conversational rate, containing word-internal sequences of two nonhomorganic stops, either across a syllable boundary (e.g., *cactus, pigpen*), or in word-final position (e.g., *act, sobbed*). Oscillograms of the critical words revealed that release bursts of the first stop occurred in the majority of tokens, except in those where the second stop was bilabial. The bursts were acoustically rather weak and difficult to detect by ear, which may account for their having been neglected in the literature. Instead of a simple 'released'-'unreleased' distinction, we propose five classification categories which make use of articulatory, acoustic, perceptual and contrastive phonetic criteria.

Introduction

In English, sequences of two nonhomorganic stop consonants are not uncommon. They occur across word boundaries (e.g., *big dog, great game*), across syllable boundaries within words (e.g., *cactus, pigpen*), and in word-final position (e.g., *act, sobbed*). Textbooks of English phonetics generally point out that the first stop in such sequences is commonly unreleased or unexploded. Some authors [e.g., LADEFOGED, 1975, pp. 45, 49; MACKAY, 1978, p. 166] say no more than that, while others [e.g., ABERGROMBIE, 1967, p. 146; CATFORD, 1977, p. 222; JONES, 1956, p. 155; KENYON, 1951, p. 47] are more explicit about the articulatory and acoustic events involved.

Without further qualification, the statement that the first stop in a two-stop sequence is unreleased may be misleading. If 'release' is correctly interpreted as a strictly articulatory term, referring to the

breaking of contact between two articulators which results in the release of overpressure built up behind the occlusion, the statement obviously cannot be true if the two stops have different places of articulation. In sequences of two nonhomorganic stops, the closure of the first stop must be released before that of the second stop; otherwise, the second stop would be produced with an incorrect or dual place of articulation. Therefore, it appears that phoneticians have used the terms 'release' and (perhaps less ambiguously) 'explosion' to refer not to the articulatory release but to its acoustic consequences, the portion of the speech signal that, for reasons of terminological consistency [cf. REPP, 1981], we prefer to call the 'release burst'. If so, then a strict interpretation of the term 'unreleased' would imply that, even in sequences of two nonhomorganic stop consonants, no release burst of the first stop is found in the acoustic record.

We were surprised, therefore, when earlier measurements of VCCV nonsense utterances (where CC was a two-stop sequence) produced by 3 speakers revealed that the large majority of the tokens contained clearly identifiable release bursts of the first stop [REPP, 1980]. In a more recent study using similar utterances produced by 2 speakers [REPP, 1982], all tokens (with a single exception) contained such bursts; moreover, the bursts were shown to have perceptual significance. Were earlier authors wrong, or did they perhaps refer only to conversational speech, of which the isolated utterances examined by REPP were not representative?

A careful reading of some of the source texts suggests that phoneticians did not intend to deny completely any acoustic manifestations of the articulatory release of the first stop. For instance, ABERCROMBIE [1967] points out that, in /pt/ sequences, "There may be "a little faintish smack" as the lips separate, as Abraham Tucker pointed out in 1773, but *for practical purposes* the stop is incomplete auditorily, and may be more specifically referred to as unexploded' (p. 146, our emphasis). And JONES [1956] points out that, in /pt/ and /bd/ sequences, 'The /p/ and /b/ *do not have normal plosion*, that is to say no ^h or ^ɶ is heard when the lips are separated' (p. 155, our emphasis). These statements suggest that the authors were aware that a release burst of the first stop may occur, but that it is substantially weaker (i.e., of lower amplitude and shorter duration) than that of a released utterance-final stop in English, or that of a similar stop produced by a French speaker [ABERCROMBIE, 1967, p. 147].

Given that such release bursts do occur, how common are they in fluent speech? Does the likelihood of their occurrence depend on the particular sequence of places of articulation of the two stops? Are the bursts so weak as to be difficult to detect by ear? The present study provides some answers to these questions. The last question, especially, relates to the criterion that phoneticians might have employed in the past for judging a stop to be 'unreleased': The criterion may have been either a perceptual one ('unreleased' then means 'without audible release burst') or a comparative phonetic one (a release burst may be heard, but it is not as strong as the burst of a 'released' stop in the same or in some other language). We intended to examine whether there is any perceptual basis for calling stops preceding a nonhomorganic stop 'unreleased'.

Acoustic Observations

Method

With three voiceless and three voiced stops in English, there are 24 possible sequences of two stops with different places of articulation. Of these, only four (/bd/, /gd/, /pt/, and /kt/) occur in word-final position, primarily in the past tense forms of verbs. All 24 sequences are permissible in word-medial position across a syllable boundary, but only two (/pt/ and /kt/) occur with any frequency, primarily in words of Romance origin. However, by including some compound words, we were successful in finding two examples of each of the 24 sequences in word-medial position.

We constructed meaningful sentences, each containing two of the words to be measured, and the subjects read from a typed list of these sentences. The sentences are shown in the 'Appendix' with the critical words in italics. As can be seen, all stop sequences were immediately preceded and followed by a vowel, with primary stress on the preceding vowel. (Note that we were not concerned here with two-stop sequences across a word boundary, although two stops crossing a morpheme boundary in words such as *bootcamp* may be considered a rather similar instance.)

6 native speakers of American English, 3 male and 3 female, were selected as subjects. They were not informed about the purpose of the experiment, but were asked to first study the sentences and then read

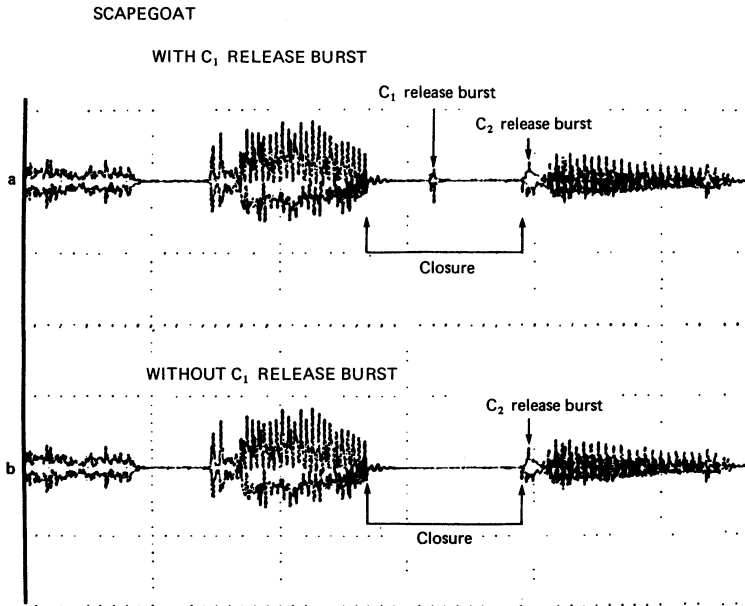


Fig. 1. Oscillogram of the word *scapegoat* produced by a female speaker. The word is shown excised from its sentence context with the release burst of the first stop (C₁) in place (above) and removed (below).

them at a normal conversational speed. Their productions were recorded on magnetic tape using a Sennheiser MKH 415 T microphone, placed approximately 8 inches from the subject's lips, and a Crown SX 822 tape recorder. The recordings were then digitized at 10 kHz using the Haskins Laboratories pulse code modulation system, and the waveforms were displayed on an oscilloscope. We zeroed in on the closure periods in the critical words to determine whether or not a release burst of the first stop was present. If present, such bursts appeared as distinct spikes of a few milliseconds duration, roughly in the center of the closure period. A typical example is shown in figure 1a, with the closure and the release bursts for both stops indicated for the utterance *scapegoat*, produced by a female speaker (C. G.). In some cases, the release bursts were of very low amplitude, and 2 of the subjects produced a few tokens containing multiple or exaggerated bursts, but the token shown in figure 1a is representative of the majority of utterances containing release bursts.

Table I. Frequencies of occurrence (in percent) of release bursts of the first stop in word-medial stop sequences

Speakers	Place of stop articulation (C ₁ /C ₂)						mean
	alveolar/ labial	velar/ labial	velar/ alveolar	labial/ alveolar	alveolar/ velar	labial/ velar	
N.M.	25.0	25.0	50.0	12.5	75.0	87.5	45.0
A.B.	0.0	0.0	50.0	87.5	87.5	87.5	52.1
B.R.	0.0	0.0	37.5	87.5	87.5	100.0	52.1
C.G.	12.5	12.5	75.0	75.0	75.0	87.5	56.3
J.M.	0.0	25.0	87.5	87.5	87.5	75.0	60.4
R.K.	12.5	87.5	100.0	87.5	100.0	100.0	81.3
Mean	8.3	25.0	66.7	72.9	85.4	89.6	58.0

Results

The frequency of occurrence of a release burst for the first stop in word-medial sequences is shown in table I. The columns represent the six possible sequences of two different places of stop articulation, while the rows represent the individual subjects. The voicing feature of the stops has been ignored in this analysis, so that the percentage in each cell is based on eight words. Looking at the means in the right margin, we see that, overall, 58 % of the words contained a release burst of the first stop, with the average percentages for individual speakers ranging from 46 to 81 %. It is further evident from the means in the bottom row that release bursts were not equally common in all consonant combinations. The main determinant was the place of articulation of the second stop. When the second stop was labial, release bursts of the first stop tended to be absent (except for 1 speaker's velar-labial sequences); when it was alveolar, release bursts were present in the majority of utterances; and when it was velar, release bursts were even more common. The place of articulation of the first stop seemed to play only a minor role, and we also observed that the voicing feature had no consistent influence on the occurrence of release bursts¹.

¹ We considered the possibility that the absence of release bursts in a number of tokens was due to the substitution of glottal stops for alveolar (and, perhaps, velar) stops. In the informal judgment of the first author, 22 words may have contained glottal stops, 18 of which preceded a labial stop. Release bursts were observed in 4 of these 18 tokens (22%), which is slightly higher than the overall incidence of 17% in this context (table 1). Thus, to the extent that glottal stops did occur, they were not responsible for the absence of release bursts.

then created a second version of each in which the release burst of the first stop was replaced with silence. Figure 1b shows this modified version of the word *scapegoat*, the original of which is displayed in figure 1a.

We then constructed two discrimination tests. In the yes/no test, each of the ten stimuli occurred ten times in random order, with inter-stimulus intervals of 3 s. In the two-interval forced-choice (2IFC) test, the two versions of each word were arranged in pairs, with the modified version either first or second. The resulting ten pairs occurred ten times in random order, with interstimulus intervals of 500 ms within pairs and 2 s between pairs.

9 subjects participated; they were the two authors and 7 colleagues at Haskins Laboratories with varying amounts of phonetic training and experience. In the yes/no discrimination test, they were provided with a written copy of the randomized tokens and were asked to indicate whether each stimulus did or did not contain a release burst of the first consonant in the two-stop sequence. In the subsequent 2IFC test, the subjects were asked to listen to each pair of words and then indicate which member, the first or the second, contained the release burst. The subjects were told that the bursts might be difficult to hear and listened to some examples before starting each test.

Results

The mean percentages of correct responses are shown in table III, with the five words displayed separately for the two tasks. We see that overall performance was poor on both tests, though better than chance (50%). The average score on the 2IFC test was only slightly higher than that on the yes/no test, even though the 2IFC test, which was administered last, had the potential benefit of practice during the yes/no test. Individual stimuli varied in difficulty, with *cactus* being near chance level while *scapegoat* (cf. fig. 1) reached a respectable 80% correct in the 2IFC task. We have not investigated in detail the acoustic properties that account for this variation, but two factors that are likely to play a role are the amplitude of the release burst and its temporal separation from the much stronger release burst of the second stop.

There was also considerable variability between subjects. In the yes/no test, the two authors performed at 83 and 85% correct, respectively, whereas the scores of the other 7 listeners ranged from 45 to 66% correct. In the 2IFC task, the corresponding values were 89 and 79% for the authors and 50–67% for the other subjects. Thus, if one

Table III. Percent correct release burst detection in two tasks

Stimuli	Discrimination task	
	yes/no	2IFC
<i>Cactus</i>	49.4	55.0
<i>Ribcage</i>	61.1	58.3
<i>Edgar</i>	62.2	63.9
<i>Bodkin</i>	64.4	62.2
<i>Scapgoat</i>	67.8	80.5
Mean	61.0	64.0

excludes the 2 subjects who had preexperimental experience with the stimuli and perhaps knew better what to listen for, there is little evidence that even phonetically trained listeners can detect the faint release bursts of so-called 'unreleased' stops. This is, then, the likely reason why the bursts were not noticed by some earlier authors who relied on their auditory impressions.

Conclusions

In this paper, we have reported some data relevant to the statement that, in English, stops followed by a different stop are 'unreleased'. We have examined several possible interpretations of that statement: (1) If it is interpreted as referring to articulation, it is clearly false. (2) If it is interpreted as referring to the acoustic signal, it is not generally true unless the definition of what is to count as a 'release burst' is restricted to acoustic events of a certain minimal duration and amplitude. While such a restrictive definition may have been implicit in some previous discussions of 'unreleased' stops, it should be noted that, on the contrary, the term 'burst' is appropriately applied only to the signal portion excluded by such a definition, i.e., to the brief transient generated by the stop release, exclusive of any following aspiration [cf. DORMAN et al., 1977; FANT, 1973]. (3) If the statement is interpreted as referring to perception, it appears to be accurate in so far as stops preceding another stop in conversational speech have release bursts that are difficult to detect by ear. In this sense, the stops in this study were indeed 'unreleased'. (4) The possibility remains that

some phoneticians have used the term 'unreleased' in a purely contrastive sense. In this usage, even a stop with a detectable release burst might qualify as 'unreleased' relative to some standard for 'released' stops. The stops recorded by REPP [1982], whose release bursts were from 10 to 40 ms long and quite detectable, may fall in this category. An obvious problem here is the absence of any clearly defined criterion separating the two classes.

These considerations illustrate the confusion that can result from terminology that is not only vague about the level of description to which it refers [REPP, 1981], but also insufficiently defined at the level intended. Many phonetic distinctions that are couched in acoustic terminology have been drawn at some remove from the speech signal. In that respect, the term 'unreleased' is similar to the term 'unaspirated', which is commonly applied to consonants, such as English [g], that exhibit a good deal of aspiration in the acoustic signal. While these terms may be sufficient for the field phonetician, they do not reflect the level of detail that acoustic phoneticians are concerned with, and therefore are of limited use.

We propose the following, more detailed classification, in which 'release' is reinstated as an articulatory term:

- (1) *Unreleased*: The occlusion is maintained, as in a stop preceding a homorganic stop or in many utterance-final stops with delayed release.
- (2) *Silently released*: No release burst in the acoustic record.
- (3) *Inaudibly released*: Visible release burst in records of the signal, but not readily detectable by ear.
- (4) *Weakly released*: Release burst detectable by ear but clearly weaker than in class 5.
- (5) *Strongly released*: Release burst is followed by substantial aspiration or voicing.

In this scheme, successive classes are separated by different criteria: classes 1 and 2 by an articulatory criterion, classes 2 and 3 by an acoustic criterion, classes 3 and 4 by a perceptual criterion, and classes 4 and 5 by a criterion of phonetic contrast or classification.

In summary, our studies indicate that, in English, stops preceding a nonhomorganic stop in conversational speech are generally released inaudibly or silently, silent releases being particularly common when

the following stop is labial. The observations of REPP [1980, 1982], on the other hand, suggest that similar stops produced in isolated disyllables are typically weakly released.

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Appendix

1. The old lady was *mugged* and *robbed* of her purse.
2. The fifth *act* of the play was a particularly hard one to *direct* in the small theatre.
3. The little girl *sobbed* incessantly although her mother *hugged* and kissed her.
4. Peter is very *apt* on occasions to forget that the journals must be *kept* in the reference room.
5. The *breakdown* of his car made it very difficult for *Edgar* to get on and off campus for his classes.
6. Last night we relaxed with a bowl of *popcorn* and watched the movie 'Dogday Afternoon' starring Al Paccino.
7. Even the Russians admit that straight *vodka* is real *rotgut*.
8. Considering he wasn't wearing a seatbelt, the driver was lucky to escape with only bruising to his *ribcage* and *abdomen*.
9. Nancy found a wonderful recipe for sugar-free *cupcakes* in her new *cookbook*.
10. The *doctors* did their rounds of the *sickbay* at 10 o'clock every morning.
11. The *cactus* was left so long in the small pot that it became completely *rootbound* and eventually died.
12. Bonnie and Clyde each carried a *shotgun* and left a *bloodbath* behind them after every bank robbery.
13. Dan bought a new *pup tent* for his *backpacking* trip on the Appalachian Trail.
14. Gary's favorite sport is *rugby* but his talents make him a good *football* player too.
15. King Edward decided to *abdicate* and leave a respectable *lagtime* before his marriage to Mrs. Simpson.
16. *Crockpots* are excellent for cooking Chinese soups such as wonton, *subgum*, and eggdrop.
17. The *oddball* in our dorm was *Egbert* who permanently locked himself in his room so he wouldn't have to socialize with any of us.

18. The army has developed *subterranean* landing pads which allow *helicopters* to escape from the radar detection of invading aircraft.
19. The incessant burrowing of the newborn pigs had turned their *pigpen* into a huge *mudpuddle*.
20. One of Deborah's favorite hobbies is *tapdancing*, especially to jazz and *ragtime* music.
21. Some people claim that Nixon was only a *scapegoat* in the cover-up of C.I.A. scheming and *subterfuge*.
22. Margaret caught her 9-year-old son trying to shoot a *magpie* with his *popgun*.
23. In the fall, the *catkins* hanging outside the *backdoor* of the cottage were really beautiful.
24. My grandmother always inserted a *hatpin* or a *bodkin* into her cakes to see if they were ready to be removed from the oven.
25. The marine biologists made a movie about the development of *tadpoles* into frogs through a *trapdoor* mechanism on the side of the artificial pond.
26. The uniforms for the Governor and *Subgovernor* of India during the early 1900s could only be differentiated by the *headgear* and the collar markings.
27. It seemed that the menu for *bootcamp* consisted largely of *potpies* and oatmeal.
28. David tried to prevent the *bogdown* of his car by putting sacks under the wheels, but after a few attempts at moving it, it sank up to the *hubcaps* in the mud.

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JANETIE B. HENDERSON, Haskins Laboratories, 270 Crown Street, *New Haven*, CT 06510 (USA)