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THE ROLE OF INTRINSIC Fo AND DURATION IN THE PERCEPTION OF STRESS*

EVA ROSENVOLD

It has been found previously that the intrinsic differences in Fo level and duration, existing between vowels of different tongue height, are compensated for perceptually. The present experiment aims at examining the role of the intrinsic differences in connection with the perception of stress. It is found that the Fo step required to identify a certain stress pattern is of a different physical magnitude for a low than for a high vowel. Similarly, the duration required to identify a vowel as being stressed is not the same for low and high vowels. It appears from the results that the hypothesized perceptual compensation for the intrinsic differences functions in the perception of isolated vowels as well as in the perception and identification of linguistic category stress, which in its turn is dependent on Fo and duration.

I. INTRODUCTION

The present experiment is a contribution to the debate about the perceptual relevance of the so-called microprosodic phenomena. The object is, more specifically, to see whether the intrinsic differences in duration and fundamental frequency level between vowels of different tongue height influence the perception of stress.

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A. PERCEPTION OF STRESS

Various perceptual tests have shown that of the three acoustic correlates to stress (Fo, intensity, and duration) fundamental frequency seems to be the factor of primary importance. Fry (1958) found that Fo had an all-or-none effect for English, and Morton and Jassem (1965) report similar results for Polish, adding that the greatest effect was achieved by varying the Fo level of the second syllable in bisyllabic words. The authors note that the different vowel qualities used in the test words seemed to influence the results, and that further experiments taking these differences into account are called for. Thorsen (1978, 1979) likewise regards fundamental frequency as the primary cue to stress in Danish; duration may be a secondary cue.

B. INTRINSIC DIFFERENCES IN FO AND DURATION

Many experiments have proved the existence of a tendency for high vowels to have a higher Fo level and a shorter duration than low vowels, other things being equal. This tendency is manifest also in Danish, see Reinholt Petersen (1978), Fischer-Jørgensen (1955), and Bundgård (1980).

It is possible that the perception of Fo and duration proceeds regardless of those acoustic properties of the signal that convey information on vowel quality, and hence without compensation for intrinsic differences resulting from differences in tongue height. It is, however, also conceivable that the perception of Fo and duration is influenced by properties conveying information on vowel quality, thus involving a compensation. If the latter is true, we might expect this same compensatory process to be functioning in the case of stress perception cued by Fo and duration.

Two experiments have investigated the perceptual relevance of intrinsic differences. Reinholt Petersen (1974) had subjects categorize as phonemically long or short vowels of identical quality which occurred in a series of stimuli in which duration was increased in equal steps. He found that perceptual boundary between long and short vowel was dependent on vowel quality, the subjects requiring low vowels to be longer than high vowels in order for them to be classified as phonemically long. This implies that two vowels of different tongue height but of identical duration may be perceived as being different in duration (and hence in length, if the perceived durations are on either side of a phoneme boundary), and that two vowels of different tongue height and of different duration may be perceived as being of equal duration (and length), both kinds of results indicating a compensatory perceptual process. J. M. Hombert (1976) compared the intrinsic differences occurring in natural speech to the differences in cross-over points emerging from

his test, and found that they were within the same range. From his experiment with isolated vowels of level Fo he concludes that there is a tendency for [ɑ+] to be judged higher in pitch than [i] or [u], but the perceived difference is smaller than the intrinsic difference. Both experiments thus point towards a compensatory process.

In a recent experiment Reinholt Petersen (1980) has found a certain degree of coarticulation between syllables with regard to inherent fundamental frequency level. In words of the type ['fimɑ+] and ['fimi] he first of all finds a general tendency for the Fo jump from the first syllable to the second to be of a greater magnitude when the second vowel is [i], attesting the expected intrinsic difference. Secondly, [ɑ+] in the second syllable may exhibit an upward shift in Fo as a coarticulatory effect from [i] of the first syllable, which indicates an articulatory compensatory process helping to maintain the difference in Fo level between the two syllables. This coarticulation is not, however, present for all subjects, and hence Reinholt Petersen concludes that the perceptual system is able to do without this articulatory compensation (the stress pattern: ˈ˳ being identified in spite of intrinsic differences). It thus seems reasonable to assume that a perceptual compensatory process is at hand both in the case of isolated vowels and in the case of stress perception based on fundamental frequency.

On the basis of Hombert's and Reinholt Petersen's results we may hypothesize that a perceptual compensatory process will make up for the "deficiencies" of Fo and duration as cues to stress which are due to intrinsic differences. Such a hypothesis would involve that the Fo interval between two syllables required for the identification of a given stress pattern must be larger when the second vowel is a high vowel than when it is a low vowel (everything else being equal), and similarly, that low vowels must be longer than high vowels to be perceived as exceeding the limit for unstressed vowels.

The above hypothesis may be verified if the shift in identification from stress on the first syllable to stress on the second syllable occurs at different magnitudes of the physical Fo interval between the two syllables, and/or at different physical durations for [i] and [ɑ+], respectively, in the second syllable.

II. EXPERIMENTAL DESIGN

A. TEST MATERIAL

1. TEST WORDS: *bidbig* [b̥id̥b̥ig̊], *bidbag* [b̥id̥b̥ɑ+g̊]

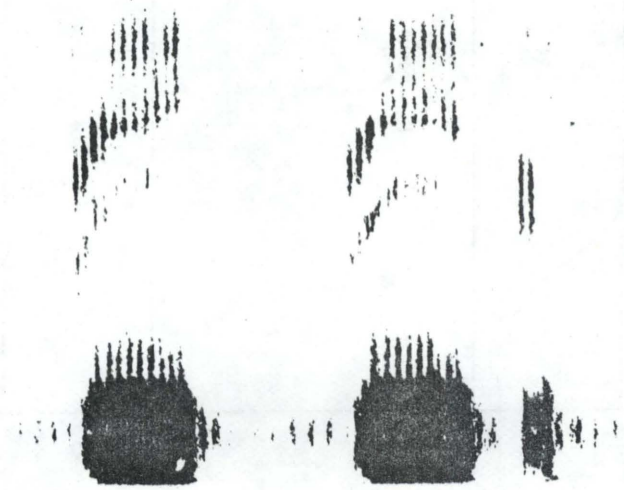
[i] and [ɑ+] represent the extremes of the intrinsic Fo and duration continuum. It is important that the vowels be perceived as speech sounds, and they were therefore embedded in disyllabic nonsense words. These nonsense words are structurally possible

in Danish. The surrounding consonants are unaspirated plosives (this type of consonant was preferred because with the synthesis procedure employed such consonants are easily given a natural sounding quality). The words were presented in isolation to avoid any influence on their perception from, say, a surrounding carrier sentence. They were synthesized on the parallel speech synthesizer of the Institute (cf. Rischel and Lyst-lund 1972). The synthesis was based on spectrograms of the two words as spoken by Danish listeners and on tables of Danish formant frequencies (Fischer-Jørgensen 1972, Holtse 1973). Figure 1 shows spectrograms of the resulting basic stimuli.

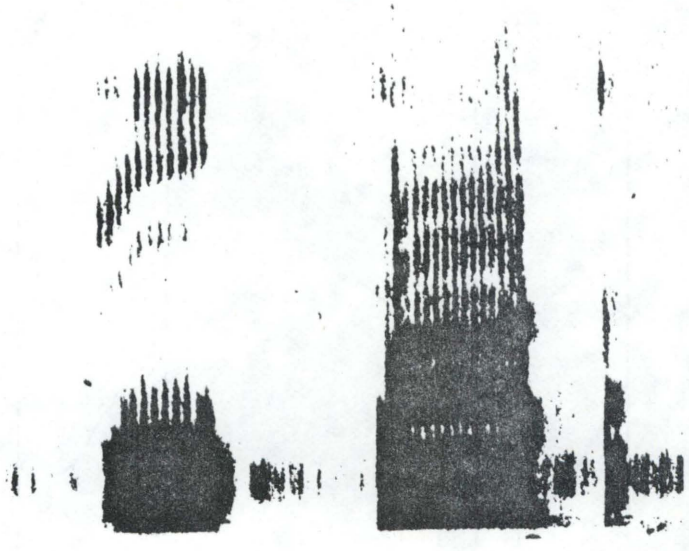
2. VARIATION OF FUNDAMENTAL FREQUENCY AND DURATION

a. Fundamental frequency. Figure 2a and 2b show Fo tracings of natural recordings of nonsense words similar to the test words of this experiment. In these recordings of real speech the two stress patterns depicted ($'_{\circ}$ = stress 1, and $_{\circ}{}'$ = stress 2) exhibit a difference in the direction as well as the slope of the Fo movement which, however, seems to be confined to the second syllable. The resemblance of the two stress patterns may appear puzzling but can be ascribed to the fact that we are dealing with one-word-utterances rendering any unstressed first syllable utterance initial, which accounts for the jump from such a syllable up to the stressed syllable. Stress 1 shows a jump to a higher level on the second syllable, as opposed to stress 2 which has an upward glide and a lower overall level in the second syllable. Due to its short average duration (10 cs) and small average range (20 Hz), this glide is probably below the threshold for audible glides (cf. Rossi 1971 and 't Hart 1977), i.e. it will be perceived as a level tone at a pitch corresponding to a frequency at 2/3 of the distance in time from vowel onset. The magnitude of the Fo jump can, therefore, be expected to be decisive for the identification of either stress 1 or stress 2 in this particular context.

For synthesizing the Fo contour, a line segment (a monotonous Fo function) of 20 cs's duration was superposed upon each syllable separately. Thus the first syllable could be kept constant and the second varied by moving its entire Fo line segment upwards. Both line segments had a slope of approximately 0.6 Hz per centisecond, far below the threshold for audible glides. This slope (falling in the first, and rising in the second syllable) was introduced to add naturalness to the stimuli. Subjective auditive criteria decided on the choice of absolute frequencies ranging from step 1: 85 Hz to step 6: 135 Hz. The first syllable was kept constant at 85 Hz. For a graphical display of the Fo variation and the frequency steps, see figure 3a.



[ɓiɠɓiɠ̊]



[ɓiɠɓɑ+ɠ̊]

Figure 1

Spectrograms of synthesized testwords.

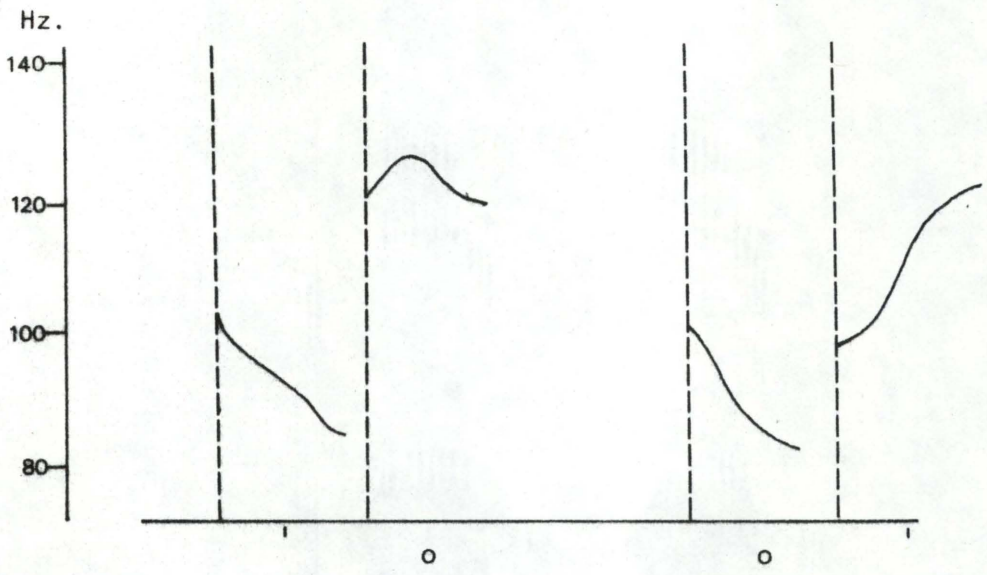


Figure 2a.

Avaraged tracings of 20 recordings of [b̥ɪɡb̥ɪg̊] and 20 of [b̥ɪɡb̥ɑ+g̊] , with the stresspatterns ' o (stress1) and o ' (stress 2). Line up point vowelstart.

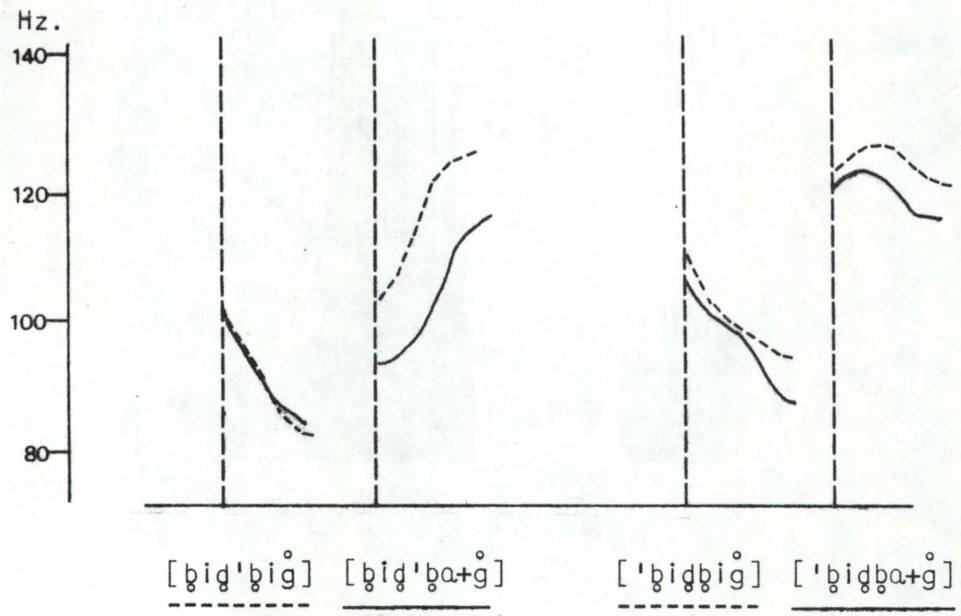


Figure 2b.

Averaged tracings of 20 recordings of the words [b̥ɪɡb̥ɪg̊] and [b̥ɪɡb̥ɑ+g] with either stress 1 or stress 2.

b. Duration The variation range of vowel duration was determined on the basis of average durations of the two vowels. It turned out that a stimulus with an [i] of a duration of 10 cs and an [ɑ+] of a duration of 13 cs had the desired natural effect both with regard to the intrinsic durational difference between the two vowels and the overall duration of the test word. 6 steps were placed around these values to provide a reasonable dispersion. The vowel of the second syllable could thus be varied in 8 steps, whereas [i] of the first syllable was kept constant at 10 cs. For graphical display of the variation of duration and the durational steps, see figure 3b.

In synthesizing the stimuli, the definition of "vowel duration" was based on the control of the voice source amplitude gate. The final stimuli were subject to auditive evaluation, according to which they were of an adequate duration without giving the impression of phonemically long vowels.

It is an essential limitation of this experiment that different criteria were applied to decide the Fo and duration steps. The variation of Fo was established on the basis of actual tracings of the two stress patterns in normal speech, whereas the variation of duration was intended only to ensure a reasonable dispersion around the normal average durations of the two vowels involved. There is no reason to assume that the Fo steps and the duration steps chosen are psychologically equidistant, and thus one cannot arrive at any final conclusions concerning the relative importance of various factors as a cue to stress in Danish on the basis of this experiment. The steps chosen do, however, make it possible to discuss the perceptual relevance of the intrinsic differences, which is the purpose of this test.

For the test every possible duration step could be combined with every possible Fo step for either [i] or [ɑ+], thus forming 96 stimuli types in all (8 x 6 x 2).

III. THE TEST

A. PREPARATIONS

Each stimulus was to be presented three times to the subjects. The three responses given per stimulus were subsequently averaged and thus reduced to one response (to be considered as a sort of random sampling). The three repetitions ought to ensure a reasonable degree of reliability in the results. A tape was recorded on a semiprofessional Revox recorder, 7½ ips. The stimuli were arranged in three randomized series, each comprising 96 stimuli (8x6 *bidbig* and 8x6 *bidbag*). On track No. 2 a pulse matching the start of every stimulus on track No. 1 was inserted in order to trigger a device for displaying numbers visually.

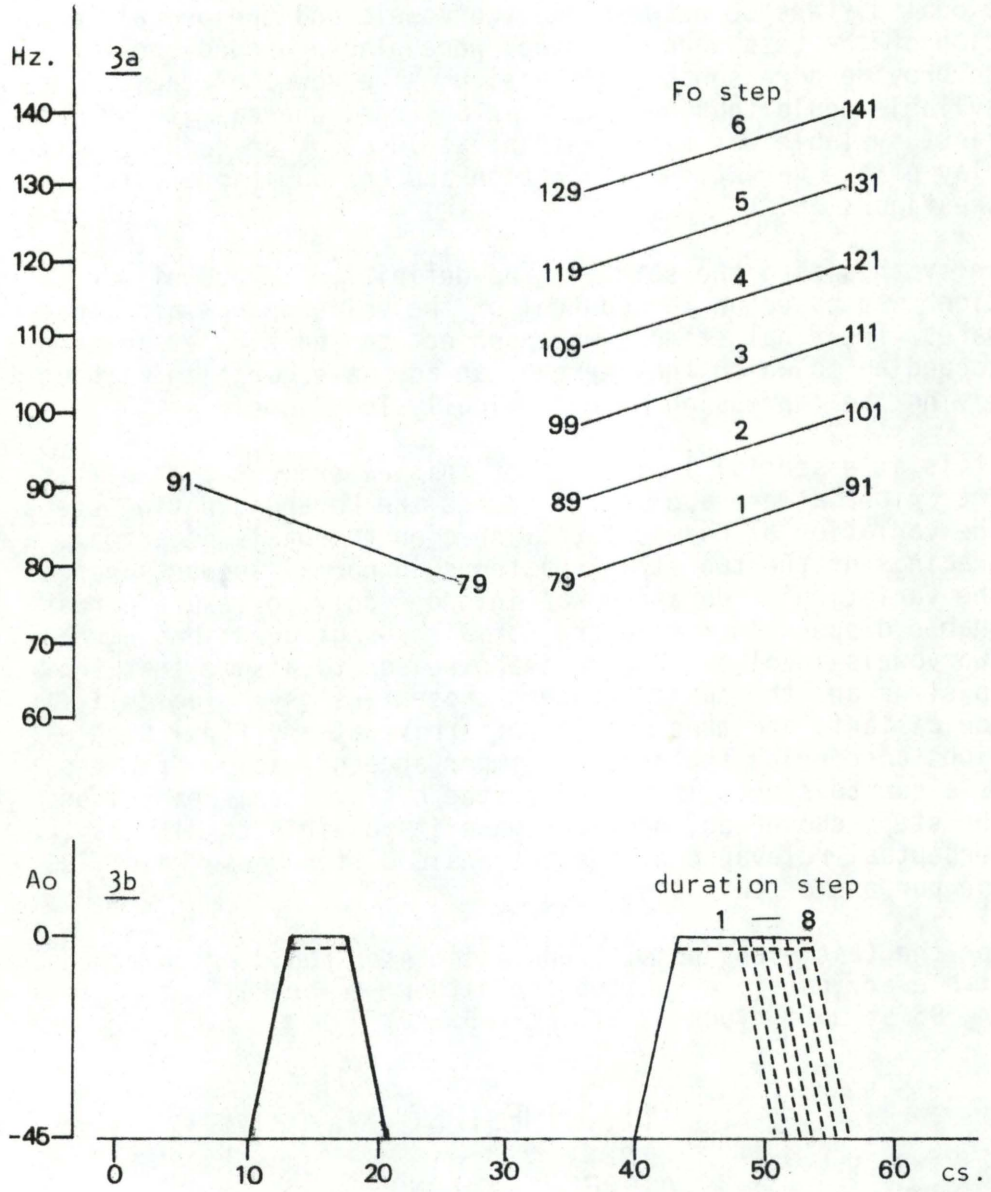


Figure 3a+b.

Variations of fundamental frequency and duration for the vowel of the second syllable, that of the first being kept constant. [ɑ+] 's intensity was slightly lowered to counteract the perceptual effect of the intrinsic intensity differences.

B. THE TEST

The test was run over three afternoon sessions holding 4, 6 and 10 subjects, respectively. The subjects were seated in a room covered with sound absorbing boards, and the stimuli were played back to them via loud speakers. The listeners were informed that they were going to hear the words *bidbig* and *bidbag* (presented in ortography), and they were instructed to note on their answer sheets whether they heard stress on the first or on the second syllable.

A TV monitor in front of the subjects displayed the stimulus numbers successively, enabling the subjects to check their progress.

All three tests were run in the same session with a 15 minutes break in between.

C. SUBJECTS

20 subjects took part in the test. As it was considered desirable to include naive listeners as well as trained phoneticians, the final group consisted of 10 phoneticians and 6 quasi-naive listeners (students attending a course in general phonetics for language students), all of whom were Danish, and in addition 4 foreign subjects who at that time attended the above mentioned course.

IV. RESULTS AND DISCUSSION

When first going through the answers it was found that 4 subjects had failed to perform the task, either because they did not follow the instructions or simply by failing to give answers. Each of the remaining 16 subjects had responded three times per stimulus, and simple majority of responses was used to decide on the preferred stress position for each stimulus (e.g. 2,2,1 = 2, or 1,1,2 = 2). This preferred stress position was from then on considered the answer. Any potential system in the responses could be read off immediately from the answer sheet. Nine out of the 16 subjects used the same criterion, while one subject showed a pattern that was very similar to that of the just-mentioned group, but reversed (see below). Two subjects (No. 11 + 12) displayed an apparently deviating and more complex pattern of response. The four foreign subjects had quite different linguistic backgrounds, and as the results for these subjects proved to be unsystematic between subjects as well as individually, this group is disregarded in the discussion of the results. The results for the "main group" (nine subjects) were pooled, while the results for the two subjects (No. 11 and 12) were left for separate treatment.

A. RESULTS FOR THE MAIN GROUP

The responses for the main group revealed a common principle for the nine subjects in question. They tended to switch from the identification of one stress pattern to the other at the same Fo step, and the influence of increased duration seems to have been of the same nature for all nine. The subjects showed agreement as to which stress pattern they associated with high and low Fo, respectively, on the second syllable. They agreed upon stress 1 at a comparatively high Fo on the second syllable, and on stress 2 at a comparatively low Fo. As already mentioned, subject No. 10 proved to have used the same differential criteria as the main group but favoured stress 1 responses at a low Fo on the second syllable, and stress 2 at a high Fo. Apart from this reversal, the results of this subject corresponded to those of the main group concerning the effect of the intrinsic differences. Figure 4a+b displays graphically the distribution of responses with the two vowel qualities pooled. The figure clearly reveals that a higher Fo in the second syllable causes a shift in identification, whereas increased duration has no such effect. As stated earlier, the steps in the two parameters, Fo and duration, cannot be said to be equidistant, and hence a definite answer to the question of primary cue to stress cannot be given; but we can conclude that variations of Fo in the second syllable can effect a shift in identification, and that increased duration of this syllable causes a decline in the number of stress 1 answers. (It might be argued that a further increase of duration could have led to a further decline and eventually to a shift in identification.)

In figures 5 and 6, vowel qualities are kept apart. Figure 5 shows the number of stress 1 responses as a function of increased fundamental frequency for each durational step, and conversely, figure 6 displays the number of stress 1 responses as a function of increased duration for each Fo step. For the sake of clarity, only stress 1 responses are plotted, and the 50% cross-over points are indicated by a vertical line. As an example, figure 5, graph 1 (dur 0) shows on the vertical axis how many stress 1 responses (out of a maximum of 9) that were given to stimuli with a vowel duration (second syllable) of step 0. The number of responses for each fundamental frequency step can be read off the horizontal axis (1-6). Thus it appears from this graph that when presented with e.g. *bidbag* dur. step 0 (the shortest stimulus) combined with Fo step 1 (the lowest Fo), 5 subjects judged the stimulus to have stress on the first syllable.

1. INTRINSIC Fo

To further investigate the difference between [i] and [ɑ+] with regard to the threshold value for the identification of one or the other stress pattern as revealed in figure 5, the 50% cross-over points were calculated for all graphs by linear interpolation. The values are plotted in figure 7. From this

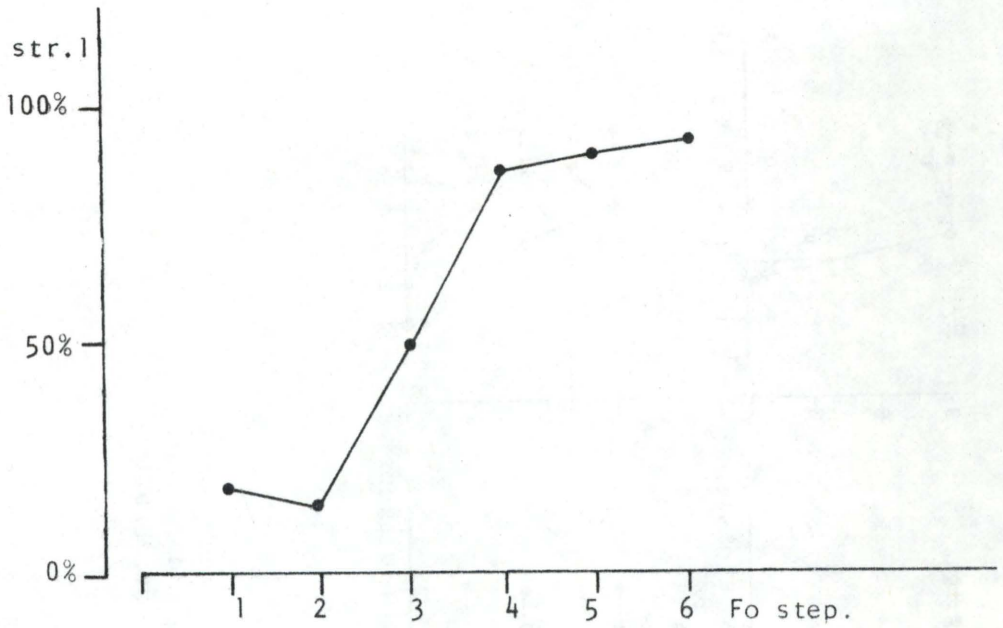


Figure 4a.

Per cent stress 1 responses given by the main group (9 subjects) as a function of increased Fo. The two vowels and all possible duration steps pooled.

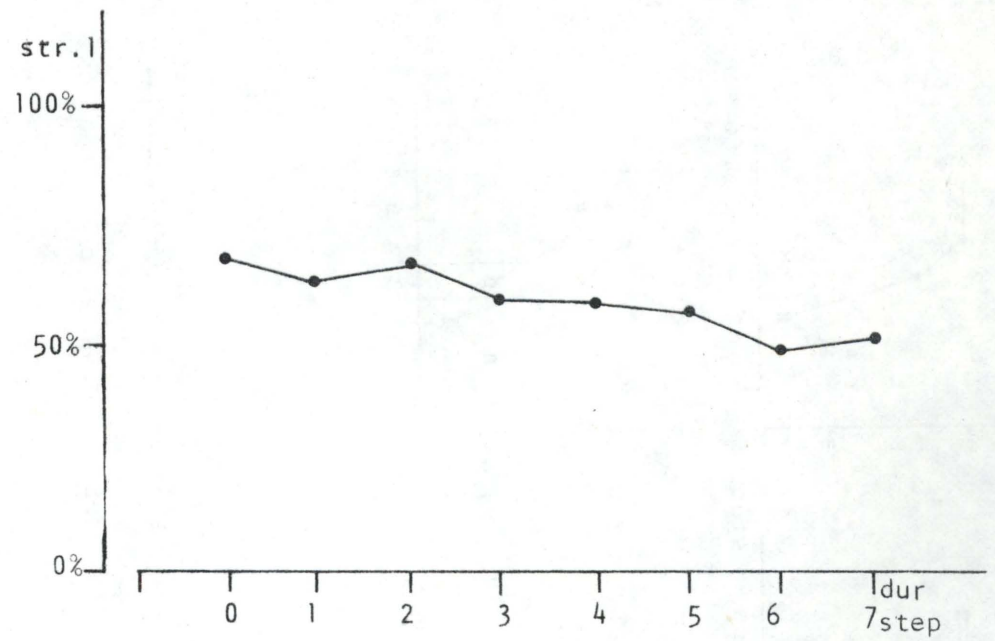


Figure 4b.

Per cent stress 1 responses given by the main group (9 subjects) as a function of increased duration. The two vowels and all possible Fo steps pooled.

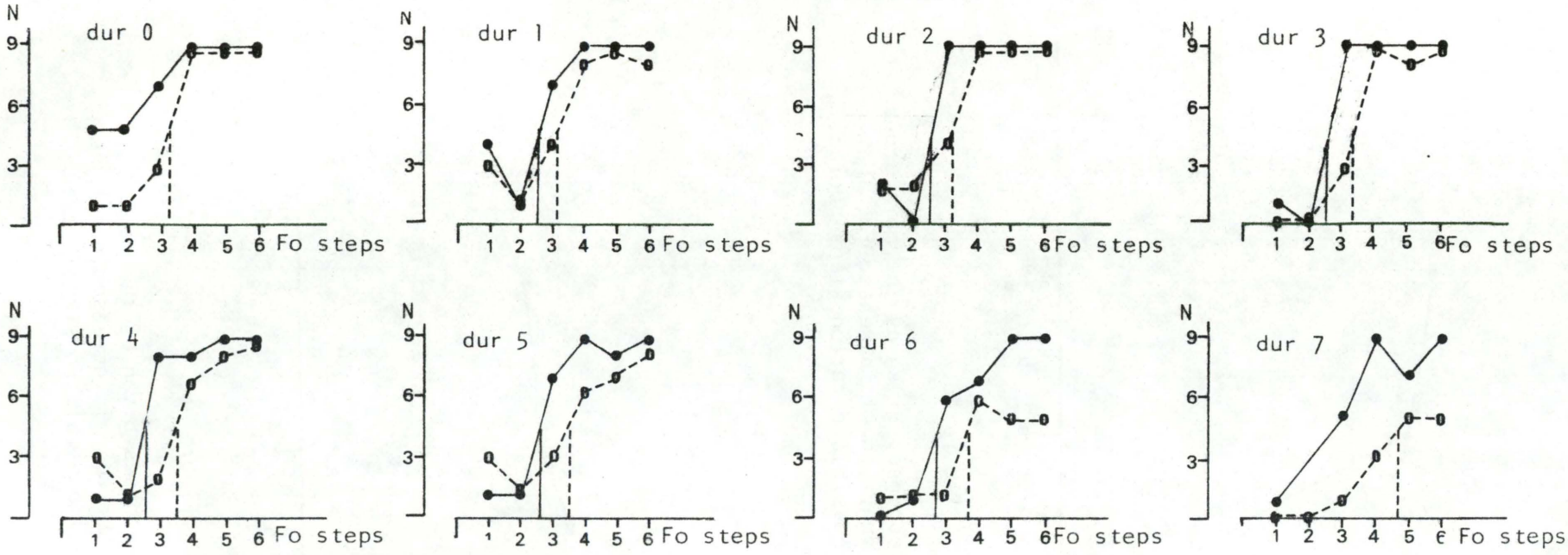


Figure 5.

Number of stress 1 responses for the main group (9 subjects) as a function of increasing Fo at each of the eight duration steps,------ *bidbig* ———— *bidbag*. In the case of duration step 7 the number of stress 1 responses for Fo step 2 is left out due to an error in the test material.

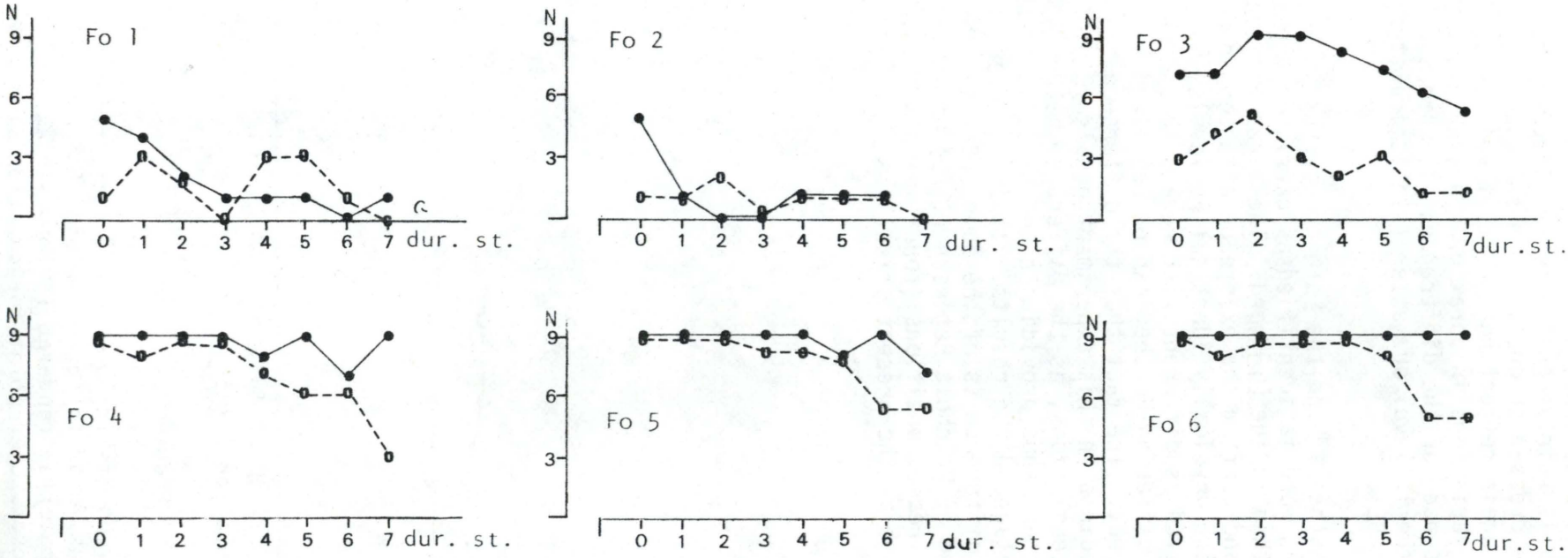


Figure 6.

Number of stress 1 responses for the main group (9 subjects) as a function of increasing duration at each of the six Fo steps, -------- *bidbig* ——— *bidbag*. In the case of Fo step 2 the number of stress 1 responses for duration step 7 is left out due to an error in the test material.

figure it appears that the distance between the [i] and the [ɑ+] cross-over points is fairly constant over different vowel durations and that the cross-over points form a horizontal line for both vowels, again reflecting the relatively insignificant influence of variations in duration. A one-tailed T-test proved significance for the difference, its direction, and its magnitude at the 1% level or better (statistical treatment based on Siegel 1956).

The difference between the [i] and the [ɑ+] cross-over points indicates that the [ɑ+] word is identified as carrying stress 1 at lower Fo levels than is the [i] word. These results conform to expectations and confirm the existence of a compensatory process. Even with physically identical Fo levels, [i] and [ɑ+] can be perceived as different with regard to stress type; with physically differing Fo they can be perceived as identical in this respect. The fact that the difference between the cross-over points in this experiment equals 10 Hz does not warrant any conclusions, as the difference between stimuli is 10 Hz per step, thus providing a quantization which obviously may have influenced the results. It is, however, interesting that this difference is of the same order of magnitude as the one found by Reinholt Petersen (1979) as an average for stressed/unstressed positions (for a voice within the same frequency range as the present stimuli).

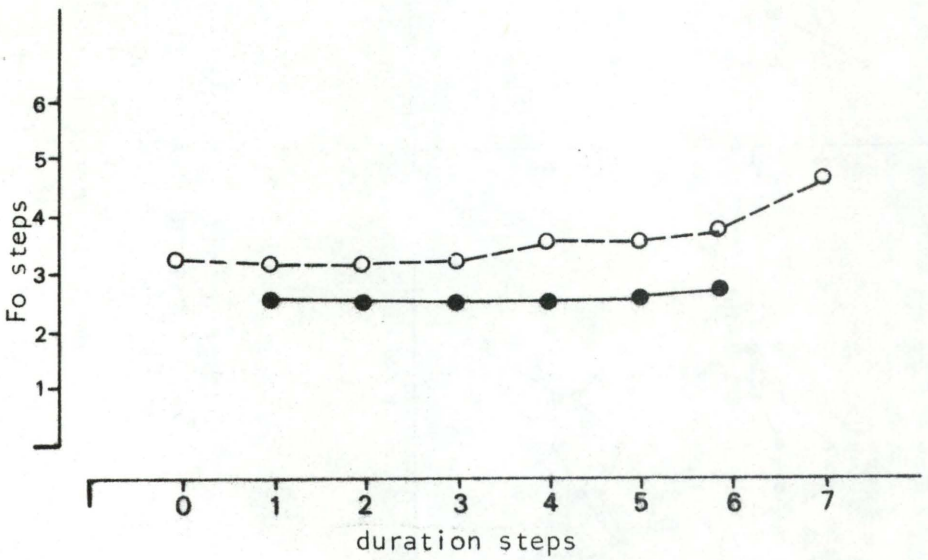


Figure 7.

50 per cent cross-over-points for *ɑ*——— and *i* --------
No cross-over-point was found for duration step 0, and an error in the test material rendered it impossible to calculate the 50% cross-over-point for duration step 7.

2. INTRINSIC DURATION

As the graphs in figure 6 do not display a shift of identification but merely a decline in the number of stress 1 responses as a function of increased duration, no cross-over points can be calculated. Instead we must search for the potential [i]/[ɑ+] difference in the graphs displaying the lowest and the highest fundamental frequency steps. If one examines the low Fo steps which strongly favour stress 2 responses, the graphs show that the shortest durations cause more stress 1 responses for [ɑ+] than for [i]. Some subjects seem to have found these short durations altogether too short for the second syllable to carry stress, more often so with [ɑ+] than with [i]. In other words, a perceptual compensatory process is observable also with regard to duration.

An [i]/[ɑ+] difference appears again in the graphs for the highest Fo steps, which strongly favour stress 1 responses: whereas increased duration with Fo step 4 and higher causes a decline in the number of stress 1 responses for [i], such a change in duration does not influence the number of stress 1 responses for [ɑ+]. This suggests that since an [i] is perceived as being longer than an [ɑ+] of the same physical duration, it does not take as long a duration to make [i] appear too long to be unstressed as is the case with [ɑ+]. Thus these data also give support to the expected compensatory process.

The absence of cross-over points precludes a comparison between physical and psychological difference in the case of duration. It was found that the duration steps chosen for this experiment were too few and covered too small a range to exceed the duration acceptable for an unstressed vowel, which would otherwise have caused a decline in the number of stress 1 responses for [ɑ+] as well. As it is, one might imagine that a further increase of duration would have brought about a downward slope in the [ɑ+] curve, perhaps starting, as it does for [i], about 3 steps from the "normal duration" of the vowel of the second syllable relative to the [i] of the first syllable, i.e. three steps from step 5. It might, however, prove futile to search for durational limits for unstressed versus stressed vowels, considering that not all subjects judged [i] at duration step 4 and 5 too long to be unstressed. The limits we are looking for may turn out to be of a highly individual character, so that one cannot expect to reach unanimity, as was the case for the Fo jump. It suffices to conclude that the perceptual compensation for intrinsic durational differences is clearly detectable even in this rather restricted material.

B. RESULTS FOR SUBJECTS 11 AND 12

The results for these subjects are shown in figures 8 and 9. The subjects appear to have used duration as a cue to stress when presented with short durations in the second syllable (favouring stress 1 responses), while the Fo jump becomes dominant as a stress cue (favouring either stress 1 or stress 2 responses depending on its magnitude) as duration reaches a

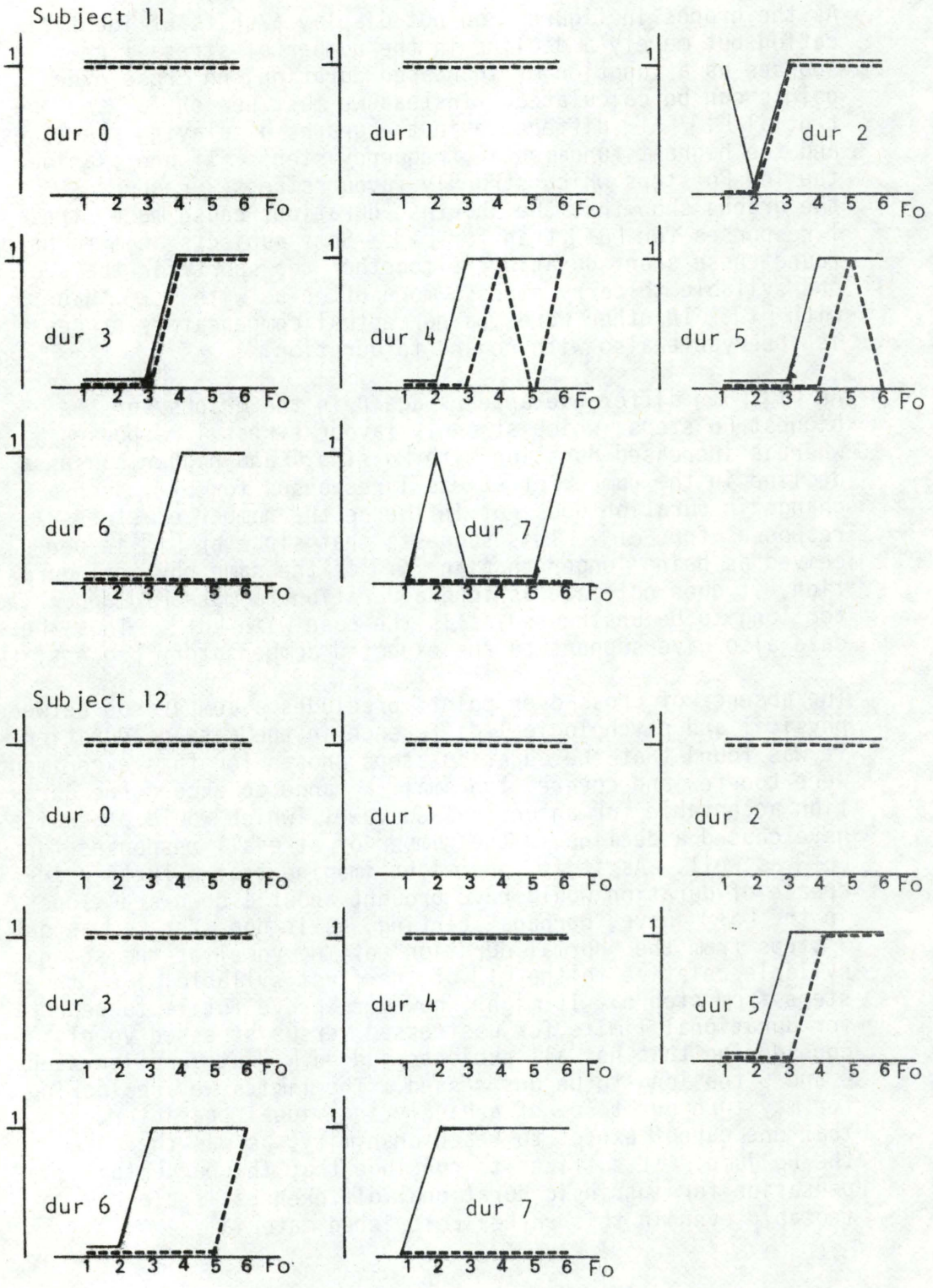


Figure 8.

Stress 1 responses for subjects no. 11 and 12 as a function of increasing Fo at each of the eight duration steps, ------ *bidbig* ——— *bidbag*.

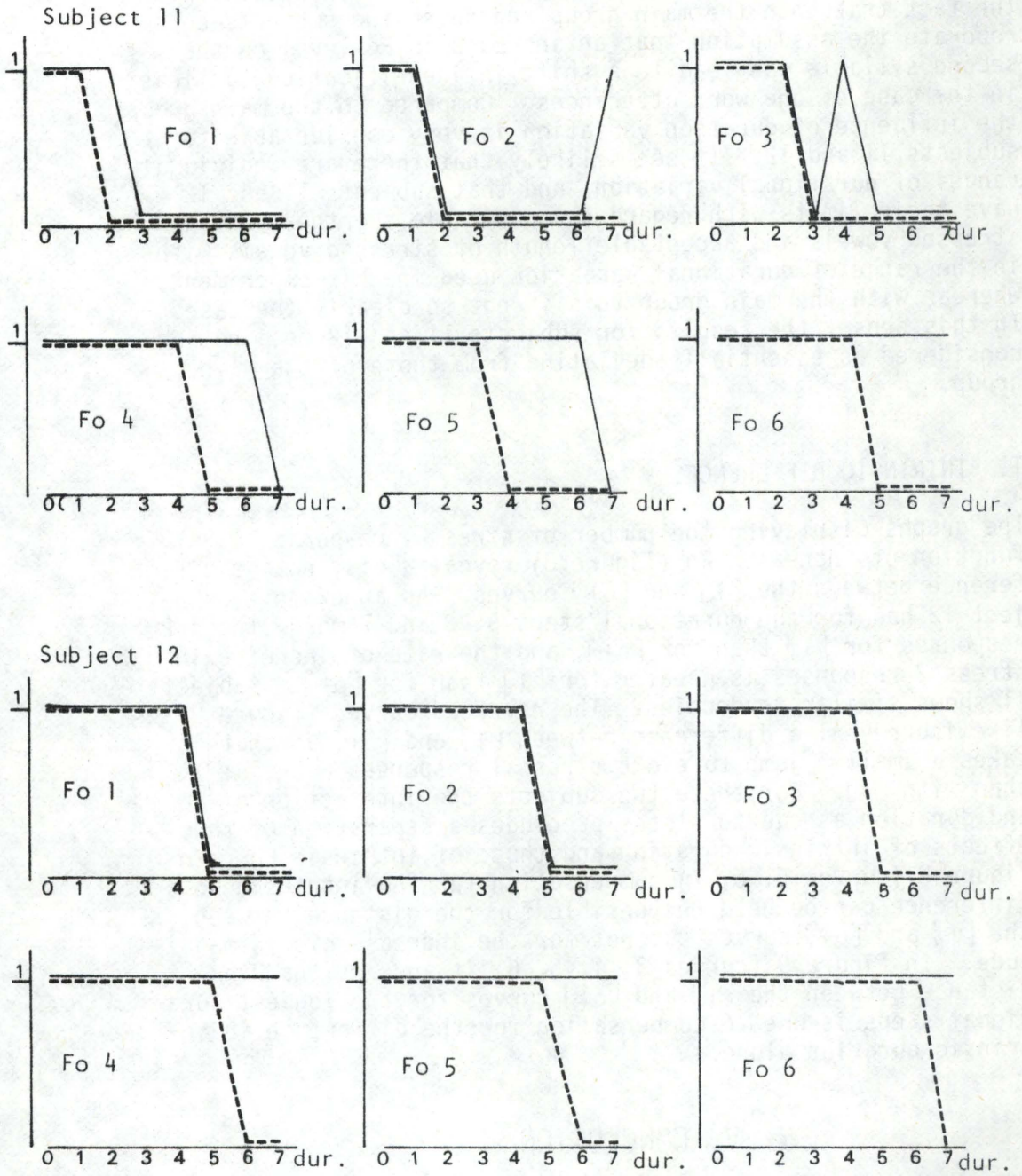


Figure 9.

Stress 1 responses for the subjects no. 11 and 12 as a function of increasing duration at each of the six Fo steps, -------- *bidbig* ——— *bidbag*.

certain critical point. It seems, however, worth pointing to the fact that both the main group and these two subjects corroborate the assumption that an increase in Fo level on the second syllable can lead to a shift in identification, at least in the case of one word utterances. Compared to the main group the influence of duration variation is very considerable for subjects 11 and 12. It seems likely that there are individual ranges of durational variation, and that subjects 11 and 12 have their limits with regard to acceptable shortness of unstressed vowels and acceptable length of stressed vowels within the range of durational variation used in this experiment, whereas with the main group this is not so clearly the case. In this sense, the results for subjects 11 and 12 need not be considered as essentially deviating from those of the main group.

1. INTRINSIC DIFFERENCES

The graphs displaying the number of stress 1 responses as a function of increased Fo (figure 8) reveal a distinctive difference between the [i] and [ɑ+] curves. As an example, subject 12 has for the durational steps 5, 6 and 7 more stress 2 responses for [i] than for [ɑ+], and the rate of increase in stress 2 responses is greater for [i] than for [ɑ+]. Subject 11 shows similar tendencies. The reversed curves (figure 9) likewise reveal a difference between [i] and [ɑ+] in that it takes a smaller jump to evoke stress 1 responses with [ɑ+] than with [i]. For these two subjects the interaction of Fo and duration as cue to stress precludes a separation of the effects of intrinsic duration and those of intrinsic Fo. In figure 8 (curves 5, 6, 7) compensation for the intrinsic Fo difference can be held responsible for the distance between the [i] and [ɑ+] curves but not for the increase of its magnitude. In figure 9 (curves 3, 4, 5, 6) it appears that the distance between the [i] and [ɑ+] curves for the longest durational steps is due to compensation for the difference in intrinsic duration alone.

V. CONCLUSION

This pilot experiment has yielded results which offer probable answers to the questions posed in the introduction, and thus it seems worth while (with relevant extensions of the material) to perform future experiments of a similar nature.

The results from the main group as well as from subjects 11 and 12 strongly suggest the existence of a perceptual compensation for intrinsic differences, as was hypothesized. A shift in identification from stress on the first syllable to stress on the second syllable occurs at different magnitudes of the physical Fo interval. [ɑ+] is perceived as being said on a higher pitch than [i] at physically the same Fo level, and consequently the shift in identification from stress on the first syllable to stress on the second syllable (which depends upon an

Fo jump of a certain magnitude) occurs at a smaller Fo step for [ɑ+] than for [i]. The range of durational variation applied in this experiment did not suffice to bring about an actual shift of identification. The results do, however, clearly indicate a perceptual compensation for the intrinsic duration difference as well. [i] is being perceived as longer than [ɑ+] of physically identical duration, and accordingly the limit at which the vowel of the second syllable is judged too long to be unstressed occurs at a shorter duration step for [i] than for [ɑ+], and [i] is judged long enough to carry stress at an earlier duration step than is [ɑ+]. These limits of duration for unstressed/stressed vowels seem to be of a highly individual character, but more experiments are called for, comprising a wider range of variation in duration.

The results of this experiment agree with Reinholt Petersen's (1974) findings concerning intrinsic duration and Hombert's (1976) results concerning intrinsic fundamental frequency, in affirming the existence of perceptual compensation. With reservations made for a certain bias due to the steps chosen, the difference between the cross-over points (the perceptual compensation) seems to be of a magnitude similar to the one found by Reinholt Petersen. The fact that Reinholt Petersen found instances in which a clear identification was made in spite of absence of a coarticulation (in terms of intrinsic Fo levels) between syllables, can be explained from the perceptual compensation suggested by this experiment.

It may then be regarded as an established fact that the perception of fundamental frequency and duration (at least at syllable and word level), and thereby the perception and identification of linguistic categories pertaining to these factors, is influenced by properties of the acoustic signal which convey information on vowel quality.

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