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Deficits in Fine Motor Coordination in Children with Unintelligible Speech*

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Summary. An auditory and acoustic analysis was performed of the voice production of 24 children between 5 and 8 years of age with unintelligible speech and 24 children without speech or language deficits matched for age. Two aspects of voice production were assessed, prephonatory tuning and phonatory modulation. The categories used for the auditory assessment were preutterance vocalizations, abnormal initiation, rough voice, breathy voice, tense voice, voice tremor, intraphonemic disruption and pitch break. The acoustic analysis consisted of calculation of the mean fundamental frequency and the pitch perturbation factor in repetitions of the series of syllables |pa|, |ta|, |ka|. Intrasyllabic pitch breaks were also noted. The children with unintelligible speech had significantly more signs of abnormal prephonatory tuning and abnormal phonatory modulation than the control children. The findings suggest that voice production in unintelligible children has not yet become automatized. This possibility is discussed in relation to the central control of phonation.

Key words: Phonation – Children – Unintelligible speech

Introduction

Developmental speech and language deficits are common in children seen by child psychiatrists. Of the children with such deficits one-third have normal IQ's and no hearing loss, major neurological abnormalities or psychiatric disorders sufficiently severe to explain the disorder. In the International Classification of Diseases these children are diagnosed as having specific developmental speech or language disorders.

The children usually start to develop language late, they are unintelligible longer than other children and their articulation remains faulty over a longer period of time (von Benda 1984). Beyond the deficits in speaking, numerous other symptoms can also be observed. Deficits in comprehending language, in constructing correct sentences, in word finding, in short-term memory and in musical abilities are just a few.

Problems with motor coordination are mentioned frequently. The children are described as being clumsy, especially with their hands (Seeman 1974). Both the problems in speaking and those with finger movements can be seen as deficits in fine motor coordination (Amorosa 1981). In addition to the articulatory system, two other systems of fine motor control are also involved in speaking, the speech breathing system as the source of energy and the sound producing system, e.g., the larynx.

If children with speech and language disorders have deficits in fine motor coordination, one would expect to find problems in the phonatory and breathing systems, too. These three systems, the articulatory, phonatory, and speech breathing systems, are highly interrelated but also have a certain independence. This paper is a report on our findings with regard to the phonatory system only, although we have also conducted experiments to evaluate the other two systems.

Two phases of phonation can be distinguished: prephonatory tuning and phonatory modulation (Wyke 1983). During the prephonatory inhalation, the vocal cords are abducted. Then about 500 ms before the audible beginning of an utterance the vocal cords start moving together to achieve the position necessary for producing the desired sound. At the same time the tension of the vocal cords is adjusted to the subglottal pressure. In other words, both the tension and the degree of adduction are adjusted prior to the beginning of phonation. Prephonatory tuning is a learned and highly automatized process. Therefore, even normal young children often have problems with this regulation, the result being, for example, prephonatory vocalizations, abrupt initiations, or vocal fry at the beginning of an utterance.

After initially adjusting the vocal folds the speaker's next task is to modulate the stiffness of the vocal folds in accordance with the changing subglottal pressure and the require ments of the prosody of the utterance. The innervation of the m. cricothyroideus, the muscle mainly responsible for the regulation of the stiffness of the vocal folds, comes from the n. laryngeus superior (Shipp 1982). An increase in fundamental frequency is dependent on an increase in the stiffness of the vocal folds. Again, this is a learned and, later on, highly automatized process. How complex and difficult this "trivial" process is can be seen in normal young children, who have problems in keeping the fundamental frequency steady. When they repeat a sentence several times, the fundamental frequency varies far more than in older children (Eguchi and Hirsh 1969; Kent 1976).

By studying the coordination and automatization of vocal fold tension and movement, we hoped to gain some insight into the problems of fine motor coordination in children with specific developmental speech and language deficits.

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Method

Subjects

The subjects were 24 children between 5 and 8 years of age from several special schools for speech and language handicapped children. They had been selected for our study because of their unintelligible speech. None of the children had a subnormal IQ or any hearing defect serious enough to explain her/his speech problems. A detailed language assessment revealed that the children had deficits of varying types and severity, including language comprehension problems, dysgrammatism and word finding problems. The control subjects were 24 children without speech or language problems matched for age.

Procedure

The auditory and acoustic analysis of prephonatory tuning and phonatory modulation was based on tape recordings of at least 30 min duration containing spontaneous speech, picture stories, picture naming tasks, and repetitions of series of simple syllables and sentences.

Auditory Analysis. Two speech pathologists assessed the speech samples for the abnormalities in voice production listed below and described in more detail elsewhere (Schäferskupper and von Cramon 1985). Sonograms were available whenever necessary. The abnormalities in prephonatory tuning were (1) preutterance vocalization and (2) abnormal initiation. Figure 1 illustrates some of these features, showing a normal initiation (a), abnormal glottal openings and closings before initiation (b), and harsh initiation (c and d). As indicators of disturbed phonatory modulation, we used the general characteristics (1) breathy voice, (2) rough voice, (3) tense voice, and (4) abnormally high or low voice, and the special events (5) voice tremor, (6) intraphonemic disruption, and (7) pitch break. Figures 2 to 4 illustrate the latter three symptoms. Figure 2 shows voice tremor during the utterance "eine Blume" (a flower). Figure 3 shows an intraphonemic disruption in the word "Bach" (creek) (the gap in the vowel "a" had a duration of about 100 ms). The last example, Figure 4, shows a pitch break of four semitones in the word "Daumen" (thumb).

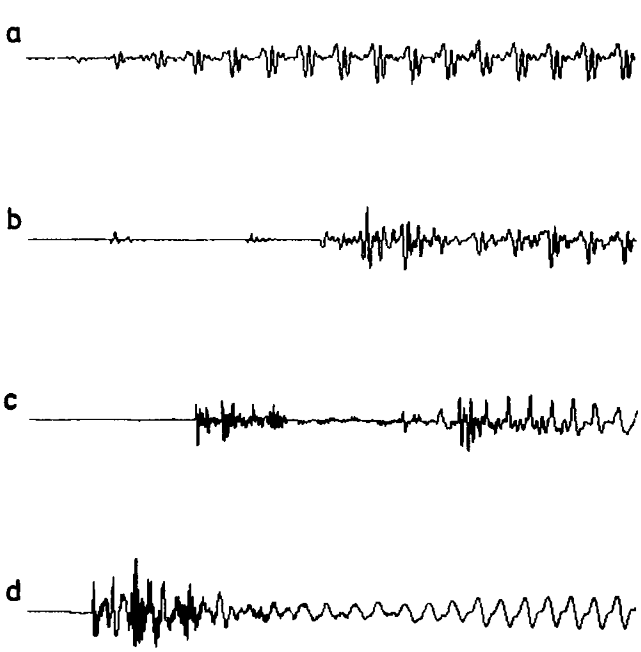

Fig. 1a–d. Four oscillograms showing initiations of the vowel "a". **a** normal, **b** several glottal openings and closings, **c** and **d** harsh initiations

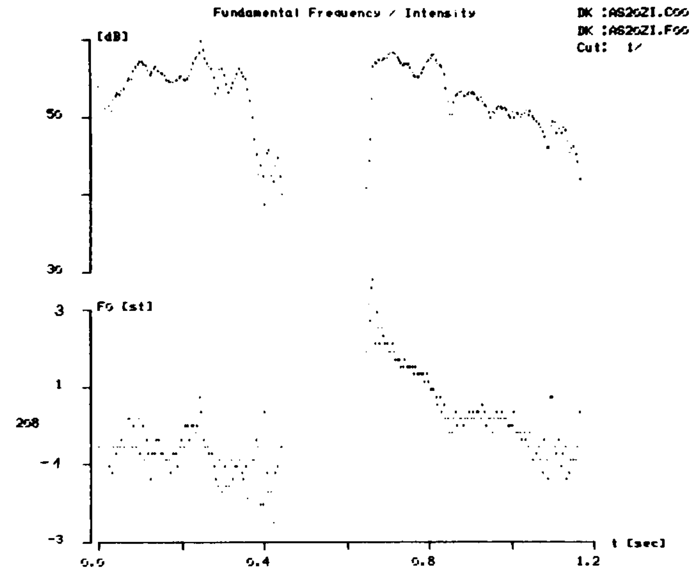

Fig. 2. Voice tremor in the utterance "eine Blume". Fundamental frequency and pitch synchronous intensity

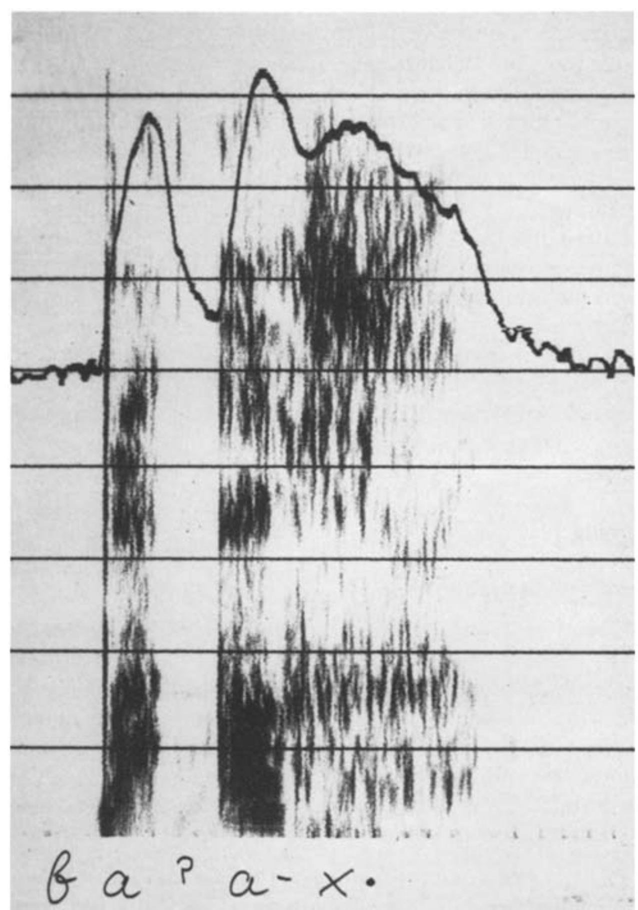

Fig. 3. Sonagram of an intraphonemic disruption of 100 ms during the vowel in the word "Bach" (creek). The frequency range on the ordinate is 0 to 8 kHz

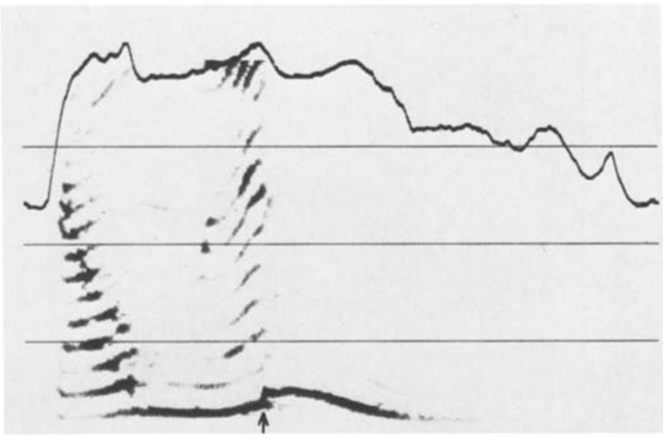

Fig. 4. Sonagram of a pitch break of four semitones in the word "Daumen" (thumb). The frequency range on the ordinate is 0 to 4 kHz

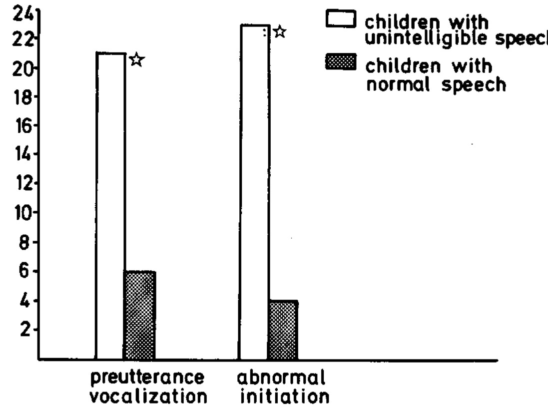

Fig. 5. Auditory analysis of deficits in prephonatory tuning. Number of children showing preutterance vocalizations and abnormal initiations. ☆ $P < 0.05$

Acoustic Analysis. Since sudden, irregular changes in fundamental frequency (F0) between syllables and a rough voice quality are strong indicators of irregular muscle tone, these parameters were studied in more detail. We used repetitions of series of the syllables |pa|,|ta|,|ka| as a paradigm of speech production with frequent onsets and offsets of phonation. The recorded speech samples were digitized with a 20 kHz sample rate, segmented into syllables and analyzed by the F0 program described in Hartmann and von Cramon (1984). A pitch perturbation factor (PP) and the mean F0 for each syllable were then calculated. If a change in mean F0 between successive syllables was greater than three semitones it was registered as intersyllabic pitch break. Changes were not counted if they affected the first or the last syllable of a task or if they appeared to be due to rhythmic patterning of the task. Children with two or more syllables with a PP factor of 3% or more were counted. An average PP for running speech in adults has been given as being below 1% (Horii 1980).

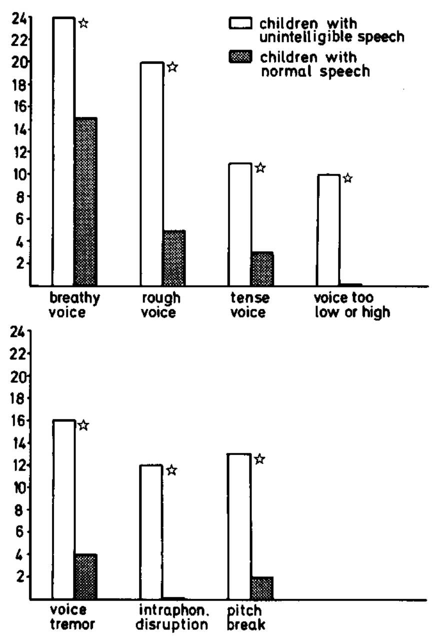

Fig. 6. Auditory analysis of deficits in phonatory modulation. Number of children showing each symptom. ☆ $P < 0.05$

Results

Auditory Analysis

Figures 5 and 6 show the results of the auditory analysis. Most of the children with unintelligible speech had pathological symptoms of prephonatory tuning and phonatory modulation. The wide variation in the severity of symptoms within a given session was remarkable. A child might start with a voice considered low and breathy and later on show signs of a rough or tense voice. Quite often there was a marked interdependence of pathological symptoms and speaking time.

Deficits in Prephonatory Tuning. Of the 24 children with unintelligible speech, 21 had preutterance vocalizations, compared to 6 children with normal speech and language development. Of the children with unintelligible speech 23 showed abnormalities of initiation, either several glottal openings and closings, a harsh beginning before the onset of a vowel or no onset of phonation, whereas only 4 children of the control group showed these symptoms.

Deficits in Phonatory Modulation. All 24 children in the experimental group and 15 children in the control group were considered to have a breathy voice, 20 (5) showed roughness

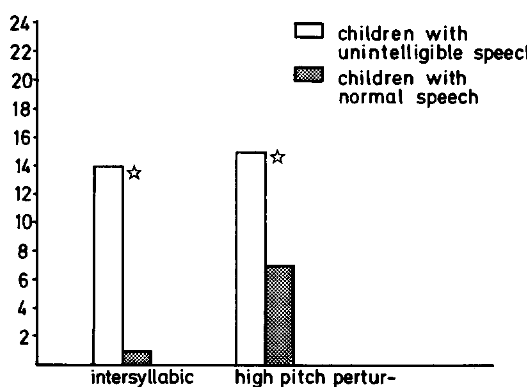

Fig. 7. Acoustic analysis of deficits in phonatory modulation. Number of children showing intersyllabic pitch break and syllables with high pitch perturbation factor. ☆ $P < 0.05$

and 11 (3) tenseness of voice. The voice of 10 (0) children was considered too high or too low for the child's age and size. Voice tremor was noted in 16 (4) and intraphonemic disruption and pitch break in 12 (0) and 13 (2), respectively.

Acoustic Analysis

In the experimental group 14 of the 24 children had at least one intersyllabic pitch break, whereas only 1 child in the control group showed this phenomenon (Fig. 7). In the experimental group, 15 children had 2 or more syllables with a high pitch perturbation factor, whereas in the control group only 7 children showed this phenomenon.

Discussion

In clinical descriptions of children with speech and language problems, voice problems are never mentioned. Martin (1981) considered problems of phonation to be a distinct entity often seen in combination with developmental speech and language problems. The large number of children in our study showing problems with phonation was unexpected. The deficits were in both prephonatory tuning and phonatory modulation of the voice.

According to Wyke (1983), these processes are learned and automatized during the period of language learning. The inability to keep the tonus and degree of adduction of the vocal folds adjusted to the subglottal pressure and the requirements of the intended sounds leads to the symptoms of intraphonemic disruptions, pitch break, sudden unmotivated changes in fundamental frequency between syllables, and high pitch perturbation. The problem lies in difficulties with the continuous adjustment of the stiffness of the vocal folds and in the lack of automatization of this process.

Our clinical observations showed that adjustment was best at the beginning of speaking and when the children focussed their attention on their voice. Our results do not permit us to draw any conclusions about the changes in these voice problems with age, but a longitudinal study now in progress should provide an answer to this question. In three older children, aged 11, 19 and 20 years, respectively, who had had unintelligible speech up to the age of 6 to 10 years, we found the same symptoms that we had observed in the younger children, although they were less obvious.

The cerebral control of phonation has been studied extensively in primates. According to Jürgens (1981) and Ploog (1984), a distinction must be made between genetically programmed sounds with emotional content and learned sound patterns important for speech. For both types of phonation the nucleus ambiguus and nucleus solitarius (Fig. 8) are important as the nuclei of the primary motor neuron and sensory neuron for the intrinsic muscles of the larynx. The sounds with emotional content are controlled by the periaqueductal gray and the gyrus cinguli and other structures affecting emotional states. For the learned sounds the cortical larynx area with its connections in the cortex and to the thalamus via the cerebellum and striatum are of importance. Possibly some of the symptoms seen, especially those due to deficits in automatization and control of muscle tone, are related to cerebellar abnormalities. In two of the older children investigated computer tomograms showed an increase in the size of the cisterna

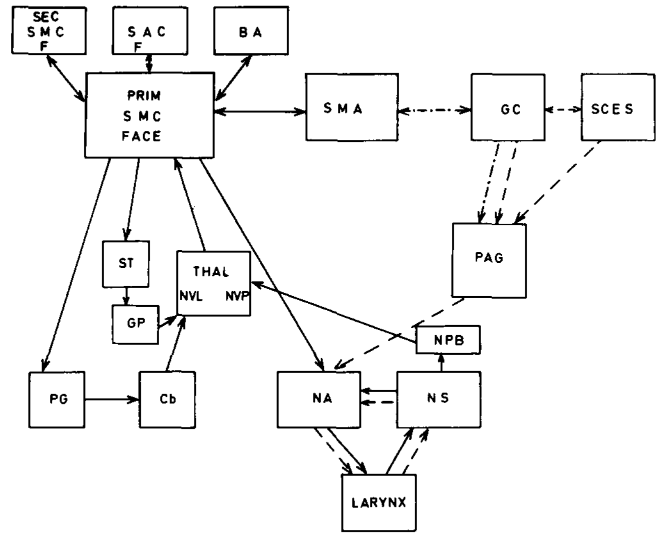

Fig. 8. Brain structures involved in the control of phonation. (———) learned vocal utterances (under volitional control); (-----) nonverbal emotional vocal utterances (genetically determined); (–·–·–·–) volitional initiation of nonverbal emotional vocal utterances. *BA* – Broca's area, *CB* – cerebellum, *GC* – gyrus cinguli, *GP* – globus pallidus, *NA* – nucleus ambiguus, *NPB* – nucleus parabrachialis, *NS* – nucleus solitarius, *NVL* – nucleus ventralis lateralis, *NVP* – nucleus ventralis posterior, *PAG* – periaqueductal gray, *PG* – pontine gray, *SACF* – sensorimotor association cortex of the face, *SCES* – structures controlling emotional states, *SMA* – supplementary motor area, *SMCF* – sensorimotor cortex of the face, *ST* – striatum, *THAL* – thalamus

cerebelli inferior and an increase in the size of the cisterna magna with retraction of the lobus posterior of the cerebellum, respectively.

The results of our study show that phonation, one of the systems of fine motor coordination contributing to speech production, is frequently disturbed in children with unintelligible speech. The most striking feature is the wide variety of symptoms occurring in each child and the variability within any one recording. The deficits observed are mainly in the prephonatory tuning of the vocal folds and in the continuous adjustment of the tonus of the vocal folds to subglottal pressure and prosodic demands, consequently both cerebellar deficits and extrapyramidal abnormalities may be responsible for the deficits seen in the control of phonation and in the other fine motor systems of speech and hand motor control in unintelligible children. Additional studies might provide both a clearer picture of development and compensatory efforts and a better understanding of the relationship between symptoms and abnormalities seen in computer tomograms.

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