VOICING IN BRITISH ENGLISH t AND d IN CONTACT WITH OTHER CONSONANTS[1]

Nina G. Thorsen

1. Introduction

Surprisingly little has been published about voicing in British English (BE) plosives. Gimson (1966 p. 145-162 and 266-27o) does say something on this subject, but his treatment is incomplete. - For instance, nothing is said about the influence of stress distribution upon voicing in plosives.

A great deal of research has been done on American English stop consonants, but mostly when these stand initially before stressed vowels.

A study of voice assimilation in French obstruents has been done by Oluf M. Thorsen (1967). Eli Fischer-Jørgensen has investigated assimilation in Dutch (1952).

2. The material

The present investigation is based on an acoustic (mingographic) analysis of 76 sentences, recorded five times by six subjects, three males and three females, all speaking RP. In addition to this material, which consisted of examples of t and d, a much smaller material containing examples with b and g was recorded twice by two subjects

---

1) Thesis work for the cand.mag.-degree, completed in June 197o. I am grateful to Eli Fischer-Jørgensen for much good advice and very helpful criticism.

(two of the previously used males).

2.1. The main corpus of the material

t and d were investigated in the following two positions: (a) X+_V where + is a morpheme- or word boundary, and X is a pause, a vowel, or a vowel followed by p, b, s, z, or l, and (b) V_+X where + is a morpheme- or word boundary, and X is a pause, a vowel, or a vowel preceded by k, g, s, z, or l.

2.2. Additional material

In addition, examples of t and d preceded by k and g respectively, and of t and d followed by p and b respectively, were recorded twice by the aforementioned two male subjects.

b and g were investigated in the following two positions: (a) X+_V where + is a morpheme- or word boundary, and X is a pause, a vowel, or a vowel followed by t, d, s, z, or l, and (b) V_+X where + is a morpheme- or word boundary, and X is a pause or a vowel.

The examples with vowels and pause before/after the consonant under investigation were included for comparison.

2.3. The clusters under investigation

Thus the material contains the following 'clusters'

a) V+t, p+t, b+t, s+t, z+t, l+t,
t+V, t+k, t+g, t+s, t+z, t+l,
V+d, p+d, b+d, s+d, z+d, l+d,
d+V, d+k, d+g, d+s, d+z, d+l

There were 3o examples of each of these clusters (in each stress distribution, see below), in some cases slightly fewer, due to mistakes in the recordings.

b) k+t, g+t, k+d, g+d, t+b, d+p, d+b,
V+b, t+b, d+b, s+b, z+b, l+b,
V+g, t+g, d+g, s+g, z+g, l+g,
b+V, g+V

There were four examples of each of these clusters (in each stress distribution, see below), in some cases fewer, due to mistakes in the recordings.

2.4. Stress distributions

The clusters (and the examples with pause before/after the consonant to be examined) in the more comprehensive material were all investigated under two stress conditions:

first syllable stressed, second syllable unstressed (strong-weak)
first syllable unstressed, second syllable stressed (weak-strong)
and some of them furthermore under a third type of stress condition:
first syllable unstressed, second syllable unstressed (weak-weak).

The clusters in the more limited material were not so extensively examined, there being, for instance, no weak-weak examples, and there were also omissions among the strong-weak and the weak-strong distributions.

A few illustrations:

b+t, weak-strong: "Subtopians are happy"
strong-weak: "There's a cab to pay"
weak-weak: "It's a subterranean spring"
d+g, strong-weak: "The cad got hurt"
weak-strong: "Did Golding do it?"
weak-weak: "Did Golightly do it?"

3. The recordings and tracings

The recordings were made in the studio at the Institute of Phonetics with a condenser microphone, and a Lyrec Professional Recorder, 1/1 track, at 7 1/2"/sec, on Scotch Magnetic Tape, SP 1o2.

The recordings were traced on a mingograph, Elema 8oo. The traces were: one duplex oscillogram, one F_o curve (Trans Pitchmeter, Børge Frøkjær-Jensen), one logarithmic unfiltered intensity curve, one linear intensity curve, high-pass filtered at 5oo Hz (Intensity Meter, Børge Frøkjær-Jensen) and an oscillogram filtered so that essentially only the first harmonic was traced (Audio-Frequency Filter, Børge Frøkjær-Jensen).

The calculations on the data thus obtained were performed on a data processing machine.[2]

4. Results

4.1. General remarks

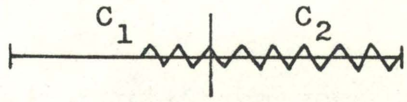
I was interested only in the duration of the voicing, whether audible or not. Audible voicing was of less interest in this study. I wanted to study the phenomenon of assimilation, the physiological mechanism itself, and the possible beginnings of a diachronic development which may be discerned.

It has previously been established that Grammont's description of the mechanism of regressive assimilation is wrong (Fischer-Jørgensen 1952 and Thorsen 1967), and it does not seem to be valid for BE either.

---

2) I am grateful to Børge Frøkjær-Jensen who was in charge of this part of the investigation.

Grammont (1939 p. 193f) maintained that a partial regressive assimilation always affected the last part of the preceding consonant. He may have imagined a situation like this:



which has not been found once in my material, nor in the Dutch and French material of Eli Fischer-Jørgensen and Oluf M. Thorsen, respectively.

There is normally some voicing to be found in a consonant immediately following a vowel - the vocal chord vibrations continue into the consonant until the pressure drop across the glottis is too small to allow vibrations. This voicing may be supported and prolonged by a following voiced consonant and the voicing, if not total, will typically be found to extend continuously through the first part of the cluster, which may end unvoiced, even when the first consonant is basically unvoiced (fortis) and the second consonant is basically voiced (lenis).[3]

4.2. Stylized display of voicing in consonant clusters

A stylized version of the typical situations found in my material (1475 clusters) is given on the following pages. - The clusters are given to the left. They are divided into groups according to the basic voicing characteristic of the first and second consonants. In Table Ia all clusters are included, and the number of examples

---

3) I shall use the terms fortis and lenis throughout about basically unvoiced and basically voiced consonants respectively - whether these be appropriate phonetic terms or not.

of each cluster is given. The figures in parentheses represent the total number of examples in each group (1a 242 examples, 2a 23 examples, etc., etc.).

Table Ia   Voicing in consonant clusters

			1a		2a		3a	
p+t	1' C fortis; 2' C fortis	47						
t+k		66		12		6		
k+t		4	(242)		(23)		(6)	
s+t		57						
t+s		68		11				
			1b		2b		3b	
d+p	1' C lenis			2		6		
b+t		38		18		33		
g+t		2				2		
d+k		29	(191)	23	(77)	33	(153)	
d+s		37		31		18		
z+t		85		3		1		
l+t						60		
		433		100		159		

continued on the
next page

Table Ia continued

p+d	1' C fortis, 2' C lenis	46	4a		5a		6a		7a
t+b		7				3		4	
k+d		4							
t+g		51		11		11		1o	
s+b		2	(197)		(13)		(15)		(24)
s+d		52				1			
s+g		5							
t+z		29		2				6	
t+l		1						4	
d+b	1' C lenis, 2' C lenis		4b		5b	5	6b	7	7b
b+d		8		4		32		43	
g+d		1				3			
d+g		23		5		37		22	
z+b			(57)		(32)	5	(18o)	3	(265)
z+d		15		16		44		11	
z+g		1				4		3	
d+z		9		7		25		45	
d+l								81	
l+b						2		6	
l+d						21		38	
l+g						2		6	
		254		45		195		289	

In table Ib the number of examples of a particular cluster in each situation is given in percentages of the total number of examples of that cluster (included the atypical ones, see below), but the clusters from the smaller material have been omitted, since percentages for

Table Ib Voicing in consonant clusters (percentages)

				1a		2a		3a		
p+t	1' C fortis	2' C fortis	100							
t+k			79	(89)	14	(9)	7	(2)		
s+t			100							
t+s			86		14					
				1b		2b		3b		
b+t	1' C lenis		43		20		37			
d+k			34	(45)	27	(18)	39	(37)		
d+s			43		36		21			
z+t			96		3		1			
l+t							100			
				4a		5a		6a		7a
p+d	1' C fortis	2' C lenis	96							
t+g			61		13		13		12	
s+d			91	(59)		(4)	2	(4)		(7)
t+z			51		3				10	
t+l			2						8	
				4b		5b		6b		7b
b+d	1' C lenis		9		5		37		49	
d+g			26		6		43		25	
z+d			17	(10)	18	(6)	49	(33)	12	(48)
d+z			10		8		29		52	
d+l									90	
l+d							36		64	

such low figures are misleading. The figures in parentheses indicate the number of examples in each situation of a particular type of cluster in percentages of the total number of examples of that type of cluster, included those from the small material, since this makes very little difference, or none at all. There are four types: fortis + fortis (F+F), 271 examples, lenis + fortis (L+F), 421 examples, fortis + lenis (F+L), 249 examples, and lenis + lenis (L+L), 534 examples. Thus "(89)" in group 1a means that the examples in this group comprise 89% of the total number of F+F examples, etc., etc.

Note that in both tables clusters in different stress distributions have been pooled.

4.2.1. Clusters exhibiting unbroken partial or total voicing

The 1475 clusters in tables Ia and Ib follow the rule that the voicing in consonant clusters, if not total, lies unbroken in the beginning of the cluster:

It will be seen that an initial[4] fortis consonant (groups 1 - 3) is usually unvoiced (533 examples or 98% of the F+F and 63% of the L+F clusters), but it may be voiced in the beginning, if the preceding (final) consonant is fully voiced (159 examples or 2% of the F+F and 37% of the L+F clusters). Final fortis consonants (groups 1a - 7a) are usually voiced only in the beginning (439 examples or 89% of the F+F and 59% of the F+L clusters), but t and s may be fully voiced (81 examples or 11% of the F+F and 15% of the F+L clusters), though only when they are unstressed. Initial lenis consonants (groups 4 - 7)

---

4) Initial means initially in a word or morpheme, not initially in the cluster, and final means finally in a word or morpheme, not finally in the cluster.

are unvoiced (299 examples or 63% of the F+L and 16% of the L+L clusters) or voiced in the beginning (195 examples or 4% of the F+L and 33% of the L+L clusters) like initial fortis consonants, but initial lenis consonants may be fully voiced, usually after a final lenis consonant (group 7b, 265 examples or 48% of the L+L clusters), but also sometimes after final fortis consonants when these are unstressed (group 7a, 24 examples or 7% of the F+L clusters).
Final lenis consonants (groups 1b - 7b) are normally voiced throughout (7o7 examples or 87% of the L+L and 55% of the L+F clusters), but they may be voiced only in the beginning (248 examples or 45% of the L+F and 1o% of the L+L clusters).

4.2.2. Clusters exhibiting discontinuous voicing

A total of 98 clusters showed discontinuous voicing. They are displayed in tables IIa and IIb. In table IIa all clusters are included, in table IIb those from the small material have been omitted and the number of examples are given in percentages like in table Ib. In these tables the different stress distributions are considered. The figures in parentheses in table IIb indicate the number of examples of each type of cluster in each situation in percentages of the total number of the same type of cluster, for instance, 22% of the fortis + lenis clusters (group 8a) were found to have discontinuous voicing in the manner indicated at the top of the column.

Note that all of these 98 clusters have a lenis second consonant, and almost all (85 examples) have a fortis first consonant. 59 examples have been found in the weak-strong distribution.

Table IIa Voicing in consonant clusters

			8a			9a			10a
		w-st	st-w	w-w	w-st	st-w	w-w	w-st	st-w	w-w
1' C fortis / 2' C lenis	t+b		2							
	t+g	1								
	p+d	2								
	t+z	9	5		4			2		
	t+l	25	21		1					
	s+d	4								
	s+b	1	3					2		
	s+g	1						2		
		43 43	31 31		5 5			6 6		
				8b			9b			10b
1' C lenis / 2' C lenis	z+d				3					
	d+z	1								
	d+l		3	4	1		1			
		1 1	3 3	4 4	4 4		1 1			
	total:	44	34	4	9		1	6		

Table IIb
percentages

		w-st	st-w	w-w	w-st	st-w	w-w	w-st	st-w	w-w
				8a (22)			9a (2)			10a (2)
1' C fortis / 2' C lenis	t+g	1								
	p+d	4								
	t+z	16	9		7			4		
	t+l	48	40		2					
	s+d	7								
				8b (2)			9b (1)			10b
1' C lenis / 2' C lenis	z+d				4					
	d+z	1								
	d+l		3	5	1		1			

4.2.2.1. Tentative explanations

Various explanations offer themselves to the 85 examples with fortis first consonant. - The vibrations are discontinued in the first consonant (a) because the glottis opens and the vocal chords are too far apart for the Bernoulli-effect to be active or (b), if the glottis remains 'closed', because an intra-oral pressure is built up gradually and the pressure drop across the glottis is thus decreased. In the first case the air flows freely into the mouth cavity and the intra-oral pressure builds up rapidly. In the second case, air escapes into the mouth at each opening of the glottis during the vibratory cycle, and it will take longer for the pressure drop to decrease, but eventually it will be small enough to impede vibrations. - In any case vibrations can only resume if the intra-oral pressure is lowered, either by an active expansion of the mouth walls or by letting air out of the mouth - which is probably the explanation for the 67 examples (9+5+4+2 + 25+21+1) of t+z and t+l. In the 5 examples (2 + 1 + 2) of t+b, t+g, and p+d it may be that the mouth walls have been actively expanded, though this phenomenon is not generally assumed to take place in BE.

The 13 examples (4 + 1+3+2 + 1+2) of s+d, s+b, and s+g are rather hard to explain: it is difficult to see how vibrations can start after the buccal closure has been made and the intra-oral pressure thus has increased. But 10 of these examples have been found where the first syllable was unstressed and the second syllable stressed. It may be that a new and forceful innervation of the expiration muscles would increase the subglottal pressure sufficiently in relation to the supraglottal pressure for an air-stream to move through the glottis and set the vocal chords in motion, provided they are sufficiently close for the

Bernoulli-effect to be active. This same requirement must be met in the 5 examples of t+b, t+g, and p+d, and indeed it seems very likely that the vocal chords approach the 'closed' position at the beginning of the lenis consonant. In both cases some expansion of the mouth walls is probably called for.

Regarding the 13 clusters with lenis first consonant: 1o of these have z or l as second consonant and may be explained in the same way as the 67 examples mentioned above, except that it is fairly certain that the glottis remains 'closed' throughout the cluster.

Really strange are only 3 examples with z+d. z is fully voiced, and d is partially voiced - but in the end. I cannot explain why. Presumably the vibrations stop because of heightened intra-oral pressure. This coincides with the buccal closure, which makes for an even higher intra-oral pressure; however, vibrations start again before the explosion of the closure. This can only be explained by assuming an expansion of the mouth walls - but then: why does not this expansion happen earlier so as to produce continuous rather than interrupted voicing?

4.3. 'Rules' for the placement of voicing in consonant clusters

The above is, of course, purely speculative. In order to be certain about these phenomena glottograms should have been made. But whether the explanations are valid or not, all examples except those in groups 9 and 1o (i.e. 1557 examples in all) can be formulated in a rule:

Fortis consonants after consonants that end unvoiced are always unvoiced (433 examples, group 1).

Fortis consonants after consonants that end voiced are unvoiced (1oo examples, group 2) or voiced in the beginning (159 examples, group 3).

Lenis consonants after consonants ending unvoiced are unvoiced (254 examples, group 4) or they may be partially voiced in the end (82 examples, group 8).
Lenis consonants after consonants ending voiced may be unvoiced (45 examples, group 5), partially voiced in the beginning (195 examples, group 6), or fully voiced (289 examples, group 7).

4.4. Measurements (averages)

The next section contains some actual data on the degree of voicing found in the consonants investigated. The data represent averages of all subjects.

"Duration" at the top of columns in the tables always means "duration in msec of the consonant" (closure only, in plosives), "voicing" means "duration in msec of the voicing in the consonant" (closure, respectively), and "%" means "relative voicing in percentages". "+" denotes morpheme- or word boundary. The first of the four columns in each group gives the number of examples (in parentheses) that form the basis of the calculations. - The statistical significance of the differences in relative voicing in the consonants before/after a fortis and the corresponding lenis consonant has been calculated. "**" indicates statistical significance at the 99% level, "*" indicates statistical significance at the 95% level.

4.4.1. Final d

The *d*-closure is usually voiced finally, regardless of the following consonant (see Table III). The slight differences found in different stress distributions are not statistically significant.

Table III Voicing in the closure of *final d*:

stress-distribution	strong-weak				weak-strong				weak-weak			
		duration	voicing	%		duration	voicing	%		duration	voicing	%
d+pause	(30)	67	61	91	(30)	79	61	77				
d+V	(30)	32	32	100	(19)	36	36	100	(25)	37	36	98
d+k	(26)	64	62	97	(30)	51	44	86	(30)	56	50	88
d+g	(28)	62	60	97	(30)	56	51	91	(30)	53	47	87
d+s	(26)	63	59	92	(30)	63	50	79	(30)	55	46	83
d+z	(30)	71	71	100	(30)	64	62	96*	(29)	61	56	92
d+l	(30)	75	74	98	(30)	56	56	100	(30)	49	46	94

Table IV shows that there is a considerable difference in the degree of voicing found in *k* vs. *g* and in *s* vs. *z* after *d*: the lenis consonant is more voiced than the fortis counterpart. - Only in the case of *z* does the voicing show statistically significant dependance upon stress distribution: *z* is more voiced when it is stressed than when it is unstressed.

Table IV Voicing in the consonants following final d:

stress-distribution	strong-weak				weak-strong				weak-weak			
		duration	voicing	%		duration	voicing	%		duration	voicing	%
d+k	(26)	86	17	20	(30)	79	13	17	(30)	70	9	13
d+g	(28)	71	30	42**	(30)	80	40	49**	(30)	63	23	36**
d+s	(26)	129	12	9	(30)	143	14	10	(30)	128	6	5
d+z	(30)	81	51	63**	(30)	118	99	84**	(29)	88	32	37**
d+l	(30)	62	60	97	(30)	88	87	97	(30)	67	61	91

4.4.2. Final t

The difference between the relative voicing in final and intervocalic t is statistically significant, but the difference in absolut voicing is small or non-existent (see table V). The relative differences appear, of course, because the intervocalic closure is comparatively shorter than the final closure. Otherwise, it seems that final t is slightly more voiced before a lenis consonant than before its fortis counterpart (though not before k vs. g when t is stressed). Unstressed t is slightly more voiced than stressed t.

Table VI shows that fortis consonants after t are completely unvoiced. g and z are unvoiced after stressed t but slightly voiced after unstressed t. l is partially voiced (in the end), more so when l is stressed.

Table V Voicing in the closure of <u>final t</u>:

stress-distribution	<u>strong</u>-weak				<u>weak</u>-strong				<u>weak</u>-weak			
		duration	voicing	%		duration	voicing	%		duration	voicing	%
t+pause	(3o)	8o	22	27	(25)	63	26	42				
t+V	(22)	53	22	42*	(19)	25	22	89**	(3o)	29	23	79
t+k	(25)	77	18	23	(3o)	47	31	66	(3o)	41	31	75
t+g	(26)	68	17	25	(3o)	47	41	87	(3o)	47	34	73
t+s	(2o)	71	26	36	(29)	55	33	6o	(3o)	49	33	67
t+z	(27)	1oo	4o	4o	(3o)	78	64	82				
t+l	(22)	1o2	32	31	(29)	67	35	53				

Table VI Voicing in the consonants following final t:

stress-distribution	strong-<u>weak</u>				weak-<u>strong</u>				weak-<u>weak</u>			
		duration	voicing	%		duration	voicing	%		duration	voicing	%
t+k	(25)	1o5	o	o	(3o)	8o	o	o	(3o)	69	o	o
t+g	(26)	91	o	o	(3o)	77	22	28**	(3o)	67	12	18*
t+s	(2o)	14o	o	o	(29)	14o	o	o	(3o)	112	o	o
t+z	(27)	11o	6	6	(3o)	137	74	54**				
t+l	(22)	77	42	54	(29)	85	61	71				

4.4.3. Initial d

Initial d is strongly influenced by the preceding consonants (see Table VII). Between vowels d is voiced (though not completely (91-92%) when unstressed). The two intervocalic d's do not exhibit marked differences. After fortis consonants d is almost completely devoiced. After lenis consonants d is partially voiced, more so when d is stressed.

Table VII Voicing in the closure of initial d:

stress-distribution	weak-strong				strong-weak				weak-weak			
		duration	voicing	%		duration	voicing	%		duration	voicing	%
pause+d	(8)[5]		47[6]		(5)[5]		38[6]					
V+d	(3o)	84	76	91	(3o)	52	52	1oo	(3o)	6o	57	9o
Vd[7]	(3o)	83	77	92	(3o)	44	44	1oo				
p+d	(29)	67	5	7	(19)	67	o	o				
b+d	(3o)	6o	5o	83**	(27)	63	28	44**	(3o)	32	17	53
s+d	(3o)	84	9	11	(27)	57	o	o				
z+d	(3o)	1o7	48	45**	(29)	73	12	17**	(3o)	62	2o	32
l+d	(29)	113	88	78	(3o)	51	51	99				

---

5) There were 3o/3o examples of stressed and unstressed initial d after pause, but only 8/5 that showed 'voicing lead'.

6) The closure duration could not be measured in initial d and t.

7) This example is one where there is no boundary between d and the surrounding vowels, included for comparison with the example just above.

Table VIII shows that lenis consonants before initial d are almost always fully voiced, independently of stress distribution (cf. Table III about final d). p and s are partially voiced in the beginning, more so when p and s are unstressed.

Table VIII Voicing in the consonants preceding initial d:

stress-distribution	weak-strong			strong-weak			weak-weak		
	duration	voicing	%	duration	voicing	%	duration	voicing	%
p+d	(29)100	27	27	(19)101	25	25			
b+d	(30) 88	88	100**	(27) 89	86	97**	(30) 79	77	97
s+d	(30) 84	36	42	(27)107	31	29			
z+d	(30) 70	69	99**	(29)101	95	94**	(30) 62	61	98
l+d	(29) 68	68	100	(30) 92	92	100			

Initial t after a pause is always unvoiced (see Table IX). Between vowels t is partially voiced, relatively more so when t is unstressed than when t is stressed. When initial t is unstressed after a stressed open syllable it is less voiced when no boundary precedes the t, but note that the differences are reversed (and statistically significant) when t is stressed. t is (almost) unvoiced after p, b, s, and z (z being partially devoiced before t, cf. Table X). t is partially voiced after l as it is between vowels.

Table IX Voicing in the closure of initial t:

stress-distribution	weak-strong				strong-weak				weak-weak			
		duration	voicing	%		duration	voicing	%		duration	voicing	%
pause+t	(30)		0		(30)		0					
V+t	(30)	98	33	34	(30)	58	32	55	(29)	65	28	42
Vt[8]	(30)	93	38	41**	(30)	43	21	48				
p+t	(27)	58	0	0	(20)	76	0	0				
b+t	(30)	61	2	4	(29)	62	7	11**	(30)	42	3	6
s+t	(30)	53	0	0	(27)	62	0	0				
z+t	(30)	96	0	0	(30)	58	0	0	(29)	61	2	3
l+t	(30)	100	33	33	(30)	51	32	63				

Fortis consonants before t are partially voiced in the beginning, more so when they are unstressed (see Table X). b is almost fully voiced. z has been partially devoiced, more so when z is unstressed. l is fully voiced. The difference between the relative voicing in s and z in the weak-strong distribution is significant, but this is hardly the case for the absolute values.

Table X Voicing in the consonants preceding initial t:

stress-distribution	weak-strong				strong-weak				weak-weak			
		duration	voicing	%		duration	voicing	%		duration	voicing	%
p+t	(27)	102	30	29	(20)	118	19	16				
b+t	(30)	85	72	85**	(29)	95	85	89**	(30)	85	78	90
s+t	(30)	113	35	31	(27)	121	28	23				
z+t	(30)	77	39	50**	(30)	97	48	49**	(29)	67	43	64
l+t	(30)	65	65	100	(30)	82	82	100				

8) This example is one where there is no boundary between d and the surrounding vowels, included for comparison with the example just above.

The results in Tables III, V, VII, and IX concerning final and initial d and t, respectively, are displayed graphically in Figs. 1 and 2.

The figures do not give any further information, but they facilitate a direct comparison of d and t, and they help illustrate the concluding remarks to this section (but note that the figures only concern d and t).

4.4.5. Conclusions inferred from the measurements

I should mention first that a vowel is always longer before a lenis consonant than before the corresponding fortis consonant, no matter what the degree of voicing in the consonants may be.

Of the consonants it might be said generally that they preserve their basic voicing characteristic better when stressed than when unstressed, cf. that the 'empty-square' curve is usually the uppermost and the 'filled-square' curve usually the lowest one in the figures.

4.4.5.1. Single d and t

Before a pause after a vowel a d-closure is approximately fully voiced, relatively, but not absolutely, more so when stressed. The t-closure is partially voiced in the beginning, more so when unstressed than when stressed.

After a pause before a vowel the d-closure is usually unvoiced (22 examples of 30 in stressed initial d, 25 examples of 30 in unstressed initial d). It may be voiced and if so, the voicing-lead always has a certain duration, about 40 msec. The t-closure is always unvoiced after a pause.

Between vowels, d is always (almost) fully voiced. The t-closure is partially voiced, the voicing being to some degree dependent upon the placement of boundaries and stress (in the case of stress this is only valid for the relative voicing in final t, cf. Fig. 1b).

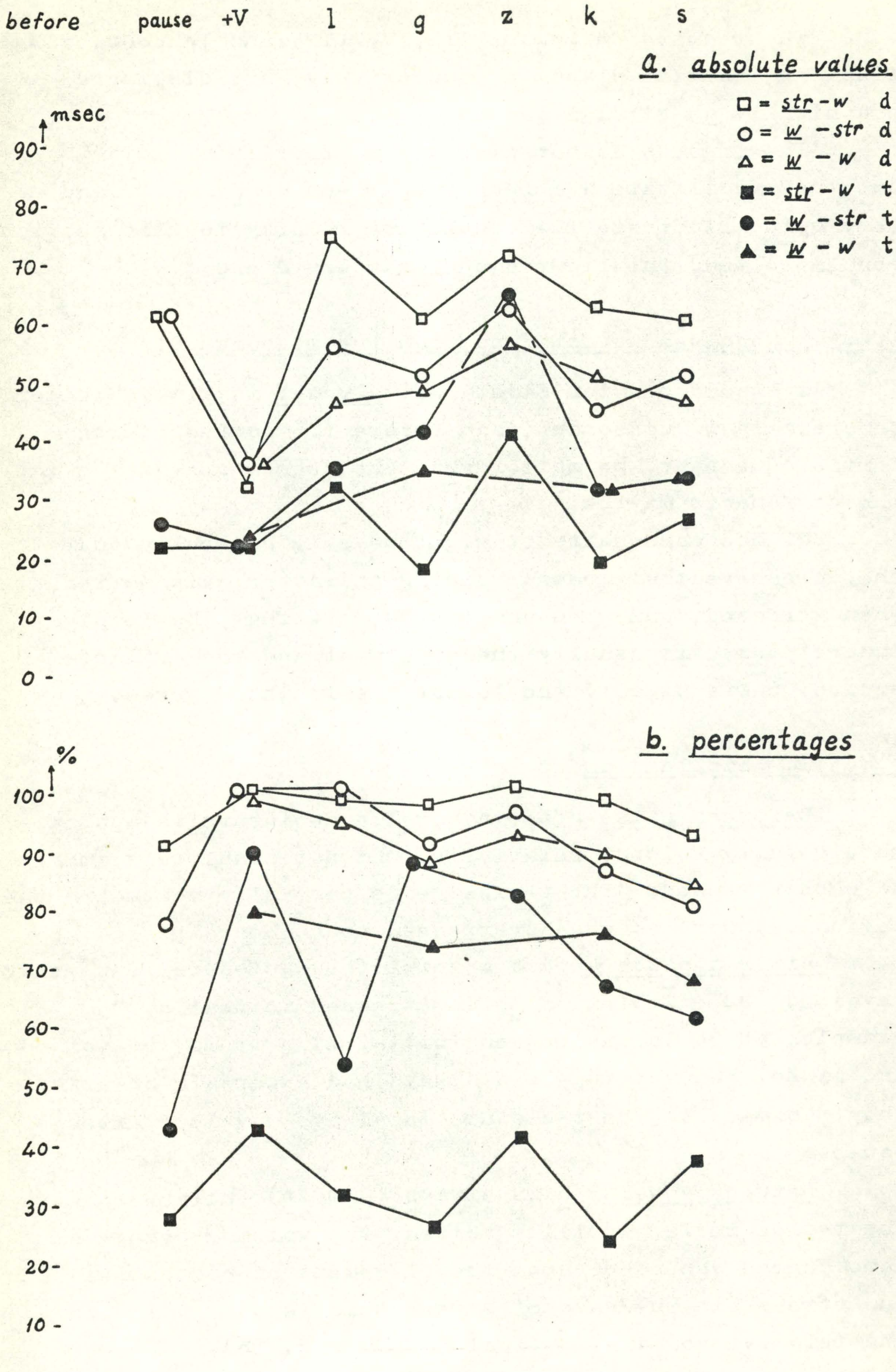


Fig. 1.

Voicing in the closure of final d and t.

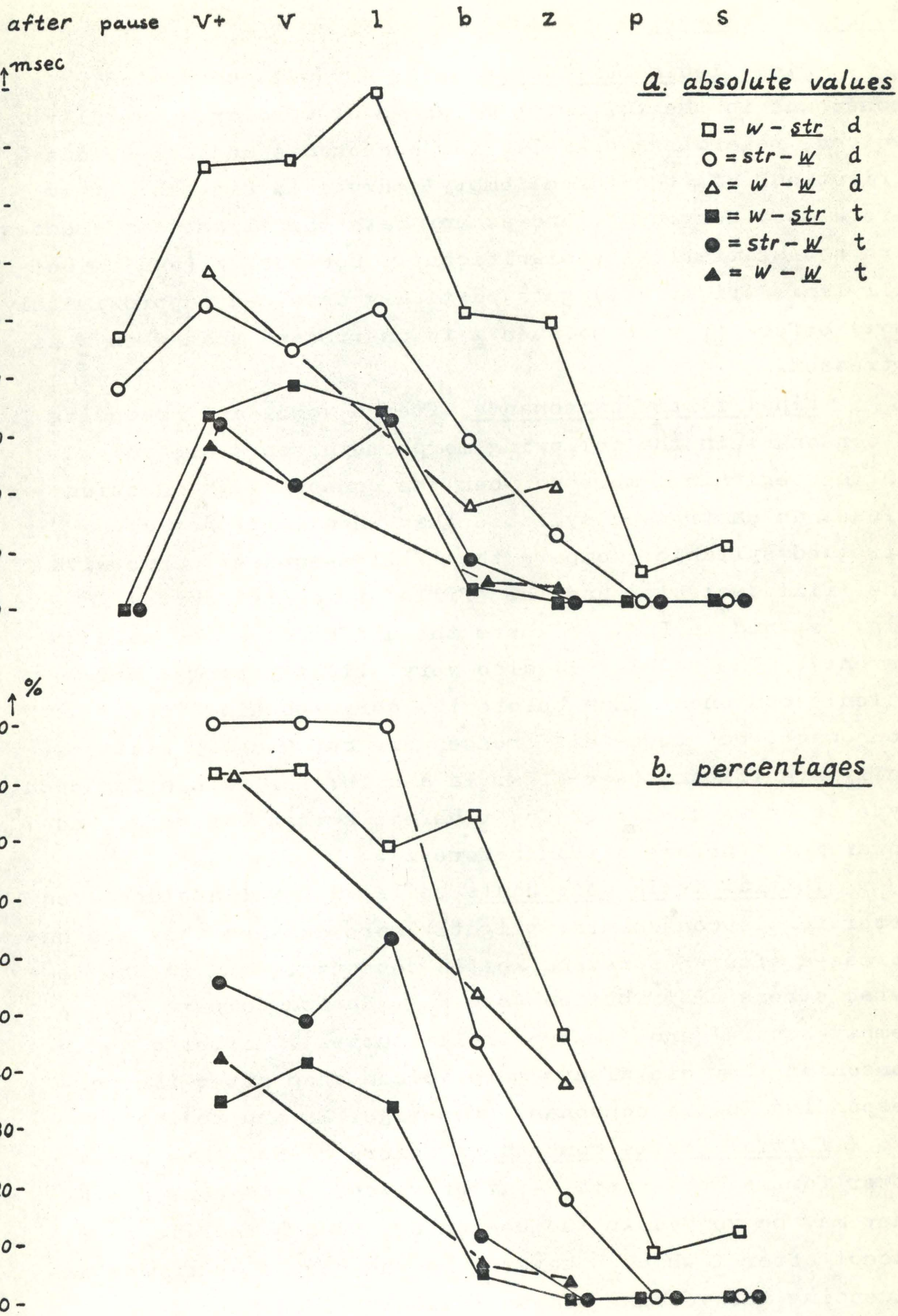


Fig. 2.

Voicing in the closure of initial d and t.

4.4.5.2. Clusters

Final lenis consonants after a vowel and preceding a consonant in the following morpheme or word are generally voiced, regardless of following consonants and stress distribution, cf. the three 'empty' curves in Fig. 1b: they are almost congruent, and at any rate the slight differences are not statistically significant. However, z (and maybe all lenis fricatives) gets partially devoiced (approximately 50%) before t, more so when z is unstressed than when z is stressed.

Final fortis consonants after a vowel and preceding a consonant in the following morpheme or word are voiced in the beginning, more so when the consonant in question closes an unstressed syllable than when it closes a stressed syllable (compare the 'filled-square' curve with the 'filled-circle' and the 'filled-triangle' curves in Fig. 1a, and in Fig. 1b where the differences are more apparent). The voicing is also very slightly longer before a lenis consonant than before the corresponding fortis consonant, but these differences are not usually statistically significant (see Figs. 1a and 1b; the values for each type of curve are lower for t before k than before g, and lower for t before s than before z).

Initial lenis consonants before a vowel are devoiced after fortis consonants, slightly more so when they are unstressed after a stressed fortis consonant than in the reverse stress distribution (see Fig. 2b and compare the 'empty-square' and 'empty-circle' curves). After a lenis consonant they are always more voiced than after the corresponding fortis consonant (see Figs. 2a and 2b).

Initial fortis consonants before a vowel are unvoiced after fortis consonants, - after voiced lenis consonants they may be voiced in the beginning, though this is rare, except after l which behaves like the vowels as far as influencing the voicing of the following consonant goes.

4.4.6. The additional material

The small material with b and g exhibited results that are in agreement with those obtained for d. It is interesting to note that b is relatively more voiced than d, and g is slightly less voiced than d. This is in accordance with what Eli Fischer-Jørgensen has found on many occasions (e.g. 1968). The fact that b is relatively more voiced than d and g supports the explanation given about the physiological conditions and mechanisms of voicing: vibrations will only occur when a sufficient air-stream passes the glottis, that is, as long as the supra-glottal pressure is not too high in relation to the subglottal pressure. As the cavities behind a labial closure is larger than behind a dental and velar closure it will take longer for the intra-oral pressure to build up to a level that prohibits voicing.

4.5. An assimilation rule

A tentative assimilation rule for clusters of two consonants, distributed over two neighbouring syllables, may be formulated:

> Voicing of fortis consonants, whether progressive or regressive, takes place only to a very small extent.
> Regressive devoicing affects only (z and presumably all) lenis fricatives, whereas progressive devoicing (more or less extensive) is frequent and affects plosives, fricatives, and l as well.
> Generally a consonant preserves its basic voicing characteristic better when stressed than when unstressed.

5. The effects of assimilation upon other properties of the consonants

Apart from voicing, Gimson (1966 p. 144-154) mentions the following features separating t and d: force of articulation, aspiration, length of preceding sounds, duration of the closure, and intensity of the burst. I have measured only three of these factors: aspiration, length of preceding vowel, and duration of the closure. Although I have not measured intra-oral pressure, which Gimson does not mention as a factor separating t and d, it is fairly certain that a difference in intra-oral pressure exists, and that it is assimilated completely with the voicing (cf. Fischer-Jørgensen 1969 and Thorsen 1967).

5.1. Duration of the preceding vowel

If duration of the vowel in -CV+ syllables ("+" denotes word- or morpheme boundary) were dependent upon the degree of voicing in the consonant one would expect the vowel to be longer the more voiced the following consonant is.

Devoicing of a final lenis consonant should shorten the preceding vowel, and voicing of a final fortis consonant should lengthen it.

In my material a vowel is always longer before syllable final d than before syllable final t, and in all cases, except two, the differences are statistically significant (at the 99% level (**) or at the 95% level (*)). - But it might be that the differences in vowel duration, although they be significant, are smaller in cases where the difference in voicing in d and t is small or eliminated, so that a partial assimilation can be said to have taken place.

5.1.1. Measurements (averages)

In Table XI are given data on the duration of vowels before d and t respectively and on the differences between the voicing (absolute and relative voicing, respectively) in d and t. - "C" stands for d or t, the lengthening marks apply only when C is d. Note that statistical significance has not been calculated for the difference in absolute voicing in d and t. About the number of examples: there were usually 3o or slightly fewer (interested readers are referred to Tables III and V for the exact figures).

5.1.1.1. The stressed vowels

[æ:] before d+pause is extra long, compared to [æ:] before d+k and d+g. The same tendency is observed in [æ] before t+pause, but not so strongly, which creates a large difference in vowel duration before d and t plus pause.

[u:] before d+z is also very long, but this is probably due to the choice of frame-word ('They booed Zacharia'). [ɛ] before d+l is rather short, I do not know why. The frameword was 'bled' in 'He bled like a pig'.

One more vowel difference is rather small, namely that between [ɛɪ] before d+ə and t+ɪ, respectively ('They would fade away', 'His fate is hard') and it is accompanied by a small difference in absolute voicing (1o msec). However, this is not the case in 'He bled like a pig' vs. 'He bet like a fool', so it is hardly significant.

5.1.1.2. The unstressed vowels

The unstressed vowels are more interesting. Firstly they are all the same, [ɪ], (in 'did' and 'it') and therefore can be compared 'vertically' as well as 'horizontally'. Secondly we find cases here where the difference in absolute voicing is small (less than, say 2o msec), and

Table XI Duration of vowels before d and t, - related to the differences in voicing in the consonants

	vowel duration before d	vowel duration before t	difference	difference in voicing in d and t in msec	difference in voicing (relative) in d and t
strong-weak					
æ(:)C+pause	288	164	124**	39	64**
ɛɪC+ə,ɪ	171	145	26**	1o	58**
æ(:)C+k	197	123	74**	44	74**
æ(:)C+g	192	119	73**	43	72**
ɔ(:)C+s	183	138	45**	33	56**
u(:)C+z	221	88	133**	31	6o**
ɛC+l	1oo	94	6	42	67**
weak-strong					
ɪC+pause	96	84	12	35	35**
ɪC+æ	6o	47	13*	14	11
ɪC+k	56	33	23**	13	2o
ɪC+g	56	38	18**	1o	4
ɪC+s	56	32	24**	17	19**
ɪC+z	59	45	14**	-2	14
ɪC+l	6o	41	19**	21	47**
weak-weak					
ɪC+æ	52	41	11**	13	19
ɪC+k	51	39	12**	19	13
ɪC+g	53	38	15**	13	14
ɪC+s	55	37	18**	13	16
ɪC+z	62				
ɪC+l	53				

the difference in relative voicing in the same cases is likewise small and not statistically significant (except in the case of IC+s in the weak-strong distribution) - we should thus expect the difference in vowel duration to be rather small.

5.1.2. Conclusion

The correlation between the difference in the duration of the vowel before d and t, respectively, and the voicing in these two consonants is displayed in Fig. 3. - The correlation, if any, does not seem to be a very simple one.[9] A hypothesis to the effect that voice assimilation in a (final) consonant affects the duration of the preceding vowel must probably be rejected. - But note that the assimilation concerns only voicing of final t, not, for instance, devoicing of final d.

The question of aspiration, or open interval, will be dealt with in the section about duration of the consonant.

5.2. Duration of the consonants

5.2.1. d and t

In Table XII are given the data on the durations of the d and t closures and their open intervals. "-" before a figure means that d is longer than t. "*" after a figure means that the difference is significantly different from zero at the 95% level, "**" indicates significance at the 99% level. "÷" denotes instances where the difference in relative voicing in d and t is not statistically signifi-

---

9) I have tried also to correlate the duration of the vowel before t with the voicing (absolute as well as relative) in t with no result, - there is no correlation to be found.

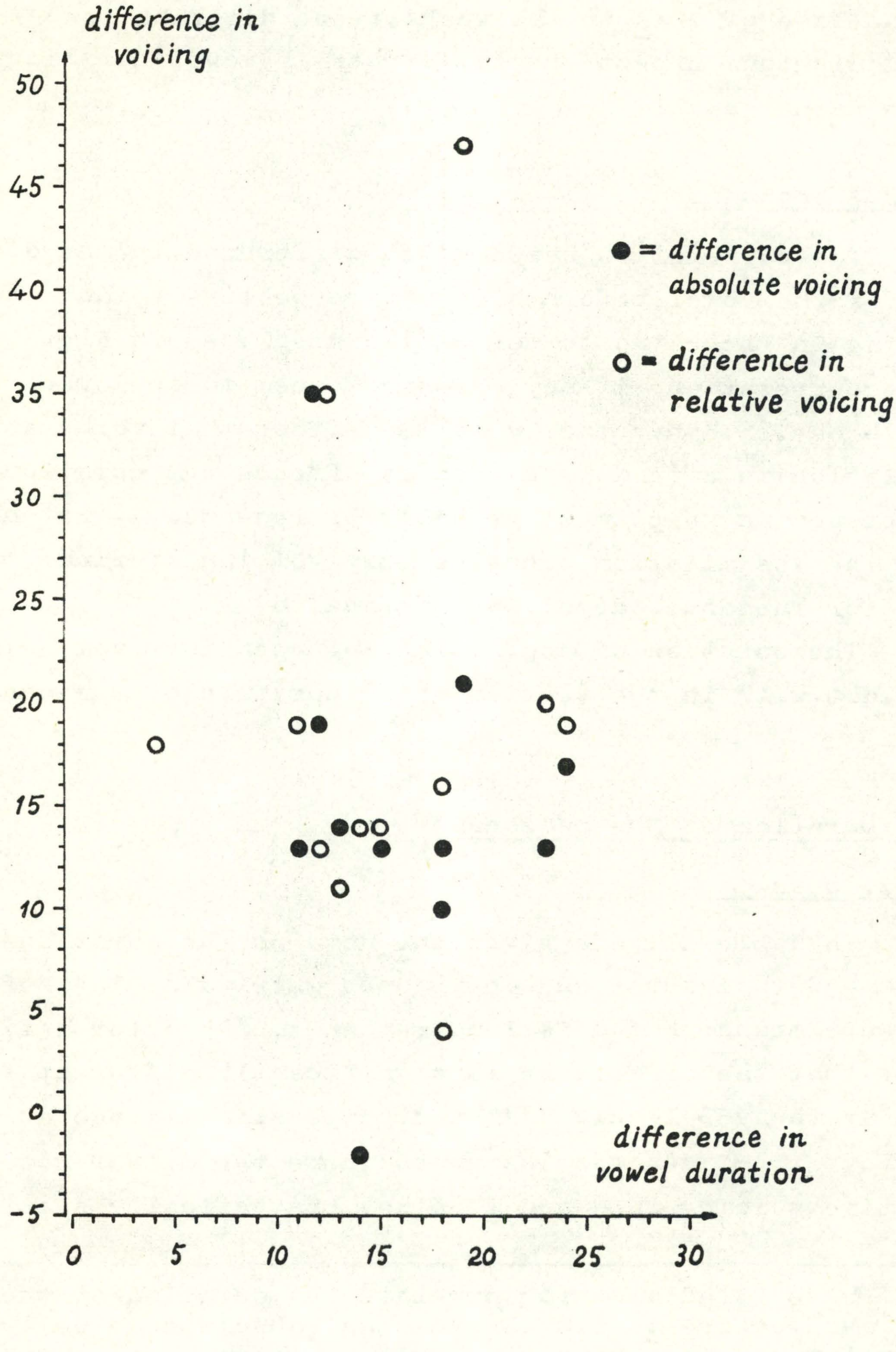

difference in voicing
50
45
40
35
30
25
20
15
10
5
0
-5
● = difference in absolute voicing
o = difference in relative voicing
difference in vowel duration
0
5
10
15
20
25
30

Fig. 3.

cant. "+" denotes instances where the difference in relative voicing in t and d is statistically significant, but less than 25 (%) (except in the leftmost column where it denotes word- or morpheme boundary). Figures that are not marked with "÷" or "+" are those where the difference in relative voicing in t and d is statistically significant and over 25 (%). "C" stands for d and t, respectively.

5.2.1.1. The open interval

Let me say with no further documentation that there is no correlation between the difference in open interval and the difference in voicing in d and t, i.e. the assimilation of voice does not affect the open interval.

It is evident that a consistent and significant difference in initial d and t before a vowel is to be found in the open interval. The difference manifests itself finally, too. But in this position the most effective cue to the distinction between d and t is probably not the open interval but rather the duration of the preceding vowel.

5.2.1.2. The closure

It is more difficult to discern a pattern in the closure durations. That is, the problem lies in establishing a pattern outside of cases of assimilation, for which the material is badly suited. - The only position that exhibits a stable difference in closure duration is finally in a stressed syllable after a vowel, where t is longer than d, as would be expected.

17 differences are negative, i.e. the d-closure is longer than the t-closure. These negative differences do tend to coincide with cases where the difference in voicing (absolute and relative) in d and t is small. -

Table XII Duration in msec of closure and open interval in t and d

	duration of t-closure	duration of d-closure	difference	open interval t	open interval d	difference
weak-strong						
pause+C				5o	11	39**
V+C	98	84	14**	47	11	36**
VC	93	83	1o	46	11	35**
p+C	58	67	- 9 ÷	4o	13	27**
b+C	61	6o	1	38		
s+C	53	84	-31**+	28	12	16**
z+C	96	1o7	$\boxed{-11}$	57	14	43**
l+C	1oo	113	$\boxed{-13}$	62	11	51**
strong-weak						
pause+C				39	13	26**
V+C	58	52	6*	4o	12	28**
VC	43	44	- 1	51	11	4o**
p+C	76	67	$\boxed{9 \div}$	33	19	14**
b+C	62	63	- 1	32	17	15**
s+C	62	57	5	43	24	19**
z+C	58	73	-15* +	39	16	23**
l+C	51	51	o ÷	45	12	33**
weak-weak						
V+C	65	6o	5	38	13	25**
b+C	42	32	1o	42	15	27**
z+C	61	62	- 1	34	17	17**
strong-weak						
C+pause	8o	67	13			
C+V	53	32	21**	44	9	35**
C+k	77	64	13*	36	23	13**
C+g	68	62	6	28	16	12**
C+s	71	63	8			
C+z	1oo	71	29**			
C+l	1o2	75	27**			

continued on the next page

Table XII continued

	duration of t-closure	duration of d-closure	difference	open interval t	open interval d	difference
weak-strong						
C+pause	63	79	$\boxed{-16}$			
C+V	25	36	-11* ÷	25	13	12**
C+k	47	51	- 4 ÷	23	2o	3
C+g	47	56	- 9**÷	19	15	4
C+s	55	63	- 8* +			
C+z	78	64	$\boxed{14^{**}\div}$			
C+l	67	56	11*			
weak-weak						
C+V	29	37	- 8* ÷	35	11	24**
C+k	41	56	-15**÷	23	18	5
C+g	47	53	- 6 ÷	22	14	8
C+s	49	55	- 6 ÷			

But there are other instances (framed in the table) where

(i) the d-closure is (considerably) longer than the t-closure and where the differences in absolute and relative voicing in d and t is rather large: 48 msec, 45 (%) in 'His doe was hurt'/'His toe was hurt' (closure difference "-11" msec), 55 msec, 45(%) in 'He'll dap again'/'He'll tap again, (closure difference "-13" msec), and 35 msec, 35 (%) in 'He'd looked at a cad'/'It looks like a cat' (closure difference "-16" msec);

(ii) the t-closure is longer than d-closure and where the difference in absolute and relative voicing in d and t is none or small: o msec, o (%) in 'The gap diminished'/

'There's a gap to fill' (closure difference 9 msec), and "-2" msec, 14 (%) in 'Did Zena do it?'/'It zipped at the back' (closure difference 14 msec).

Therefore I do not think that assimilation can be made responsible for the comparatively longer d-closures (or shorter t-closures).

A possible explanation might be that in syllable final position (where the unstressed d-closure usually is longer than the t-closure) the syllables chosen were 'it' and 'did'. 'it' may have been still more weakly stressed than 'did' and thus the t-closure shorter than the d-closure. But this explanation is not valid in the 5 (7) cases where the d-closure is longer than the t-closure initially.

5.2.1.3. Fortis-lenis

One thing may be deduced from this rather confused picture: If force and duration of the consonants go together in BE, i.e. if the consonant is longer the more 'fortis'[10] it is, and if length is thus a measure of 'fortisness', then the duration of the preceding vowel cannot be the result of the force of the following consonant, since I have examples of 'long' vowels followed by 'long' consonants. (Delattre (1940) explains the vowel length in French in this way, i.e. a vowel is shorter the more fortis (and the longer) the following consonant is.)

5.2.2. Consonants other than d and t

As regards the other consonants under investigation (p b k g s z): these behave according to expectations and not like t and d. The vowel preceding these consonants is

10) From now on 'fortis' and 'lenis' are used in their ordinary sense about force of articulation.

always longer before b g z than before p k s, and p k s are always longer than their basically voiced counterparts, Also where the difference in voicing has been eliminated. k vs. g and s vs. z exhibit differences in consonant duration that are independent of their phonetic voicing (I cannot say whether this would be true also of p vs b, since these two consonants have only been investigated finally in a syllable after a vowel, where their voicing does not vary much).

5.2.2.1. Duration of the consonants and their voicing

In Table XIII (which is only a sample) I have looked at some consonants after d and t, namely k and z after d and t, respectively, and s before d and t (these consonants are in otherwise identical positions).

Table XIII Voicing in and duration of k/z after d/t and of s before d/t

	voicing in msec	voicing in percentages	duration of the consonant (closure)
d+k/t+k	17/o	2o/o	86/1o5
d+z/t+z	51/6	63/6	81/11o
s+d/s+t	31/28	29/23	1o7/121

It will be seen that a higher degree of voicing is correlated with a shorter duration of the consonant (closure). Thus it seems that the assimilation of voicing causes a partial assimilation of the duration of the consonants, though not to such an extent that a basically unvoiced consonant becomes as short as its basically voiced counterpart.

5.2.2.2. d and t

Again d and t are atypical (see Table XIV).

Table XIV Voicing in and duration of d after s/z and before k/g and of t before s/z

	voicing in msec	voicing in percentages	duration of the closure
s+d/z+d	9/48	11/45	84/1o7
d+k/d+g	44/51	86/91	51/56
t+s/t+z	26/4o	36/4o	71/1oo

In about half of my examples (of which those above are only a sample) that closure is longer which is also the most voiced. This is true of both initial and final d's and t's. Thus it seems that d and t have behaved differently from the other consonants. I am not sure why this is so.

It is possible that the t-closure is shorter than the d-closure because of the longer open interval of t, i.e. the strong aspiration and affrication may be due to a rather loose closure which tends to be exploded rather early. The loose closure would explain why we find shorter t-closures also in such cases where there is no proper open interval (finally in a syllable before a consonant in the following syllable). But since not all t-closures are shorter than the d-closures, the loose closure cannot be operating always and may therefore be only a part of the explanation, the rest of which I am unable to offer.

5.3. Final remarks about vowel duration before voiced and unvoiced obstruents

Chomsky and Halle (1968 p. 3o1) propose vocal chord adjustment rate as an explanation for the lengthening of vowels before voiced obstruents, i.e. the movement to the open position for unvoiced consonants should be more rapid and cut off the vowel earlier than the supposedly more complicated movement to the vocal chord position for voiced consonants. This explanation is probably not generally valid: the vowel before final voiced t in my material is shorter than the vowel before voiced d (but, admittedly, it may be that the vocal chord position is different in voiced t from that in voiced d). In these cases t occurs in 'it' which is very short and weak, and therefore the vowel is particularly short. But there are also examples where the vowel before voiced p is shorter than before voiced b, and in these cases the choice of frame-word cannot be made responsible for the relatively shorter vowel before p.

6. Concluding remarks

Gimson (1966 p. 267-27o) writes about assimilation, partly under the heading 'Allophonic Variations', partly under the heading 'Fortis/Lenis Variations'.

Among allophonic variations at word boundaries he mentions:

(i) Devoicing of l in 'at last' and other close-knit entities. A similar sequence in my material ('It looks like a cat') exhibited 71% voicing in l.

(ii) Devoicing of word final lenis fricatives and plosives. d in my material is only devoiced to a very small extent (91% voiced in stressed syllables, 77% voiced in unstressed syllables).

(iii) Lenis fricatives followed by fortis consonants get devoiced. z before t in my material was never less than 49% voiced, slightly dependent upon stress placement.

(iv) Initial lenis fricatives and plosives after a pause are unvoiced. In my material were found only a few instances with voicing lead.

Among fortis/lenis variations Gimson mentions:

(v) Word final lenis fricatives followed by a word initial fortis consonant may be realised as the corresponding fortis fricative, and the phonemic change may be complete in that a preceding long vowel may be realized in the reduced form appropriate to a syllable closed by a fortis consonant. This does not hold for my material. All subjects have more voicing in z than in s finally, all have s longer than z, and all have the vowel longer before z than before s.

(vi) b d g finally are not usually influenced in the same way as final lenis fricatives by a following fortis consonant. This is confirmed by my material, where final d after a vowel regardless of stress placement and regardless of the following consonant was voiced.

(vii) Word or morpheme final fortis consonants rarely show tendencies to assimilate to their lenis counterparts. This is confirmed by my material.

Gimson does not mention the progressive devoicing from final fortis to initial lenis consonants found in my material.

References

Chomsky, Noam and Morris Halle 1968: The Sound Pattern of English (New York).

Delattre, Pierre 1940: "Anticipation in the Sequence: Vowel and Consonant Group", The French Review XIII.

Fischer-Jørgensen, Eli 1952: "Om Stemthedsassimilation", _Festskrift til L.L.Hammerich_, p. 611-617.

- 1968: "Les occlusives françaises et danoises d'un sujet bilingue", _Word_ 24.

- 1969: "Voicing, Tenseness and Aspiration in Stop Consonants, with Special Reference to French and Danish", _ARIPUC_ 3/1968, p. 63-115.

Gimson, A.C. 1966: _An Introduction to the Pronunciation of English_ (London).

Grammont, Maurice 1939: _Traité de Phonétique_ (Paris), p. 185-228.

Thorsen, Oluf M. 1967: "Voice Assimilation of Stop Consonants and Fricatives in French and Its Relation to Sound Duration and Intraoral Air-Pressure", _ARIPUC_ 1/1966, p. 67-76.