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ABSTRACT

This study investigates the influence of initial and final consonants /p, b, s, z/ on the duration of four vowels /I, i, u, ae/ in 64 CVC syllables uttered by eight speakers of English from the same dialect area. The CVC stimuli were presented to the subjects in a frame sentence from a master tape. Subjects repeated each sentence immediately after hearing it from the tape. Vowel duration measurements for the 512 utterances were taken from duplex oscillograms produced at 20 cm./sec. A repeated measures analysis of variance was performed on the vowel duration measurements (initial voicing by initial manner by final voicing by final manner by vowel). Vowel duration was increased significantly (1) if the initial consonant was voiced rather than voiceless, (2) if the final consonant was a fricative rather than a stop, (3) if the final consonant was voiced rather than voiceless. The vowels showed significantly different mean vowel durations, /I/ being shortest and /ae/ being longest. (Author/AMM)

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INFLUENCE OF INITIAL AND FINAL CONSONANTS ON VOWEL DURATION IN CVC SYLLABLES

REPORT FROM THE PROJECT ON LANGUAGE CONCEPTS AND COGNITIVE SKILLS RELATED TO THE ACC[illegible]N OF LITERACY

WISCONSIN RESEARCH AND DEVELOPMENT

CENTER FOR COGNITIVE LEARNING

THE UNIVERSITY OF WISCONSIN
Madison, Wisconsin

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Technical Report No. 130

INFLUENCE OF INITIAL AND FINAL CONSONANTS ON VOWEL DURATION IN CVC SYLLABLES

by

Margaret A. Naeser

Report from the Project on Language Concepts and Cognitive Skills Related to the Acquisition of Literacy

Robert C. Calfee and Richard L. Venezky, Principal Investigators

Wisconsin Research and Development
Center for Cognitive Learning
The University of Wisconsin
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The Wisconsin Research and Development Center for Cognitive Learning focuses on contributing to a better understanding of cognitive learning by children and youth and to the improvement of related educational practices. The strategy for research and development is comprehensive. It includes basic research to generate new knowledge about the conditions and processes of learning and about the processes of instruction, and the subsequent development of research-based instructional materials, many of which are designed for use by teachers and others for use by students. These materials are tested and refined in school settings. Throughout these operations behavioral scientists, curriculum experts, academic scholars, and school people interact, insuring that the results of Center activities are based soundly on knowledge of subject matter and cognitive learning and that they are applied to the improvement of educational practice.

This Technical Report is from the Language Concepts and Cognitive Skills Related to the Acquisition of Literacy Project in Program 1. General objectives of the Program are to generate new knowledge about concept learning and cognitive skills, to synthesize existing knowledge, and to develop educational materials suggested by the prior activities. Contributing to these Program objectives, this project's basic goal is to determine the processes by which children aged 4 to 7 learn to read, examining the development of related cognitive and language skills, and to identify the specific reasons why many children fail to learn to read. Later studies will be conducted to find experimental techniques and tests for optimizing the acquisition of skills needed for learning to read. By-products of this research program include methodological innovations in testing paradigms and measurement procedures; the present study is an example.

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ABSTRACT

The study investigates the influence of initial and final consonants /p, b, s, z/ on the duration of four vowels /ɪ, i, u, æ / in 64 CVC syllables uttered by eight speakers of English from the same dialect area. The CVC stimuli were presented to the subjects in a frame sentence from a master tape. Subjects repeated each sentence immediately after hearing it from the tape. Vowel duration measurements for the 512 utterances were taken from duplex oscillograms produced at 20 cm./sec. A repeated measures analysis of variance was performed on the vowel duration measurements (initial voicing by initial manner by final voicing by final manner by vowel). Vowel duration was increased significantly (1) if the initial consonant was voiced rather than voiceless, (2) if the final consonant was a fricative rather than a stop, (3) if the final consonant was voiced rather than voiceless. The vowels showed significantly different mean vowel durations, /ɪ/ being shortest and /æ/ being longest.

I

INTRODUCTION

The purpose of this study is to investigate the effect of initial and final consonants (voiceless or voiced, stop or fricative) on vowel duration in CVC (consonant-vowel-consonant) stressed syllables as spoken by several speakers of English. Peterson and Lehiste (1960), the only investigators to study the influence of initial consonant on vowel duration in CVC utterances, reported no systematic influence. Only one speaker provided data, however, and no statistical analyses were made.

The influence of final consonant on vowel duration in English has been demonstrated in previous studies (Peterson & Lehiste (1960); House & Fairbanks (1953); and House (1961)). The first-mentioned authors, using 10 subjects (Ss) pronouncing CVC syllables containing the same initial and final consonant, found that final voiced consonants have the greatest effect in increasing vowel duration and final fricatives have a greater effect than stops. The final voicing and manner of articulation effects were statistically significant ($p < .01$).

Peterson and Lehiste (1960) found similar results with five Ss although no statistical analysis was applied. The vowel duration before a voiceless consonant was approximately 2/3 of that before the homorganic voiced consonant. The average durations of the syllable nuclei, in ascending order, were: .184 sec. before the voiceless stop, .228 sec. before the voiceless fricative, .280 sec. before the voiced stop, and .376 sec. before the voiced fricative. House (1961) reports findings similar to those mentioned above with three Ss. The intrinsic vowel durations (e.g., /æ/ is always longer than /ɪ/ in the same consonant environment) for 12 vowels of American English were reported; the final consonants exerted a similar effect on the duration of vowels which were of short or long intrinsic duration. No statistical analyses were included.

The present study investigates the influence of both initial and final consonants on the duration of four vowels.

II
METHOD

DESIGN

A completely repeated 2 × 2 × 2 × 2 × 4 design with eight Ss was used, initial voicing (voiceless or voiced) by initial manner (stop or fricative) by final voicing by final manner by vowel (/ɪ, i, u, æ/).

STIMULUS MATERIALS

The voiceless stop and fricative chosen for testing were /p/ and /s/, respectively. The voiced stop selected was /b/; the voiced fricative, /z/. For each of the four vowels, /ɪ/ (close lax, short intrinsic duration), /i/ (close tense, medium intrinsic duration), /u/ (close tense, medium intrinsic duration), and /æ/ (open tense, long intrinsic duration), 16 CVC syllables were formed using all possible CVC combinations of the four consonants. The 64 CVC syllables were then ordered with the provision that no single feature (consonant voicing, consonant manner, vowel quality) followed itself in the list (see Appendix).

Each item was spoken in the frame sentence "A_________is a word," and the sentences were recorded in list order. The speaker was a male graduate student in linguistics who had experience in recording phonological items for testing; his dialect closely approximated Upper Midwest. Sentences were recorded at a conversational speed with 231↓ intonation. Recording was done at 7 1/2 ips on 1.5 mil. mylar Audiotape at the Department of Linguistics Phonetics Lab, using a Sony tape recorder (TC-777-4) and an Altec microphone (684 B).[1]

SUBJECTS

The Ss were eight monolingual adult speakers (four male, four female) who had grown up in central Wisconsin. All were staff members at the Wisconsin Research and Development Center for Cognitive Learning and had had no previous training in speech science.

PROCEDURES

The Ss heard the master tape over two speakers from an Ampex tape recorder (1100). Each subject was instructed to repeat each sentence immediately after he heard it. Responses were recorded with an Ampex microphone (2001) on an Ampex tape recorder (1100) at 7 1/2 ips on 1 mil. mylar Audiotape.

A subject consistency check was carried out 3 months later in which two of the Ss (one male, one female) were recorded repeating the entire list again under the same recording conditions.

The utterances of the speakers were transcribed by the author and two other persons trained in phonetic transcription work. CVC items which the Ss had misarticulated were rerecorded at a later date.

The 512 utterances from the eight speakers were analyzed acoustically with duplex oscillograms made from a four-channel Siemens Oscillomink (1966 model), a direct-writing jet oscillograph. The vowel duration measurements were taken in millimeters from duplex oscillograms produced at a paper speed of

[1] Despite the uniqueness of the ordering of the means for the vowel /æ/—.258 before voiceless stop, .331 before voiced stop, .340 before voiceless fricative, .384 before voiced fricative—the tape was not re-recorded as the first time through the 64-item list was considered by the author to be a normal reading. Thus, no effort was made to alter the vowel durations recorded for repetition by the subjects.

20 cm./sec.; the millimeter measurements were transformed to seconds.

Vowel duration was measured following initial consonant from the point where the established vowel amplitude pattern began (see Figs. 1 - 5 on pages 10 - 14. Neither the aspiration of voiceless stops nor the release of voiced stops was included in the vowel duration measurements. Occasionally there was a transition period of zero amplitude which followed the fricative and preceded the vowel. If such a glottal transition period were present, it was not included with the vowel duration measurement (see Figs. 3 - 5 on pages 12 - 14. Vowel duration was terminated before stop consonants when the established vowel amplitude pattern terminated. Vowel duration was terminated before fricatives with the marked onset of high frequency energy. If a glottal transition period occurred after the vowel pattern and before the fricative, the transition period was measured as part of the vowel duration (see Fig. 5).[2]

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[2] For complete explanation of production of duplex oscillograms and discussion of segmentation procedures, see Naeser, M. A., Criteria for the segmentation of vowels on duplex oscillograms. Technical Report from the Wisconsin Research and Development Center, The University of Wisconsin, 1970. No. 124.

III
RESULTS AND DISCUSSION

A repeated measures analysis of variance was performed on the vowel duration measurements (initial voicing by initial manner by final voicing by final manner by vowel). A Geisser and Greenhouse correction for repeated measures was applied where appropriate.[3]

Initial voicing was found to affect vowel duration significantly ($F(1,7) = 133.298$, $p < .001$). Vowels following a voiced consonant were longer (.219 sec.) than those following a voiceless consonant (.199 sec.), giving a ratio of 9/10 for vowels preceded by voiceless vs. voiced consonants. This ratio is much smaller than the 2/3 ratio for vowels followed by voiceless vs. voiced consonants. This difference can be seen in the graphs shown in Figs. 6 - 7 on pages 15 and 16. On the master stimulus tape, only the two vowels /ɪ/ and /æ/ were longer following a voiced consonant than following a voiceless consonant. In the vowel duration data obtained from Ss' responses, however, the effect held for all four vowels. See Table 1 and Fig. 6 for the influence of the initial consonant on the separate vowels.

Vowel duration was significantly increased before the final consonant when the final consonant was a fricative rather than a stop ($F(1,7) = 131.4$, $p < .001$), or when it was voiced rather than voiceless ($F(1,7) = 125.4$, $p < .001$); see Table 2 and Fig. 7 (pages 9 and 16. Vowels occurring before fricatives showed longer duration (.245 sec.) than those before stops (.173 sec.) in a pattern which is in agreement with previous studies (Peterson & Lehiste (1960); House & Fairbanks (1953); and House (1961)). Vowels before a voiced consonant were longer (.248 sec.) than those before a voiceless consonant (.170 sec.). The ratio of vowel duration before voiceless consonant to vowel duration before voiced consonant was 68.5%. This overall effect of voicing is in agreement with that found in previous studies (Peterson & Lehiste (1960); House & Fairbanks (1953); and House (1961)), where vowel duration before voiceless consonants was found to be 2/3 the duration before voiced consonants.

The close vowels /ɪ/, /i/, and /u/ showed the voiceless/voiced ratios 63%, 61%, and 63%, respectively. The stimulus tape showed the same general pattern with ratios of 65%, 57%, and 67%, respectively. The 67% voiceless/voiced ratio does not hold, however, for the open vowel /æ/; duration before a voiceless consonant was 82% of that before the voiced consonant in the response data. The same was true of the stimulus tape, where the ratio was 83%. The high ratio was found for both the final stop consonant environments and final fricative consonant environments (stimulus tape values given in parentheses): .208 (.258) /-æp/ vs. .261 (.331) /-æb/ = 80% (78%) ratio and .287 (.340) /-æs/ vs. .344 (.384) /-æz/ = 83% (89%) ratio. Only homorganic CVCs were used in the previous studies (Peterson & Lehiste (1960); House & Fairbanks (1953); and House (1961)). If one looks only at vowel duration with the homorganic CVCs used in this study (both on the stimulus tape and the Ss' responses), the /æ/ ratios before voiceless (.179 (.235) sec.) vs. voiced segments (.270 (.345) sec.) are seen to be the expected 66% ratio with the homorganic stops, but the ratios before voiceless (.272 (.335) sec.) vs. voiced segments (.331 (.365) sec.) are the unexpected 82% ratio with fricatives. This discrepancy in the /æ/ ratios not found in other studies may show that (1) the Ss followed the stimulus tape very closely (previous studies used no stimulus tape; the subjects read the items from a list) or (2) the

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[3] Geisser, S. & Greenhouse, S. W. An Extension of Box's Results on the Use of the F Distribution in Multivariate Analysis. Annals of Mathematical Statistics, 1958, 29, 885-891.

subjects from this dialect area consistently articulate the open vowel /æ/ differently from the close vowels before final consonants.

There was a significant interaction between final manner and final voicing ($F(1, 7) = 14.3$, $p < .01$). This study shows overall ordering of mean vowel duration to be very similar to the Peterson and Lehiste findings. The overall means for the eight Ss for all vowels in ascending order were: .142 sec. before voiceless stop, .198 sec. before voiceless fricative, .205 sec. before voiced stop, .291 sec. before voiced fricative. However, according to a Newman-Keuls test, the mean for vowels preceding a voiceless fricative is not significantly different than the mean for vowels preceding a voiced stop. Each of the three close vowels /ɪ/, /i/, /u/, followed the expected ordering of means; for both /i/ and /u/ each adjacent pair of means for final consonant were significantly different in vowel duration, $p < .01$. For /ɪ/ the vowel duration before a voiced stop was not significantly greater than that before a voiceless fricative (see Table 2 for means). Means for the open vowel /æ/, however, were not in the expected order for either the eight speakers or the master tape; the obtained means, in ascending order (master tape values given in parentheses), were: .208 (.258) before voiceless stop, .261 (.331) before voiced stop, .287 (.340) before voiceless fricative, .344 (.384) before voiced fricative. Subsequent tests (Newman-Keuls) showed each of these means significantly different from the others ($p < .01$). It is again not clear whether this is due to the Ss' imitation of the taped sentences or to the normal articulation of the open vowel /æ/ by these speakers.[4]

The separate vowels showed significant differences in intrinsic duration as had been found but not tested for significance in the three previous studies, ($F(1, 7) = 247.3$, $p < .001$). The four vowel means were as follows: /ɪ/, .162; /i/, .199; /u/, .199; /æ/, .275. Subsequent tests (Newman-Keuls) showed that these mean durations were significantly different ($p < .01$).

The glottal transitions were observed in approximately 37% of the 512 fricative environments with vowels across data from all subjects; the CVC displays extracted from the master tape showed no glottal transitions. Glottal transitions occurred when the open vowel /æ/ in 45% of all initial and final fricative environments where the open vowel occurred. The glottal transitions with /æ/ occurred more frequently in voiceless fricative environments (70%) than in voiced fricative environments (20%). Glottal transitions occurred with the close vowels /ɪ/, /i/, /u/ in 29% of the fricative environments with each vowel. The overall average duration for glottal transitions in the study was .018 sec. (.016 in voiceless environments, .019 in voiced environments); the longest average duration of .022 occurred after /æ/ before voiced fricatives.

The high frequency of occurrence of the open vowel /æ/ in glottal transitions before and after fricatives is in accordance with the suggestions set forth by Stevens, et al. (1967) concerning the necessity of different vocal cord positioning for consonant and vowel production. Stevens states that for higher first formant frequencies the sound pressure is less than that found in consonants; first formant frequency for /i/ is 270 Hz, for /ɪ/, 390 Hz, for /u/, 440 Hz, and for /æ/, 660 Hz (Denes & Pinson, 1963). In the air flow trace for vowels preceding voiceless or voiced consonants, the air flow in the latter part of the vowel tends to increase in anticipation of the consonant (Klatt, 1967). Because the open vowel /æ/ has the highest first formant frequency and thus the lowest sound pressure level in this study, this vowel may require more accommodation time for sound pressure adjustment before consonants, hence show more overt glottal transitions. This is also what might be expected from the hypothesis set forth by House, that the secondary lengthening of open vowels and vowels before fricatives is a function of the articulatory process itself.

The subject consistency check showed the vowel duration measures for each of the two subjects to correlate .96 (male) and .93 (female) over the two recording sessions.

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[4] When the glottal transitions are not included in the /æ/ vowel duration before voiceless fricative—.287 vs. .273—the same pattern still holds for ordering of the means for this vowel as when the glottal transitions are included.

IV
SUMMARY

The initial consonant increased vowel duration significantly if it was voiced. The ratio of 9/10 for vowels preceded by a voiceless vs. a voiced consonant was found. The final consonant increased vowel duration significantly if it was a fricative rather than a stop or if it was voiced rather than voiceless. For the close vowels /ɪ/, /i/, /u/ the mean vowel duration before final voiceless consonants was 62% of the duration before final voiced consonants. For the open vowel /æ/ it was 82%. These percentages are very similar to those of the master tape used. Previous studies (Peterson & Lehiste (1960); House & Fairbanks (1953); and House (1961)) show a ratio of 67% voiceless/voiced for all vowels. The reason for the discrepancy for the /æ/ vowel in this study is not known; it may be due to (a) imitation of the vowel durations on the master tape or (b) the fact that the open vowel /æ/ is normally articulated differently from the close vowels by the speakers of this dialect area. The ascending order of vowel duration means before voiceless stop, voiceless fricative, voiced stop, voiced fricative found in other studies (Peterson & Lehiste (1960); House & Fairbanks (1953); and House (1961)) for all vowels, was found only in the close vowels tested in this study. The open vowel was significantly longer before a voiceless fricative than before a voiced stop.

The four vowel qualities showed significantly different intrinsic durations /ɪ/ < /i/ = /u/ < /æ/ as expected from other studies (Peterson & Lehiste (1960), House & Fairbanks (1953), and House (1961)). A frequency of occurrence of glottal transitions after the open vowel /æ/ before fricatives was found in this study.

This study has provided normative data on differential vowel duration in adult speech. In a subsequent study, the acquisition of differential vowel duration, by very young children (age 20 - 24 months), will be traced; data from the adult study will be used to define the endpoint of acquisition. The developmental study will provide a test of the language acquisition theory (rule-governed) which has been assumed in the model of reading used in project research.

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APPENDIX

Each word repeated in the frame sentence: "A__________is a word."

RANDOMIZED LIST OF 64 CVCs

(C → /p, b, s, z/; V → /ɪ, i, u, æ/)

1. pɪp __________
2. siz__________
3. bus__________
4. zæb__________
5. bip__________
6. sɪs__________
7. zub __________
8. pæz __________
9. sup __________
10. zɪs __________
11. pib __________
12. bæz __________
13. sɪp __________
14. pæb __________
15. buz __________
16. zis __________
17. sæp __________
18. puz __________
19. zib __________
20. bɪs __________
21. pip __________
22. zæs __________
23. bɪb__________
24. suz__________
25. bæp__________
26. zɪz__________
27. pus__________
28. sib__________
29. zup__________
30. biz__________
31. sæb__________
32. pɪs__________
33. zip__________
34. sæs__________
35. bɪz__________
36. pub__________
37. bis__________
38. pæp__________
39. zuz__________
40. sɪb__________
41. bup__________
42. zæz__________
43. pɪb__________
44. sis__________
45. zɪp__________
46. piz__________
47. bæb__________
48. sus__________
49. sɪz__________
50. pis__________
51. bub__________
52. zæp__________
53. bib__________
54. sæz__________
55. pup__________
56. zɪb__________
57. bæs__________
58. sub__________
59. ziz__________
60. bɪp__________
61. pæs__________
62. sip__________
63. zus__________
64. pɪz__________

Table 1

Influence of the Initial Consonant on Vowel Duration in CVC Syllables
(Time in Sec.)

		#s--	#p--	#z--	#b--
/ɪ/	Master Tape Stimulus Items	.185	.214	.211	.241
	Subjects' Responses	.149	.157	.163	.179
/i/	Master Tape Stimulus Items	.248	.275	.238	.272
	Subjects' Responses	.195	.185	.197	.220
/u/	Master Tape Stimulus Items	.260	.278	.256	.275
	Subjects' Responses	.188	.196	.197	.216
/æ/	Master Tape Stimulus Items	.335	.321	.334	.348
	Subjects' Responses	.272	.250	.285	.293

Table 2

Influence of the Final Consonant on Vowel Duration in CVC Syllables
(Time in Sec.)

		--p#	--s#	--b#	--z#
/ɪ/	Master Tape Stimulus Items	.140	.196	.210	.305
	Subjects' Responses	.102	.149	.152	.246
/i/	Master Tape Stimuls Items	.164	.206	.288	.350
	Subjects' Responses	.128	.176	.206	.288
/u/	Master Tape Stimulus Items	.191	.241	.282	.354
	Subjects' Responses	.127	.181	.200	.288
/æ/	Master Tape Stimulus Items	.258	.340	.331	.384
	Subjects' Responses	.208	.287	.261	.344

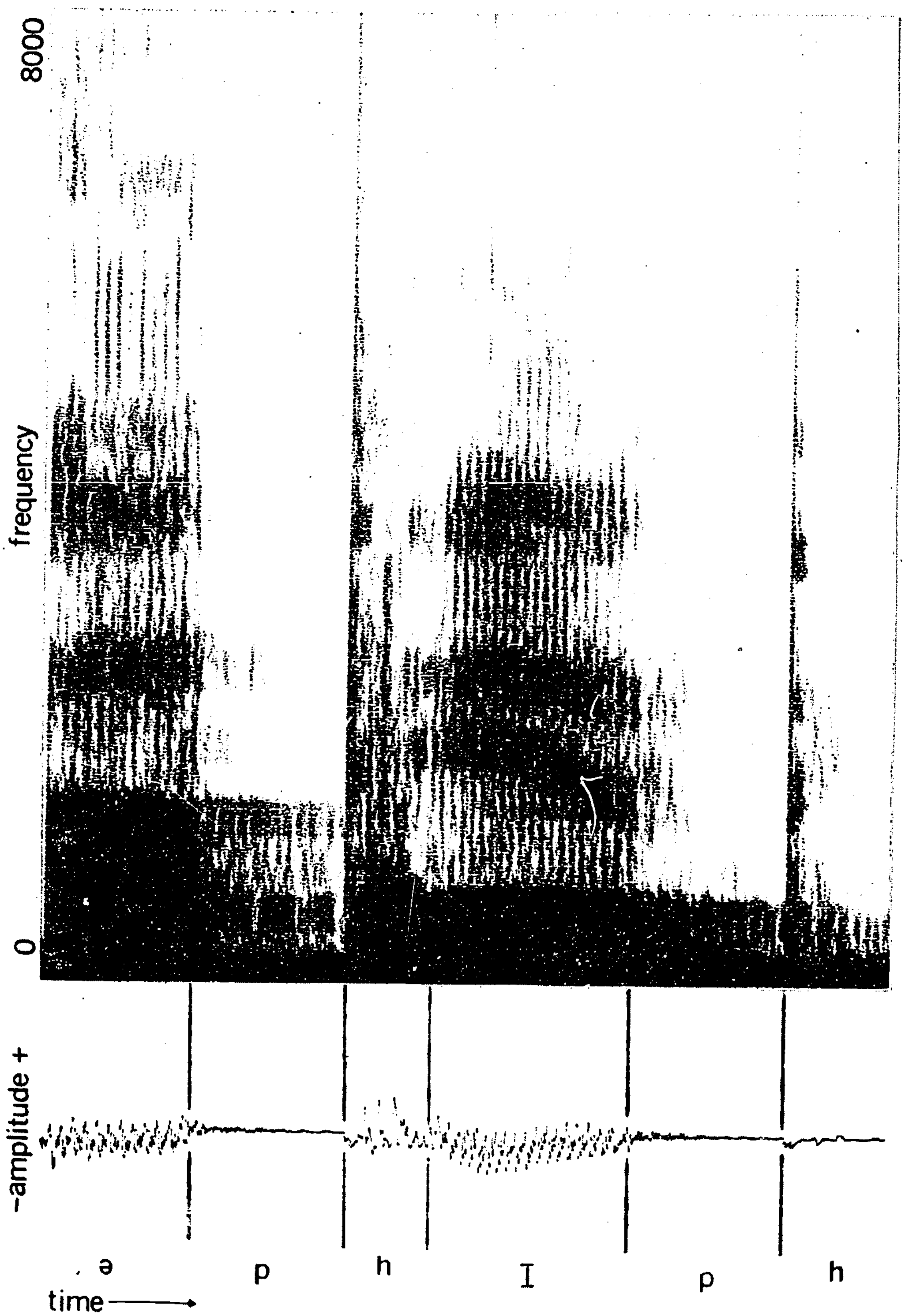

Fig. 1. Male speaker. Sound spectrogram (enlarged) above, duplex oscillogram (real time 20 cm./sec.) below.

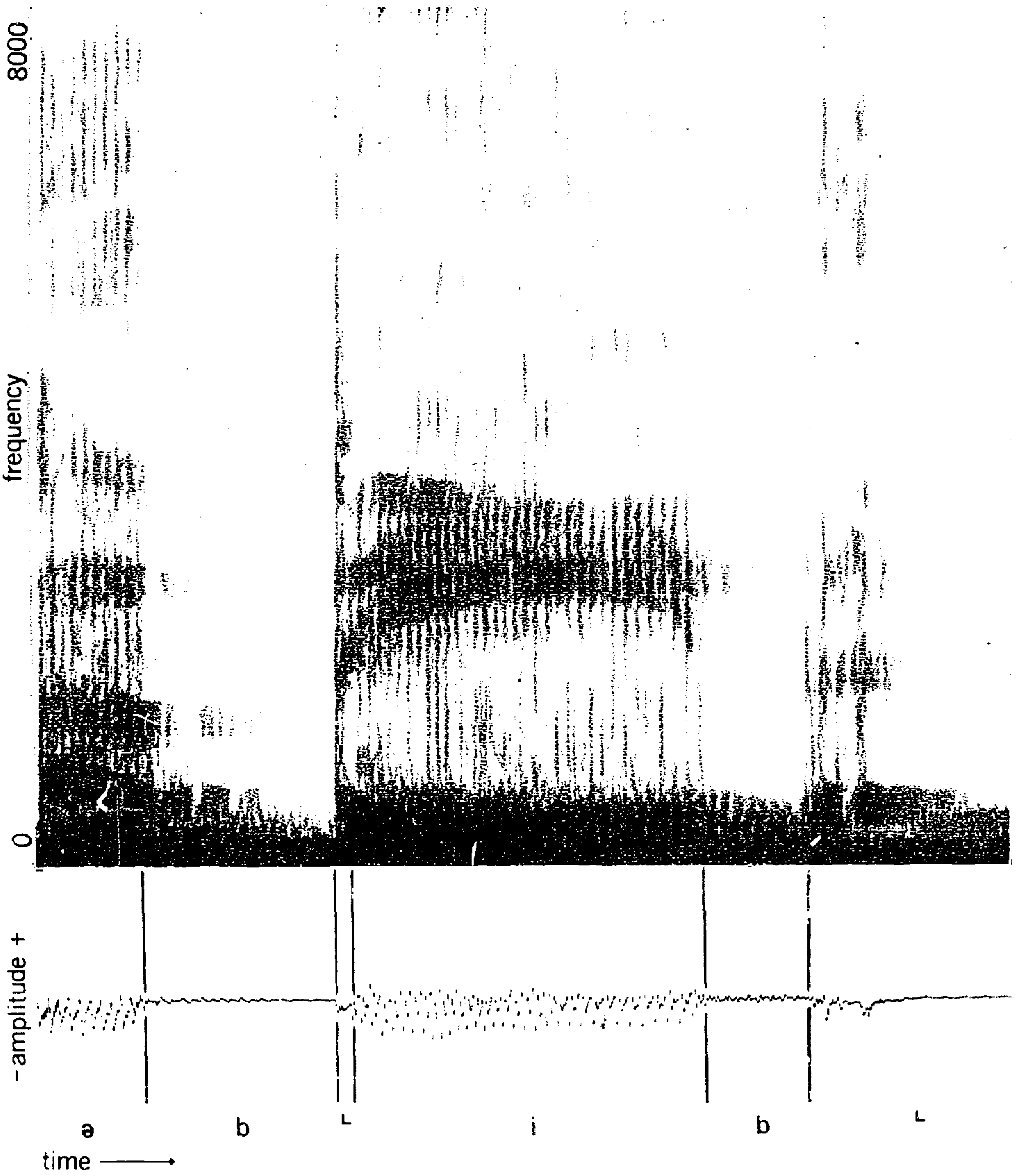

Fig. 2. Male speaker. Sound spectrogram (enlarged) above, duplex oscillogram (real time 20 cm./sec.) below. (∠ = release of voiced stop.)

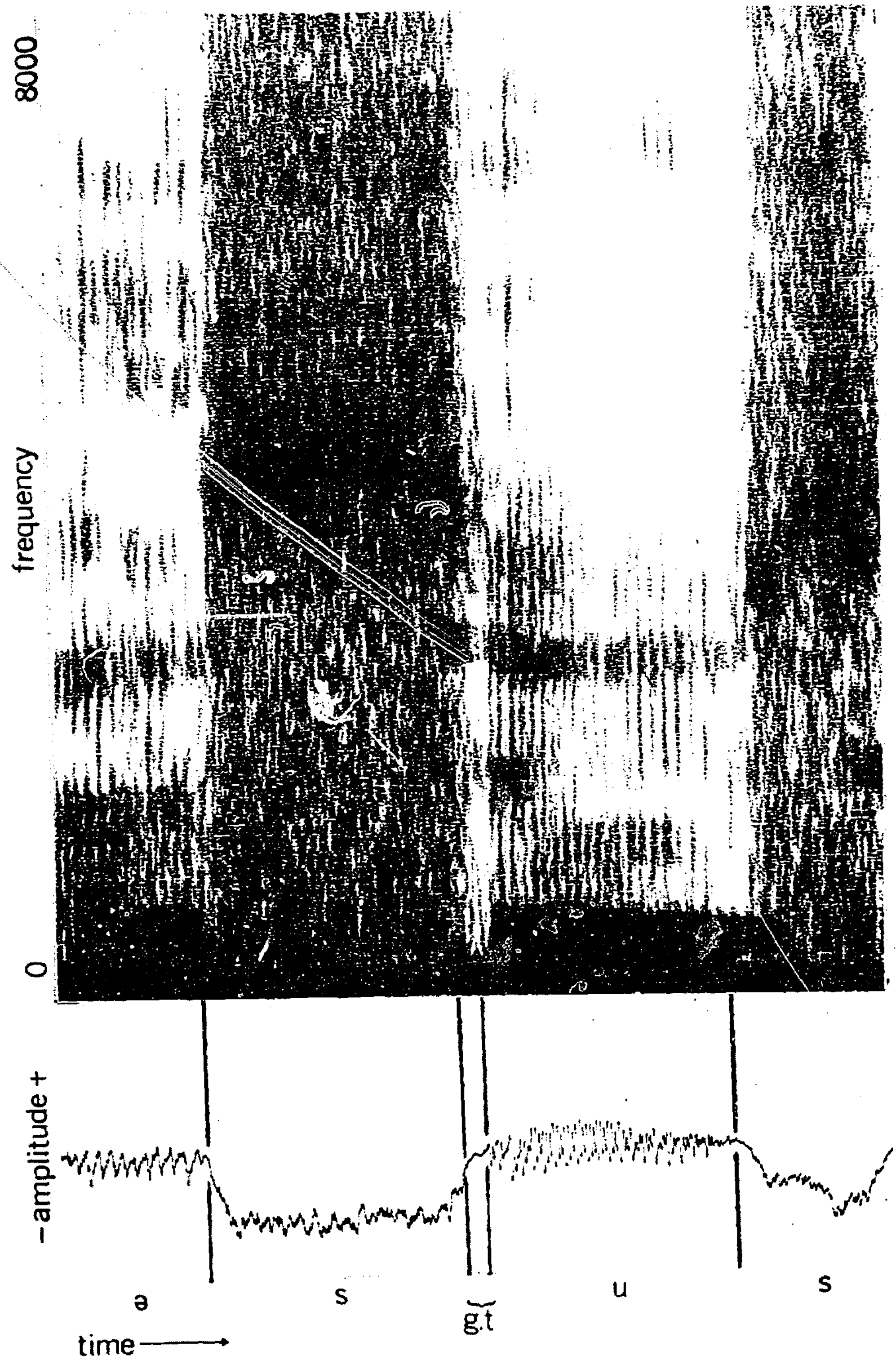

Fig. 3. Male speaker. Sound spectrogram (enlarged) above, duplex oscillogram (real time 20 cm./ sec.) below. (g.t. = glottal transition.)

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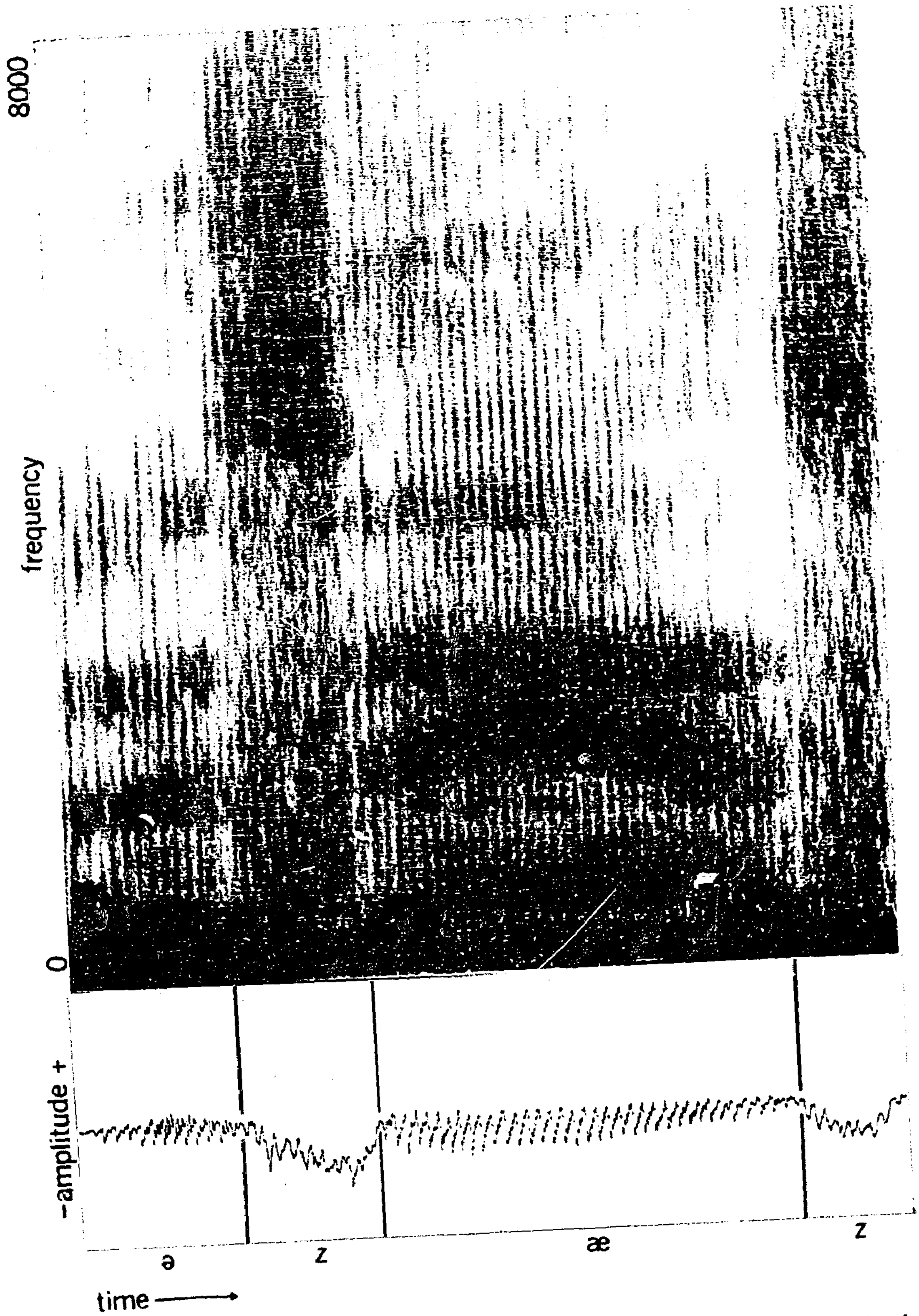

Fig. 4. Male speaker. Sound spectrogram (enlarged) above, duplex oscillogram (real time 20 cm./sec.) below.

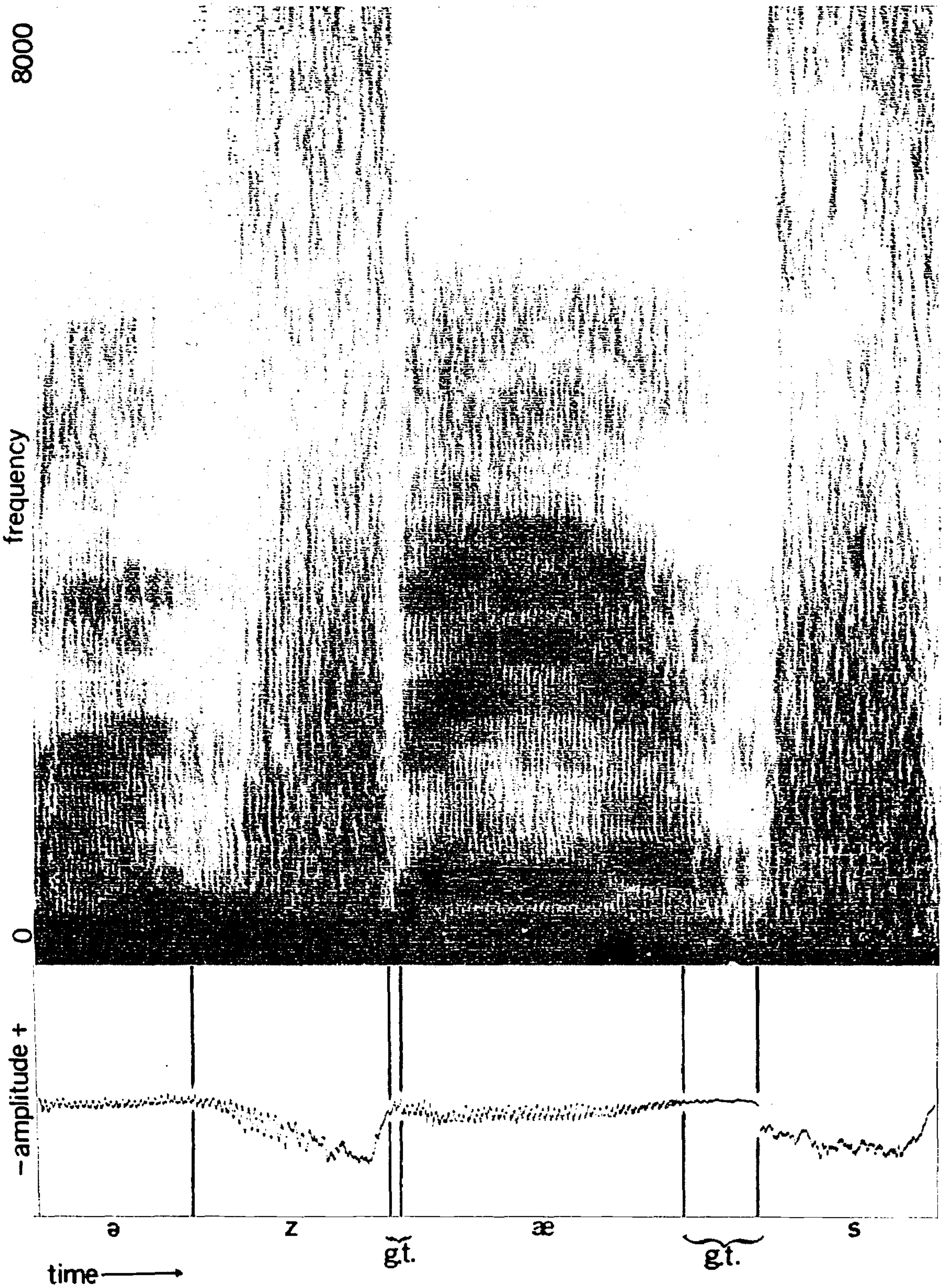

Fig. 5. Female speaker. Sound spectrogram (enlarged) above, duplex oscillogram (real time 20 cm./sec.) below. (g.t. = glottal transition.)

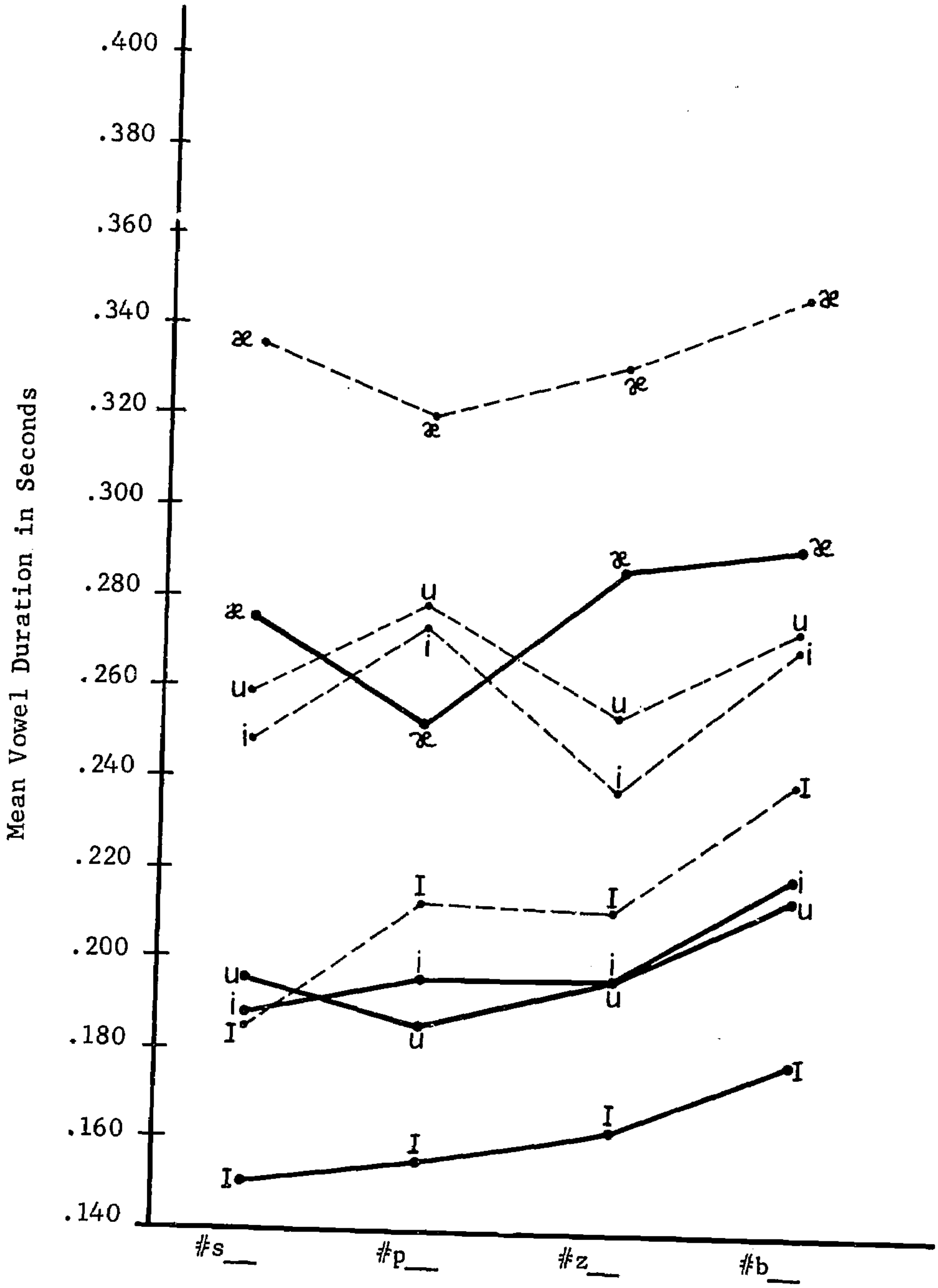

Fig. 6. Influence of the Initial Consonant on Vowel Duration in CVC Syllables

----Master Tape Stimulus Items (1 Male)

____Subjects' Responses (4 Male, 4 Female)

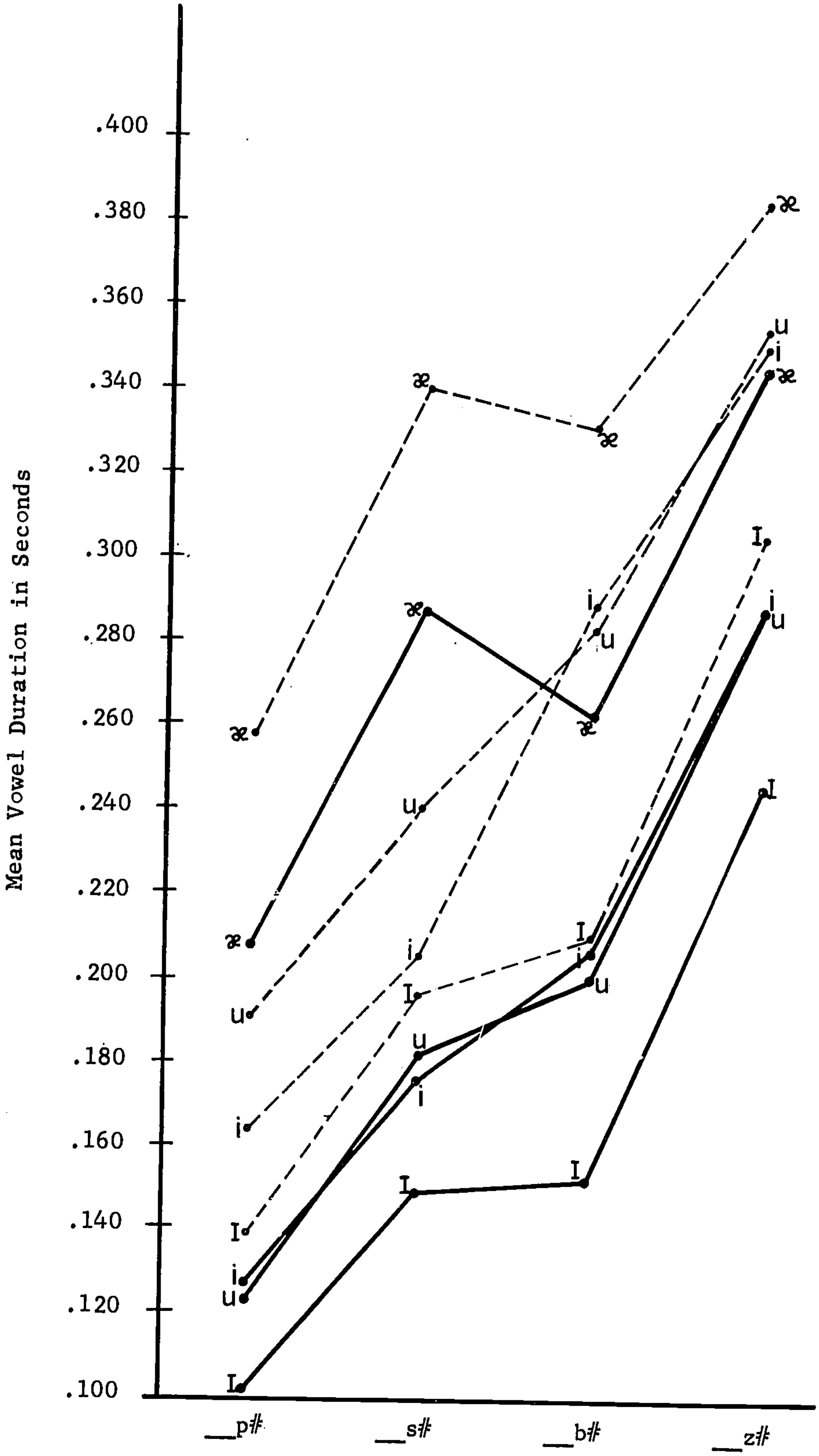

Fig. 7. Influence of the Final Consonant on Vowel Duration in CVC Syllables

----Master Tape Stimulus Items (1 Male)

_ _Subjects Responses (4 Male, 4 Female)

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