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FUNDAMENTAL FREQUENCY AND VOWEL DURATION UNDER FREQUENCY SHIFTED AUDITORY FEEDBACK IN STUTTERING AND NONSTUTTERING ADULTS

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INTRODUCTION

A number of studies with delayed and premature auditory feedback revealed an online mechanism controlling vowel duration, which was named ‘audiophonatory coupling‘ (Kalveram, 1991; Jäncke, 1991; Natke, 1999). Delayed auditory feedback leads to a prolongation of vowels in long stressed syllables, whereas premature auditory feedback shortens it (for realization of premature auditory feedback see Kalveram, 1984). Unstressed and short stressed syllables remain almost unaffected. In two studies a higher degree of audiophonatory coupling, defined as a stronger prolongation effect under delayed auditory feedback was found in people who stutter, compared to people who do not stutter (Kalveram & Jäncke, 1989; Jäncke, 1991). Jäncke (1991) found, that people who stutter severely show a stronger prolongation effect than people with a moderate stuttering severity. In two recent studies however, this group difference could not be replicated (Natke, 1999). Langefeld et al. (this volume) found preliminary evidence that a public speaking condition leads to a stronger prolongation effect only in nonstuttering people. Therefore results are conflicting and more research regarding differences in the auditory control of vowel duration by nonstuttering and stuttering people is needed.

As stated above, manipulations in the time domain by delayed or premature auditory feedback reveal control mechanisms regarding temporal parameters of speech production like vowel duration. For the investigation of control of fundamental frequency the frequency domain of the auditory feedback must be manipulated. Several studies using frequency shifted auditory feedback suggest a mechanism controlling fundamental frequency via the auditory feedback loop (Elman, 1981; Kawahara, 1994; Burnett et al., 1998; Larson, 1998; Natke & Kalveram, submitted). In these studies, except for our own one, subjects had to produce a vowel continuously, while after a randomly determined duration of 500 to 1500 msec after onset, the frequency of the feedback signal provided by headphones was shifted. Subjects usually respond with a small compensation effect in fundamental frequency. Natke and Kalveram (submitted) used the frequency shifting while subjects were speaking test words. Using frequency shifts of -1/10 and -1/2 octave turned on immediately before the subject started to utter the test word, a small increase of the fundamental frequency of the vowel by 1 and 2 Hz was observed in long stressed syllables. Unstressed syllables were not affected, if they were the first syllables within the test word. Regarding the second syllable, fundamental frequency increased in long stressed as well as in unstressed syllables. These results suggest a mechanism, which controls the fundamental frequency via the auditory feedback loop at syllable level. However, unstressed syllables seem to be too short for online control, and complete compensation of frequency shifts is missing widely. Control of fundamental frequency at syllable level depends on stress or duration. This corresponds to control of vowel duration by audiophonatory coupling, although the type of control may be different (see Natke & Kalveram, submitted). As stated above, there is some indication for differences between stuttering and nonstuttering people in auditory control of vowel duration. Until now there is no data from people who stutter regarding control of fundamental frequency.

In the study described above auditory feedback was manipulated intermittently and unpredictably during single productions of a test word. This technique prevents adaptation processes and makes sure that compensation mechanisms can not be installed in advance. The objects under investigation are speech control mechanisms, which also operate in natural speaking. If auditory feedback is manipulated continuously instead of intermittently by masking, delaying or frequency shifting it, fluency in people who stutter can be enhanced. Whereas the fluency enhancing effect of masking and delayed auditory feedback has been known for several decades, frequency shifted auditory feedback was first investigated with regard to stuttering by Howell, El-Yaniv and Powell (1987). They found a reduction in stuttering frequency with a frequency shift of -1 octave. In a number of studies the fluency enhancing effect of frequency shifted auditory feedback was confirmed (Kalinowski et al., 1993; Hargave et al., 1994; Stuart et al., 1996). However, current results point to large interindividual differences (Ingham et al., 1997; Armson & Stuart, 1998; Natke, 2000).

The underlying mechanisms of the fluency enhancement by frequency shifted auditory feedback are unknown. Wingate (1970) suggested that in delayed auditory feedback as well as other strongly fluency enhancing conditions, a modified vocalization, especially the prolongation of vowels, leads to fluency enhancement. Such a prolongation can be very small and limited to long stressed syllables, as indicated by studies with intermittent delayed auditory feedback regarding audiophonatory coupling. Therefore prolongation is not necessarily perceivable by a listener and may not lead to a decrease of speech rate, if other segments are shortened instead of vowels (Stager & Ludlow, 1993). There is no data on effects of frequency shifted auditory feedback on vowel duration. Therefore it is an open question, whether the fluency enhancing effect of frequency shifted auditory feedback may be based on modified vocalization.

In the presented study, possible differences between stuttering and nonstuttering people regarding the control of fundamental frequency at syllable level are examined. Furthermore it is investigated, whether frequency shifted auditory feedback influences vowel duration.

METHOD

Subjects

The study included 12 male nonstuttering and 12 male stuttering subjects whose mother language was German (nonstuttering people: *M*=24.9 years, *SD*=2.86; stuttering people: *M*=27.7 years, *SD*=4.91). None of the participating subjects showed a hearing deficit of more than 20 dB (audiometric test: Hortmann DA 323, Neckartenzlingen, Germany). Furthermore the subjects did not show any neurological impairments or took any medication that affects the nervous system, as reported by a standardized questionnaire. Only subjects were included, who had not participated in an earlier experiment, in which a test word had to be uttered repeatedly. The nonstuttering subjects did not reveal any speech or language disorders, the stuttering subjects no other speech or language disorders but stuttering. All subjects who stutter took part in stuttering therapies, but not in the two years prior to their participation in the experiment. With Riley’s Stuttering Severity Instrument (Riley, 1972) the degree of stuttering severity was determined. In four subjects the stuttering severity was judged as mild, in three as moderate, in four as severe, and in one subject as very severe (Riley scale: *M*=19.5, *SD*=8.10).

Apparatus

The frequency shift was operated with a commercial device (DFS 404, Casa Futura Technologies, Boulder, USA), that works on a digital basis with a sampling frequency of 32 kHz and a sampling depth of 14 Bit. This device was modified by installing a relais for switching between non altered (NAF) and frequency shifted auditory feedback (FAF). A headset with closed ear pads (Blackhawk DSP 5DX, Flightcom, Portland, USA) was used, which itself attenuates the air conduction by 24 dB. For calibration the feedback gain was adjusted in a way that a sine tone of 75 dB (A) at the microphone led to a feedback volume of 70 dB (A) in the headphones. Subjects perceived the adjusted volume as a normal feedback volume. In addition, a binaural low frequency noise, which was produced by 900 Hz-low pass filtered white noise with a volume of 70 dB (A) was added in order to mask the bone conduction. An electroglottograph (EGG) (Laryngograph, Kay Elemetrics, Pine Brook, USA) recorded the vibrations of the vocal folds. Control of the experiment and data acquisition was handled by a commercial personal computer with a stereo soundcard. This computer was also used for playing a tone sequence, for the relais control in the FAF device to switch between NAF and FAF, and for the speech and EGG signal recording. Recording was based on sampling frequency of 11025 Hz and a sampling depth of 16 Bit.

Procedure

The subjects‘ task was to utter the test word [tatatas] with the speech rate and the stress pattern given by a rhythmical target tone sequence which had been presented twice previously. The tone sequence consisted of three sinusoidal tones of 440 Hz, where an unstressed syllable was indicated by a duration of 200 msec and a long stressed syllable by a duration of 400 msec. Two prosodic conditions were provided (['ta:tatas] and [ta'ta:tas]). There was an interval of 3.5 sec between tone sequences during which the subject had to utter the test word.

The experimental procedure included 30 trials with a long stress on the first syllable and 30 trials with a long stress on the second syllable of the test word. Only the first syllable of the test word was analyzed, because observations on later syllables may be based on processes of preceding speech segments. Therefore, data was available for long stressed and unstressed syllables from both prosodic conditions. During 20 % of all trials the frequency of the auditory feedback was shifted by -1/2 octave. Frequency shifting was turned on immediately before the subject started to utter the test word, so the whole test word was produced with frequency shifted auditory feedback. After speaking the test word, frequency shifting was turned off and subjects heard their non altered voice. The FAF trials were determined randomly with the restriction, that at least two NAF trials had to precede a FAF trial.

Presentation of the target tones and recording was done automatically while the subject was sitting alone in a sound isolated chamber. Subjects were asked to speak clearly and with normal volume.

Data Analysis

The speech signal was used to control whether the test words had been spoken correctly and, in the case of the stuttering subjects, also perceptually fluently. Determination of vowel duration T and mean fundamental frequency F_0 of the vowel was based on the EGG signal (for details see Natke & Kalveram, submitted). Vowel duration and fundamental frequency within each subject and each prosodic condition was averaged over the six trials with frequency shifted auditory feedback and over the six non altered trials immediately preceding the shifted ones. There were no missing data. Data from nonstuttering subjects stem from the study of the authors mentioned above, in which two levels of frequency shifts were compared.

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For comparisons between frequency shifted and non altered auditory feedback within the groups, two sided t-tests for dependent samples were calculated. Regarding the change of fundamental frequency, differences between the groups were tested with two sided t-tests for independent samples. Since ten simultaneous tests were performed the significance level ? = 5 % was corrected according to Bonferroni to ? ' = ? /10 = 0.005 %.

RESULTS

Figure 1 shows the results for the vowel duration *T* for (a) long stressed and (b) unstressed syllables. Both are the first syllables within the test words. Long stressed syllables had a mean vowel duration of 321 msec, unstressed syllables a mean vowel duration of 122.5 msec. A small tendency for a vowel prolongation of 3 msec occurred only in the case of an unstressed syllable in nonstuttering subjects.

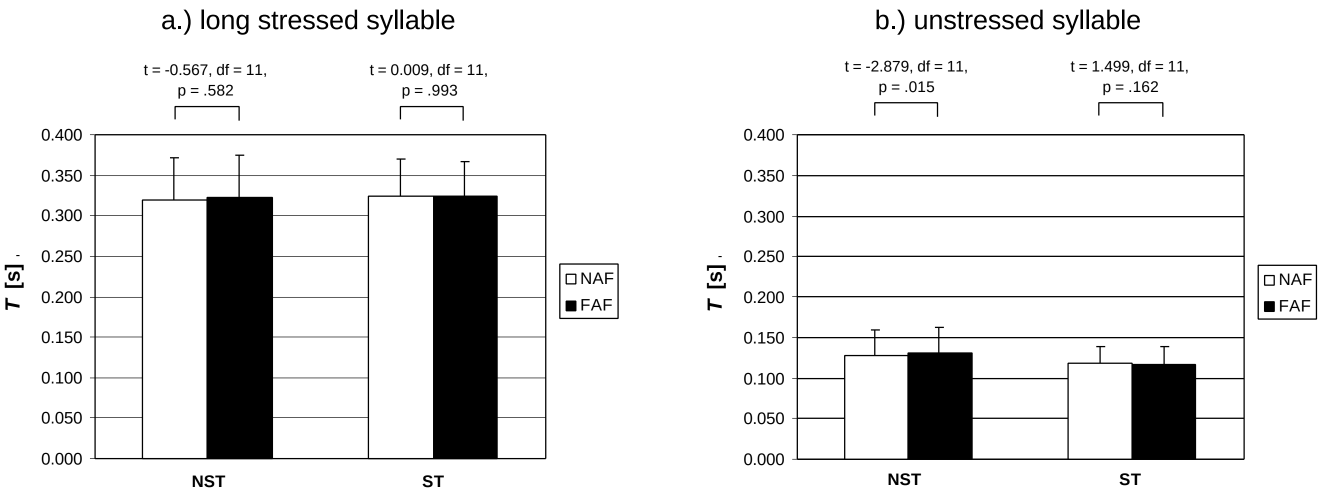

Figure 1: Vowel duration *T* and standard deviation for NAF (non altered auditory feedback) and FAF (frequency shifted auditory feedback) with a frequency shift of -1/2 octave in stuttering (ST) and nonstuttering (NST) subjects for long stressed (a) and unstressed syllables (b). p-values are based on two sided t-tests for dependent samples.

Figure 2 shows the results for the fundamental frequency F_0 of the long stressed (a) and unstressed syllable (b) in first position within the test words. Long stressed syllables had a mean fundamental frequency of 123.8 Hz, unstressed syllables a mean fundamental frequency of 120.1 Hz. The frequency shift of -1/2 octave resulted in a significant increase by 2 Hz in nonstuttering subjects. In terms of cents, mean response magnitude equals 25.5 cents. Response magnitude was therefore 2.1 % of the magnitude of the feedback shift. Subjects who stutter did not show a change in fundamental frequency (comparison of change in fundamental frequency between groups: t=2.784, df=22, p=.011). There was no effect for the unstressed syllable in neither groups.

Results regarding the second syllable of the test word in nonstuttering subjects were reported by Natke and Kalveram (submitted). In long stressed as well as unstressed syllables an increase of fundamental frequency between 2 and 5 Hz was found. Stuttering subjects in the presented study did not show any effect with regard to fundamental frequency or vowel duration in the second syllable, regardless whether it was long stressed or unstressed.

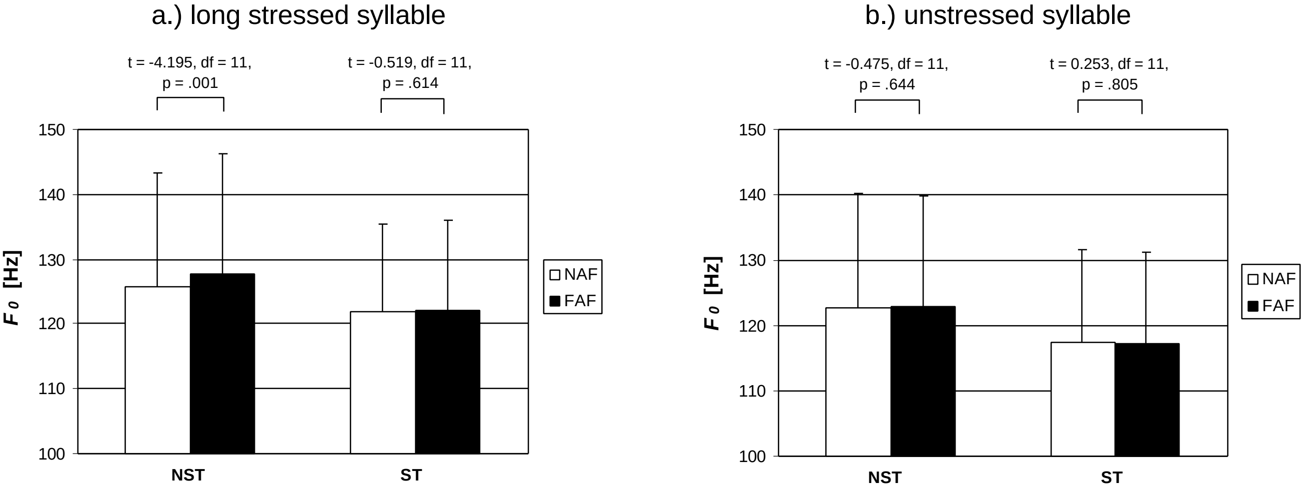

Figure 2: Fundamental frequency F_0 and standard deviations for NAF (non altered auditory feedback) and FAF (frequency shifted auditory feedback) with a frequency shift of -1/2 octave in stuttering (ST) and nonstuttering (NST) subjects for long stressed (a) and unstressed syllables (b). p-values are based on two sided t-tests for dependent samples.

DISCUSSION

In nonstuttering people frequency shifted auditory feedback leads to a compensatory response in fundamental frequency of the vowels within a test word. This response could only be observed in the first syllable of the test word, when it was long stressed. When the first syllable was unstressed and therefore short, no effect occurred. Natke and Kalveram (submitted) reported, that in the second syllables of test words a response could always be observed in nonstuttering subjects. Thus, a negative feedback mechanism controlling fundamental frequency via the auditory feedback loop on syllable level in speech like productions was found, which is only effective within syllables, if they are long enough.

Since in this study effects of frequency shifts on the mean fundamental frequency of syllable vowels were examined, the fundamental frequency was averaged over the interval prior to the response. Therefore, the actual response magnitude was likely greater than reported. Nevertheless a response magnitude regarding fundamental frequency was found, which corresponds to those found in studies with continuous vocalization (e.g. Burnett et al., 1998). Complete compensation for frequency shifting at syllable level is missing widely. Natke and Kalveram (submitted) suggested, that control of fundamental frequency is rather important on a supra-segmental level i.e. for intonation, whereas, with respect to comprehension control of vowel duration, is much more important on the level of syllables.

People who stutter did not show a compensatory response to frequency shifted auditory feedback. This result may indicate that people who stutter use the auditory feedback channel less or deficiently for the control of fundamental frequency. This may also be indicated by a study of Bosshardt et al. (1997), in which interrogative sentences with different intonation patterns had to be reproduced. Subjects who stutter responded with a smaller increase of fundamental frequency in stressed syllables than nonstuttering subjects. Besides of other characteristics, stressed syllables are marked by a longer duration and increased fundamental frequency, and in long stressed syllables periphal feedback seems to be more important than in the production of unstressed syllables (Natke & Kalveram, submitted). Furthermore, stuttering moments occur more often in stressed syllables than in unstressed syllables (Brown, 1938; Wingate, 1976; Bergmann, 1986). Therefore, there may be a link between stuttering, linguistic stress and the auditory control of vowel duration and fundamental frequency. However, at present it is an open question how to explain these relationships.

In this study no substantial prolongation of vowels due to frequency shifting was found. This suggests that also during continuous frequency shifting of auditory feedback for fluency enhancement in people who stutter, no prolongation occurs. Although effects of continuous frequency shifting on speech parameters in ongoing speech have to be examined further, it seems unlikely that the fluency enhancing effect of frequency shifting is based on modified vocalization as it is proposed e.g. for delayed auditory feedback (Wingate, 1970). It remains an open question, why frequency shifting enhances fluency in people who stutter.

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ABSTRACT

Twelve stuttering and twelve nonstuttering subjects had to utter a test word repeatedly with different stress patterns. In randomly selected trials auditory feedback provided by headphones was shifted in frequency by -1/2 octave. Nonstuttering subjects responded with an increase by 2 Hz of fundamental frequency of the first syllable vowel, if it was long stressed. Stuttering subjects did not show this effect. In both groups unstressed syllables remained unaffected. Vowel duration of syllables did not change substantially in any group. Results indicate a compensatory mechanism that controls fundamental frequency via auditory feedback in speech like productions, but even in long stressed syllables it is unable to compensate for interferences completely. In stuttering people, this control mechanism might be not as effective as in nonstuttering people. Results indicate, that the fluency enhancing effect of continuous frequency shifting is not based on modified vocalization.

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