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ABSTRACT

A study of fundamental vocal frequency values in 14 children aged 11 to 25 months, an age period characterized by changes in physiological and linguistic development, is reported. A developmental trend downward in vocal frequencies is traced across a number of previous studies, but is only tentative and is not documented in the age group under consideration. Although the decrease in average frequency can be explained by physical growth, the decrease in frequency variability cannot be explained as easily, especially in this age group. Based on analysis of spontaneous language samples of this study's 14 infants, the hypothesis that developmental decreases in average frequency and frequency inter-utterance variability occur before 3 years of age, and in infants as young as 11 months, is supported. A list of references, a summary of studies of frequency characteristics in children from birth to five years, and individual characteristics and statistical results of the present study are appended. (MSE)

THE RELATIONSHIP BETWEEN VOCAL FUNDAMENTAL FREQUENCY CHARACTERISTICS AND DEVELOPMENTAL LEVELS OF LANGUAGE ACQUISITION IN YOUNG CHILDREN

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ABSTRACT

Fundamental frequency (F_o) values are reported for 14 children between the ages of 11 to 25 months, an age period characterized by changes in physiological and linguistic development. Both average F_o and F_o variability were found to decrease as subject age increased. Average F_o change reflected increased physical development with age. F_o variability change is discussed relative to the interaction of age and linguistic development.

Research into the acoustic characteristics of speech productions of young children has been conducted with increasing frequency in recent years. One of the major parameters of speech on which acoustical measurements has been made is the assessment of average voice fundamental frequency (i.e., rate of vocal fold vibration). Measurements of vocal fundamental frequency (F_o) are used by researchers to obtain information regarding a) indirect estimates of the physiological state of the glottis, and b) the stability or variability evidenced in the rate of vocal fold vibration.

The stability of vocal fold vibration has been described as an indicator of laryngeal coordination reflecting the young child's control over his/her vocal apparatus (Kahane, 1982; Buhr, 1980; and Kent, 1976). Researchers in the area of F_o characteristics in young children have examined a variety of speech and non-speech vocal events. A summary of results from selected studies of F_o in young children is presented in Table 1. Fairbanks (1942), Ringel and Kluppel (1964), and Prescott (1975) have examined the cry patterns in a total of 16 children within the first nine months of life and all report average F_o's in excess of 400 Hz. Fundamental frequency patterns of noncry vocalizations in children younger than six months of age have been reported by Laufer and Horii (1977) and Sheppard and Lane (1968). Laufer and Horii sampled four children during the first 24 weeks of life and reported an average F_o and F_o variability of 335.0 Hz and 42.6 Hz respectively, while Sheppard and Lane examined two children during the first five months of life and reported average F_o and range of F_o of 428.8 Hz and 384-481 Hz respectively.

Aside from the F_o research cited above pertaining to children's speech productions under 12 months of age, most acoustic research on speech development has focused on children three years of age or older. Eguchi and Hirsh (1969) have provided the most complete information on F_o speaking characteristics in children above three years of age. The authors, in their comprehensive acoustic study, reported average F_o, inter-subject standard deviation (Sd), and intra-subject Sd data for 84 subjects ranging in age from three to 13 years and adulthood.

Because of the different types of vocalizations, response conditions and analysis methods specific to each of these studies, comparisons of F_o information across studies is difficult. However, when the studies are arranged according to the chronological age of the subjects, a tentative developmental trend begins to emerge. The emergence of a developmental trend is enhanced when the data from Eguchi and Hirsh (1969) for older children are considered. Group average fundamental frequencies for children aged below 12 months are generally above 400 Hz, with the exception of the babies studied by Laufer and Horii (1977). When compared to the 36 month old children of Eguchi and Hirsh who had an average F_o of 297.8 Hz, it appears that sometime prior to three years of age F_o begins to decrease.

INSERT TABLE 1 ABOUT HERE

Presently, there is no comparable F_o information for children between the ages of one and three years with which to compare the apparent decrease in F_o and F_o Sd. Although Kent (1976) in his review of the acoustic research on speech development indicated that

F_o and F_o variability decreases with age, he stated that the exact age which the decrease begins is not yet known. This is because of the absence of information on F_o for children between the ages of one and three years.

The decrease observed in average F_o as a function of age can be explained by the physical growth in children, particularly the increases in vocal fold length and mass. However, the decrease in F_o variability is less easily explained by growth alone. The decrease in F_o variability involves an interaction between maturation of the nervous system and the gain in control over laryngeal adjustments for linguistic function (Kent, 1981; and Netsell, 1981).

Explanation of F_o variability is further confounded when children between the ages of one and three years are considered. For example, the primary non-anatomical, non-physiological factor influencing F_o variability between the ages of one and three is the development of language. Lieberman (1977) has reported that language development has two separate levels of influence upon vocal F_o. The first level, the prosodic level, deals with variations in stress and intonation placed upon intentional oral verbal expressions. According to Lieberman, children innately use a specified amount of breath grouping in proportion to utterance lengths. These respiratory volume changes influence the rising or falling pattern of F_o in signaling the end of an utterance. A second, more general, function of language development on the pattern of F_o deals with the child's neuromotor maturation of the speech mechanism. As the child's utterances begin to increase in length and complexity, the neuromuscular adjustments of his laryngeal mechanism must increase also.

The influence of linguistic growth upon a child's speech development between the ages of one and three years is prominent. However, it is between the ages of one and three in which information pertaining to F_o characteristics of children's speech productions is limited. Researchers of F_o in young children's speech productions have acknowledged that subjects sampled belonged to various stages of linguistic development. The increase in linguistic complexity and utterance length, however, has not been a primary variable of interest in these studies. Although variations in vocal F_o are known to be related to changes in prosody, the literature fails to relate the influence of utterance length to variations in F_o.

As we have mentioned, relatively little is known about the F_o speaking characteristics of young children between the ages of one and three years - a period in which physical growth and language development are changing rapidly. The interaction between the child's physiologically maturing vocal apparatus and the developing linguistic complexity represented in the child's speech productions was the focus of this study. The purpose of the investigation was to examine the quantitative relationship between average F_o and F_o variability among young children between the ages of one and three years and the influence of increasing length of linguistic utterances.

METHOD

Subjects

Selection Criteria. All subjects were identified on the basis of a ten-item questionnaire which was circulated to educated middle class parents of children attending day care centers located in Syracuse, New York. The questionnaire served as a screening instrument designed to aid in identifying children who met the age, environmental, developmental and medical criteria for inclusion in the study. Fourteen Caucasian children (seven males, seven females) ranging in age from 11 months to 25 months, were selected for participation in the study. All children had normal hearing sensitivity as determined by an acoustic reflex test or behavioral indications, normal developmental histories, no obvious anatomical or physiological abnormalities, and demonstrated within-normal-limits performance on the Bayley Scales of Infant Development (1969).

Utterance Length Groups. A spontaneous language sample was obtained from each of the 14 children. Based upon analysis of the language samples, four groups of subjects were formed reflecting a continuum of linguistic development ranging from prelinguistic to multiple word utterances. Mean length of utterance (MLU) in morphemes was used to group subjects beyond the prelinguistic level into comparable linguistic groupings (Brown, 1973). At least three children were placed into each of the four vocal expression groups. The four utterance groups developed were defined as follows:

1) prelinguistic utterances - any intentional oral verbal expression produced by the infant. An expression was considered intentional when the infant a) made eye contact with the listener b) attempted to direct the listener's attention toward a desired goal by gesturing and/or looking c) persisted in that pattern until the goal was accomplished and d) terminated the pattern when the goal was achieved (Harding and Golinkoff, 1979).

2) single word utterances - the child's systematic use of the same syllable or word-like production to represent particular objects or events. Of the utterances collected, 80% had to be one grammatical morpheme in length with an MLU of 1.0 grammatical morphemes (Brown, 1973).

3) Early MLU Stage I - a succession of separate single word utterances, with 80% of the utterances collected being one to two morphemes in length with an MLU of 1.1 to 1.5 grammatical morphemes (Brown, 1973).

4) Late-MLU Stage I - an ordered arrangement of two or more words with 80% of the utterances being of one to three morphemes in length with an MLU of 1.6 to 2.0 grammatical morphemes (Brown, 1973).

Table 2 contains the individual subject characteristics of the 14 children. Included in the table are individual measurements of age in months, MLU in morphemes, performance on the Bayley Scales of Infant Development, and a physical index. The physical index was derived by converting measurements of weight, height and head circumference (Illingworth, 1975; and Krogman, 1977) of each child into z-scores. The z-scores were then added together for each child and formulated into an overall positive z-score by adding a constant integer of six.

INSERT TABLE 2 ABOUT HERE

Recording Procedure

Audio recordings of the children's spontaneous speech productions were recorded individually in a sound-treated room. A minimum of 70 utterances (ranging between 70-100 utterances per subject) were obtained for each child. The children were seen individually for each recording with only the parent(s) and one of the experimenters present. The parent(s) and experimenter used familiar toys and picture books as well as elicitation techniques similar to that described by Miller (1981) in generating all language samples. Utterances that were imitations or partial imitations of preceding adult speech (totaling 9% for the entire subject sample) were included in assessing the language development of each child (in accordance with Miller's, 1981 suggestions), although the imitations were not subjected to acoustic analysis because of the possibility of imitations of the prosodic features of the stimulus.

Language samples were recorded on low noise, high density, quality magnetic tape using a cassette tape recorder (Nakamichi 550) and electret condenser microphone (Sony ECM 50 PS). A constant 3" to 5" mouth-to-microphone distance was maintained for all subjects by attaching the microphone to the children's clothing with a lapel clip.

The first 70 utterances of each subject for which acoustic measurements could be made were selected for analysis. Utterances were transcribed in standard orthography unless the transcriber was uncertain of the appropriate interpretation in which case the International Phonetic Alphabet was used. Reliability of transcription was determined by having another graduate student in the Department of Communicative Disorders make independent transcriptions of five percent of the utterances obtained. Interjudge agreement for the transcription of spontaneous speech was 92 percent.

Fundamental Frequency Analysis

A calibrated sound spectrum analyzer (Kay 7030A) along with a Nakamichi 550 cassette deck input were used for the acoustic analysis of the reproduced speech sounds. The sound segments (consonant-vowel (CV), VC and CVC) were reproduced by the sound spectrograph by displaying narrow band harmonics (45 Hz filter) of each utterance. A total of 1556 speech sound segments, consisting of vowels and uninterrupted voiced diphthongs, were measured from the narrow band spectrograms. Due to the children's high F_o's, the harmonics were sufficiently spaced so as to provide easy hand analysis.

Data Analysis

Each vowel/vowel-like segment was hand measured for (1) average F_o (i.e., average of ten equally spaced points on a segment), and (2) F_o onset (defined as the first measureable point on a segment). Figure 1 illustrates the following measures taken from a sample narrow band spectrogram of the vowel /i/. All average F_o values were based on ten values for each vowel/vowel-like segment. F_o onset values consisted of one measured value for each of the vowel/vowel-like segments.

All hand-measured values were stored in the data bank of a computer (DEC - 10). An integrated, interactive statistical computer program (STATPACK, 1974) was used to calculate the appropriate statistics in characterizing individual and group data values. Intra-judge and inter-judge reliability of hand measured spectrograms was assessed by having one of the examiners and another graduate student make independent measurements on five percent (78) of the vowel/vowel-like segments obtained. A comparison of the sample measurements made indicated an average intra-judge reliability of 92 percent with an inter-judge reliability of 87 percent.

INSERT FIGURE 1 ABOUT HERE

RESULTS

The results are reported in two sections. The first section contains the statistical descriptions of the mean and variability for the F_o measures for the total group of children. Included also in the first section is the analysis of bivariate correlations between the

F_o measures and the subject characteristic measures. Analysis of the F_o measures as a function of subject age is presented in the second section.

Fundamental Frequency Characteristics of the Total Group

A total of 1556 vowel/vowel-like segments were analyzed acoustically for average F_o and F_o onset. The individual means, ranges and standard deviations in Hz for average F_o and F_o onset of the 14 children are presented in Table 3. Each mean is based on a minimum of 70 utterances per child.

Mean F_o. The overall mean F_o for the 14 subjects (mean of the means) was 357.0 Hz with a range of average F_o values for individual subjects of 164-1366 Hz. The average F_o inter-utterance Sd for the group was 105.2 Hz with a range of 45.3 to 238.0 Hz. The inter-utterance Sd value reported for the group was an average of the inter-utterance Sd's calculated for each child.

Mean F_o Onset. The overall F_o onset value for the group was 362.6 Hz, with individual subject range for F_o onset of 158-1600 Hz. The average F_o onset inter-utterance Sd for the 14 children was 101.4 Hz with a range of 38.9 to 214.5 Hz. The values observed for average F_o and F_o onset were very similar to one another. The similarity evidenced for these measures, at least for grouped data, was noted in subsequent analysis as well.

INSERT TABLE 3 ABOUT HERE

Correlations Between Variables. A correlation matrix for the eight variables considered in the analysis is shown in Table 4. Examination of Table 4 indicates a number of significant correlations (Minium, 1978). Average F_o was significantly correlated with F_o onset (r = .98). The high positive correlation supported the previous observation that measures of average F_o and F_o onset yielded essentially the same values. Because of the similarity noted between average F_o and F_o onset in the present study, only one of the measures (i.e., average F_o) is discussed further in this section.

Further examination of the correlation matrix revealed that age was significantly related to inter-utterance Sd (r = -.69); MLU (r = .72); physical index score (r = .66) and performance on the Bayley Scales of Infant Development (r = .92). The variable of MLU was found to be significantly related to performance on the Bayley Scales of Infant Development (r = .87), as well as age.

The results of the correlation analysis indicated that age was significantly related to a majority of the variables analyzed, whereas MLU was not. Because age was related to the subject characteristic variables, and thus probably reflected the best index of development, the F_o characteristics of the 14 children were further analyzed as a function of age.

INSERT TABLE 4 ABOUT HERE

F_o Characteristics as a Function of Age

Mean F_o and Age. Analysis of F_o was done on the group of children according to their chronological age in three month intervals. Table 5 contains the means, ranges, inter-utterance Sd's and a ratio of inter-utterance Sd to the mean for the 14 subjects. A decrease in average F_o of 91.5 Hz between children aged 11-13 months ($\bar{X}$ = 402.1 Hz) and children aged 23-25 months ($\bar{X}$ = 310.6 Hz) was evidenced. Examination of the grouped F_o values reveals large variability around the mean for each of the age groups, particularly at the 14-16 month age group.

When grouped as in Table 5 the mean values appear to decrease with age. A one-way analysis of variance (ANOVA) was performed for age and average F_o and resulted in a non-significant F for the age main effect. This is not surprising when the large individual subject variability for average F_o is considered.

INSERT TABLE 5 ABOUT HERE

F_o Variability and Age. Also included in Table 5 are inter-utterance Sd values calculated for each of the age groupings. An overall decrease in inter-utterance variability of 127.2 Hz between children aged 11-13 months (inter-utterance Sd = 187.0 Hz) and children aged 23-25 months (inter-utterance Sd = 59.8 Hz) was observed. Examination of the grouped Sd values reveals high inter-utterance variability for the 11-13 month (inter-utterance Sd = 187.0 Hz) and 14-16 month (inter-utterance Sd = 153.5 Hz) age groups. The variability observed in these two age groups was quite large in comparison to the older children in the study whose inter-utterance variability ranged from 68.1 Hz for the 17-19 month old group to 50.3 Hz for the 20-22 month old group to 59.8 Hz for the 23-25 month old group.

An ANOVA for age and F_o variability was performed and yielded a significant F ($F = 3.705$, $p < .05$) for the age groups. The significant age effect was further confirmation of the decrease in F_o variability observed and reported earlier as a significant correlation (r = -.69) between age and F_o Sd.

The ratio of inter-utterance Sd to the mean F_o for each of the age groups is reported also in Table 5. A ratio of the Sd to the mean F_o was used to allow comparison of variabilities at different F_o levels. The 11-13 month age group yielded a ratio of .465. There were progressively smaller ratios as a function of age reaching a minimum of .155 at 20-22 months of age. The variability ratio for the 23-25 month age group showed a slight reversal in magnitude, yielding a ratio of .192. The trend toward a lower variability as age increased was clearly demonstrated.

DISCUSSION

The average F_o values for the 14 children grouped into three-month intervals, along with the F_o values from previously cited studies are shown in Figure 2. In general, the average F_o values for the studies cited between birth and three years, including the present investigation, demonstrate a relatively systematic decrease as a function of age in children. The decrease in F_o occurring prior to three years of age indicates an earlier developmental trend then what was previously reported by Eguchi and Hirsh (1969) who noted that average F_o begins to decrease in three year olds continuing until the onset of puberty.

INSERT FIGURE 2 ABOUT HERE

The lowering of average F_o as a function of age can be explained in terms of overall physical growth. Anatomical and physiological changes in the child's development during the first three years of life directly influence vocal F_o. For example, the vocal folds grow in length from 3.0 mm at birth to nearly 30 mm in an adult male (Negus, 1962; Zemlin, 1963; and Kahane, 1982). Kaplan (1971) reports that approximately 50% of this laryngeal growth occurs primarily during a child's first three years of life. The large growth in vocal folds represents the voice changes (i.e., lowering in vocal F_o) which accompany growth in children. Similarly, rapid growth in vocal tract length, size, shape, and constriction is noted (Fant, 1973), as well as subglottal air pressure changes and modifications in airflow from the lungs (Titze, 1979), all of which contribute to vocal cord vibration.

Large decreases in average F_o are expected in children until they reach puberty after which changes in F_o are more gradual continuing on into adulthood (Eguchi and Hirsh, 1969; and Kent, 1976). The correlations observed in the present study for the physical index and age ($r = 0.66$) and the Bayley Scales of Infant Development and age ($r = .92$) are interpreted to mean that physical development as well as neuromotor development, are closely related to the chronological aging of the child. Because of their relationship to age, especially during the 11 to 25 month period sampled in the study, decreases in average F_o are probably influenced by both.

Inter-utterance standard deviation (Sd) plotted as a function of age is also shown in Figure 2. The graph consolidates longitudinal data from Laufer and Horii (1977), Prescott (1975) and Ringel and Kluppel (1964) as well as the cross section of three year olds studied by Eguchi and Hirsh (1969). A consistent decrease in inter-utterance variability for the 14 subjects in the present study is evidenced when the children are grouped in three month intervals according to chronological age.

Because F_o variability was related to F_o level in an absolute way, a ratio of inter-utterance Sd to the mean F_o for each age group was calculated to facilitate comparison across groups and to other studies. A systematic decrease in absolute variability and variability ratio is shown in Figure 3. Also included in Figure 3 are the variability ratios of three year old children developed by Eguchi and Hirsh (1969) as well as the calculated ratios derived from the pre-one year studies of Ringel and Kluppel (1964), Laufer and Horii (1977) and Prescott (1975). Overall, the present F_o variability data indicate an earlier decreasing trend in inter-utterance Sd then what was previously reported by Eguchi and Hirsh who noted that inter-utterance Sd begins to decrease in three year old children continuing on into puberty.

In looking further at Figure 3 one notes that inter-utterance variability for the 14 subjects in the present study is larger than the values reported in the comparison studies, particularly for the children in the 11-13 month and 14-16 month age groupings. The large variability for the two age groupings (average Sd = 170.2 Hz) is not consistent with the inter-utterance Sd values reported for children ten months of age and younger (average Sd = 37.2 Hz) (Laufer and Horii, 1977; Prescott, 1975; and Ringel and Kluppel, 1964). From the available data it is not obvious as to why this is so. There appears to be an increase in inter-utterance variability once a child reaches 11 months of age.

INSERT FIGURE 3 ABOUT HERE

Interestingly, the extent of variability displayed in the present study is in general agreement with that observed by Keating and Buhr (1978). A post-hoc comparison of the F_o ranges of the children in the present study to the six children (33 to 169 weeks of age) studied by Keating and Buhr revealed that the vocal behavior of the subjects in the two studies was relatively similar. Comparison of the F_o range for the present group (range = 164-1366 Hz) to the group range reported by Keating and Buhr (range = 30-2500 Hz) indicate the occurrence of very low and very high F_o to be common.

The 11 month to 16 month age period of high utterance variability demonstrated in the current study corresponds to the ages in which children first begin to use purposeful utterances. The development of these intentional utterances may account for the sudden increase observed in inter-utterance variability. Laufer and Horii (1977) and Prescott (1975) have reported small increases in F_o inter-utterance Sd for children using non-meaningful utterances (i.e., non-distress vocalizations and cry) ranging in age from birth to nine months. The increases in variability reported by the authors, however, are not of the magnitude that is apparent at 11 months of age and thus cannot be considered continuous with the function reported for the 14 subjects in the present study.

Taking into account that such a discontinuity in F_o variability exists between non-meaningful and meaningful utterances, an interesting trend for the developmental course of F_o variability is suggested.

The child's transition from meaningless, phonologically undifferentiated babbling to an age period of 11 to 16 months, or more specifically to when children first produce meaningful speech, is a period in which large inter-utterance variability would be expected to decrease. This continuous function of decreasing inter-utterance Sd relative to age is depicted quite clearly in Figure 3.

These findings demonstrate that decreases in average F_o and F_o Sd occur in children as young as 11 months of age. The findings imply that F_o characteristics in young children's speech between the ages of 11 and 25 months follow a developmental pattern continuing on into adulthood. A significant feature of the present data is that age tended to be the primary variable which accounted for decreases in average F_o. The interaction of age and linguistic growth, as measured by MLU, appear to be two factors accounting for decreases in F_o inter-utterance Sd. This suggests that F_o measures obtained for children during the early stages of linguistic development are primarily representative of the child's chronological age. One should keep in mind though, that the development of language may have an influence on F_o variability in young children's speech productions. Because of possible linguistic influence on F_o inter-utterance Sd, variations in utterance length become a sampling concern when acoustic measures of children's speech productions between the ages of one and three years are performed.

In conclusion, the present results support the hypothesis that developmental decreases in average F_o and F_o inter-utterance variability occur prior to the age of three years. There still remains, however, a lack of information about the F_o characteristics of children's speech productions during the developmental period of birth to three years of age. Further research is needed in order to more fully understand the changes in F_o that may shed light on neuromotor and anatomical changes that take place in the development of early childhood speech.

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TABLE 1. Summary of studies of F_0 characteristics of children from birth to five years of age.

Study	Sample Type	Analysis Method	Age & Sex	Mean F_0 (Hz)	Range (Hz)	Inter-Utt Sd (Hz)
Ringel & Kluppel (1964)	cry	spectrograph	4-40 hrs. (both)	413.1	290-508	30.0
Laufer & Horii (1977)	noncry	computer	0- 4 mos. (both)	335.0	317-342	42.6
Sheppard & Lane (1968)	any vocalization	computer	0- 5 mos. (both)	428.8	384-481	*
Prescott (1975)	cry	spectrograph	6- 9 mos. (both)	415.0	348-451	39.0
Fairbanks (1942)	cry	oscilloscope	composite of 1-9 mos. (male)	556.0	63-2631	*
Keating & Buhr (1978)	noncry	spectrograph	6-42 mos. (both)	*	30-2500	*
McGlone (1966)	1-3 word utt.	oscilloscope	13-23 mos. (both)	443.3	*	*
Eguchi & Hirsh (1969)	sentences	spectrograph	36 mos. (both)	297.8	*	39.2
Eguchi & Hirsh (1969)	sentences	spectrograph	4 yrs. (both)	285.6	*	26.0
Eguchi & Hirsh (1969)	sentences	spectrograph	5 yrs. (both)	288.7	*	22.8

*Information not available

TABLE 2. Individual subject characteristics of each of the 14 children.

SUBJECT	AGE (months)	MLU	UTTERANCE GROUP	BAYLEY SCALES (months)	PHYSICAL INDEX
E.C.	11	none	pre-linguistic	12.0	1.868
M.R.	12	none	pre-linguistic	14.2	.791
L.B.	15	1.0	single word	19.7	6.130
E.B.	15	1.0	single word	16.8	8.650
L.L.	15	1.0	single word	19.9	5.107
M.L.	15	1.0	single word	17.8	7.165
A.B.	18	1.2	Early Stage I	23.2	3.900
J.C.	18	1.3	Early Stage I	21.6	2.737
T.M.	18	1.5	Early Stage I	21.2	7.076
M.F.	20	none	pre-linguistic	16.8	8.672
S.M.	21	1.4	Early Stage I	28.2	5.367
D.T.	24	1.6	Late Stage I	30.0	6.642
M.T.	25	1.6	Late Stage I	30.0	10.070
A.R.	25	2.0	Late Stage I	30.0	9.495

-23-

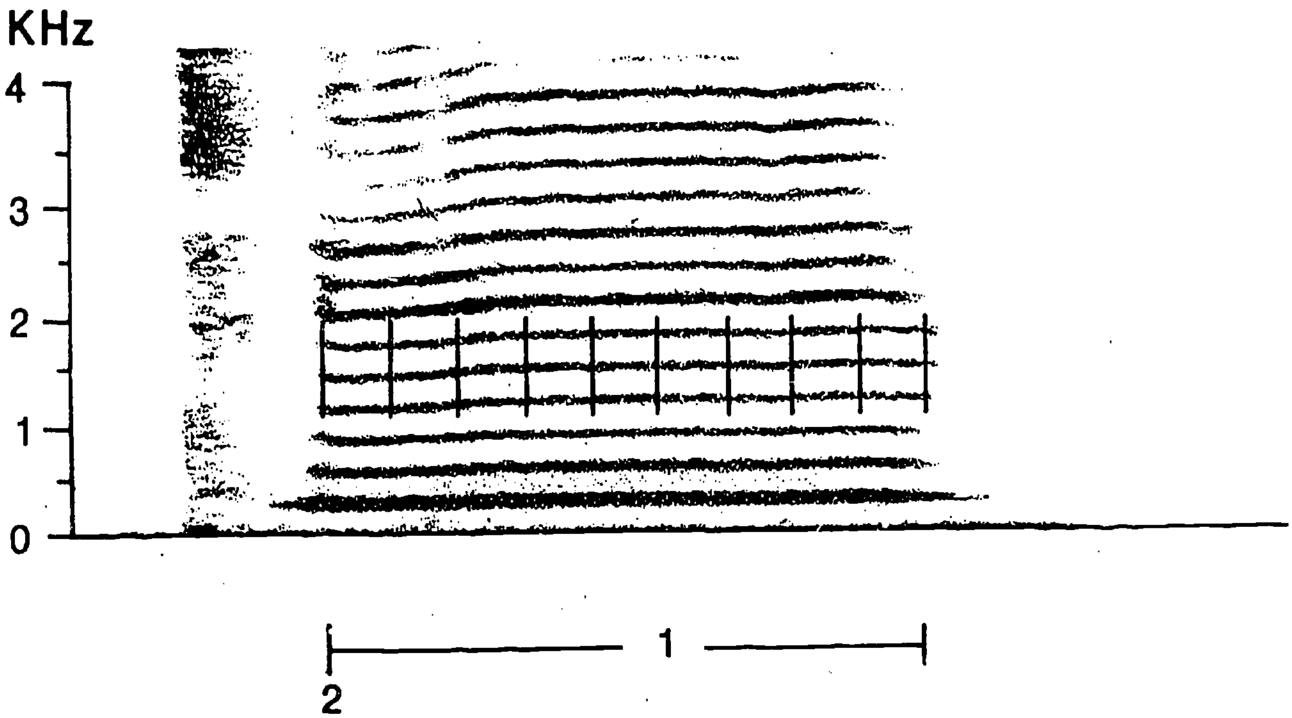

Figure 1. Narrow band spectrogram of the word "tea". Average F_0 (1) was measured as the average of ten equally spaced points along the fifth harmonic of a voiced segment. F_0 onset (2) was the first measureable point on the segment.

TABLE 3. Mean, standard deviation and range of measures of F_0 onset and average F_0 for each of the 14 children.

Subject	average F_0			F_0 onset		
	mean	Sd	range	mean	Sd	range
E.C.	365.6	182.5	234-1354	363.9	194.1	191-1491
M.R.	434.9	191.6	292-1352	420.0	206.3	250-1600
L.B.	329.3	238.0	193-1226	317.2	214.5	158-1258
E.B.	536.7	218.1	277-1366	512.6	191.5	258-1333
L.L.	305.4	95.0	192-775	332.9	86.9	225-808
M.L.	339.9	62.8	227-502	349.5	48.4	242-491
A.B.	407.4	84.2	281-691	432.1	83.6	300-817
J.C.	319.6	67.4	187-500	319.8	60.4	191-475
T.M.	361.6	52.7	274-512	379.5	56.1	250-575
M.P.	345.4	55.4	242-555	348.9	59.4	258-666
S.M.	309.6	45.3	228-443	323.6	38.9	250-442
D.T.	364.1	69.9	164-610	377.9	74.6	183-600
M.T.	310.7	56.7	174-486	327.3	50.6	208-450
A.R.	268.5	52.9	175-443	271.8	53.9	158-491
TOTAL GROUP	357.0	105.2	164-1366	362.6	101.4	158-1600

TABLE 4. Intercorrelation matrix between anatomical, neurological and cognitive variables for the 14 children.

	AVERAGE F_o	INTER-UTTERANCE Sd	F_o ONSET	AGE	MLU	BAYLEY SCALES	PHYSICAL INDEX
AVERAGE F_o	1.00						
INTER-UTTERANCE Sd	0.58	1.00					
F_o ONSET	*0.98	0.46	1.00				
AGE	-0.46	*-0.69	-0.41	1.00			
MLU	-0.37	-0.49	-0.31	*0.72	1.00		
BAYLEY SCALES	-0.49	-0.61	-0.42	*0.92	*0.87	1.00	
PHYSICAL INDEX	-0.17	-0.34	-0.16	*0.66	0.50	0.49	1.00

31

TABLE 5. AVERAGE FUNDAMENTAL FREQUENCY MEASURED ACROSS ALL VOWELS AND DIPTHONGS FOR ALL SUBJECTS GROUPED IN THREE-MONTH INTERVALS.

GROUP (months)	n	F_0 MEAN (Hz)	F_0 RANGE (Hz)	INTER-UTTERANCE Sd (Hz)	RATIO OF INTER-UTTERANCE Sd to MEAN
11-13	2	402.1	366-435	187.0	.465
14-16	4	393.8	305-537	153.5	.389
17-19	3	366.1	320-407	68.1	186
20-22	2	324.3	310-362	50.3	.155
23-25	3	310.6	269-364	59.8	.192

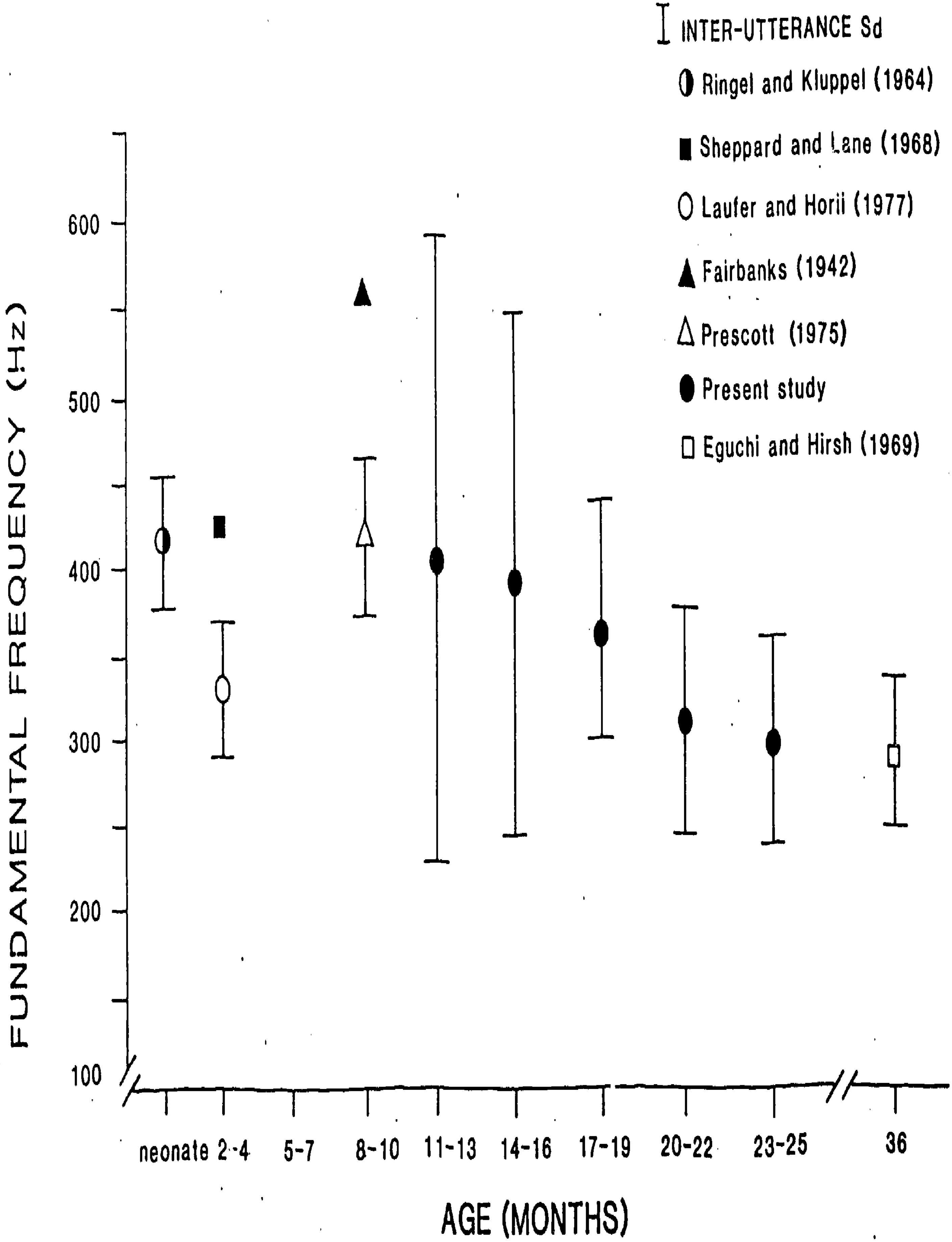

Figure 2 Average fundamental frequencies. The symbols represent average F_0 for each group. The verticle lines show inter-utterance Sd.

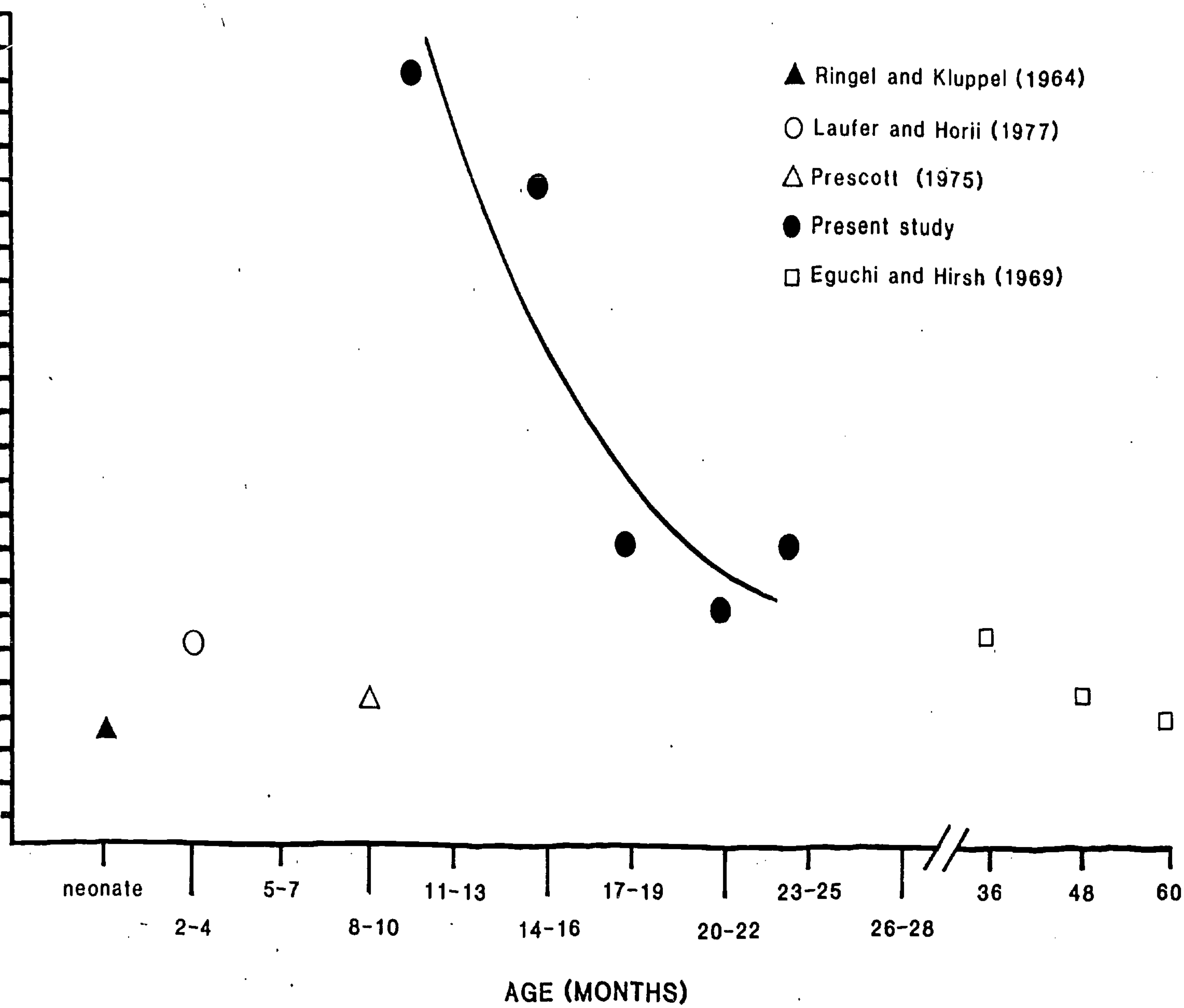

Figure 3 Variability in average fundamental frequency expressed as a ratio of Sd to mean fundamental frequency. A curve of best fit is drawn using the ratio points from the present investigation.