Temporal Compensation in a Quantity Language*

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This paper explores the temporal relationships between the segments in three sets of Estonian words. While a considerable amount of interest has been shown previously in the duration of sounds with contrastive function, the temporal structure of the whole word of which the contrastive sounds constitute a part has received relatively little attention.[1] It is the thesis of this paper that the word is programmed as a whole, and that significant relationships exist among all segments that constitute a word, although not all segments participate in segmental quantity oppositions.[2]

The material analyzed for the study consists of three minimal triples: vaga 'pious' (nom. sg.), vaka 'bushel' (gen. sg.), vakka 'bushel' (part. sg.); sada '100' (nom. sg.), saada 'send' (2. sg. imperative), saada 'send' (-da-inf.); saag 'saw' (nom. sg.), saak 'prey' (nom. sg.), sakk 'sawtooth' (nom. sg.). According to traditional analyses, the intervocalic consonant /k/ is in short, long and overlong quantities in the first set (short, long and overlong will be referred to as quantities 1, 2 and 3); in the second set, the contrastive sound is the vowel of the first syllable, which appears in quantities 1, 2, and 3; and in the third set, /a/ is in quantity 3 in the first two words and in quantity 1 in the third, while final /k/ is in quantity 1 in the first word and in quantity 3 in the second and third.[3] These words were recorded by two speakers, each of whom repeated each test word between 100 and 110 times in sequence. The recordings were made in Tallinn in the autumn of 1970.[4] The tapes were processed through a Frøkjær-Jensen trans-pitchmeter and intensity meter; the curves were displayed by means of an Elema-Schönander Mingograf (at a speed of 10 cm/second). Measurements of duration were made from mingograph traces; the results were analyzed statistically by means of an IBM 360 computer.[5] To normalize for variations in tempo, the average durations of all words were computed, and a subset of 50 utterances whose durations were closest to the mean duration was extracted for each word. Further computations were performed on these subsets. This procedure of tempo normalization is essentially the same as that employed by Ohala and Kozhevnikov and Chistovich in previous temporal studies.[6]

One form of temporal compensation within Estonian words has been frequently referred to in previous descriptions. This is the compensation in the duration of the vowel of the second syllable, which adjusts itself inversely to the duration of the

first syllable, so that a first syllable in quantity 1 is followed by a so-called half-long vowel in the second syllable, and first syllables in quantity 2 and 3 are followed by successively shorter second syllable vowels. Evidence for this type of compensation, which is part of the phonological structure of Estonian words, is given in Table 1 and in Figures 1, 2, and 3.

Figure 1 shows the average durations of segments in productions of vaga-vaka-vakka by the two speakers. As may be seen, there is some adjustment in the duration of the vowel of the second syllable, which partly compensates for the increasing duration of the intervocalic consonant. A similar observation may be made with respect to the set sada-saada (2) - saada (3), displayed on Figure 2. Here the duration of the vowel of the second syllable is inversely correlated with the vowel of the first syllable, whose duration is contrastive.[7]

Figure 3 shows the set saag-saak-sakk. Here the compensation is between the vowel and the final consonant, both of which are contrastive on the segmental level. It is interesting that the total durations of the words saag and saak are practically identical: the compensation is complete, and the two monosyllabic words really differ only in the distribution of duration among the two contrastive segments. The third member of the set, sakk, contains what is commonly analyzed as a quantity 1 vowel and a quantity 3 final consonant. In terms of measurable duration, this adds up to somewhat less than the 3 + 1 sequence in saag, where a vowel in quantity 3 is followed by a consonant in quantity 1. As far as the word saak is concerned, the assignment of the vowel and the final consonant to phonemic quantities remains ambiguous on phonetic grounds. For both speakers, the duration of /a/ in saak is longer than that of /a/ in saada (2), but shorter than /a/ in saada (3); the duration of /k/ in saak is likewise between the durations of /k/ in vaka and vakka. The pertinent data are given in Table 1.

The temporal compensation with which we are primarily concerned in the current paper is of a different kind. It is manifested not in the pattern itself, but in its realization. We hypothesize that there exists a temporal program for the production of an utterance. At a certain level in the process of the production of the utterance, the sequence of articulatory gestures is programmed, and the utterance is assigned an overall basic duration. If this is true, then repeated productions of the same utterance will aim at a duration close to the average for a series of productions. In order that this may be accomplished, temporal adjustment will take place between successive segments during a single production: if one of the segments is produced with a duration that is longer than its own average, another segment within the same utterance will be relatively shorter than its respective average, so that the duration of the word as a whole will remain more or less constant, i.e. vary as little as possible from the average duration programmed for the word. Each segment will, of course, have some variability, which may be

statistically expressed in terms of variance. If the segments were independent of each other, their variances would be additive, and the variance of the whole word would be the sum of the variances of the segments. If, however, there is temporal compensation among the segments constituting the word, the variance of the word should be less than the sum of the variances of the segments.

Table 2 contains the mean durations of each test word, the sum of variances of the segments, and the variance of the word taken as a whole. Figure 4 presents the same data graphically for the vaga-vaka-vakka set. As is obvious from the table and the figure, temporal compensation is indeed present in all test words, and in general the hypothesis appears to be validated. The study was continued to establish the statistical significance of correlations between all subsets of segments in each test word. A summary of the results is presented in Table 3 and in Figures 5-7.

Figure 5 shows the correlation coefficients (Pearson correlations) for all segments contained within the words vaga, vaka and vakka produced by the two speakers. Specifically, these correlations show the relationship of the first three segments to the fourth. (Correlations between various other combinations of segments are given in Table 3.) As may be seen, the degree of negative correlation is extremely high. The two vertical lines on the figure represent r values that show significance at the .005 and .0005 level respectively; the actually obtained correlations are significant at an even higher level.

Figure 6 presents correlation coefficients for the words sada, saada (2), and saada (3). In this case, the displayed negative correlations were found to obtain between the two syllables--segments 1 and 2 on the one hand, and 3 and 4 on the other hand. As before, the correlations are highly significant.

Figure 7 presents similar data for the monosyllabic words saag, saak and sakk. Here the first consonant and vowel have been correlated with the final consonant. Again, the degree of negative correlation is highly significant.

Not all combinations of segments yielded equally high negative correlations. In most cases, correlations involving the initial consonant and other parts of the word were either significant at a lower level or not significant at all. This may reflect the fact that the duration of the initial consonant is non-contrastive at the segmental level. However, combinations that involved all segments yielded significant negative correlations in all cases.

The hypothesis presented at the beginning of this paper was that words are programmed as units, and that significant relationships exist among all segments that constitute a word. The results of the study have clarified these relationships: the durations of segments constituting a word are negatively correlated, and the level of significance of these negative correlations is much too high to be attributed to chance. Since the timing patterns extend

over the whole word, it may be concluded that words do indeed constitute units of programming. Further research is needed to establish to what an extent these patterns are modified when the word becomes part of a higher-level unit such as a phrase or sentence.

Footnotes

*This research was supported in part by PHS Research Grant No. 1 RO3 MH18122-01 from the National Institute of Mental Health, and in part by Grant No. 534.1 from the National Science Foundation to the Computer and Information Science Research Center, The Ohio State University.

[1]The problem is surveyed, and literature cited, in Ilse Lehiste (1970) Suprasegmentals. Cambridge: M.I.T. Press.

[2]For a discussion of the problem, cf. Ilse Lehiste (1971) "Temporal organization of spoken language," in Form and Substance: Phonetic and Linguistic Papers Presented to Eli Fischer-Jørgensen. Edited by L. L. Hammerich, Roman Jakobson, and Eberhard Zwirner. Copenhagen: Akademisk Forlag, 159-169.

[3]The words are given in standard spelling. The letter g stands for a voiceless lenis plosive, which is the realization of /k/ in quantity 1. Traditional spelling does not distinguish between long and overlong vowels, both of which are written with two vowel letters.

[4]I would like to thank my informants for the generous contribution of their time, and the researchers at the Institute for Language and Literature and the Laboratory of Experimental Phonetics of the Academy of Sciences of the Estonian S.S.R. for their cooperation and assistance in making the recordings.

[5]The analysis techniques are described in detail in L. Shockey, R. Gregorski, and I. Lehiste (1971) "Word unit temporal compensation"." Ohio State University Working Papers in Linguistics No. 9.

[6]John Ohala (1970) Aspects of the Control and Production of Speech. UCLA Working Papers in Phonetics No. 15, Los Angeles; V. A. Kozhevnikov and L. A. Chistovich (1965) Speech:Articulation and Perception. Translated by J.P.R.S., Washington, D.C., No. JPRS 30543. Moscow-Leningrad.

[7]There is some controversy over the question whether a first syllable in quantity 2 is followed by a half-long vowel or not. In the present set of data, one of the speakers had successively shorter second-syllable vowels in vaga-vaka-vakka, the other in sada-saada-saada.

Table 1

Mean durations (in milliseconds) of segments in nine test words produced by two speakers. N = 50.

Word and speaker	C_1	V_1	C_2	V_2
ÕP vaga	71.34	120.74	98.68	257.26
ÕP vaka	57.24	103.54	188.82	223.84
ÕP vakka	57.86	105.54	397.26	187.68
EJ vaga	51.40	128.22	71.94	257.24
EJ vaka	45.06	94.54	204.20	210.28
EJ vakka	50.18	92.42	376.32	203.02
ÕP sada	131.30	128.38	73.56	251.98
ÕP saada (2)	136.72	255.88	76.96	190.68
ÕP saada (3)	139.30	454.56	100.80	185.40
EJ sada	130.96	101.62	53.84	232.16
EJ saada (2)	117.88	191.46	72.36	196.44
EJ saada (3)	122.94	275.96	78.10	165.76
ÕP saag	141.14	486.20	85.96	
ÕP saak	136.78	316.46	271.00	
ÕP sakk	119.86	115.98	316.70	
EJ saag	158.16	419.82	118.40	
EJ saak	131.72	222.64	351.14	
EJ sakk	143.68	104.82	350.80	

Table 2

Mean durations (in milliseconds) and variances of nine test words produced by two speakers. N = 50.

Word and speaker	Mean duration	Sum of variances of segments	Variance of word
ÕP vaga	548.02	527.33	118.38
ÕP vaka	573.44	582.72	84.06
ÕP vakka	748.34	1345.85	487.63
EJ vaga	508.80	796.56	199.75
EJ vaka	554.08	598.35	132.31
EJ vakka	721.94	1138.20	193.13
ÕP sada	585.22	452.00	238.56
ÕP saada (2)	660.24	896.20	161.56
ÕP saada (3)	880.06	1257.32	305.63
EJ sada	518.58	610.43	203.75
EJ saada (2)	578.14	390.80	70.88
EJ saada (3)	642.76	751.75	213.50
ÕP saag	713.30	601.10	297.19
ÕP saak	724.24	592.22	173.06
ÕP sakk	552.54	621.51	202.13
EJ saag	696.38	1753.70	655.06
EJ saak	705.50	1196.46	264.25
EJ sakk	599.30	1005.59	330.63

Table 3

Correlation coefficients between various combinations of segments in productions of nine test words by two speakers.

$N = 50$; $r = \frac{1}{N} \sum \left(\frac{X - \bar{X}}{\sigma X} \right) \left(\frac{Y - \bar{Y}}{\sigma Y} \right)$. Significance of r at .235 - .95, at .279 - .99, at .361 - .995, and at .451 - .9995.

Word	Segments involved in the correlation	Correlation coefficient	
		Speaker ÕP	Speaker EJ
vaga	1, 2	-0.178	-0.468
	2, 3	-0.142	-0.367
	3, 4	-0.353	-0.386
	1, 2, 3, 4	-0.738	-0.660
vaka	1, 2	-0.310	-0.148
	2, 3	-0.046	-0.333
	3, 4	-0.652	-0.523
	1, 2, 3, 4	-0.770	-0.730
vakka	1, 2	0.058	-0.035
	2, 3	-0.186	-0.219
	3, 4	-0.509	-0.717
	1, 2, 3, 4	-0.556	-0.776
sada	1, 2	-0.236	-0.170
	2, 3	-0.404	-0.428
	3, 4	0.166	-0.391
	1, 2, 3, 4	-0.530	-0.543
saada (2)	1, 2	0.121	-0.381
	2, 3	-0.328	-0.314
	3, 4	0.104	-0.116
	1, 2, 3, 4	-0.834	-0.765

Word	Segments involved in the correlation	Correlation coefficient	
		Speaker ÕP	Speaker EJ
saada (3)	1, 2	-0.467	-0.288
	2, 3	-0.382	-0.609
	3, 4	-0.139	0.028
	1, 2, 3, 4	-0.667	-0.668
saag	1, 2	-0.155	-0.191
	2, 3	-0.604	-0.529
	1, 2, 3	-0.637	-0.590
saak	1, 2	-0.257	-0.312
	2, 3	-0.475	-0.205
	1, 2, 3	-0.668	-0.768
sakk	1, 2,	-0.100	0.112
	2, 3	-0.406	-0.326
	1, 2, 3	-0.708	-0.685

Figure 1. Average durations of segments in the three words vaga, vaka and vakka, produced by two informants.

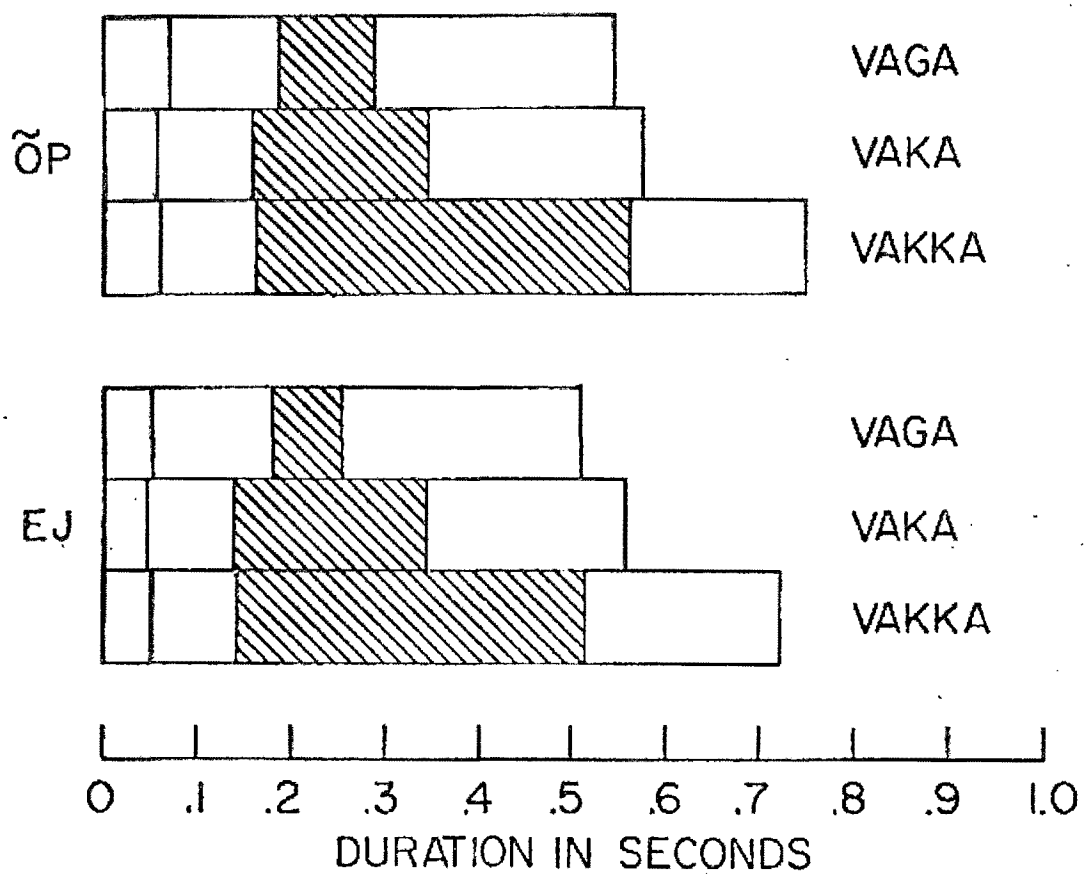


Figure 2. Average durations of segments in the three words sada, saada (2) and saada (3), produced by two informants.

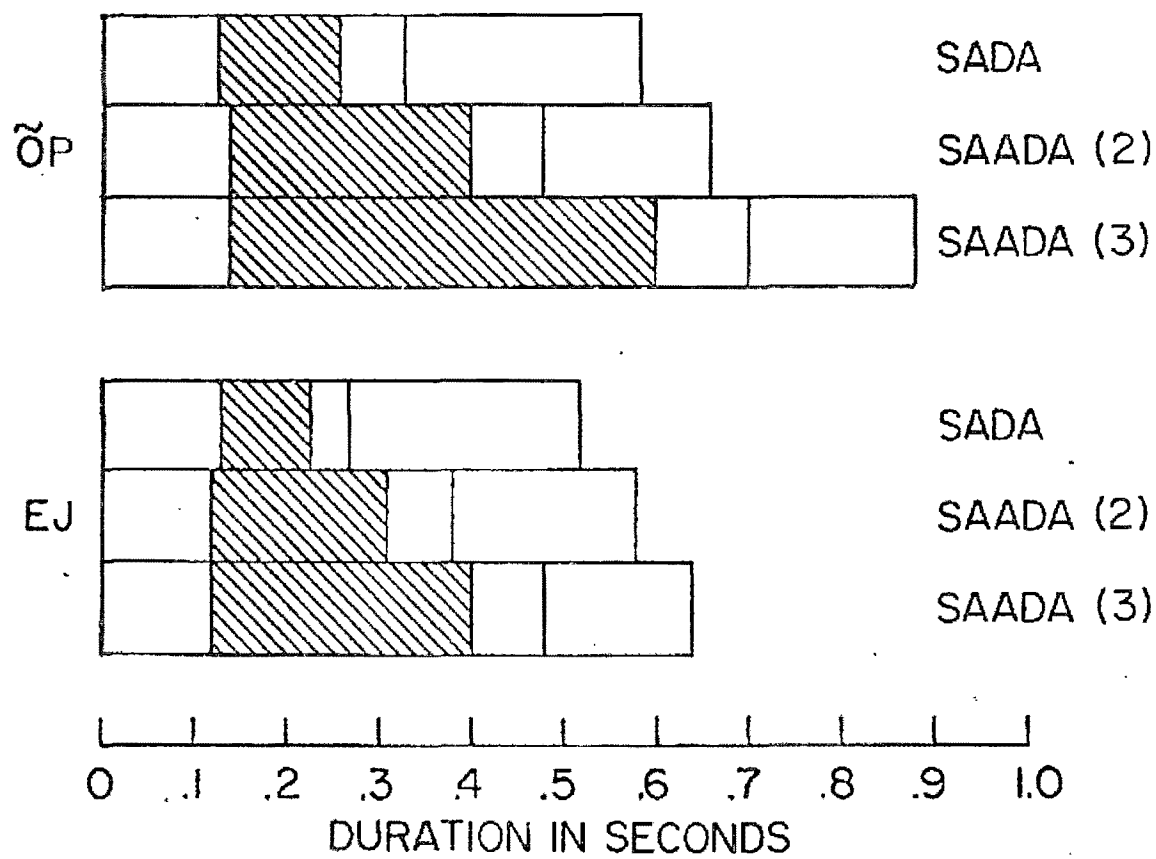
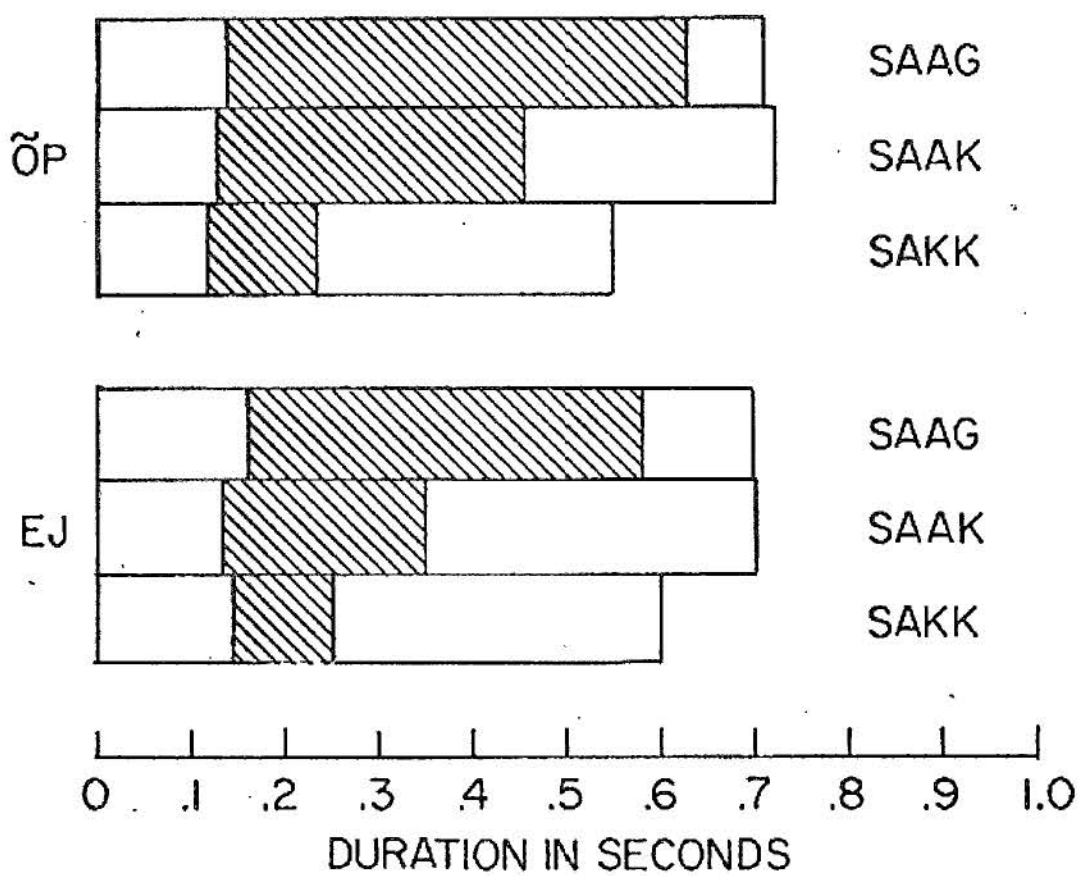


Figure 3. Average durations of segments in the three words saag, seak and sakk, produced by two informants.



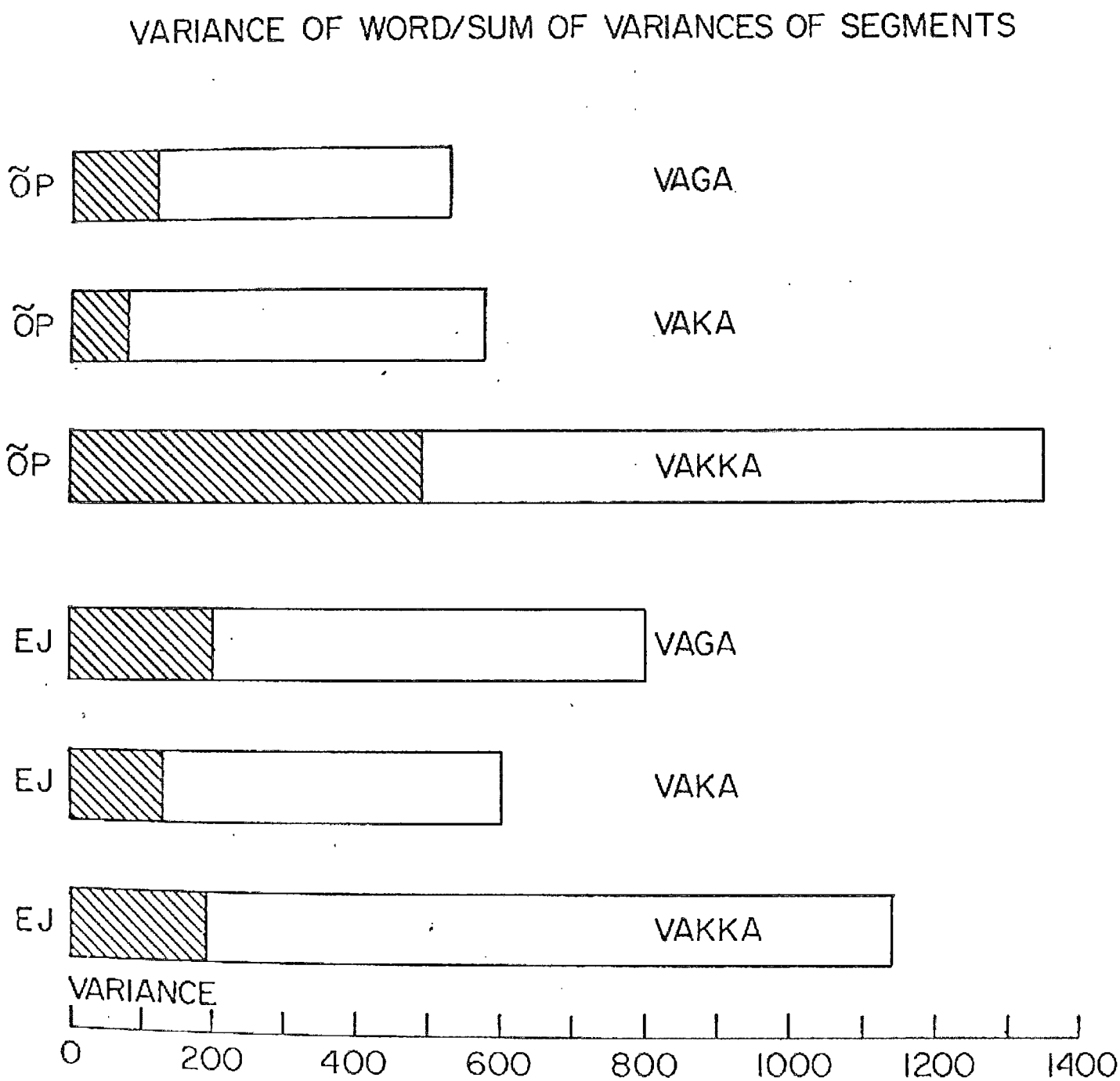


Figure 4. Variance of the word (diagonally hatched) and sum of variances of segments in productions of the words vaga, vaka and vakká by two speakers. Variance of word is superimposed on the sum of variances of segments.

Figure 5. Correlation coefficients (r) between the first three segments and the fourth segment contained in the words vaga, vaka and vakka produced by two speakers.

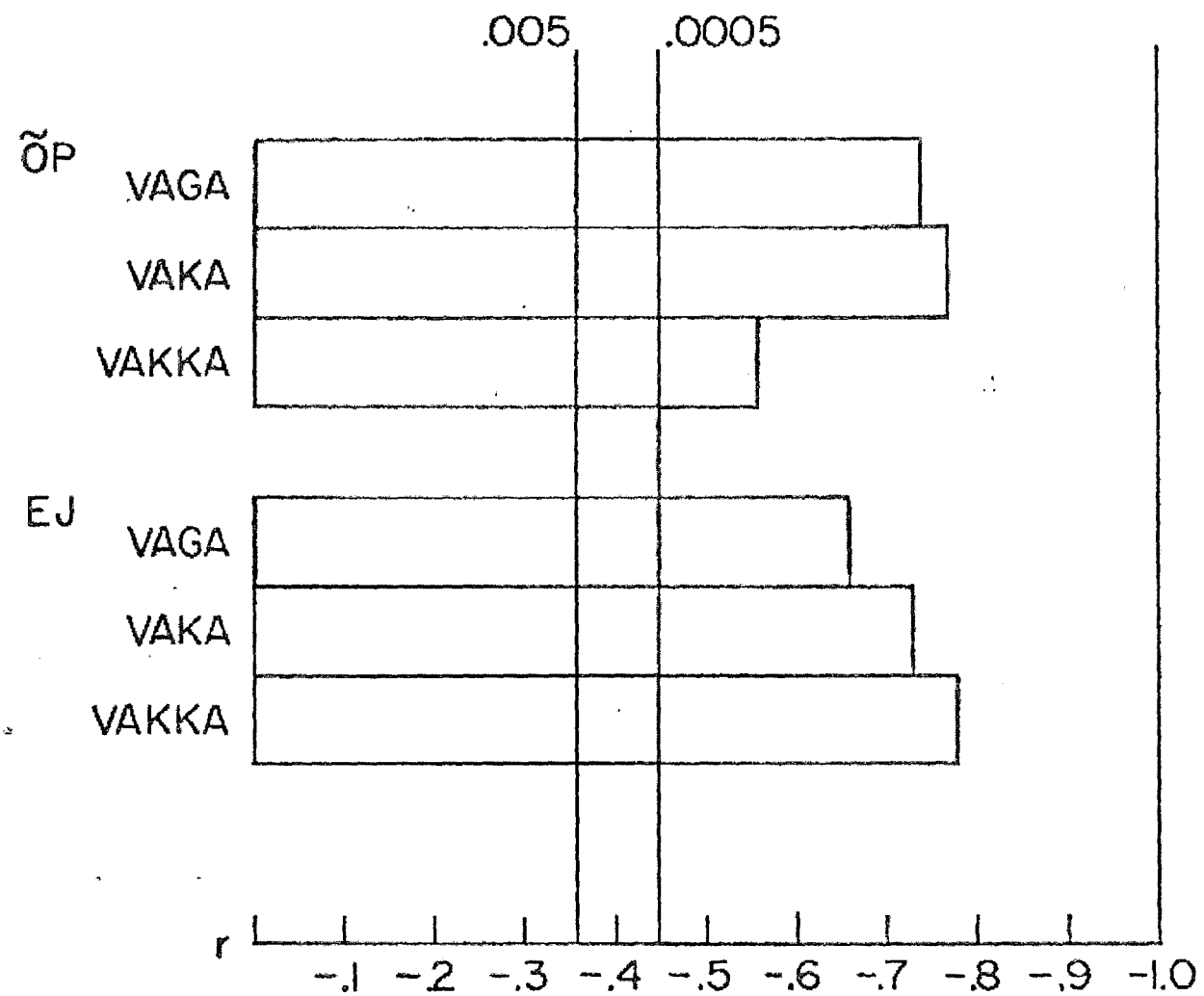


Figure 6. Correlation coefficients (r) between the first two and last two segments contained within the words sada, saada (2) and saada (3) produced by two speakers.

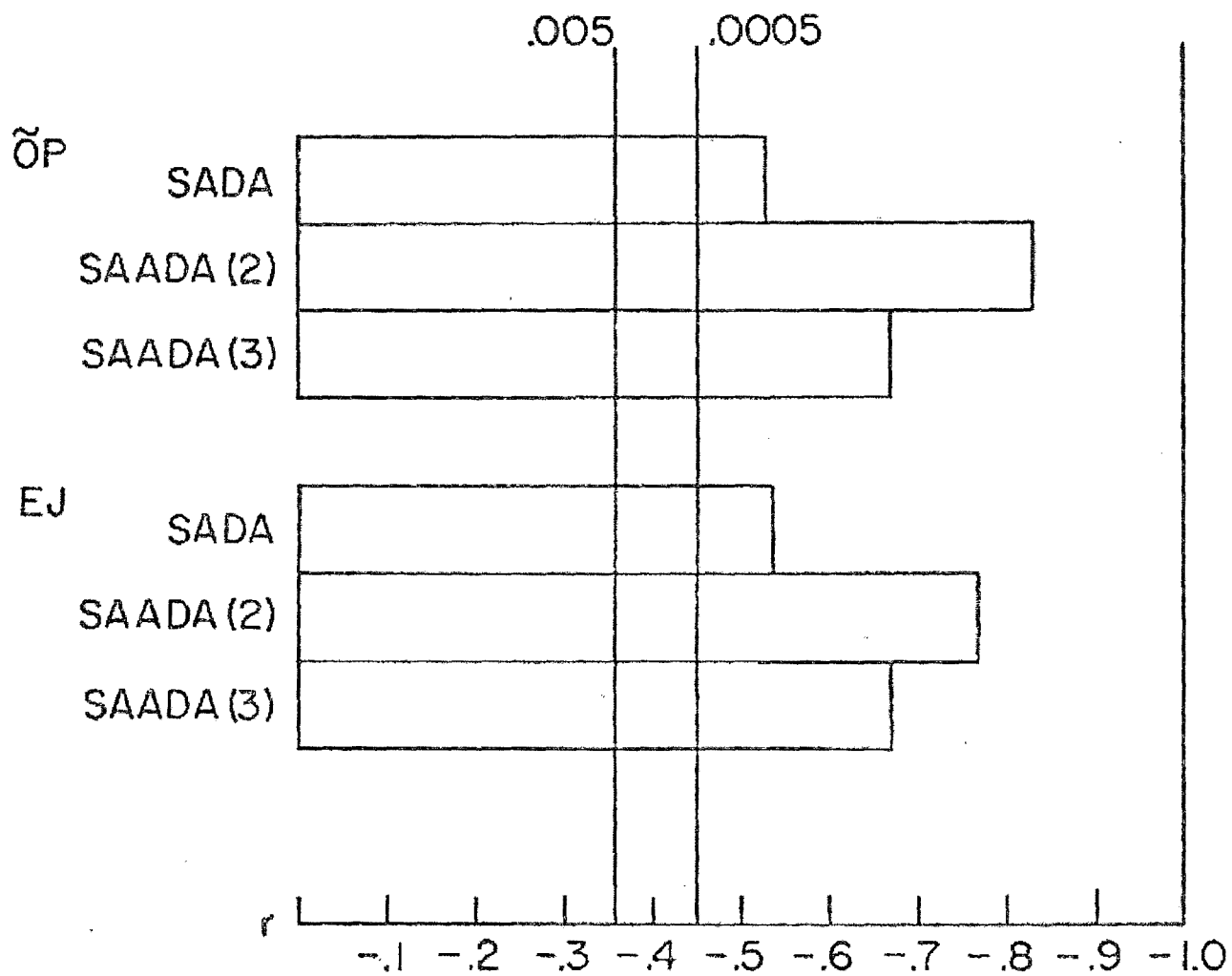


Figure 7. Correlation coefficients (r) between the first two segments and the third segment contained within the words saag, saak and sakk produced by two speakers.