IS A STOP CONSONANT RELEASED WHEN FOLLOWED BY ANOTHER STOP CONSONANT?*

Janette B. Henderson+ and Bruno H. Repp

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 a five-way classification that makes 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., Abercrombie, 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 that 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

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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 three 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 two speakers (Repp, in press), 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 9 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 Appendix 1 with the critical words underlined. 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.)

Six native speakers of American English, three male and three 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 them at a normal conversational speed. Their productions were recorded on magnetic tape using a Sennheiser MKH 415T 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 (CG). In some cases, the release bursts were of very low amplitude, and two 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.

Results

The frequency of occurrence of a release burst for the first stop in word-medial sequences is shown in Table 1. 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 percent of the words contained a release burst of the first stop, with the average percentages for individual speakers ranging from 46 to 81 percent. 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
Figure 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 in place (above) and removed (below).
### Table 1

**Percentage of Words with $C_1$ Release Bursts**

<table>
<thead>
<tr>
<th>Place of Stop Articulation</th>
<th>Speakers</th>
<th>$C_1$: ALV</th>
<th>VEL</th>
<th>VEL</th>
<th>LAB</th>
<th>ALV</th>
<th>LAB</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NM</td>
<td>25.0</td>
<td>25.0</td>
<td>50.0</td>
<td>12.5</td>
<td>75.0</td>
<td>87.5</td>
<td>45.8</td>
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<tr>
<td></td>
<td>AB</td>
<td>0.0</td>
<td>0.0</td>
<td>50.0</td>
<td>87.5</td>
<td>87.5</td>
<td>87.5</td>
<td>52.1</td>
</tr>
<tr>
<td></td>
<td>BR</td>
<td>0.0</td>
<td>0.0</td>
<td>37.5</td>
<td>87.5</td>
<td>87.5</td>
<td>100.0</td>
<td>52.1</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>12.5</td>
<td>12.5</td>
<td>75.0</td>
<td>75.0</td>
<td>75.0</td>
<td>87.5</td>
<td>56.3</td>
</tr>
<tr>
<td></td>
<td>JM</td>
<td>0.0</td>
<td>25.0</td>
<td>87.5</td>
<td>87.5</td>
<td>87.5</td>
<td>75.0</td>
<td>60.4</td>
</tr>
<tr>
<td></td>
<td>RK</td>
<td>12.5</td>
<td>87.5</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>81.3</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>8.3</td>
<td>25.0</td>
<td>66.7</td>
<td>72.9</td>
<td>85.4</td>
<td>89.6</td>
<td>58.0</td>
</tr>
</tbody>
</table>

### Table 2

**Percentage of Words with $C_1$ Release Bursts**

<table>
<thead>
<tr>
<th>Place of Stop Articulation</th>
<th>Speakers</th>
<th>$C_1$: Labial</th>
<th>Velar</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NM</td>
<td>100.0</td>
<td>75.0</td>
<td>87.5</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>75.0</td>
<td>75.0</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td>BR</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>JM</td>
<td>100.0</td>
<td>25.0</td>
<td>62.5</td>
</tr>
<tr>
<td></td>
<td>RK</td>
<td>50.0</td>
<td>75.0</td>
<td>62.5</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>87.5</td>
<td>75.0</td>
<td>81.25</td>
</tr>
</tbody>
</table>
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 one 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 bursts.1

Table 2 shows the same analysis for the word-final stop sequences (see Sentences 1–4 in the Appendix), with the columns representing the only two possible sequences of place of articulation, and the rows representing the same individual subjects. Again the voicing feature has been ignored so that the percentage in each cell is based on four words here, since no words containing stop sequences differing in voicing (e.g., /bt/, /kd/) occur in word-final position in English. The means in the right margin show that, overall, 81 percent of the words contained a release burst of the first stop, with the average percentages for individual speakers ranging from 63 to 100 percent. The means in the bottom row indicate that, as in word-medial position, the place of articulation of the first stop had no consistent effect.

Discussion

The pattern in these data can be understood by considering the articulatory maneuvers involved. When the second stop is labial, the speaker has the option of closing the lips before an earlier alveolar or velar closure is released, and if this option is followed, the release of the first stop occurs during the labial closure and therefore has minimal acoustic consequences. On the other hand, if the first stop is labial, although an alveolar or velar closure may be established before the lips are parted, the labial release, when it occurs, will generally produce a burst because there is no occlusion anterior to the lips. The occasional absence of a detectable burst may be due to changing local conditions (e.g., dryness of the lips) that affect sound generation. When one stop is alveolar and the other velar, we must take into account that the same articulator—i.e., the tongue—is involved. Even though, in principle, the tongue tip could establish contact with the palate before the tongue body releases its contact (and vice versa), this seems a difficult maneuver that speakers do not commonly employ. Our data show that release bursts occur both in alveolar-velar and velar-alveolar sequences, suggesting that the second closure is established shortly after the release of the first. If the closure periods of the two stops had overlapped, release bursts in velar-alveolar sequences should have been considerably less frequent because the velar release would have been silenced by the alveolar closure.

Our findings refute a strictly acoustic interpretation of the statement that the first stop in nonhomorganic two-stop sequences is unreleased. Contrary to that interpretation, which predicts the absence of release bursts, we have found that release bursts are generally present, at least in those two-stop sequences that occur most frequently in English (i.e., those in which the second stop is alveolar). There is no reason to believe that our results would not generalize to the more common case of two-stop sequences across a word boundary. In fact, a word boundary might be expected to increase the
probability of occurrence of a release burst of the first stop. As for two-stop sequences in word-final position, which are typically cited in discussions of "unreleased" stops, our data show that release bursts of the first stop are actually more frequent than in word-medial position.

Although some authors (Abercrombie, 1967; Jones, 1956) mentioned faint release bursts, it is our impression that their occurrence has not been generally acknowledged. One reason for this may be that they are difficult to detect by ear. We conducted a brief experiment to address this issue.

BURST DETECTION EXPERIMENT

Method

Five typical utterances were chosen from speaker CG's productions, all containing release bursts of the first stop (cactus, ribcage, Edgar, bodkin, scapegoat). Using the Haskins Laboratories pulse code modulation system, we excerpted the words from their sentence context and 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 interstimulus intervals (ISIs) of 3 sec. In the 2IFC test (two-interval forced-choice 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 ISIs of 500 msec within pairs and 2 sec between pairs.

Nine subjects participated; they were the two authors and seven 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 3, 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 percent). 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. Figure 1) reached a respectable 80 percent 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.

Table 3
Mean Percentage Correct Discrimination

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>Yes/No</th>
<th>2IFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cactus</td>
<td>49.4</td>
<td>55.0</td>
</tr>
<tr>
<td>Ribophage</td>
<td>61.1</td>
<td>58.3</td>
</tr>
<tr>
<td>Edgar</td>
<td>62.2</td>
<td>63.9</td>
</tr>
<tr>
<td>Bodkin</td>
<td>64.4</td>
<td>62.2</td>
</tr>
<tr>
<td>Scapegoat</td>
<td>67.8</td>
<td>80.5</td>
</tr>
<tr>
<td>Mean</td>
<td>61.0</td>
<td>64.0</td>
</tr>
</tbody>
</table>

There was also considerable variability between subjects. In the Yes/No test, the two authors performed at 83 and 85 percent correct, respectively, whereas the scores of the other seven listeners ranged from 45 to 66 percent 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 excludes the two subjects who had pre-experimental 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—viz., to the brief transient generated by the stop release,
exclusive of any following aspiration (cf. Dorman, Studdert-Kennedy, & Raphael, 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 (1980, in press), whose release bursts were from 10-40 msec 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 (5).
(5) Strongly released: Release burst is followed by substantial aspiration or voicing.

In this scheme, successive classes are separated by different criteria: (1) and (2) by an articulatory criterion, (2) and (3) by an acoustic criterion, (3) and (4) by a perceptual criterion, and (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, in press), on the other hand, suggest that similar stops produced in isolated disyllables are typically weakly released.
REFERENCES


FOOTNOTE

We considered the possibility that the absence of release bursts in some tokens was due to the substitution of glottal stops for alveolar (and, perhaps, velar) stops. In the informal judgment of the first author, 22 utterances may have contained glottal stops. In 18 of these, the putative glottal stop preceded a labial stop. Release bursts were observed in 4 of these 18 tokens (22 percent), which is slightly higher than the overall incidence of 17 percent in this context (cf. Table 1). Thus, to the extent that glottal stops did occur, they did not change the pattern of our results.
APPENDIX 1

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 theater.

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 Pacino.

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 new-born 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 1900's 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.