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DEVELOPMENTAL CHANGES IN THE IDENTIFICATION OF A STOP CONSONANTS CONTINUUM

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At age 6 the ability to perceive all phonemic distinctions in natural language is about completely acquired, but some more complex phoneme processing capacities are still developing. We wondered whether there would also be a further development in perception tasks in which the ceiling effect is eliminated by greater perceptual difficulty. In this study synthetic speech stimuli on a stop consonant continuum from /p/ to /t/ were presented in identification tasks. Children at the start and near the and of first grade, third- and fourth-grade children either dyslexic, poorly performing, well performing or in special education, and adults were compared with respect to the slope and the phoneme boundary of their identification curves. It was found that, in general, with increasing age, the slope tends to become steeper, and the phoneme boundary is located at higher second formant values. Moreover, many of the youngest children could not consistently identify some stimuli.

It is often implicitly accepted that normal children of 3 or 4 years old are able to perceive all phonemic distinctions of their language. The most convincing and simplest argument for this is that they can produce all phonemes. So they should also be able to hear the phonemic differences they produce. Jakobson (1941) proposed a universal acquisition order for production, and e.g. Garnica (1973) collected similar data for perception. Garnica's subjects ranged in age from 17 to 22 months, as a pilot-study had shown older children could already perceive most of the phonemic distinctions.

At the same time, a different line of research suggested that even at the age of 6 these phoneme distinctions are far from perfect (e.g. Wepman, 1958; Oakland, 1969). These studies used the minimal contrast paradigm with verbal responses. A minimal contrast pair consists of two syllables or words differing in only one phoneme (usually the initial one, e.g. 'cat-rat'). Such pairs and pairs with identical stimuli alternate randomly, and the subject is to respond verbally whether he judges the utterances in each pair to be same or different.

Many children starting elementary reading instruction make frequent errors on such tests (e.g. the Wepman Auditory Discrimination Test, Wepman, 1958). Kamil and Rudgeair (1972) criticized this minimal contrast methodology and showed that nonperceptual task demands play an important role. Wallach, Wallach, Dozier and Kaplan (1977) eliminated these disturbing factors whith a procedure in which the child was to respond by pointing to one of two pictures carefully associated with the minimally contrasted words. Now even socially disadvantaged children of 6 years old made only very few errors. Only one out of 76 children of low-income families made more than one error on a 16-item test. Thus, the mere discrimination of phonemes is very close to perfect at the age of 6. The usual verbal response with the labels 'same' or 'different' is the source of the majority of the errors.

However, in educational circles it is widely accepted that at the age reading instruction starts, several phoneme-processing capacities are still developing (e.g. phoneme segmentation: Liberman, Shankweiler, Fischer & Carter, 1974; phoneme recognition: Wallach et al., 1977; sound blending: Helfgott, 1976). Often high correlations between early reading achievement and phoneme tasks are observed. Hence, a certain level of development of these capacities is sometimes viewed as a prerequisite for reading. These capacities are usually thought of to be in the cognitive realm. We might ask whether there is also a perceptual component in this later development. The technology of computer speech allows the framing of more difficult phoneme perception tasks. So the ceiling effect in natural speech tasks measuring pure discrimination may be eliminated.

Specifically, the research paradigm of the stop consonants continuum seems promising for this purpose. A series of stimuli is produced by varying one or two acoustic parameters for synthesis and keeping all other constant. Thus a continuum is produced in which at the one end a certain phoneme is heard, and at the other end another phoneme. The typical finding in identification tasks with stop consonants is the sudden transition from one phoneme to the other. So there is a very sharp phoneme boundary. The identification curve has a steep slope. Moreover, in discrimination tasks, pairs of such stimuli can only be discriminated if they are at opposite sides of the phoneme boundary. Even very small acoustic differences can be detected around the phoneme boundary, whereas much larger differences between stimuli belonging to the same phoneme category are not detectable. This phenomenon is called categorical perception and it is specific for stop consonants. With vowels, for instance, the transition is gradual, there is no sharp phoneme boundary and equal steps along vowel continua are about equally well discriminated.

Stop consonants can be categorised along the dimensions of voicing and place of articulation. The voiced-voiceless distinction (/b/, /d/, /g/ versus /p/, /t/, /k/) is effected, in articulatory terms, by the time lag between the release burst of the stop and the onset of voicing (vibration of the vocal cords). This distinction can be cued in synthetic sounds without release burst by varying the relative onset times of the first and the other formants (Lisker & Abramson, 1970). The place of articulation (bilabial for /p/ and /b/, postdental for /t/ and /d/, velar for /k/ and /g/) is sufficiently cued by the second (and third) formant transition (Liberman, Cooper, Shankweiler & Studdert-Kennedy, 1967). These conclusions are very well documented for adult perception of synthetic speech. Infants have also been a group of considerable research interest. With heart-rate habituation-dishabituation and high-amplitude sucking procedures it was demonstrated that infants can discriminate between very small acoustic differences in speech sounds. With stop consonants both the voicing and place distinctions are, in some form, present at a very early age (2 or 3 months). Moreover the critical values along these dimensions, around which discrimination is best, correspond with adult phoneme boundaries (Eimas & Tartter, 1979).

The intermediate ages received much less attention by synthetic speech researchers. Wolf (1973) presented stop consonants varying along the voicing dimension to groups of children with mean ages of 5;4 and 7;5. She found that they perceived these sounds very much like adults do. The phoneme transition was very sudden and occurred at the same acoustic value as with adults. Brandt and Rosen (1980) presented voicing and place continua to somewhat older (10;5) normal and dyslexic children. They concluded that for both groups the perception is categorical too. The phoneme boundaries on their place of articulation continua (/ba/–/da/–/ga/) corresponded very well with adult data on the same stimuli (Blumstein, Stevens & Nigro, 1977). Godfrey, Syrdal-Lasky, Millay and Knox (1981) collected similar data for dyslexic and normal control children (age 7;4 to 15;1). In identification tests on /ba/–/da/ and /da/–/ga/ continua these groups did not differ relative to their phoneme boundaries. But the dyslexic group was significantly less consistent in the identification. Their phoneme transitions were less sudden than their controls's, so the slope of their identification curves was less steep. The steepness of the slope of an identification curve clearly is a measure of speech perceptual capacity that cannot be obtained with natural speech. Although natural speech sounds may be easily identified and discriminated at some age by all children, there might remain differences in the sharpness of these perceptions and in the stability or quality of the resulting representations. Such differences might underlie differences in more complex natural speech tasks that require phoneme processing (e.g. reading). Therefore, we believe there is a need for more data on speech perception at the ages intermediate between infancy and adulthood. The classical identification task permitting phoneme boundary and slope calculations seems a good starting point.

Using identification tasks, we collected some data on the development of the perception of a place of articulation continuum (/pə/–/tə/). These data were gathered in separate studies specially concerned with the relation between reading ability and speech perception capacities. In a first study first-grade children were administered the speech perception tasks in the beginning and at the end of the schoolyear. Several reading measures were obtained as well. In a second study the same speech perception tasks were used with somewhat older subjects. Dyslexic children were compared with two control groups. One performed poorly at school and was matched with the dyslexic group in verbal IQ. The second group performed very well at school and had a much higher verbal IQ. A group of special education children of the same age was also included. Finally, the same tests were presented to first-year psychology students. We shall present here the results on the identification tasks of these several groups, only referring to reading data if such is convenient for the discussion. With the Godfrey et al. (1981) results in mind, we look especially for slope differences between groups. As we found nobody reporting systematic differences in phoneme boundaries, we do not expect them in our study either.

METHOD

Subjects

Forty-eight children for the first time in first grade served as our youngest subjects. Six boys and six girls were randomly selected among the Flemish pupils of 4 first grades in schools with predominantly middle-class children. At the time of their first testing (September) their mean age was 6;2. Eight months later (May) all subjects were tested a second time. The next 3 groups each consist of 5 third grade and 8 fourth grade children (9 boys and 4 girls). The dyslexic group contains children diagnosed as developmentally dyslexic and treated as out-patients in a rehabilitation centre. It was controlled whether these subjects met the criteria Vellutino (1979) proposed for research on dyslexia. So, the reading retardation must clearly be apparent at the level of individual word analysis. Moreover, there should be no support for attributing the reading difficulties to such ordinary factors as low general intelligence; sensory, neurological or physical disabilities; emotional, social or instructional factors. By individual matching in sex, age and their parents' educational level, two control groups were formed parallel to the dyslexic group. One group contains children performing rather poor at school. These were, in addition, individually matched in WISC Verbal IQ with the dyslexics (dyslexics: $M = 92.4$, $SD = 8.1$; poor performing group: $M = 92.8$, $SD = 6.4$). Another group contains very well performing children, with a much higher VIQ ($M = 129.8$, $SD = 11.9$). For 7 out of the 13 thus composed triads of a dyslexic, a poor performing and a well performing child, the instructional experience had been the same. Pupils within each of these seven triads started and continued reading instruction in the same classes and with the same teachers. Mean ages were 9;5 for the dyslexic and the high-VIQ group, and 9;4 for the low VIQ-group. A group of 16 special education children with language or general learning disorders was included too. Eleven boys and 5 girls from several teaching groups of a school for learning-disabled children were chosen so to be otherwise as equally as possible to the dyslexic, high VIQ and low VIQ groups. This was very well possible with respect to age ($M = 9;5$), but more difficult for VIQ ($M = 85.1$, $SD = 11.5$) and parents' educational level. In general the lower education levels were overrepresented. The adult groups consists of 5 male and 5 female first-year psychology students, participating in partial fulfillment of their course requirements.

Stimuli

Ten three-formant stimuli were synthesised with a digital formant synthesiser (Ballet, 1981). They varied only in their second formant transition, thus producing a continuum in which stimulus 1 is heard as /pə/ and stimulus 10 is heard as /tə/. All stimuli are 130 ms long and all formant transitions occur in the first 50 ms. In the remaining 80 ms the steady state values for the dutch 'schwa' sound /ə/, as determined by Govaerts (1978), were implemented. The first formant rises gradually from 190 to 465 Hz and the third formant falls from 2534 Hz to 2275 Hz. The bandwidths gradually change as follows during the first 50 ms: for F1 (first formant) from 48 to 40 Hz; from 62 to 110 Hz for F2 and from 106 to 325 Hz for F3. The second formant always reaches 1475 Hz after 50 ms, but starts at a different value for the 10 stimuli. For stimulus 1 the starting point is at 1208 Hz and for stimulus 10 at 1782 Hz. The intermediate stimuli start at intermediate values, differing in equal steps (1272 Hz for stimulus 2, then 1336 Hz for stimulus 3, etc...). All transitions are negatively accelerated. In the first 10 ms about 37% of the transitions are effected; in the next 10 ms about 27%, etc. The pitch falls over the entire length of the stimuli from 143 to 87 Hz.

These stimuli are designed to be minimally different. In this way, we hoped, individual perception differences might be more easily detected. Although place of articulation differences are usually cued by varying second *and* third formant transitions, it proved possible in pilot-testing to do so with only second formant variations. Also, our stimulus steps are rather small (64 Hz), compared for instance with those of Godfrey et al. (1981) (about 140 Hz for their second formant starting values).

With these 10 stimuli a criterion test and an identification test were prepared. The criterion test contains only stimuli 1 and 10, each 10 times recorded in a random order. In the identification test the remaining eight stimuli (2 to 9) are each presented 10 times. This is done in five blocks each containing all stimuli in a different random order. These five blocks are recorded twice. The recording of both tests was done with a computer-steered REVOX A700 tape recorder on high quality TDK GX tape. A silent interval of 4.2 s was left between all stimuli.

Procedure

All subjects were tested individually in a quiet room at their school or university. The stimuli were played over a PHILIPS NR 400 tape recorder. Subjects listened binaurally at a constant comfortable loudness level over BEYER DT 220 Headphones. For the child subjects a warm-up story was told about a computer learning to talk. The computer has only learned two sounds and speaks in a strange voice. Before testing, stimuli 1 and 10 are each presented five times, with the experimenter explicitly labeling them /pə/ or /tə/. The subjects were told to listen carefully to each stimulus and then to report immediately whether they heard /pə/ or /tə/.

First the criterion test was presented. The purpose of the criterion test is to make sure all subjects get to understand the procedure well, so that nonperceptual factors be eliminated in the identification test. If the subject made less than five errors in the (20-item) criterion test, the identification test was started. If there were five or more errors, the criterion test was presented a second time. If the criterion was reached then, the identification test was started too. In the other case a procedure for further inquiry was started. With the first grade subjects in the first testing some synthetic vowels were to be identified. If this presented no problem, the subjects got a third chance on the criterion test. But some vowels were easily identifiable for all subjects. This showed task-demand factors are not responsible for failure on the criterion test. So far all other groups under study, this vowel task was substituted by another procedure for further inquiry. After the second failure on the criterion test, an extended stimulus continuum was presented with F2 starting values ranging from 889 to 2100 Hz. This was meant to establish whether some subjects failed because they had their phoneme boundary outside our test continuum.

RESULTS AND DISCUSSION

General results

In the first testing only 39 out of the 48 youngest subjects passed the criterion test (33 in their first trial, 3 in both second and third trial). In the identification test with 14 of these 39 subjects something unexpected happened. After a while they responded to all stimuli of the continuum with /tə/. We called this phenomenon 'perseveration'. The experimenter suggested the perseverating subjects that if they would listen very carefully, they would probably also hear /pə/'s. With four of them this intervention stopped the deviating behaviour. They again consistently identified the stimuli with the lowest 2nd formants as /pə/. The others 10 subjects kept reporting only /tə/'s. In sum, only for 25 subjects could uncontaminated identification data be obtained.

Eight months later 40 of the 48 same subjects passed criterion, 3 of them needing a second presentation of the criterion test. In the procedure for further inquiry 3 subjects clearly showed a phoneme boundary more to the left and outside our stimuluscontinuum. The remaining 5 behaved inconsistently. So 40 subjects started the normal identification test. Only one subject perseverated (only /tə/'s) and another one responded inconsistently. So for 38 subjects workable data could be gathered. These included the 25 that had already yielded complete data in their first testing.

The four groups of older children did markedly better. 53 out of 55 subjects passed the criterion test in the first trial. One subject of the lower VIQ group and one of the special education group turned out to have more left (lower F2) phoneme boundaries. In the identification test one subject of the dyslexic group heard nothing but /tə/. So for 12 dyslexic, 12 poorly performing, 13 well performing and 15 special education children complete data were obtained. All adult subjects ran through the tests without any difficulty.

Slope and phoneme boundary

For each individual with complete data the slope and the phoneme boundary (50% cross-over point) were obtained by calculating the best fitting logistic curve to the identification data. This procedure is analogous to the well known probit method (Finney, 1964). Instead of transforming the raw response proportions P_i to their z-values, the logistic deviates are applied: $ln(P_i/1\text{-}P_i)$ (Baker & Nelder, 1978). The 'logit analysis' results were preferred because the maximum likelihood goodness of fit measures (scaled deviances) with this method were slightly smaller than those resulting from the probit method ($M = 7.83$ for the probit method vs. $M = 7.35$ for the logit results, with 6 degrees of freedom).

Tab. 1. — Phoneme boundaries and (arctan) slopes of the different groups under study

	phoneme boundary M	phoneme boundary SD	(arctan) slope M	(arctan) slope SD
first-grade				
September	4.213^{a}	1.37	0.837^{a}	0.21
May	4.845^{ab}	0.96	1.003^{ab}	0.28
third- & fourth-grade				
dyslexic	5.498^{b}	1.15	0.950^{ab}	0.26
low VIQ	5.131^{ab}	0.97	0.975^{ab}	0.14
high VIQ	5.759^{b}	0.80	1.051^{ab}	0.23
spec. educ.	4.926^{ab}	1.11	0.948^{ab}	0.24
adults	5.616^{b}	0.80	1.138^{b}	0.20

Note. Means not sharing a superscript differ at the .05 level.

As the raw slope distribution is markedly skew, arctangent transformations are applied and used for all further analysis. Table 1 shows mean phoneme boundaries and (arctan) slopes for the different groups under study. The phoneme boundaries are expressed in stimulusstep units; the arctan slopes in radians.

Separate analysis of variance were performed to test group differences in phoneme boundary and slope. For this purpose the groups of first and second testing in first grade were considered as separate and independent, although they were in fact overlapping. Both the slope and phoneme boundary differences are significant. The differences are more pronounced for the phoneme boundary ($F(6,118) = 4.51$, $p < .001$) than for the slope ($F(6,118) = 2.54$, $p < .03$). A posteriori pairwise comparisons of group means were performed with the Tukey (a) procedure (also called the honestly significant difference procedure, Winer (1962)). For the phoneme boundaries differences of at least 1.18 stimulus steps are significant at the 5% level. So only the youngest subjects differ significantly from the dyslexic, high VIQ and adult groups. For the slope, differences of at least 0.26 radians are significant at the 5% level. Now the youngest subjects differ only significantly from the adult group. The shifting of the phoneme boundary and steepening of the slope within the first year of elementary instruction was much more pronounced in repeated measures analysis of variance for only the 25 subjects with complete data in both 1st and 2nd testing (for the phoneme boundary $F(1,24) = 8.49$, $p < .01$), for the slope $F(1,24) = 21.57$, $p < .001$).

However, we cannot reject the possibility that for the first testing of the youngest subjects the slope is dependent on the phoneme boundary. With the phoneme boundary diverging more from the centre of the stimuluscontinuum, we fear that a flatter slope is to be expected. The more the phoneme boundary is away from the centre, the larger the flat part of the identification curve. In rather extreme cases the phoneme transition might not occur completely inside the continuum. For the 25 first grade subjects in the first testing a positive correlation is indeed found between slope and phoneme boundary values ($r = .389$, $p < .05$), while for the 38 subjects of the second testing and the four combined groups of older children ($N = 52$) only small and nonsignificant positive correlations are obtained. ($r = .091$ resp. $r = .143$) We see no way for determining whether the correlation is real or artefactual, but by presenting stimuluscontinua symmetrically enclosing each individual's phoneme boundary (for instance in interactive testing).

Some nonsignificant differences are found between the four groups of older children. The high VIQ children are more similar to the adult group with respect to phoneme boundary and slope. The special education and lower VIQ subjects have phoneme boundaries more similar to the first grade children. This might suggest a phoneme boundary more to the right and a steeper slope are signs of a higher developmental level. If this would be so, we should also expect the better performing children in first grade to have a more right phoneme boundary and a steeper slope. For these children some performance indices are available: the overall school results and a battery of six reading tests represented by their first principal component scores. The reading tests are described elsewhere in detail (De Weirdt, 1985). In general, they are centred on decoding, containing only single nonsense and real words. The correlation between slope and reading ability is nonsignificant for the 25 subjects of the first testing ($r = .067$). With the 38 subjects of the second testing those with the steeper slope are indeed better readers ($r = .296$, $p < .05$). The same pattern of weak positive correlations holds also with the overall school results ($r = .212$ for first testing, $r = .173$ for second testing). So, the identification slope might be weakly associated with some kind of general developmental level. For the phoneme boundary, a similar conclusion is clearly contradicted by analogous correlations. The phoneme boundary values of the first testing correlate negatively with both overall school results ($r = -.388$, $p < .05$ two-tailed) and with the reading first principal component scores ($r = -.484$, $p < .02$ two-tailed). In the second testing (May) a similar but weaker pattern is observed ($r = -.22$ with both reading score and school results, $.15 > p > .10$ two-tailed). So the subjects with phoneme boundaries more to the left are the better performers.

The same school performance indices were also used to determine whether the first graders who could not pass the tests in a normal way (23 in September, 10 in May) were perhaps inferior to those who yielded complete data. This was clearly not so. Both in first and second testing mean reading scores and school results of the subjects who could pass the identification tests in the expected way, were inferior to those of subjects either perseverating or failing to pass criterion. The differences were not significant, all F-values being smaller than 1.

Beside comparisons of slope and phoneme boundary values, inspection of the raw identification curves is instructive too. As the identification curves of the four groups of older children (dyslexic, high

VIQ, lower VIQ and special education) are rather similar, their data were taken together in Figure 1.

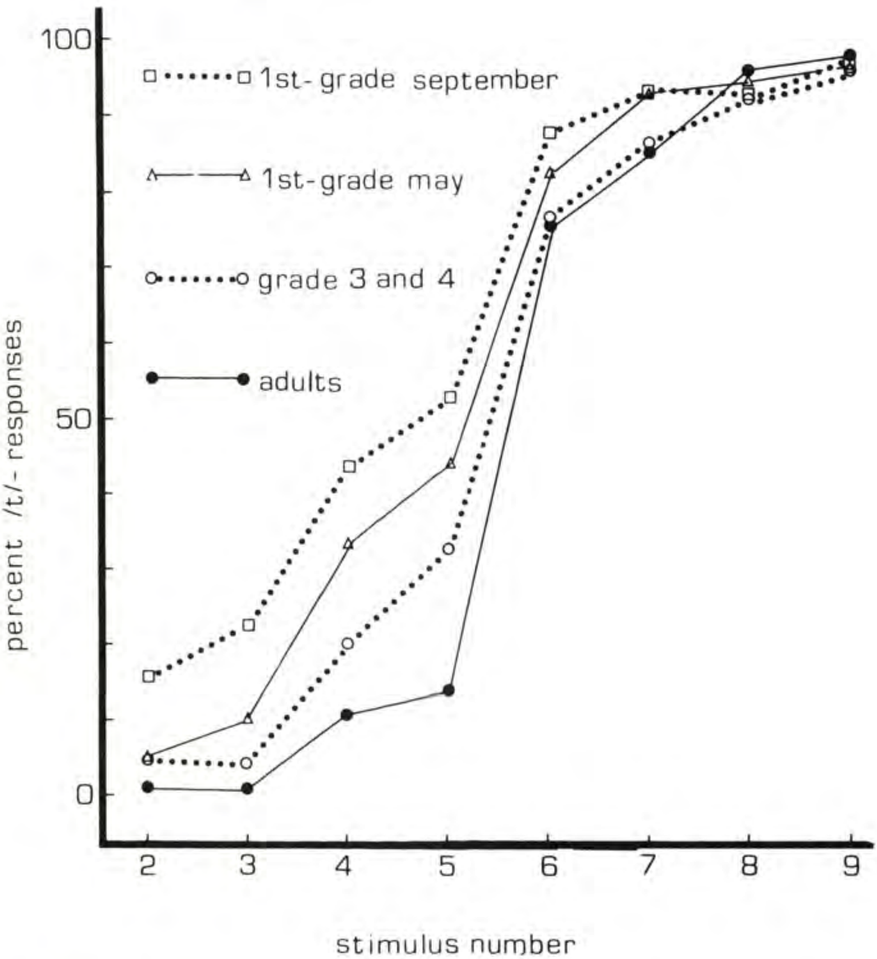

Fig. 1. — Identification curves of the different groups. Data of Dyslexic, High VIQ, low VIQ and special education children are taken together (grade 3 & 4).

This figure clearly shows that the largest group differences occur at the leftmost stimuli. At the right of the continuum stimuli are identified in much the same way by all groups. It looks like (some of) the youngest children never heard an unambiguous /pə/. The fact that 14 out of 48 heard all stimuli as /tə/ in the first testing, points in the same direction. These subjects had probably passed the criterion test by quickly learning to respond /pə/ to all stimuli that were not clearly /tə/. As it turned out, in the second testing some subjects had a genuine phoneme boundary at still lower F2 values than the lowest in our continuum. We do not know whether this was also the case for all perseverating subjects in the first testing. If this would have been so, we would at that age (6;2) have found a bimodal distribution of the /p/–/t/ phoneme boundary. However, the present data are inconclusive. We had not expected phoneme boundary differences between groups, as we never had met such effects in research reports. On the contrary, it is often explicitly mentioned that phoneme boundaries tend to be stable and constant over groups (Wolf, 1973; Godfrey et al., 1981). Perhaps a special characteristic of our stimuli is responsible for this surprising result. Usually the bilabial-postdental distinction is cued by varying both 2nd and 3rd formants. Roughly, if these are both rising, the bilabial sound is heard; if both are falling the postdental sound is heard. With all our stimuli, the third formant is slightly falling (from 2534 to 2275 Hz), as in the postdental sounds /t/ and /d/. So, in the leftmost stimuli, conflicting information might be present. The second formant points to a /pə/, while the third formant suggests a /tə/. Then there might be differential conflict resolution in different age groups. This would explain the greater variability in the perception of the left stimuli, while with the stimuli more to the right the unanimity in perception is also explained. In these stimuli both F2 and F3 point to a /tə/. By varying both second and third formant we will, in future research, be able to evaluate this hypothesis. An example of an alternative explanation would be the following: perhaps our formant transitions are so short (50 ms) that they cannot be detected by the youngest subjects in our study. In that case they would only hear a suddenly starting /ə/. There might then be a bias for labeling such sudden start as the stop consonant /t/ (cfr. in dutch the sound of a klaxon is usually imitated as 'tuut').

In sum, it is clearly demonstrated that with the specific stimuli of this study, a developmental trend is present. Adults and children of 9 or 10 have little difficulty with identification tasks. A considerable subgroup of the youngest children in our study (mean age 6;2) could not take this simple identification test. Those who could do so showed a deviating phoneme boundary and a flatter slope. A pilot study suggested that with still younger subjects (age 5) probably a higher proportion cannot pass such tasks. As all subjects could readily identify and repeat natural speech sounds uttered by the experimenter (even with his mouth covered), it is difficult to imagine extra-perceptual factors in identification tasks.

The failure of some children to run through identification tests with synthetic speech sounds was also noted by Wolf (1973). She reported only in passing that in one experiment both for kindergarten and second-grade children 2 out of 10 subjects failed to perceive her stimuli (on a voicing continuum) with any consistency. We believe such findings are important data too, that should not be viewed as devaluing for a particular study. In the first year of elementary school the synthetic phoneme perception seems to be in full development. The phoneme boundary, slope and the proportion of subjects able to pass the test have substantially changed during the 8-month period between the two presentations. We should be careful, of course, as the same subjects were used. The first presentation might have facilitated a more consistent performance eight months later. As the age effect is also substantial between independent groups, we believe we should only doubt the magnitude of the development during this first instruction year. If it would turn out that the main part of the developmental road is indeed run through during this first year, some interesting connections with the process of learning to read might be considered and researched. Learning to read clearly encompasses the acquisition of various phoneme processing capacities. Our present results are compatible with a view in which learning to read even influences the more perceptual level. Still with respect to reading, we failed to replicate Godfrey et al.'s results (1981). Although our results are in the expected direction, we found no significant slope differences between dyslexic and well reading children. Also, the data of the first grade subjects only mildly suggest the better readers have steeper slopes. At last, for the unexpected findings of the shifting phoneme boundary, some easily testable hypothesis are proposed. Systematic variation of the F3 transition and the transition duration of the stimuli might already be very instructive.

REFERENCES

Baker, R.J., & Nelder, J. (1978). *The GLIM System. Release 3. Generalised Linear Interactive Modelling*. Harpenden, Herts: Rothamsted Experimental Station.

Ballet, C. (1981). *Synthese van spraak uit fonetische gegevens.* Niet-gepubliceerd werk, Rijksuniversiteit Gent, Laboratorium voor Elektronika en Meettechniek, Gent.

Blumstein, S.E., Stevens, K.N., & Nigro, G.N. (1977). Property detectors for bursts and transitions in speech perception. *Journal of the Acoustical Society of America, 61*, 1301-1313.

Brandt, J., & Rosen, J.J. (1980). Auditory phonemic perception in dyslexia: Categorical identification and discrimination of stop consonants. *Brain and Language, 9*, 324-337.

De Weirdt, W. (1985). *Spraakperceptie en technisch lezen.* Ongepubliceerde doctoraatsverhandeling, Rijksuniversiteit Gent, Laboratorium voor Differentiële, Experimentele en Genetische Psychologie.

Eimas, P.D., & Tartter, V.C. (1979). On the development of speech perception: Mechanisms and analogies. In H.N. Reese & L.P. Lipsitt (Eds.), *Advances in child development and behavior* (Vol. 13, pp. 155-193). New York: Academic Press.

Finney, D.J. (1964). *Probit analysis* (2nd ed.). London/New York: Cambridge University Press.

Garnica, O.K. (1973). The development of phonemic speech perception. In T.E. Moore (Ed.), *Cognitive development and the acquisition of language*. New York: Academic Press.

Godfrey, J.J., Syrdal-Lasky, A.K., Millay, K.K., & Knox, C.M. (1981). Performance of dyslexic children on speech perception tests. *Journal of Experimental Child Psychology, 32*, 401-424.

Govaerts, G. (1978). Perceptuele strukturen van synthetische en natuurlijke klinkers. *Psychologica Belgica, 18*, 27-67.

Helfgott, J.A. (1976). Phonemic segmentation and blending skills of kindergarten children: Implications for beginning reading acquisition. *Contemporary Educational Psychology, 1*, 157-169.

Jakobson, R. (1941). *Kindersprache, Aphasie und allgemeine Lautgesetze*. Uppsala: Almquist & Wiksell. (English translation by A. Keiler: *Child language, Aphasia and general sound laws*. The Hague: Mouton, 1968.)

Kamil, M.L., & Rudegeair, R.E. (1972). Methodological improvements in the assessment of phonological discrimination in children. *Child Development, 43*, 1087-1091.

Liberman, A.M., Cooper, F.S., Shankweiler, D., & Studdert-Kennedy, M. (1967). Perception of the speech code. *Psychological Review, 74*, 431-461.

Liberman, I.Y., Shankweiler, D., Fischer, F.W., & Carter, B. (1974). Explicit syllable and phoneme segmentation in the young child. *Journal of Experimental Child Psychology, 18*, 201-212.

Lisker, L., & Abramson, A.S. (1970). The voicing dimension: Some experiments in comparative phonetics. *Proceedings of the Sixth International Congress of Phonetic Sciences, Prague, 1967* (pp. 563-567).

Oakland, T.D. (1969). Auditory discrimination and socio-economic status as correlates of reading ability. *Journal of Learning Disabilities, 2*, 326-329.

Vellutino, F.R. (1979). *Dyslexia: Theory and research.* London: MIT Press.

Wallach, L., Wallach, M.A., Dozier, M.G., & Kaplan, N.E. (1977). Poor children learning to read do not have trouble with auditory discrimination but do have trouble with phoneme recognition. *Journal of Educational Psychology*, *69*, 36-39.

Wepman, J.M. (1958). *Auditory Discrimination Test* (manual of directions). Chicago: Language Research Associates.

Winer, B.J. (1962). *Statistical principles in experimental design*. New York: McGraw-Hill.

Wolf, C.C. (1973). The perception of stop consonants by children. *Journal of Experimental Child Psychology*, *16*, 318-331.

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