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Second formant transitions in fluent speech of persistent and recovered preschool children who stutter

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Abstract

This study investigated frequency change and duration of the second formant (F2) transitions in perceptually fluent speech samples recorded close to stuttering onset in preschool age children. Comparisons were made among 10 children known to eventually persist in stuttering, 10 who eventually recovered from stuttering, and 10 normally fluent controls. All were enrolled in the longitudinal Stuttering Research Project at the University of Illinois. Subjects fluently repeated standard experimental sentences. The same 36 perceptually fluent target segments (syllables embedded in words) from each subject's repeated sentences were analyzed. The syllables were divided into three phonetic categories based on their initial consonant: bilabial, alveolar, and velar placement. The frequency change and duration of F2 transitions were analyzed for each of the target CV segments. F2 transition onset and offset frequencies and their interval (duration) were measured for each utterance. Data indicate that near stuttering onset, children whose stuttering eventually persisted demonstrated significantly smaller frequency change than that of the recovered group. It is suggested that the F2 transitions should continue to be investigated as a possible predictor of stuttering pathways.

Learning outcomes: (1) Readers will learn about studies regarding second formant transition related to stuttering. (2) Readers will learn about differences between children

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who persist in stuttering and those who recover from stuttering. (3) Readers will learn about research concerned with early identification of risk criteria in persistent stuttering.

Keywords: Childhood stuttering; F2 transitions; Persistent stuttering; Recovered stuttering; Predicting stuttering

1. Introduction

Results of many motor and acoustic studies appear to lead to an overall conclusion that the speech production process in adults who stutter is different from that of normally fluent controls (Alfonso, 1991; Kent, 2000). With young children who stutter, however, many past investigations in the same domains showed little or no differences from normally speaking controls (Conture, 1991). More recent studies with preschool age children, however, yielded a few positive findings in fundamental frequency of fluent speech (Hall & Yairi, 1993), voice onset time (VOT) (Adams, 1987), and temporal aspects of specific segments of disfluencies (Throneburg & Yairi, 1994). Additionally, whereas most studies with adults who stutter have evaluated differences from nonstuttering controls, research with preschool children who stutter has seen growing interest in internal subgroup comparisons. An important reason for this trend has been the phenomenon of natural or spontaneous recovery. Recent longitudinal studies (Yairi & Ambrose, 1992, 1999) support other high estimates of recovery (e.g., Andrews & Harris, 1964; Mansson, 2000) that now appear to be at the level of 75–80%, much of which takes place during the first 3 years after the disorder begins.

The phenomenon of recovery gives rise to important questions pertaining to the nature of the differences between persistent and recovered stuttering. Separating those who will persist from those who will recover should increase precision of experiments in various aspects of childhood stuttering and provide data-based grounds to re-consider traditional views of stuttering as a unitary disorder (St. Onge, 1963). From a clinical point of view, perhaps the most immediate question involves prognosis; that is, are there means to determine in the early stage of the disorder which of the children who begin stuttering will recover spontaneously and which will become persistent? Do they exhibit different speech and/or nonspeech characteristics even before developmental processes separate them? Early prediction of the eventual course of the disorder will allow clinicians to make informed decisions about selective treatment strategies. For example, children showing high chances for recovery may be closely monitored for a period of time, whereas children predicted to persist in stuttering might immediately receive clinical intervention.

In the past, there have been a few attempts at predicting persistent and recovered stuttering. Van Riper (1971) implied that persistence and recovery are associated with the type of onset, patterns of early stuttering, and other speech characteristics that typify different developmental tracks. Cooper and Cooper

(1985) and Riley (1981) included a wide array of disfluency characteristics as well as affective reactions as means for making prediction. Their prognostic instruments, however, appear to be greatly influenced by observations of older children that are more prone to become persistent, whereas the most critical application for a prognostic instrument is at the early stage of stuttering.[1]

A surge of interest in early prediction of stuttering pathways has been seen during the past 5 years in a series of reports based on longitudinal investigations. The studies explored the possibilities that disfluency profiles (Yairi & Ambrose, 1999; Yairi, Ambrose, Paden, & Throneburg, 1996), language skills (Watkins & Yairi, 1997; Watkins, Yairi, & Ambrose, 1999; Yairi et al., 1996), phonological skills (Paden, Ambrose, & Yairi, 2002; Paden & Yairi, 1996; Paden, Yairi, & Ambrose, 1999), and patterns of familial incidence of stuttering (Ambrose, Cox, & Yairi, 1997), are potentially predictive of persistence and recovery in stuttering. Amongst these generic skills were specific parameters that were also studied by other researchers to assess their predictive usefulness. One such parameter, formant frequency, was explored in two studies. Stromsta (1965) investigated the second formant (F2) transitions in 63 children identified by their parents as having stuttering. Disfluent segments in their speech were analyzed spectrographically and divided into two categories: (a) displaying formant transitions and normal termination of phonation or (b) displaying lack of formant transitions and/or abnormal termination of phonation. Ten years later, parents' classifications of 38 of these children as either "stuttering" or "not stuttering" were checked against the initial spectrographic information. In the great majority of cases, children displaying formant transition aberrations were those whose stuttering became persistent while children exhibiting normal formant transitions were recovered. Unfortunately, methodological details, such as disfluency type, age of the children, and the procedure for measuring F2 transitions was not provided. Also in this study the subject sample over-represented children who persisted in stuttering by several times their expected proportion, hence it is impossible to assess the generality of the data to the majority of children who stutter. Furthermore, recovery was based only on parent reports with no definitions of either stuttering or recovery given.

More recently, Yaruss and Conture (1993) studied the F2 transition differences between seven young children who were considered as being "low risk" and six as "high risk" for chronic stuttering, based on the Stuttering Prediction Instrument (Riley, 1981). Several measures of F2 transition in sound/syllable repetition were made in comparing the extra disfluent segment with the fluent segment (e.g., b — but; a — and). The authors concluded that the presence of abnormal F2 transitions was not sufficient to differentiate the two groups. A critical issue, however, is the validity of the classification of a child as "high" or "low" risk that remained unverified through longitudinal observations.

[1] Both the Cooper and Cooper (1985) and Riley (1981) prognostic instruments appear to include criteria describing children who have already stuttered for a while.

Although past literature did not provide clear rationale for studying F2 as a predictor of the developmental patterns in stuttering, it is significant to note that several reports that adults exhibiting chronic stuttering tend to reveal appreciable aberrations in this acoustic parameter. For example, Harrington (1987), Howell and Vause (1986), and Howell, Williams, and Vause (1987) found irregular or abnormal F2 transitions in very high percentages of consonant-to-vowel junctions in either fluent or disfluent speech of adults who stutter. Klich and May (1982) found limited F2 movement in fluency enhanced speech, and Robb and Blomgren (1997) reported larger, faster transitions in the fluent speech of stuttering than in nonstuttering adults. Also Yaruss and Conture (1993) reported that several children who stuttered produced abnormalities in their formant transitions. The significance of F2 transitions received further support in recent years from the work of other investigators who used them to study coarticulation, developing locus equations that predict the articulatory movement toward the stop sound (Löfqvist, 1999; Sussman, Bessell, Dalston, & Majors, 1997; Sussman, Fruchter, & Cable, 1995). In 2002, Chang, Ohde, and Conture reported significant differences in F2 transition rate between young children who stutter and normally fluent controls.

Inasmuch as variations in formant structure along the temporal and frequency domains reflect articulatory dynamics, especially of the tongue (Gay, 1978), and to the extent that stuttering is a disorder that involves difficulties with temporal programming and with executing complex articulatory movements or maintaining spatial organization of the articulators (Alfonso, Watson, & Baer, 1987; Kent, 1984; Van Riper, 1982), information regarding F2 in individuals who stutter would seem to be relevant. It is also reasonable to hypothesize that those children who are destined to become adults with chronic stuttering present formant abnormalities from early on. These irregularities in children with persistent stuttering would be similar to those found in adults with chronic stuttering but are not exhibited by children who will eventually recover. Thus, in view of contradictions and methodological problems in two previous F2 studies with children who stutter, our general goal was to investigate the potential use of second formant data in differentiating subgroups of preschool children just beginning to stutter who will eventually exhibit different developmental paths, and to compare these groups with control (nonstuttering) children. A previous exploratory study by Kowalcyzk and Yairi (1995) found that there were differences in the values for F2 transition among the different groups. The present investigation was designed to study this aspect further asking three specific questions: (a) are F2 transitions different for children who stutter and those who do not, (b) are F2 transitions good predictors of persistent stuttering, and (c) does extent of frequency change or duration contribute to differences in F2 transition.

This study was conducted with the advantage of having children who had been followed longitudinally for several years and their classification was confirmed through rigorous criteria. Additionally, contrary to the Stromsta (1965) and the Yaruss and Conture (1993) investigations that analyzed disfluent speech, the present study focuses on F2 in perceptually *fluent* speech, a procedure that has been assumed to investigate the broader abnormality in the speech motor system of people who stutter.

2. Method

2.1. Subjects

Thirty children, 20 with stuttering histories and 10 normally fluent, without stuttering histories, participated. They were chosen from more than 200 subjects currently enrolled in the longitudinal Stuttering Research Project at the University of Illinois. The children were divided into three groups of 10 each: persistent stuttering, recovered stuttering, and control. The first available children, who fulfilled the classification criteria and were age and sex-matched in all three groups, were selected. It is important to emphasize, however, that during the initial visit, when the speech samples were obtained, the eventual classification of the subjects as persistent or recovered was not known.

To qualify as a child who stutters for the subset of this study, a potential participant had to meet the following criteria: (a) under 6 years old at the time of the first visit, (b) first evaluation occurring no longer than 12 months after the onset of stuttering, (c) judged by both parents as having a "stuttering problem," (d) judged by two senior staff members, speech–language pathologists experienced with stuttering, as exhibiting a "stuttering problem," (e) the stuttering exhibited at the time of the initial evaluation rated by the two staff members as 2 or higher on an eight-point stuttering severity scale (with 0 being "normal speech," 2 "mild" stuttering, and 7 "very severe" stuttering), (f) parent severity rating of stuttering at least 2 on an eight-point scale, (g) a minimum of 3 stuttering-like disfluencies (SLDs) per 100 spoken syllables defined in Yairi and Ambrose (1992) as consisting of part-word repetition, single-syllable word repetition, and disrhythmic phonation (primarily sound prolongation and broken words), and (h) no history of neurological disorders.

The control children were regarded by their parents as *not* having a history of stuttering or any neurological disorders. They were also judged by the two senior staff members as not exhibiting a stuttering problem and their speech samples contained fewer than 3 SLDs per 100 syllables. All children passed a hearing screening, were within normal range of language development (Watkins et al., 1999), and were familiar with the stimulus material used.

All participating children were followed longitudinally and were re-evaluated and tape-recorded every 6 months. Persistent stuttering was defined as having continued for a minimum of 36 months post-onset of stuttering, and currently apparent. Children classified as recovered from stuttering exhibited no stuttering and had not stuttered for a minimum of 12 consecutive months. To be considered recovered, subjects had to meet the following criteria: (a) parental judgment that

Table 1
Gender, mean age (standard deviations) at first visit, age ranges, months post-onset, and SLD for the persistent, recovered, and control groups

Gender	Mean age (S.D.) in months at first visit	Age ranges (months)	Months post-onset	SLD
Persistent				
7 males, 3 females	45.1 (3.25)	41–48	9.1	14.4
Recovered				
8 males, 2 females	45.1 (4.84)	36–51	7	9.4
Control				
7 males, 3 females	44.8 (3.85)	38–48		1.2

the child does not stutter, (b) speech–language pathologist judgment that the child does not stutter, (c) parent's and clinician's stuttering severity ratings of lower than 1 on the eight-point scale described above, and (d) fewer than 3 stuttering-like disfluencies per 100 spoken syllables. None of the stuttering children received treatment prior to the recording of the speech samples.

For each of the three subject groups, the mean age (and standard deviations), age ranges, gender composition, months post-onset of stuttering at the time of the initial visit, and number of stuttering-like disfluencies are summarized in Table 1.

2.2. Speech samples

As part of a comprehensive recording and testing battery administered during the initial evaluation, subjects repeated five different sentences. Each sentence contained four words and was uttered following a model by an investigator. A taped speech model was not employed because it is often impractical for children at the ages of our subjects. The investigator, however, paid considerable attention to utter the sentences in a consistent manner so they sounded normal and natural. Although not specifically designed to study formant transition, this material was used because it comprised a set of uniform sentences that were available for all the subjects enrolled in the study. The sentences were: (1) "The black cat jumped," (2) "We ate tacos today," (3) "He is peeking again," (4) "You pet my dog," and (5) "They baked cookies today."

Three productions of each of 12 CV segments (a total of 36 productions) contained in 10 target words in each child's perceptually fluent repeated sentence sample were selected for analysis. The 12 CV segments represent three different places of articulation for the consonants. The phonetic categories included consonants that were: (a) bilabial — three CV segments, (b) alveolar — four CV segments, and (c) velar — five CV segments. The three syllables for each place of articulation were grouped together in spite of their different positions and stress levels. Preliminary examination indicated no significant differences in frequency change and duration among syllables within the same place of articulation. Contrasting voiced and voiceless segments, however, was deemed unfeasible because of the small number of tokens. The target words were as follows:

Bilabial	*Alveolar*	*Velar*
*pee*king	*ta*co	ta*co*
*pe*t	*to*day	*ca*t
*ba*ke	*do*g	a*gai*n
	to*day*	*coo*kies
		coo*kie*s

2.3. Recording

The children were asked to repeat a sentence following a model by the investigator until three fluent productions were obtained. Because of disfluencies or word errors, 7 of the 30 subjects required four or five repetitions of some sentences to obtain three fluent utterances. Of these seven subjects, three belonged to the persistent group, three to the recovered group and one was a control. More than three repetitions were required for a maximum of two sentences per child.

The sentences were audio- and video-recorded in an IAC soundproof room using a Crown PPC-160 cardioid microphone connected to a Yamaha KM608 preamplifier (mixer). Each child was seated at the same fixed distance (approximately 24 in.) from the microphone. This position was at the zero degree point, or head-on from the microphone that was placed on a stand facing the seated subject. The subjects were instructed to sit quietly, and not to move about as they repeated the sentences. The investigators ensured that the proper position was maintained. The audio signal was directed to a Tascam 122 MKII cassette recorder, and recorded onto Maxell II S-90 cassette tapes.

2.4. Data analysis

Two speech–language clinicians initially screened all experimental speech productions to identify any phonological inaccuracy in the sentences produced by the children. Sentences that were judged inaccurate were not included in the analysis. Next, an enhanced spectrographic display of each segment of interest was viewed by the investigators to verify that all relevant elements of the formant transition were visible. Sentences in which the transition was not clearly displayed, or in which the aspiration of the opening plosive (typically voiceless consonants) masked the transition, were also excluded. Furthermore, inasmuch as different combinations of consonants and vowels in the CVs used could yield different formant frequency changes due to frequency differences between the locus of consonant and the adjacent ‘‘high’’ or ‘‘low’’ vowel, the experimenters reviewed all remaining tokens, assuring that the proportion of all different combinations of CV were similar across the three groups. These procedures also reduced the number of tokens.

The tape-recorded words were low-pass filtered (Frequency Devices Series 900) at 7.5 kHz, digitized at 20,000 samples per second (Data Translation 2821 A/D converter) and stored on a computer disk. Signals were then low-pass filtered at 7.5 kHz for playback during the analysis. Acoustic measurements were made from a wide-band (400 Hz) spectrogram display using the CSpeech analysis computer program (Milenkovic, 1987). This display was selected because it enabled a visual representation of the formants and their transition without the influence of the harmonics. First, the full word was displayed on the screen and then the investigators "zoomed in" on the target syllable. The segment was visually and auditory verified to ensure that both the beginning and the ending of the transition were included. The duration of the speech segment that was visually examined for each measurement was approximately 300 ms. Cursors were placed at the initiation and termination of the formant transition segment in each word. The initiation of the transition, point a in Fig. 1, was defined as the first glottal pulse following the release of the stop. It was required that at this point both the first and the second formants be identifiable on the spectrographic display and that this point also correspond with the first peak of periodical spectral energy within the vowel on the time–intensity waveform. The investigators also used LPC splices at the points where the energy was strongest. These splices also contributed to the identification of energy concentration that aided in the identification of the second formant frequency. Because this definition of the initiation of the transition does not involve the consonant, measurements were not affected by the voice onset time duration.

In the analysis of voiceless consonants, great care was taken to ensure that the VOT release was not identified as the second formant transition. In cases where the two experimenters could not agree on the location of the initial point of the transition, the token was rejected from the analysis. This careful inspection of

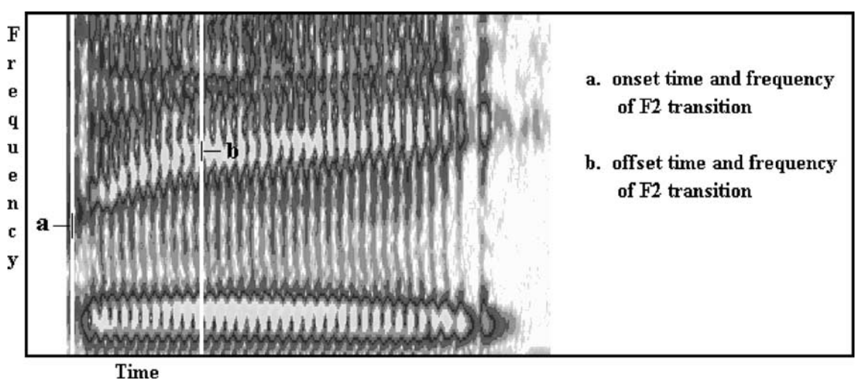

Fig. 1. Spectrographic analysis of the word "bake." Acoustic measurements are indicated.

voiceless (as well as voiced) transitions also eliminated a number of tokens. Eventually 610 tokens, a mean of 20.3 tokens per child, were finally measured. Considering the difficulties encountered in acoustic analyses of children's speech, and the need to equalize the materials used for the different groups, the number of segments that was actually analyzed was expected, reasonable, and larger than in past research.

The end of the transition was defined as the first glottal pulse in which a steady state was identified in the following vowel (point b in the figure). When a steady state was not readily identifiable in the running speech, the first pulse in a region of unchanging frequency extended over three pulses was chosen. The onset frequency and the offset frequency of the transition were measured using both the LPC spectrum and the spectrograph at the points a and b as specified above. For the LPC measurements, only one cursor was used. This was placed at the point where the transition was thought to be starting or ending, as required. At this point, LPC measures were made to corroborate the identification of the second formant frequencies by the investigators. Because formant transitions depend on both the duration of the transition and the frequency change, two measures were made directly from the spectrogram: (1) the extent of change in Hertz along the frequency domain between points a and b and (2) the duration in millisecond along the time domain between points a and b.

To minimize individual bias in reading spectrograms, all measurements were performed jointly by two investigators who had at least 100 h of experience with such tasks. Working together, they had to agree on the accuracy of both the beginning and final points.

2.5. Reliability

Inter-judge agreement was calculated approximately five weeks later by both judges re-measuring together the frequency and duration of five randomly chosen segments from each of seven children in each group, yielding a total of 105 reliability measures. The mean difference for frequency change was 28.38 Hz, and for duration it was 2.9 ms. Because movement of one cursor point in the frequency domain of the spectrogram was equal to 20 Hz, a mean difference of 28 Hz in reliability represents a shift of less than 1.5 cursor points. In the time domain, each movement of a cursor point depended upon the length of the segment on display. The differences between one cursor point and the next ranged between 0.050 to 0.50 ms. Thus, reliability was deemed high.

2.6. Statistical analysis

The analyzed individual data were collapsed together to yield mean values for frequency change and duration in each of the places of articulation per child. These individual means were used to derive group data. The two dependent variables, frequency change and duration, were subjected to separate mixed ANOVAs. The between subject factor in these analyses was group, while place of articulation was the within subject factor. Although the role of place of articulation was not of prime interest in this study, it was deemed necessary to rule its effect on possible group differences. To control the overall level of errors of type 1, the significance level for each of the ANOVAs was $0.05/2 = 0.025$. Post hoc testing for statistically significant results was conducted using Bonferroni pair-wise comparisons.

3. Results

The mean values for the frequency change and duration in each group, averaged across the three places of articulation for all the groups are given in Table 2.

A preliminary test of sphericity was conducted on the entire data to ensure that the different variables are indeed independent measures without a common variance. The Mauchly test of sphericity was significant ($P < 0.05$) for the duration data. Therefore, in analyzing this measure, we applied an adjustment to the degrees of freedom to obtain valid statistical tests of the research hypotheses.

For the measure of duration, the repeated measures ANOVA resulted in lack of statistical significance for place of articulation ($F = 0.18$, d.f. 1.2, 29.9; $P > 0.025$) using the adjusted degrees of freedom. This finding implies that the duration of the transition did not differ across the three places of articulation. The between subject variable, group, was also found to be nonsignificant ($F = 0.27$, d.f. 2, 25; $P > 0.025$), indicating that all the groups were similar in the duration of their utterances. The interaction between place and group was not significant either ($F = 0.305$, d.f. 2.4, 29.9; $P > 0.025$), indicating that the groups did not have different duration measurements for the different places of articulation.

The ANOVA for frequency change of the F2 transition yielded more interesting findings. For the within subject factor of place, frequency change was found to vary significantly ($F = 18.66$, d.f. 2, 50; $P < 0.025$). This implies that the value of frequency change differed for the various places of articulation as would be expected. Frequency change was the greatest for bilabial sounds (475.95 Hz), smallest for the velar sound (304.37 Hz), and intermediate for the alveolar sounds (407.03 Hz). Such a trend is expected due to differences in energy concentration (locus) of sounds along the frequency range as determined by their places of articulation (Baken, 1987; Delattre, Liberman, & Cooper, 1955; Kent & Read, 1992). For example, because bilabial consonants are acoustically characterized by

Table 2
Means and standard deviations (in parentheses) of the three groups for frequency change (Hz) and duration (ms)

Measure	Persistent	Recovered	Control
Duration	58.75 (22.72)	59.07 (19.61)	66.14 (37.12)
Frequency change	395.78 (196.72)	583.99 (229.77)	502.35 (232.10)

energy locus in the low-frequency region, transitions to mid-frequency vowel-formant typically will rise considerably. Velar consonants, on the other hand, are typically characterized by energy concentrations at a higher locus, thus they are expected to fall during coarticulation in order to reach the appropriate target following second-format vowel-frequency. However, the acoustic locus of the velars is distributed on a relatively larger frequency range than that of the bilabial consonants. It appears that the larger variability of velars' loci, in comparison with that of other consonants, diminished the statistical power of the difference between the three places of articulation.

We did not find a significant interaction between place and group ($F = 1.41$, d.f. 4, 50; $P > 0.025$) suggesting that all the subjects, irrespective of group, produced similar transitions for the different places of articulation. We did, however, find significant differences between the frequency changes in the three groups ($F = 4.75$, d.f. 2, 25; $P < 0.025$). Post hoc pair-wise comparisons of the groups using the Bonferroni procedure identified a statistically significant difference between the persistent and recovered groups for frequency change. The control group was not different from either the persistent or the recovered group.

4. Discussion

The need to develop a scientifically based means for early prediction of children who will continue to stutter and those who will exhibit natural recovery presents a challenging task. Two past studies (Stromsta, 1965; Yaruss & Conture, 1993) that applied acoustic analyses of F2 transition in *disfluent* speech to investigate this issue yielded conflicting results. The present findings of statistically significant differences for frequency change are based on a larger number of children than used in past research as well as a larger amount of speech material — 610 tokens — carefully screened. They provide impetus for continuing research into the features of speech formants that might discriminate between children who stutter and normally fluent children, and between children who persist in and those who recover from stuttering. As mentioned earlier, although the effect of place of articulation was not of prime interest in this study, the fact that all three subject groups demonstrated the expected effect of articulatory placement for frequency change and that observed group difference was evident in two of three places of articulation, strengthens the validity of the present findings by indicating that the three groups produced the sounds in similar general patterns and that phonological differences in the material did not determine the group differences in the frequency change. Thus, in general, our results concerning the formant transitions are reminiscent of Van Riper's (1971) and Wingate's (1964, 1969) statements that a transition deficit is significant, perhaps central, to stuttering. Recent findings reported by Robb and Blomgren (1997) for adults, as well Chang, Ohde, and Conture (2002) who studied children who stutter also support this assertion.

Of the two contradictory past studies that focused on the prognostic usefulness of F2, the present findings agree with Stromsta's (1965) conclusion that the second formant transition may have merit in predicting persistent stuttering. Our findings, however, are based on fluent speech whereas Stromsta's findings were based on disfluent segments. The disagreement with Yaruss and Conture (1993) can be explained by several procedural factors: (1) they obtained data from stuttering children whose final classification as persistent or recovered was not confirmed, (2) their speech samples consisted of variable conversational speech, and (3) the materials they analyzed included formant transitions in a relatively small number — a total of 78 *disfluent* segments. In contrast, the present study (1) tracked children for several years to establish their final classification, (2) used speech materials that were controlled, uniform utterances, and (3) was based on the analysis of a large corpus of 610 of fluent segments.

The direction of the present findings is particularly interesting, indicating that the frequency dimension of the formant transition, rather than the time dimension, is the more significant contributor to the differences between stuttering and nonstuttering children as well as between the two stuttering subgroups. Previous reports of differences between stuttering and normally fluent groups have emphasized durational and other temporal characteristics. Only recently, Hall, Amir, and Yairi (1999) and Kloth, Kraaimaat, Janssen, and Brutten (1999) reported articulatory rate difference between stuttering and normally speaking preschool children and between recovered and persistent subgroups. The current finding of group differences in the frequency dimension of the second formant draws more attention to the *spatial* than to the temporal domain.

Inasmuch as F2 transitions represent the continued movement of the articulators either to realize the full vowel or to realize anticipatory coarticulation of the gestures for the next sound(s), the smaller frequency change in the persistent group may be interpreted to reflect restricted movement of the articulators on a spatial plane. In other words, children with persistent stuttering may have difficulty with transitions and/or blending across sounds (Zimmermann, 1980) resulting in undershooting their articulatory targets. The differences in speech motor control strategies among children who stutter, however, may reflect the way they handle the varying demands on their speech motor skills rather than the etiology of stuttering (Van Lieshout, 1995). This would appear to support the notion of the "limited degrees of freedom" of the speech motor control system (see Gracco, 1997), as well as Van Riper's (1971) speculation that the stutterer's difficulty is not with sounds but with transitions between them. In other words, to be efficient in organizing articulatory gestures, the speech motor system of children who stutter limits, or controls, the degrees of freedom of articulatory movement. Different interpretations, however, could be entertained. Based on the research by Sussman and his associates (Sussman et al., 1995; Sussman et al., 1997; Sussman, Dalston, & Gumbert, 1998) using locus equations, smaller frequency changes within the same duration would indicate strong coarticulation.

To the extent that changes in the frequency dimension can be considered to reflect the degree of coarticulation and the actual tongue movement, smaller frequency changes observed in the persistent subgroup may reflect stronger coarticulation. Löfqvist (1999), however, questioned the notion that reduced frequency range in formant transitions indicates stronger coarticulation.

It is also tempting to speculate that the change in the frequency of the formant transition could have been influenced by difficulty in the duration variable. If stuttering is a disorder that involves reduced capacity to generate temporal patterns (Kent, 1984), children who would eventually develop chronic stuttering exhibit this problem to a greater degree right from the beginning. This is particularly intriguing in light of reported genetic differences between these two groups (Ambrose et al., 1997). One way of coping with the difficulty is to simplify articulatory movement in the spatial domain. When a child is unable to make the predicted articulatory target, he/she must do one of two things: increase the speed or change the spatial plane. It appears that the children who eventually persist in stuttering do have problems when having to change the tempo of speech movements and, therefore, would minimize the frequency target rather than increase speed. In their study of articulatory rate Hall et al. (1999) reported that children who persisted in stuttering had faster articulation rate than those who recovered. Thus, it could be speculated that, due to their already faster articulation rate, the persistent children had to resort to making changes in the spatial plane to reach the target production. One point to consider is whether this restriction represents a compensatory behavior to achieve fluency, a peripheral execution adjustment, or central programming characteristic of persistent stuttering.

There are additional points. First, because this study was conducted close to the onset of stuttering, the differences observed suggest that problems with speech programming or motor control are present at the formative stage of the disorder. These findings appear to complement previous data indicating that, during the early stage of stuttering, children who eventually persist in stuttering are more likely to exhibit phonological delay than children who recovered (Paden et al., 1999; Watkins et al., 1999). Second, our data, being obtained from analyses of fluent speech, also appear to support the view that stuttering reflects a disorder that continually affects speech programming and execution and is not limited to observed disfluent segments. Such difficulties appear to be more pronounced in children who are destined to develop a more persistent problem.

Finally, some caveats. To begin with, the normal speech of young children is more variable than that of adults, with incomplete phonological mastery adding to the problem. And, substantial heterogeneity is common in stuttering, including characteristics seen in acoustic features (Adams, 1987; Zebrowski, Conture, & Cudahy, 1985). In this light, one aspect that needs to be stressed here is the variability within the groups of children. The small values for degrees of association and large standard deviations suggest caution in interpreting and generalizing the results. Furthermore, although this study is larger than previous investigations, additional children in both stuttering groups, as well as larger speech samples are required before conclusions can be drawn regarding the clinical applicability of the data. Perhaps there are subgroups within the groups as defined in the current study. In addition, Alfonso and Van Lieshout (1997) reported evidence suggesting that neither traditional spatial nor temporal organizational characteristics were stable among control subjects across sessions. Their conclusions should be borne in mind in interpreting the findings. Also, in spite of advantages of controlled speech samples, limiting the child's speech to four-word utterances may affect naturalness of articulatory movements. Although an attempt was made to maintain constancy in the model provided to the child for imitation, some inherent differences from one repetition to another may have occurred. In future research, investigating formant transitions in both controlled and conversational speech of the same subjects is desirable, as well as comparing data recorded in more than one session. At this point it would appear that promising trends call for additional data to assess the usefulness of F2 or frequency information in predicting chronic stuttering.

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Appendix A. Continuing education

1. Second-format transition best serves as indicator of:
   a. Lip movement rate.
   b. Tongue movement rate.
   c. Glottal movement rate.
   d. Jaw movement rate.
   e. All of the above.

2. Results of the present study indicate which groups of children to be significantly different in the frequency change parameter?
   a. None of the groups were different from each other.
   b. All the three groups differed from each other.
   c. Both the stuttering groups (persistent and recovered) were different from each other, but not from the control group.
   d. The group with persistent stuttering was different from the control group.
   e. The group who recovered from stuttering was different from the control group.

3. The present finding would seem to indicate which of the following?
   a. Children who persist in stuttering speak slower than children who recover.
   b. Children who recover from stuttering speak faster than children who persist.
   c. The format transition of normally speaking children are shorter than those of either children who persist or children who recover.
   d. The duration of the format transition does not differentiate among the three groups.
   e. The frequency extent of the format transition does differentiate between children who persist and those who recover.

4. Based on the data presented, can clinicians use the second formant transition as a valid predictor of persistence in stuttering within a clinical setting?
   a. Yes, for all groups of children.
   b. Yes, but only for predicting recovery in early childhood.
   c. Yes, but only for predicting recovery for adults.
   d. No, the current data is not yet sufficient for predicting recovery or persistence.
   e. No, the data is not yet sufficient for predicting recovery in the clinical setting, however this measure is valid for differential diagnosis in research.

5. Based on the literature review presented here, which statement would be always true about F2 transition among people who stutter?
   a. Young children who stutter exhibit slower F2 transitions than those who do not stutter.
   b. Young children who stutter exhibit faster F2 transitions than those who do not stutter.
   c. Adults who stutter exhibit slower F2 transitions than those who do not stutter.
   d. Adults who stutter exhibit faster F2 transitions than those who do not stutter.
   e. None of the above is true.

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