

Relations between vocal registers in voice breaks

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Abstract

1783 modal-falsetto register breaks and 853 falsetto-modal register breaks, produced by seven untrained adult male subjects, were recorded and analyzed with respect to jumps in fundamental frequency and sound pressure level (SPL) using a computer phonetograph. SPL and relative positions of modal and falsetto registers were the most important factors underlying the results. Whereas sub- or supraglottal coupling certainly cannot explain the results, models of intrinsic non-linear behavior of the vocal folds may need to be extended for explanations of breaks outside the overlap area of the two registers.

1. Introduction

The modal and falsetto registers make up most of human vocal possibilities. Their specific physiological and acoustical properties have been described extensively (Titze [1]). Breaks are a well-known feature of vocal registers. During speaking or singing in modal register it may suddenly occur that the voice switches into the falsetto register, or vice versa. This happens most frequently in boys when there is a lack of phonatory control during mutation. Breaks may also occur in girls and male and female adults, either spontaneously or voluntarily. Whereas during puberty the voice break usually is not voluntary, in later life this is rarely the case in speech. But in singing, especially in loud singing in high pitch ranges, breaks may easily happen without intention. It is characteristic of a break that it occurs during continuous phonation. The vocal folds vibrate in one mode and due to some slight change in the physiological or acoustical conditions, the system switches very rapidly, but continuously, into the other mode. For classical singers this creates an uncertainty that should be avoided in all cases. Learning to make smooth and fully controlled register transitions is therefore a major issue in their training. Pop singers, on the other hand, don't care, and regularly use voluntary voice breaks as special effects.

Several authors (Vennard [2]; Van den Berg [3]; Titze [4]) have tried to explain the voice break as a consequence of a mismatch between sub- or supra-glottal resonance and the fundamental frequency of vocal fold vibration. Because subglottal resonances are not likely to vary much, however, this would predict limitations to the starting frequency of the break. This does not seem to be the case, however: a voice break can occur in a wide range of fundamental frequencies. Vowels do not seem to have a major effect on break characteristics either.

An interesting explanation of voice breaks is proposed by Berry et al. [5], who point at the intrinsic instability of the movement of the vocal folds. They describe the vocal folds as a non-linear system with two overlapping vibratory

patterns (registers). Berry et al. suggest that in the area of overlap the same configuration of control parameters can result in either one or the other vibratory pattern, although with different fundamental frequencies. This may result in spontaneous breaks between registers. They showed this in excised canine larynxes.

Breaks between modal and falsetto registers that were induced by a sudden increase in expired airflow were reported by Švec and Pešák [6]. They found a frequency change between modal and falsetto register of about 7 semitones (ST) for a range of about one octave (e-e') for the frequency in modal register. Švec, Schutte and Miller [7] elaborated on this and refer to a detuning of normal modes (of a two-mass model) of the vocal folds. Švec, Schutte and Miller [8] induced voice breaks in excised human larynxes by changing the longitudinal tension in the vocal folds. A frequency jump of 12 ST (one octave) was reported for modal-falsetto jumps and of 9 ST for falsetto-modal jumps. In living subjects, reported ranges of jump intervals were 10-17 ST for a bass-baritone, 5-10 ST for a baritone, and 0-5 ST for a mezzo-soprano singer. An attempt was made to describe the jumps in terms of certain ratios of the starting and end frequencies in modal and falsetto register.

A phonetogram allows one to study and to visualize acoustic properties of vocal registers across the whole range of fundamental frequency (F_0) and sound pressure levels (SPL) (Bloothoof et al. [9]). Such a framework is very helpful in the study of voice breaks, because it better demonstrates acoustical conditions for which breaks may occur. This paper presents data on 1783 modal-falsetto breaks and 853 falsetto-modal breaks, produced by seven adult male subjects, and analyzed within the phonetogram framework. Relations of SPL and F_0 before and after the break were investigated.

2. Method

Seven untrained adult male subjects participated in the experiment. A subject was seated in a sound-treated booth in front of a monitor. A microphone (B&K 2032) was mounted on a headset, 30 cm in front of the mouth. The monitor displayed the phonetogram window, with fundamental frequency (F_0) on the horizontal axis and sound pressure level (SPL) on the vertical axis. During phonation the momentous position on the F_0 /SPL plane was indicated by a moving dot. The subject was asked to start phonation in modal register at fundamental frequencies of (about) 196 Hz (g), 293 Hz (d') and 392 Hz (g'). This was rehearsed using the phonetogram feedback. The subject was then asked to phonate a vowel (/a/, /i/ or /u/) and to make a voluntary register break. The subject was deliberately requested not to exert any control over the resulting phonation in the falsetto register, but just to let it happen. About 30 repetitions were recorded at the same

starting F_0 , with modal SPL varying from soft to very loud (about 60 - 90 dB SPL). The three vowels were recorded after another before proceeding to the next starting frequency.

It proved to be very difficult for subjects to make breaks from falsetto to modal register with varying SPL at the same F_0 . Therefore, the requirements were relaxed in that subjects were asked to make about 50 breaks from falsetto to modal register with as many combinations of starting F_0 and SPL as they could realize.

In addition, we made a registration of the entire voice field (vowel /a/) of the subjects to permit an interpretation of the voice breaks within the framework of the complete vocal possibilities of the subjects. For each vowel, a separate phonetogram in falsetto register only was recorded as well. For some subjects, the modal register was also recorded separately. Fig. 1 gives an example of register positions in the phonetogram framework.

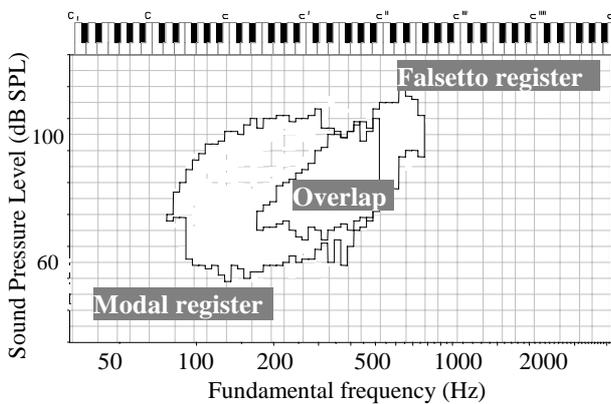


Figure 1: Positions of the modal and falsetto registers in the plane of F_0 and SPL.

Acoustic measures were computed every 15 ms. These included, besides F_0 and (calibrated) SPL, jitter (= regularity of pitch periods in percent of period duration) and crest factor (= ratio between maximum amplitude and RMS value in dB). The voice break intervals were identified on the basis of F_0 change. Then, the interval before and after the break was determined during which F_0 varied less than 0.5 semitones (see Fig.2). F_0 and SPL were averaged over 225 ms in these stable intervals.

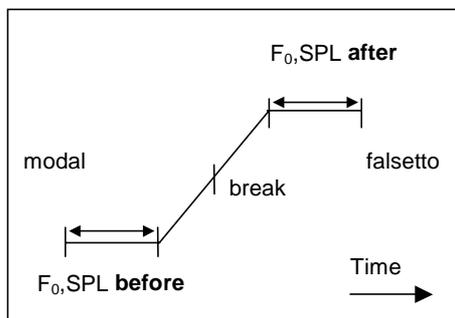


Figure 2: Schematic overview of a voice break from modal to falsetto register with arrows indicating the measurement interval before and after the break.

Because subjects performed voice breaks voluntarily, their realizations were not always successful. To filter out these realizations, additional requirements were: (1) the crest factor in falsetto should be less than 6 dB, (2) the crest factor in falsetto should be lower than in modal register, (3) F_0 should be higher in falsetto register than in modal register, and (4) duration of the break from stable modal to stable falsetto phonation (or reverse) should be less than 300 ms (in most cases it was much less, on average 150 ms). The crest factor is useful for making the falsetto - modal distinction because it varies from 3 dB for the sinusoidal signal to be expected in falsetto register to over 10 dB for the complex signals of the modal register.

3. Results

3.1. Modal-Falsetto register breaks

A total of 1783 modal-falsetto register breaks were analyzed. We first give a presentation of typical data against the background of the phonetogram of subject FW, making 34 modal-falsetto breaks at a starting frequency of about 196 Hz with varying SPL (Fig. 3).

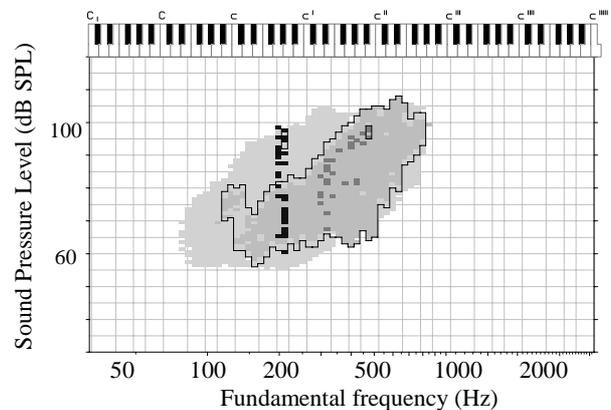


Figure 3: Starting-points and end-points of 34 breaks from modal (black points) to falsetto register (dark gray points), against phonetogram display (light gray = full phonetogram, darker gray and with contour = falsetto register, including some register errors at low F_0). Subject FW, vowel /u/.

The data in Fig. 3 do not show the precise relations between the combinations of starting-points and end-points, but general observations can already be made. Firstly, there is a limited end-area in the falsetto register, indicating that conditions in modal register strongly determine conditions in falsetto register. The starting F_0 of about 196 Hz in modal register corresponded to an end F_0 in falsetto register of at least 300 Hz, which increased at the higher SPL levels.

Although not explicitly visible in figure 3, the SPL-values in both registers were related during the same break. This is shown in figure 4. Regression between SPL in modal and falsetto register was significant ($p < 0.05$) for all seven subjects for all three vowels for an F_0 of 196 Hz. For a starting F_0 of 293 Hz, 18 out of 21 cases were significant, while at 392 Hz this was only the case for three subject/vowel combinations.

Fig. 5 shows the relation between the frequency difference in semitones between modal and falsetto register in a break, as a function of SPL in modal register for the data from Fig. 3.

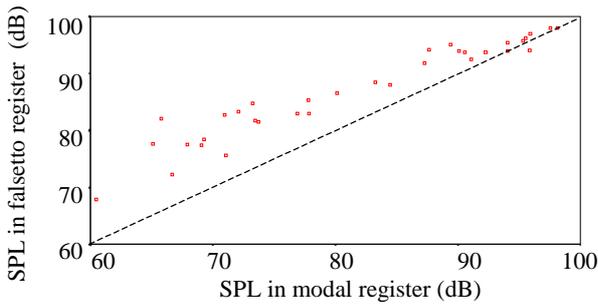


Figure 4: Relation between SPL in modal and falsetto register before and after the voice break, for the data presented in Fig. 3. Starting F_0 is 196 Hz, subject FW, vowel /u/. The dashed line indicates equal SPL in both registers. For low SPL in modal register, the subject produced a higher SPL in falsetto register, while at modal SPL higher than 90 dB, the same SPL was obtained in falsetto register.

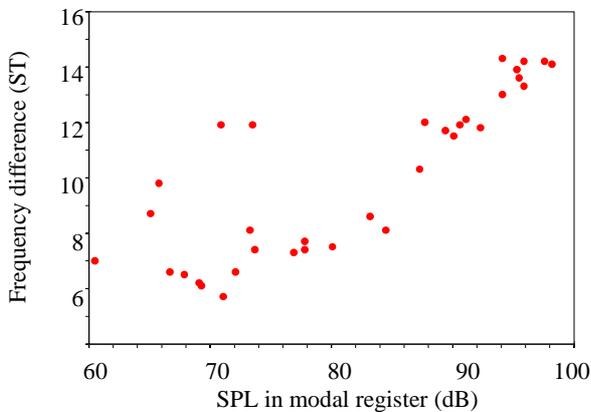


Figure 5: Relation between the jump in F_0 between modal and falsetto register as a function of SPL in modal register, for data presented in Fig. 3. Starting F_0 is 196 Hz, subject FW, vowel /u/.

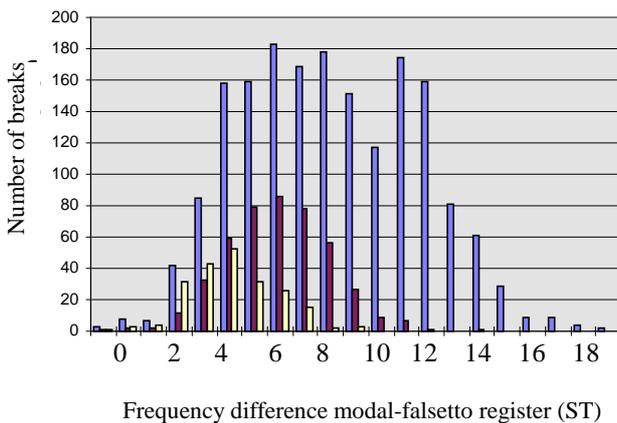


Figure 6. Distribution of frequency differences before and after the modal-falsetto voice break, summarized over all subjects. Per bin, bars denote from left to right starting frequencies of 196, 293, and 396 Hz, respectively.

Results suggest a linear relation for starting values beyond 75 dB SPL and variable behavior (including some octave jumps) at lower SPL starting values. In 15 out of 21 cases a significant relation ($p < 0.05$) was found for a starting frequency of 196 Hz. This number reduced to 10 cases for 293 Hz and 3 cases for a start at 396 Hz.

Fig. 6 presents the histogram of the frequency jumps in all breaks from modal to falsetto register for all subjects. These values seem to be normally distributed with a mean at respectively 7, 6 and 4 ST for starting $F_0 = 196, 293,$ or 396 Hz, with the exception of a preference for an octave jump (12 ST) when the starting F_0 in modal register is low (196 Hz).

3.2. Falsetto-modal register breaks

A total of 853 falsetto-modal register breaks were analyzed. Fig. 7 gives an example of 52 breaks from falsetto to modal register, with phonetogram display in the background. There were no pre-defined starting conditions, but the widest possible range of starting F_0 in falsetto register was aimed at.

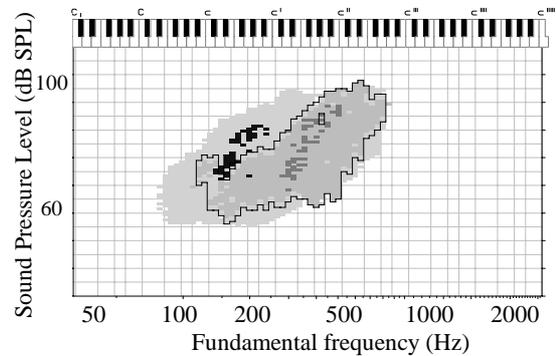


Figure 7: 52 breaks from falsetto (dark gray starting points) to modal register (black end points), displayed against the same phonetograms as presented in Fig. 3. Subject FW, vowel /u/.

Although subjects were free to choose their initial F_0 and SPL, they always chose high SPL levels in the falsetto register. The target area in the modal register was restricted. Fig. 8 gives the relationship between the starting F_0 in the falsetto register and the end F_0 in the modal register.

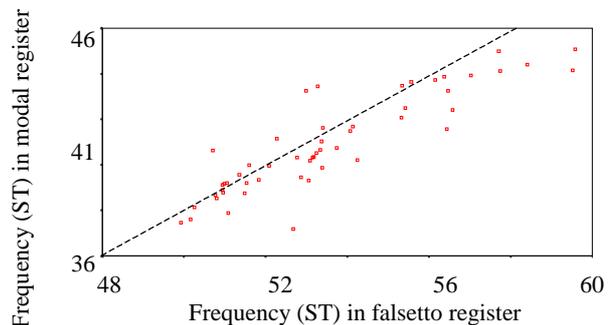


Figure 8: Relationship between F_0 in falsetto and modal register (in ST) before and after the falsetto-modal voice break, as presented in Fig. 7. The dashed line indicates a frequency difference of precisely one octave. Subject FW, vowel /u/. The x-axis runs from 262 to 523 Hz, the y-axis from 131 to 233 Hz.

Fig. 8. shows a significant ($p < 0.05$) linear relation between frequencies in falsetto and modal register, before and after the voice break, for subject FW. Such a linear relationship was found in 20 out of 21 cases (7 subjects x 3 vowels). The direction coefficient varied among subjects between 0.4 and 1.9. This implies that some subjects tend to jump to the same frequency in modal register (0.4), whereas others kept a constant difference in semitones (1.0), or tended to make relatively bigger jumps at lower falsetto frequencies (1.9).

The relationship between SPL in the falsetto register and SPL in the modal register was linear as well (significant ($p < 0.05$) in 19 out of 21 cases), with the same levels in both registers before and after the voice break.

An overview of all frequency jumps from falsetto to modal register for all subjects is presented in Fig.9. It shows a normal distribution with a mean at 12 ST (octave).

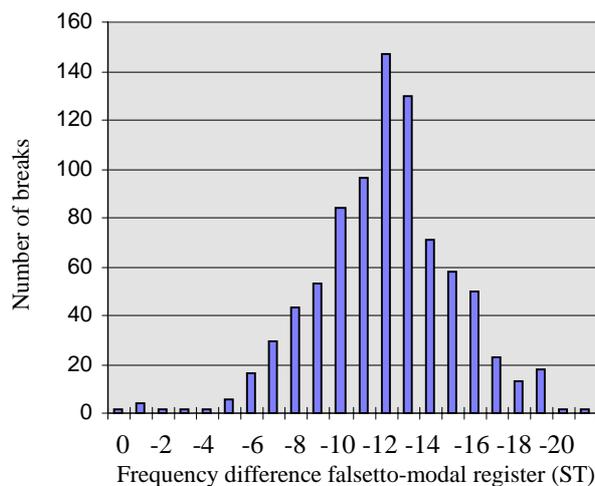


Figure 9: Distribution of the frequency difference before and after the falsetto-modal voice break in semi-tones. The minus sign indicates that the jump was from high to low frequency.

4. Discussion

A first general observation is that the results were not vowel dependent, which excludes a major supra-glottal factor in the explanation of voice breaks.

Modal-falsetto voice breaks

Subjects could make voluntary register breaks in a very wide range of starting F_0 and SPL in the modal register. Starts could be positioned outside the overlap area of both registers. This rules out an explanation of register breaks that is limited to the overlap area only.

For a starting F_0 in modal register outside the overlap area with falsetto register, the end F_0 in the falsetto register tended to be the lowest frequency possible at the same SPL as before the break. As a consequence, the size of the frequency jump depended on the position of the falsetto register relative to the starting F_0 in modal register. This positioning is subject-dependent. This rules out any expectations on ratios of frequencies before and after the break. An exception should be made for one-octave jumps, which happen relatively more frequently (see Fig. 6).

Breaks that were initiated in the overlap area of modal and falsetto registers tended to be more difficult to produce,

yielding more variable results. Because acoustic properties indicate no full glottal closure in the register overlap area (Bloothoof et al. [9]), glottal leakage might make it harder to initiate voluntary breaks. On the other hand, this may help singers to learn making smooth register transitions.

End phonations in the falsetto region fell within the overlap area with the modal register. Outside that region there most likely is no glottal closure at all in falsetto register, which seems to be a condition that excludes voice breaks.

Falsetto-modal voice breaks

Subjects started breaks in an area of the falsetto register that was strongly limited in F_0 and SPL. The area was comparable to the area where modal-falsetto breaks ended (the overlap area between both registers). This again suggests minimum requirements of glottal closure (vocal fold adduction), usually realized in loud falsetto phonations only.

In most cases, the break ended in an area of modal register that did not overlap with the falsetto register. The average frequency jump was one octave (12 ST). It is probably not by accident that this is a preferred jump in yodeling.

The presented data demonstrate the usefulness of the phonetogram environment for the study of voice breaks, and provide input for models that can explain this vocal behavior. The large number of measurements also helps us to find systematic relations between modal and falsetto registers, because little is known about what subjects actually do when initiating voluntary voice breaks. Although subjects were instructed not to force the break but to let it happen, it remains uncertain *what* they let happen and whether they did it all in the same way.

5. References

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