The effects of distinctive features on the perception of vowel categories

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ABSTRACT

The effects of formant movements related to the number of distinctive features on vowel discrimination of Finnish and Spanish-speaking subjects were studied by measuring response speed and accuracy. Two Finnish vowel continua, which had different formant pattern changes, were compared; the /æ – ø/ continuum had parallel formant frequency movements (F1 and F2 frequencies lowered) while in the /æ – e/ continuum formants changed to the opposite directions. For Spanish subjects both continua had a similar phonemic structure (i.e., /e/ and /ø/) are both allophones of /e/ in Spanish.

It was found that a parallel movement in F1 and F2 was perceived faster and more accurately than their movements in the opposite direction. This finding was independent of the subjects' language experience. However, the Spanish-speaking subjects had overall slower RTs than the Finnish speaking subjects.

1. INTRODUCTION

The role of formant movement directions on the perception of vowels has been discussed mainly on the basis of difference limen (DL) measurements. Flanagan [1] showed that the rising second formant (F2) frequency was perceived more accurately than the lowering F2. In contrast, Nord & Svantelius [2] presented opposite results. According to them, the lowering F2 had a smaller DL than the rising F2. Hawks [3] studied the perception of formant frequencies by changing F1 and F2 simultaneously. He found that parallel movements of the formant frequencies had a lower DL than the opposite movement direction. However, these studies do not take into account possible effects of language experience of the listeners on the discrimination performance. It can be assumed that the auditory discrimination is affected by such phonemic factors as, e.g., the number of distinctive features changing on the vowel continuum in the given language.

For the present study, two continua were chosen to investigate vowel discrimination. The first continuum, Finnish /æ – e/, had an opposite formant pattern change, in which the F1 frequency decreases and the F2 increases. The second continuum, Finnish /æ – ø/, had a parallel formant pattern (both F1 and F2 frequencies decreased). In terms of distinctive features, the /æ – e/ continuum endpoint vowels differed by one feature, vowel height, while in the /æ – ø/ continuum, besides height, also roundedness was changed. To control for the effects of language experience, we used Spanish-speaking subjects who are unfamiliar with rounded/unrounded difference in front vowels. The end point vowels (/e/, /ø/) of both continua are allophones of /e/ in Spanish.

2. METHODS

2.1 Subjects, Stimuli and Procedure

The Finnish speaking subjects were 15 students at the University of Turku (mean age 23.6 years, range 20 – 25 years, all female, two left-handed). The Spanish-speaking subject group consisted of seven exchange students (mean age 23,5 years, range 20 – 26 years, two females, one left-handed)

The stimuli for the discrimination test were chosen on the basis of an identification test (see Table 1 for formant values). The standard stimulus /æ/ and three deviating stimuli (33, 66, 100 mel in the Euclidean space) were presented in an oddball paradigm. Two pseudorandomized blocks consisted of 275 (p = 0,82) standard stimuli and 20 (p = 0,06) per each deviant stimuli. The subjects were asked to push a button as fast as possible when they heard a sound, which deviated from the stream of the standard stimuli. The session took about 20 minutes.

Table 1. The formant values (Hz) of the stimuli in Experiment 1.

Cont.	/æ –e/				/æ – ø/			
Stim.	stand	Dev.1	Dev. 2	Dev.3	stand.	Dev. 1	Dev. 2	Dev. 3
F1	636	601	566	532	636	601	566	532
F2	1773	1808	1843	1879	1739	1706	1672	1640
F3	2474	2474	2474	2474	2474	2474	2474	2474

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3. RESULTS

The results of the Finnish-speaking subjects are presented in Table 2 (upper part). The overall error rate was 2,5 % and false alarm rate 0,96 %. The miss rate for the deviants was 4,0 %. RTs longer or shorter than three standard deviations from the individual means (comprising a total of 0,5 % of the responses) were excluded from further analysis. The individual miss rates were subjected to repeated measures Analysis of Variance (ANOVA). The factors were Continuum type (/æ – e/, /æ – ø/) and Acoustic distance of the deviant stimuli (33, 66, 100 mels). Acoustic distance had a significant effect on the miss rate ($F(2,18) = 19{,}277$ $p<0.01$), the longer the acoustic distance, the lower the miss rate.

The individual mean RTs for each condition were subjected to ANOVA using the same model as for the miss rates. The RTs reflected significantly the acoustic distance between stimuli ($F(2,26) = 55.292$ $p < 0{,}001$). The shortest acoustic difference (33 mel) was perceived significantly slower (505 ms) than the 66 mel (432 ms, $p < 0{,}001$) and the 100 mel difference (428 ms, $p < 0{,}001$). More importantly, the Continuum type had a significant effect on the RTs ($F(1,13) = 21{,}441$ $p < 0{,}001$), which was due to the fact that the /æ – ø/ continuum was perceived faster (474 ms) than the corresponding /æ – e/ continuum (436 ms).

The results of the Spanish-speaking subjects are presented in Table 2 (lower part). The overall error rate was 7,5 % and false alarm rate 1,03 %. The miss rate for deviants was 16,5 %. One subject was excluded from the analysis because of the lack of sufficient data in one condition. The RTs longer or shorter than three standard deviations from the individual means (comprising a total of 2,0 % of the responses) were discarded from further analysis. The repeated measures ANOVA on miss rates showed a significant effect of Acoustic distance ($F(2, 12) = 32{,}450$ $p < 0.01$); the longer the acoustic distance the lower the miss rate. Also, the main effect of Continuum type was significant ($F(1, 6) = 6{,}503$ $p = 0.43$) indicating that the parallel formant movements were perceived more accurately (20,0%) than the movements in opposite directions (13,0%).

The individual mean RTs of the Spanish-speaking subjects for each condition were subjected to ANOVA, which showed a main effect of Acoustic distance ($F(2,12) = 37{,}437$ $p < 0.001$). The shortest acoustic distance (33 mel) was perceived significantly slower (604 ms) than the longer acoustic distances (66 mel, 513 ms; 100 mel, 497 ms, both p's < 0.001). The main effect of Continuum type was also significant ($F(1,6) = 8{,}617$, $p = 0.026$). The /æ – e/ continuum was perceived slower (558 ms) than the /æ – ø/ continuum (518 ms).

Finally, to directly compare the discrimination performance of Finnish and Spanish-speaking subjects an additional ANOVA was run using Subject group as a between-subject factor. The results showed a significant difference in the miss rates between the subject groups ($F(1,18) = 22{,}153$, $p < 0{,}001$). The overall miss rate of the Spanish subjects was 16,5% compared to 4 % of the Finnish subjects. The interaction between Subject group and Acoustic distance was also significant ($F(2,36) = 23{,}036$, $p < 0{,}001$). The Spanish subjects made more misses in the shorter acoustic distances compared to the Finnish subjects. Finally, the Spanish subjects made more errors on the /æ – e/ continuum compared to the /æ – ø/ continuum resulting in a significant interaction between Subject group and Continuum type ($F(1,19) = 5{,}421$, $p = 0.031$).

Comparison of the RTs showed that the Spanish subjects were slower (538 ms) than the Finnish subjects (455 ms) in overall response speed ($F(1,19) = 9{,}688$, $p = 0{,}006$). However, the factor Group did not interact with Continuum type nor Acoustic distance.

Table 2. RTs and miss rates for the Finnish and Spanish-speaking subjects in the discrimination task on the two vowel continua.

Finnish subjects						
	/æ – e/ continuum			/æ – ø/ continuum		
Deviant	1	2	3	1	2	3
Mean RT (s.d.)	528 (63)	456 (63)	439 (65)	483 (65)	408 (53)	417 (54)
Miss rate	13,2	1,1	0	9,3	0,7	0
Spanish subjects						
	/æ – e/ continuum			/æ – ø/ continuum		
Deviant	1	2	3	1	2	3
Mean RT (s.d.)	625 (102)	534 (70)	517 (60)	582 (80)	493 (57)	478 (59)
Miss rate	48,5	10	1,5	36,0	2,1	0,7

4. DISCUSSION AND CONCLUSIONS

We studied whether discrimination speed and accuracy was affected either by the phonemic structure of the language or the acoustic pattern reflected in the direction of formant frequency movements. Two vowel continua (/æ – ø/ and /æ – e/) had the same Euclidean acoustic distance in F1 and F2, but different, parallel or opposite, formant pattern change. Furthermore, in Finnish, the continua also differed phonemically so that the /æ – ø/ endpoint vowels differed more in terms of distinctive features compared to /æ – e/. In Spanish, there is no such distinction.

The results showed that the /æ – ø/ continuum with the parallel formant movements was perceived significantly faster than the /æ – e/ continuum with the opposite formant movements. This finding resembles earlier results obtained by Hawks [3], and Nord and Svantelius [2], who also suggested that language specific factors might affect formant discrimination. Our results do not support this claim, because both Finnish and Spanish-speaking subjects demonstrated a similar performance pattern regardless of the different phonemic status of the two continua in Finnish and Spanish.

The only language dependent result was the slower overall response speed and less accurate discrimination performance of the Spanish subjects as compared to the Finnish subjects. This can be attributed to the fact the stimuli were synthesized using typical values for Finnish vowels, and were thus less familiar for the Spanish subjects.

The perception of auditory features relevant to the discrimination of vowel seems not to be based on the labeling of stimuli. Our results suggest that the movements in the formant pattern (possibly reflecting differences between some invariant *auditory* attributes such as the center of gravity of the spectrum [5]) may be perceived independently from the phonemic structure of the vowel inventory.

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