SOME DEVELOPMENTAL PATTERNS IN THE SPEECH OF 6-, 8- AND 10-YEAR OLD CHILDREN: AN ACOUSTIC PHONETIC STUDY

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ABSTRACT

The process of the development of fine motor speech skills co-occurs with the maturation of the vocal apparatus. This brief study presents some acoustic phonetic characteristics of the speech of twenty pre-adolescent (6-, 8- and 10-year-olds) boys and girls. The speech data were elicited via a picture-naming task. Both age and sex differences in the acoustic phonetic characteristics of selected vowels and consonants are examined. The acoustic phonetic characteristics that were investigated included formant frequency values and coarticulation (or gestural overlap) patterns. Age, sex and age-by-sex differences for the acoustic phonetic characteristics are presented and discussed for the data with reference to speech development and the sexual dimorphism of the vocal apparatus.

1. INTRODUCTION

During the process of developing fine speech motor skills, the child is faced with the task of mastering both the timing and co-ordination of articulators in a multi-layered system, to produce gestures that are smooth and overlapping. These gestures also need to be distinct so that they can be are perceptually recovered from the speech signal. The process of developing these fine motor speech skills co-occurs with the maturation of the vocal apparatus. The acoustic characteristics of adults' speech display robust sex differences [1]. Therefore, it is expected that during the processes of fine motor speech development, the speech characteristics of children will also display acoustic patterns graduating towards the sex differences that are observed in adult speech [2].

Studies that have investigated the acoustic phonetic characteristics of children's speech have included investigations into the coarticulation patterns of children's speech [3, 4, 5, 6, 7]. These studies have also compared the coarticulation patterns in children's speech with those of adults, and have reported inconsistent results. Some, studies have shown that articulatory levels of children exceed those of adult values [4, 5], while others have shown that they are lower than adult values in some phonetic contexts [3]. The inconsistent pattern of results is further highlighted by evidence that suggests that the levels of coarticulation in children's speech are similar to those of adults [6, 7]. However, it must be stated that while it has been reported that the coarticulation patterns are similar for both children (aged 3 to 7 years) and adults, it has also been reported that these coarticulatory effects were found to be less consistent for the children [6]. This pattern of inconsistency could be interpreted as evidence for the refinement of speech motor skills in children, and therefore, the graduation towards a skilled adult motor speech system.

Numerous studies investigating the acoustic phonetic developmental characteristics of children's speech have focussed on the acoustic changes that occur with increasing age [2, 8, 9, 10, 11]. The acoustic changes that have been reported have included changes in the patterns of fundamental frequency and formant frequencies [2, 8, 9, 10, 11].

This study investigates some acoustic phonetic characteristics of the speech of twenty pre-adolescent (6-, 8- and 10-year-olds) boys and girls. The speech data were elicited via a picture-naming task. This investigation examines both age and sex differences in the acoustic and phonetic characteristics of vowels and consonants. These characteristics include formant frequency values, coarticulation (or gestural overlap) patterns, assimilation patterns. Significant age, sex and age-by-sex differences are reported for the acoustic phonetic characteristics and realisations of both vowels and consonants. The results are discussed with reference to the developmental patterns of speech and the sexual dimorphism of the vocal apparatus [2].

2. METHOD

2.1. Subjects

Three boys and three girls from two age bands: 6 years (mean age 6.03 yrs.) and 8 years (mean age 8.18 yrs.), and four boys and four girls aged 10 years (mean age 9.97 yrs.), served as subjects in the study. The 20 children were all from the same local primary school in the north east of England (Tyneside). All children had lived in the local area all their life and spoke English as their first language. None of the 20 children had any speech, language or hearing difficulties.

2.2. Data collection

The recordings were made in a quite room using a portable AIWA HDS1 DAT recorder and a stereo microphone. Picture cards were used to elicit a possible total of nine target phrases from the children, (*The red/blue/green bar/jar/car*). Also included in the elicitation, were four distracters, for example, *The red boat*, *The green balloon*. Prior to the actual collection of the data, children were asked to name the colours and the pictures separately. This was done to ensure that none of the children were colour blind and also to establish picture names and therefore avoid confusion during the recording session

2.3. Acoustic Analyses

The elicited data were digitised with a sampling rate of 10 kHz using a Kay Computerised Speech Lab (CSL- Model 4300). All acoustic analyses were performed on the KAY CSL using routines, which are outlined below.

2.3.1. Formant frequencies (F2 and F3) of /r/

The midpoint of /r/ was located in *red*, with the help of time-aligned wide-band spectrograms and the speech pressure waveform. F2 and F3 values were obtained using LPC analysis. A frame length of 10ms was used and LPC measurements were validated using wideband FFT spectrograms.

It has been shown that in the case of retroflex consonants, F3 is a more reliable indicator of coarticulation than F2 [12, 13]. Therefore in order to examine the degree of coarticulation of /r/ with /ɛ/, F3 values, in addition to those of F2, were obtained for /r/.

2.3.2. Formant frequencies (F2 and F3) of /ɛ/

The midpoint of /ɛ/ and was located in *red* using wide-band spectrograms. F2 and F3 values were obtained using the same method outlined above for /r/ (2.3.1.).

2.3.3. Onset and mid points of F2 - /ɑː/ in *bar*

Formant frequency values for the onsets and mid points of the vowel /ɑː/ in the context *bar* was obtained as follows. F2 values were taken at the onset of the vowel and F2 values were taken at the temporal midpoint of the vowel (half way through the vowel from the onset of the vowel).

2.3.4. Coarticulation Patterns

Measures that were taken to investigate some coarticulation patterns included:

- Differences between the F2 values of /ɛ/ and the F2 values of /r/ (Hz). It is predicted that F2 may not be sensitive enough to detect patterns of gestural overlap that involve retroflexion.
- Differences between the F3 values of /ɛ/ and the F3 values of /r/ (Hz), where patterns of greater F3 differences could be interpreted as evidence for less coarticulation, due to the greater sensitivity of F3 to the retroflex gesture.
- Differences between the midpoint F2 values and the onset F2 values of /ɑː/ in the contexts *bar* and *jar*, where patterns of greater F2 differences could also be interpreted as evidence for less coarticulation.

3. RESULTS

3.1. Acoustic Phonetic Parameters

3.1.1. Formant frequencies (F2 and F3) of /r/

The mean F2 and F3 values for the mid point of /r/ are given in Table 1 according to both sex and age group. A two-way ANOVA (by age and sex) for the F2 data indicated that were no significant age differences. There were however, significant sex differences (F(1, 54)=15.5, p<.0001), with the female children exhibiting higher F2 values than their male peers. No age by sex interactions were found for the F2 data.

When the F3 data were subjected to a two-way ANOVA (by age and sex), similar trends to the F2 data were observed. Again, no significant age differences or age by sex interactions were found. However, significant sex differences were found (F(1, 54)=4.9, p<.05), with the female children's data generally exhibiting higher F3 values than that of their male peers.

Parameter	Sex	Age 6 yrs.	Age 8 yrs.	Age 10 yrs.
F2 of /r/ in "red" (Hz)	F M	1695.6 1577.7	1727.8 1496.8	1738.8 1404.1
F3 of /r/ in "red" (Hz)	F M	2581.4 2616.1	2562.9 2317.3	2709.8 2323.1

Table 1: Mean F2 and F3 values (Hz) for /r/ by to sex and age.

3.1.2. Formant frequencies (F2 and F3) of /ɛ/

The mean F2 and F3 values for /ɛ/ are given in Table 2 according to both sex and age group. A two-way ANOVA (by age and sex) for the F2 data indicated that were significant age differences (F(2, 52)=7.3, p<.005). Further to this, a post-hoc Scheffé test indicated that there were significant differences (p<.05) between the F2 data of the six year olds and those of the 10 year olds, with the six year olds having higher F2 values. There were also significant sex differences (F(1, 54)=15.5, p<.0001), with the female children exhibiting higher F2 values than their male peers. No age-by-sex interactions were found for the F2 data.

Parameter	Sex	Age 6 yrs.	Age 8 yrs.	Age 10 yrs.
F2 of /ɛ/ in *red* (Hz)	F M	2389.3 2371.2	2395.7 2247.8	2328.8 2087.3
F3 of /ɛ/ in *red* (Hz)	F M	3582.6 3714.1	3305.2 3489.4	3404.8 2879.3

Table 2: Mean F2 and F3 values (Hz) for /ɛ/ according to both sex and age.

When the F3 data were subjected to a two-way ANOVA (by age and sex), results indicated that were significant age differences (F(2, 52)=10.1, p<.0001). Further to this, a post-hoc Scheffé test indicated that consistent with the F2 data, there were significant differences (p<.05) between the F3 data of the six year olds and those of the 10 year olds, with the six year olds having higher F3 values. No significant sex differences were found for the F3 data, however, there was a significant age by sex interaction (F(2, 52)=6.7, p<.005). This interaction took the following form: both the male and female children exhibited a marked fall in the frequency of F3, between the ages of 6 and 8 years. However, between the ages of 8 and 10 years, the girls exhibited a slight rise in the frequency of F3, whereas in contrast to this pattern, the boys exhibited a marked fall in the frequency of F3. This pattern age-by-sex interaction is illustrated in Figure 1.

3.1.3. Formant frequency values for /ɑː/

The mean F2 values for vowel onset and mid vowel points of /ɑː/ for the contexts *bar* are given in Table 3. When the F2 onset values for *bar* were subjected to a two-way ANOVA (by age and sex), results indicated that were significant age differences (F(2, 49)=9.2, p<.0001). Further to this, a post-hoc Scheffé test indicated that there were significant differences (p<.05) between the F2 onset data of the six year olds and those of the 10 year olds, and also between the data of the 10 year olds and those of the eight year olds. In both comparisons, the 10-year olds had the lowest F2 values. In addition, significant sex differences were found (F(1, 49)=47.0, p<.0001) however, there was no significant age-by-sex interaction.

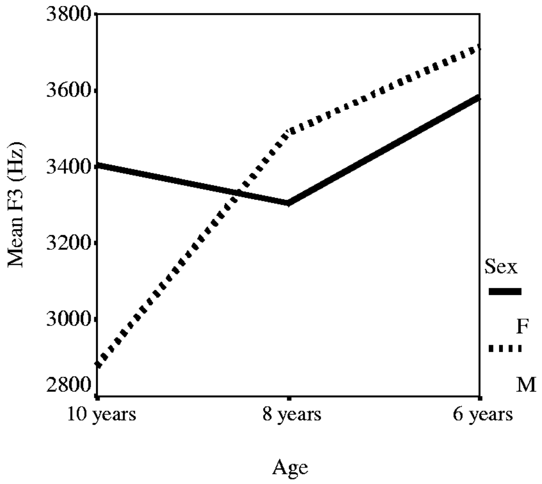

Figure 1: F3 values (Hz) for the vowel /ɛ/ in 'red' showing an age-by-sex interaction.

The F2 mid point values for *bar*, were also subjected to a two-way ANOVA (by age and sex). Results here indicated that were both significant sex (F(1, 49)=39.2, p<.0001) and age differences (F(2, 49)=8.5, p<.005). Further to this, a post-hoc Scheffé test indicated that the between group significant differences (p<.05) replicated those found for the F2 onset *bar* data as outlined above. In both comparisons, the 10-year olds had the lowest F2 values. No significant age-by-sex interaction was found for these data.

Parameter	Sex	Age 6 yrs.	Age 8 yrs.	Age 10 yrs.
F2 onset of /ɑː/ (*bar*) (Hz)	F M	1642.0 1474.0	1638.9 1384.3	1508.4 1287.6
F2 mid of /ɑː/ (*bar*) (Hz)	F M	1534.9 1381.6	1538.1 1381.4	1426.1 1269.3

Table 3: Mean F2 values (Hz) for vowel onset and mid vowel points for /ɑː/ in the context *bar* by sex and age.

3.2. Coarticulation Patterns

3.2.1. F2 and F3 change between mid /r/ and mid /ɛ/

The values for mean F2 and F3 differences (Hz) between the midpoint of /r/ and the midpoint of /ɛ/, are given in Table 4 by sex and age.

Parameter	Sex	Age 6 yrs.	Age 8 yrs.	Age 10 yrs.
F2 difference between midpoints of /r/ and /ɛ/	F M	-595.8 -792.6	-667.9 -767.0	-590.0 -683.2
F3 difference between midpoints of /r/ and /ɛ/	F M	-1032.2 -1100.4	-742.3 -1222.4	-695.0 -556.3
F2 change: /ɑː/ mid vowel minus /ɑː/ onset (*bar*)	F M	-107.1 -92.2	-100.8 4.1	-82.3 -18.3

Table 4: Mean F2 and F3 differences (Hz) between the midpoint of /r/ and the midpoint of /ɛ/ by sex and age.

The F2 differences were subjected to a two-way (by age and sex) ANOVA, results indicated no significant differences were found for any of the comparisons. When the F3 differences were subjected to a two-way (by age and sex) ANOVA, a different picture emerged. Results showed that although no significant sex differences or age-by-sex interactions were found, there were significant age differences (F(2, 48)=5.4, p<.01). A subsequent post-hoc Scheffé test indicated that there were significant differences between the data of the 6-year olds and the 10-year olds, with the 6-year olds showing greater F3 differences.

3.2.2. F2 differences between mid vowel and vowel onset of /ɑː/ in *bar*

The values for the mean F2 difference (Hz) between the vowel mid point and vowel onset for /ɑː/ in the context *bar*, are also given in Table 4 by sex and age. When the F2 differences for *bar* were subjected to a two-way (by age and sex) ANOVA, results indicated no significant differences were found for any of the comparisons.

Parameter	Sex	Age 6 yrs.	Age 8 yrs.	Age 10 yrs.
F2 change: /ɑː/ mid vowel minus /ɑː/ onset (*bar*)	F M	-107.1 -92.2	-100.8 4.1	-82.3 -18.3

Table 5: Mean F2 difference (Hz) between the mid point and onset of /ɑː/ in *bar* context by age and sex.

4. DISCUSSION

The data reported here show evidence of sex differences in the formant frequencies of the 6-, 8- and 10-year olds in this study, with the female children having higher formant frequencies than their male peers. Moreover, the evidence appears to be robust, because these patterns were found for the data of the alveolar approximant /r/, the vowel /ɛ/ and both the onset and mid point values of the vowel /ɑː/. These sex differences in the patterns of formant frequencies replicate those of adults [1, 14] and could be explained by females having smaller vocal tracts than their male peers. It would therefore appear that there is already evidence of robust sex differences in the formant frequencies of pre-adolescent children, a finding that replicates those of previous developmental studies [9, 11]. What is perhaps more striking in the data reported here is the age-by-sex interaction that was found for the F3 data of the vowel /ɛ/. Here, the F3 data for the male children exhibited a significant fall in frequency between the ages of 8 and 10 (see Table 2 and Figure 1), whereas those of the female children exhibited a slight rise between these ages. This could be interpreted as some evidence for marked changes in the vocal tracts of the male children between these ages.

The sample of coarticulation patterns reported here indicated that there were no significant age, sex or age-by-sex differences for the F2 differences between the mid points of /r/ and /ɛ/ gestures. There were however, significant age differences for the F3 differences between these two gestures. These findings suggests that F2 were not be sensitive enough to detect the gestural overlap of retroflexed consonants, a finding which has been reported elsewhere [12, 13]. In addition, the age differences in the F3 data suggest that the 6-year old children show less overlap than both the 8-year olds and the 10-year olds, between the gestures of alveolar approximant and the vowel. The pattern of no significant age, sex or age-by-sex differences for the F2 differences of the vowel /ɑː/ in the context bar, suggest that all three age groups and males and females displayed similar patterns of gestural overlap for the /bɑː/ gestures. These findings suggest that the development of coarticulation patterns is sensitive to phonetic context. It is suggested that because some gestures involve more complex and secondary articulations (such as those that are involved in the alveolar approximant /r/), are mastered later than those that do not (e.g. in the case of /b/). On this premise, it is therefore proposed that the former types of gesture will display less gestural overlap with neighbouring gestures in the speech of the 6-year olds because they have a less skilled and therefore, less flexible and accommodating articulatory system, which is still undergoing development.

These preliminary data are indicative of both the age and sex differences that co-occur during speech development. The data for sex differences in formant frequencies replicate those of adult studies [1, 14] and indicate that these differences are present before puberty. The coarticulation data suggest that phonetic context is an important factor when investigating the developmental patterns of coarticulation, in that we may find a range of age-related differences in different gesture sequences.

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