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To cite this article: Anna Eva Hallin, Karin Fröst, Eva B. Holmberg & Maria Södersten (2012) Voice and speech range profiles and Voice Handicap Index for males — methodological issues and data, Logopedics Phoniatrics Vocology, 37:2, 47-61

To link to this article: http://dx.doi.org/10.3109/14015439.2011.607469

Published online: 05 Sep 2011.

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Voice and speech range profiles and Voice Handicap Index for males - methodological issues and data

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Abstract
Reference data for speech range profiles (SRP), voice range profiles (VRP), and Voice Handicap Index (VHI) are presented for Swedish males (n = 30). For comparisons, individual data for four male contact granuloma patients are also reported. For the vocally healthy group mean values were: speaking fundamental frequency 123 Hz (SD 12.1), speaking equivalent level, Leq, 72.2 dB (SD 2.1), SRP area 142 STa dB (SD 24.1), and VRP area 1,706 STa dB (SD 340). Mean VHI was 5 (SD 4.8). Test-retest recordings of VRP and SRP for three subjects suggested good reliability. SRP and VRP values for three of the patients fell more than 2 SD outside the reference values. Protocols and results are discussed and standardized recording and analyses procedures are suggested.

Key words: Contact granuloma, healthy voice, male voice, phonetogram, speech range profile, voice range profile, voice handicap index

Introduction
Phonetogram recordings of speech and voice range profiles are increasingly used as tools in acoustic voice assessments in the voice clinic (1,2). The profiles are two-dimensional graphs of the voice in terms of fundamental frequency and intensity ranges (3). A speech range profile (SRP) reflects a person’s frequency-intensity range during running speech, and a voice range profile (VRP) is a display of a person’s maximal vocal performance in terms of frequency and intensity. In a physiological VRP the upper contour is performed with high subglottal pressures and reflects the loudest possible phonation along the frequency range without the vocal folds starting to vibrate in an aperiodic manner (4,5). The lower contour reflects the softest possible phonation along the frequency range and is thought to be related to the lowest subglottal pressure required to initiate vocal fold vibration, i.e. the phonation threshold pressure (PTP) (3,6,7). There are other definitions of VRPs apart from the physiological VRP, such as ‘musical range of phonation’ (8–11), ‘singing VRP’ (12), and ‘performance VRP’ (13); for an overview see Lamarche (14).

Apart from fundamental frequency and voice intensity, a third dimension in SRPs and VRPs is the grey-scale, which reflects the accumulated time each ‘tone’ has been used by the speaker. This information has been found useful for qualitative information on how much time and effort was used to reach a certain voice region (1). There are also phonetogram systems with additional acoustic voice measures such as jitter, shimmer, and crest factor (15), or measures corresponding to perceptual voice parameters such as roughness, sharpness, and breathiness (16), or sonority (S. Granqvist, personal communication) as a third dimension.

VRP recordings and displays have been found useful as visual feedback for voice patients to understand frequency and intensity variation and gain vocal control, as well as for illustrations of across-therapy changes (1). VRP recordings with self-reported real-time feedback have also been shown helpful for singers for identifying and communicating difficult vocal areas (13).

VRP recordings have been used to study gender differences (3,8,17), voice changes during puberty...
The SRP and VRP results are to a large extent dependent on the recording situation, the instructions, and the speech material. The amount of prompting of the subject and the subject's effort affect the results. This influence of the recording procedure on the VRP data has been pointed out and discussed previously (35–38), and suggestions have been made for structured recording protocols, although mainly for manual recording procedures (19,39,40). SRP and VRP data from vocally healthy speakers have been presented previously from studies with different recording methods (1,3,4,8,17,22,24,41). However, methodological differences among studies and lack of detail in descriptions of recording procedures often make data comparisons difficult, which limits the clinical use. A method to facilitate comparisons of VRP contours obtained from different systems and sources has recently been described (42). Since the SRP and VRP results are to a great extent dependent on both recording and analysis procedures, there is a need for further standardization.

The primary aim of the present study was to collect data for speech range profiles, voice range profiles, and Voice Handicap Index for vocally healthy adult men. The data should be useful as reference data in voice clinics as well as for further research. A second aim was to suggest protocols for recordings and analyses of speech range profiles and voice range profiles as a step towards standardized procedures in clinical work as well as in research.

Methods

The data were collected during spring 2007. Ethical considerations were made according to guidelines for master thesis projects. Each participant signed an informed consent form after agreeing to participate in the study.

Subjects

Thirty vocally healthy men with a mean age of 32 years (SD 8.6; range 21–50) volunteered to participate as subjects in the study. All subjects were native Swedish speakers. Exclusion criteria were smoking, self-reported hearing impairment, history of voice problems, respiratory difficulties, and/or severe allergy. At the recordings the subjects reported that they were free from throat infections. None of the subjects was a professional singer or sang regularly, for example in choirs.

Four Swedish male patients with contact granuloma (G1, G2, G3, and G4) were included in the study. The main reason for their inclusion was to examine the clinical usability of the methods and to give an example on how individual patients can be compared with normal reference data. The patients were recruited through ENT specialists and phoniatricians at the Karolinska University Hospital. The patients were 45, 33, 60, and 40 years old. They had been diagnosed with unilateral granuloma according to routine videofiberstroboscopic assessments performed within 1 month prior to the recordings. The patients were all medically treated for gastroesophageal reflux. None of them had received voice therapy.
**Voice Handicap Index**

The vocally healthy subjects and granuloma subjects filled out the Swedish version of the Voice Handicap Index (VHI) prior to the acoustic recording (43,45,46). The 30 statements are on voice symptoms and vocal function in daily life. Each statement is rated by the subject on a five-category scale from ‘never’ to ‘always’. The ratings are transformed to numbers from 0 to 4, giving a total score between 0 and 120. The statements can be divided into three subscales: functional, physical, and emotional.

**Speech and voice range profiles**

Since speech and voice range profile results are dependent on instructions and amount of prompting, the recording procedures were tried out and decided on prior to the study. The recordings of the speech and voice range profiles for all subjects were carried out in a sound-treated booth. The subjects stood up in front of a computer screen during the recordings in order to obtain an optimal posture for the vocal tasks and to get visual feedback from the screen during the recordings of the voice range profiles. The instructions were given by one of the two first authors who communicated with the subject from outside the booth via a microphone and a see-through glass window. In the interest of assuring reliable recording procedures the other instructor was always present in the room monitoring instructions and feedback.

**Software and calibration**

The speech and voice range profiles were recorded with the use of the computer software programme Phog (Saven Hitech AB, Täby, Sweden). An omnidirectional microphone (Sennheiser MKE-2, Sennheiser, Wennebostel, Germany) was mounted on a headset to maintain a constant distance of 15 cm from the subject’s mouth. The sound pressure level (SPL) was calibrated using a sound level calibrator (Sennheiser K402, Sennheiser, Nærum, Denmark). An adapter was used between the microphone and the calibrator to ensure air-tight connection. The time threshold level for voice registration was set to 25 ms as recommended by the manufacturer. The x-axis in the SRPs and VRPs showed fundamental frequency in Hz on a logarithmic scale and in semitones (ST). The y-axis showed intensity in dB(C) (hereafter dB) at 15 cm. To fit the recommended 30 cm standard (40) a 6 dB correction was applied for all level values post-recording. The third dimension, the grey-scale, registered the accumulated time of phonation, which is seen in Figure 1.

**Speech range profile recording procedure**

As the first task each subject’s speech range profile (SRP) in habitual voice was recorded during running speech. The subject read aloud a text in Swedish of about 35–40 s duration and, after the reading, narrated a story from a series of six pictures. Both tasks were saved in the same file to constitute the SRP. The text and pictures are used routinely as speech materials in the standardized recording setting at the Department of Speech Language Pathology at the Karolinska University Hospital.

**Voice range profile recording procedure**

As the second task each subject performed a voice range profile (VRP). First the task was described. The picture of the subject’s SRP was used to explain variations in loudness and pitch. The investigator then demonstrated loudness and pitch variations, and the subject practised with the visual feedback from the computer screen. The subject was told that the VRP was meant to show ‘the maximal voice function without overstraining the voice or feeling vocal pain’. Sustained phonations and glissandi on /a:/ vowels were used. The computer screen image was used as feedback to the subject, and instructions were given by the investigator when needed during the VRP recording. The VRP recording was performed in six steps:

1) The recording began with phonation in soft voice for the low-intensity contour. The subject started at a comfortable pitch and then, keeping that F0, decreased intensity until he reached his softest pitch. Then he was asked to keep the soft voice while he decreased F0, until his lowest F0 limit in soft voice was reached. After completion of low F0 in soft voice, the subject was asked to find his comfortable pitch in soft voice again, and increase F0 to reach his highest possible F0 in soft voice, including the falsetto register. The soft-voice task was repeated as many times as needed until a connected low-to-high F0 contour for lowest possible intensity was accomplished.

2) The recording continued with loud phonation to form the upper contour in the VRP. The same procedure as for the lower contour was used. Thus, the subject began with loud voice at a comfortable pitch, and decreased F0 in loud voice until the lowest possible F0 in loud voice was reached. The subject then went back to comfortable pitch in loud voice, and increased F0 until maximum F0 in loud voice was reached. The high-intensity tasks were repeated until a connected upper contour was accomplished.
Aregisterchangewasoftennotedasadisruption orafrequencydipintheuppercontour(Figure 1a). The subjects were not asked to fill out this disruption. For most subjects the VRP clearly showed a register change while for others the change was less pronounced.

3) After having accomplished the lower and upper contours, the subject was asked to connect the contours with help of the visual feedback, until an enclosed area was reached. This was achieved by changing vocal loudness in the very low and the very high frequencies.

4) When a connected VRP contour was accomplished, the subject was instructed to try to expand the area further starting with the upper contour. For this task controlled shouting phonations of /haha:/, modelled by the instructor, were allowed to help increasing the level of the upper contour without yelling.

5) After extension of the loud voice contour the subject went back to soft voice and tried to lower the soft voice contour even further. Breathy phonation was allowed to reach the softest voice possible. Intermittent aphonia in soft phonation was allowed and interpreted to be the subject’s lowest possible voice intensity.

6) Finally, as the last task the subject was asked to phonate again at his own choice in terms of loud-soft and high-low voice still using the vowel /æ:/, and in that way try to expand the area even more. No extreme phonations such as yelling, screams, or very pressed phonations were allowed.
During the VRP recordings the subjects were asked to focus on the contours in the interest of expanding the VRP as much as possible. The subjects did not have to fill the inner parts of the VRP or the dip at the register change. To assure that the subjects had performed at their maximum, the instructor looked for one of two properties in the final VRP: 1) dark contours indicating repeated trials at the same frequency and intensity (Figure 1a), or 2) broad contours indicating several trials but with a variation in intensity (Figure 1b). The recording was considered complete when the instructor found that one or both properties above in the VRP were present and the subject felt that he could not expand the area further.

Prompting and feedback

During the VRP recordings, the computer screen provided instant visual feedback to the subject. The instructor prompted and encouraged the subject to reach his maximal performance and provided voice examples for imitation. The instructor also made sure that the subject did not over-use his voice. Examples of verbal feedback used were ‘try to paint with your voice’ to enhance the visual feedback or ‘use a girly voice’ to help the subjects find the falsetto register. During the recordings the instructor sometimes observed registrations of low-pitched phonation around or below 70 Hz, auditorily perceived as vocal fry. In such cases the subject was asked to go back to the modal register, and the experimenter took careful notes about these registrations. In a few subjects, registrations of overtones could be seen as two registrations simultaneously about one octave apart during the recording. Such observations were noted during the recording and later disregarded in the analyses in the few cases such registrations were outside the area contour.

Reliability measurements

Three randomly selected subjects from the vocally healthy group performed SRP and VRP recordings again 3–4 months after the first recording for test-retest calculation of reliability. The time-span was chosen to mimic a common clinical pre–post voice therapy time interval (1).

Analyses

Voice Handicap Index (VHI). For the vocally healthy subjects and the four granuloma patients, mean, minimum, and maximum values of the total VHI score and results for each of the three subscales were calculated. In addition, for the vocally healthy group median values were calculated.

Speech range profiles (SRP). Using analysis tools in the Phog program, the SRPs from all subjects (healthy and patients) were analysed in terms of the following variables, also illustrated in Figure 2a: average speaking frequency (Hz and ST); lowest frequency in the area (Hz and ST); highest frequency in the area (Hz and ST); frequency range (ST); speaking equivalent level, Leq, (dB); lowest intensity in the area (dB); highest intensity in the area (dB); intensity range (dB); area in semitones times decibels (ST*dB).

Voice range profiles (VRP). Using analysis tools in the Phog programme, the VRPs from all subjects (healthy and patients) were analysed in terms of the following variables as shown in Figure 2b: lowest frequency in the area (Hz and ST); highest frequency in the area (Hz and ST); frequency range (ST); lowest intensity in the area (dB); highest intensity in the area (dB); intensity range (dB); area in semitones times decibels (ST*dB).

In case of registrations of overtones and vocal fry as well as of single registrations more than 4 dB or 4 semitones from the connected area of the speech range profile were omitted (Figure 2a). Total recording time (minutes and seconds) was also measured.

Statistical analyses. For the vocally healthy group, descriptive statistical analyses were performed using SPSS (version 16.0). Histograms and skewness ratios were used to examine the degree to which the SRP area, mean F0 (in ST), Leq, and the VRP area distributions were skewed for the vocally healthy men. Based on the fact that the histograms were reasonably symmetric and all skewness ratios were below 2.0, it was concluded that the data were approximately normally distributed (skewness ratios: SRP area 1.14; Leq 1.46; mean F0: –0.51; and VRP area 0.91).

Means, standard deviations (SD), minimum and maximum values, median values, and percentiles 25 and 75 were calculated for all variables. Mean frequency values in Hz were also calculated in ST from a reference tone of 110 Hz, using the formula

\[ 12\cdot \ln(x/110)/\ln(2). \]

The reason for the ST
calculation was to enable linear interpretation of frequency mean values and standard deviations.

For the reliability measurements correlations were computed between the two sets of data for the three subjects who were recorded twice in terms of VRP and SRP areas (dB*ST), VRP and SRP ranges (dB and ST), and SRP average F0 (ST).

The inter-speaker variation for the four granuloma patients was considerable, and no group mean values were calculated. The SRP and VRP variables for each patient were compared to the means and SD for the vocally healthy group. A value with a difference larger than two standard deviations from normal mean (measured in ST, dB, or ST*dB) was considered atypical.

### Results

**Voice Handicap Index (VHI)**

The Voice Handicap Index (VHI) results for the healthy subjects are presented in Table I. The total scores were overall low with a mean of 5.0. For all but three subjects the total VHI scores varied between 0 and 8. Three subjects received somewhat higher total scores—11, 18 and 20 respectively. The physical subscale received the highest score of the three subscales (mean 2.37).

The four patients with contact granuloma received total VHI scores of 12, 27, 40, and 40, respectively (mean 29.8). Also, the patients scored highest on the physical subscale: 7, 16, 24, and 19 (mean 16.5), and
Table I. Total VHI scores, mean and standard deviation (SD), and scores for the subscales function, physiology, and emotion for Swedish vocally healthy men ($n = 30$).

<table>
<thead>
<tr>
<th></th>
<th>Total Function</th>
<th>Physical</th>
<th>Emotion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
<td>5.00 (4.77)</td>
<td>1.30 (1.84)</td>
<td>2.37 (2.46)</td>
</tr>
<tr>
<td>Median</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>20</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

lower on function: 2, 7, 9, and 12 (mean 7.5), and emotion: 3, 4, 7, and 9 (mean 5.75).

**Vocally Healthy Subjects**

**Speech range profiles.** Table II presents the speech range profile (SRP) data for the vocally healthy subjects. All SPL measurements are corrected for a 30 cm mouth-to-microphone distance and given in dB.

Average speaking frequency ($F_0$) in the group was 123.0 Hz (SD 12.13) and varied from 102.2 to 144.5 Hz. The variable with the largest group variation was the highest frequency in the area, which varied from 146.8 to 261.6 Hz, with a median of 196 Hz. The inter-subject variation in SRP area was also large, varying from 99 to 197 ST$^\ast$ dB.

The mean speaking equivalent level, Leq, was 72.2 dB (SD 2.14). Mean sound pressure level for the highest intensity in the area (upper contour) was 80.3 dB (SD 2.52). Mean sound pressure level for lowest intensity (lower contour) was 58.9 dB (SD 2.46). The mean intensity range was 21.4 dB (SD 2.85).

**Voice range profiles.** The voice range profile (VRP) results for the vocally healthy subjects are presented in Table III. All SPL measurements are corrected for a 30 cm mouth-to-microphone distance and reported in dB.

The lowest frequency in area varied between 51.9 and 110.0 Hz with a median of 77.8 Hz, and the highest frequency between 523.3 and 1396.9 Hz with a median of 784.0 Hz. The frequency ranges varied between 33 and 51 ST. The mean of the VRP area was 1706 ST$^\ast$dB (SD 340.3) with a median of 1676. For the area the inter-subject variation was large, between 1163 ST$^\ast$dB and 2499 ST$^\ast$dB. In contrast, for the highest intensity in the area (upper contour) the inter-subject variation was small with a mean of 109.3 dB and a SD of 1.77. Mean value for the lowest intensity in the area (lower contour) varied from 39 to 53 dB with a mean of 44.0 (SD 3.65). The intensity ranges varied between 57 and 71 dB.

**Qualitative observations of voice range profiles.** Qualitative observations of the VRPs showed that the shape of all VRPs resembled a tilted oval, since all subjects were able to produce louder phonations in the upper modal register and falsetto register, than in the low part of the modal register. However, the size of the falsetto register varied considerably, which affected the highest frequency in the area as well as the VRP area to a large extent (Figure 3). A register change (i.e. the change between modal and falsetto register) was indicated as a dip in the upper contour in many (but not all) VRPs, between 250 and 400 Hz (Figure 3). In some of the subjects the register change was seen also in the lower contour (Figure 3a). For all vocally healthy subjects, the upper contour of the VRP was smooth except for the register change. The lower contour was smooth in most, but not all VRPs.

Table II. Speech range profile data for vocally healthy men ($n = 30$). Intensity is corrected for a 30 cm mouth-to-microphone distance in dB. Speaking frequency and highest and lowest frequency in area in ST values are relative to a 110 Hz reference value.

<table>
<thead>
<tr>
<th>Frequency measures</th>
<th>Mean (SD)</th>
<th>Min</th>
<th>Max</th>
<th>Median</th>
<th>25th, 75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speaking frequency (Hz)</td>
<td>123.0 (12.13)</td>
<td>101.2</td>
<td>143.5</td>
<td>123.7</td>
<td>112.0, 133.7</td>
</tr>
<tr>
<td>Lowest frequency in area (Hz)</td>
<td>89.4 (11.88)</td>
<td>73.4</td>
<td>110.0</td>
<td>87.3</td>
<td>77.8, 98.0</td>
</tr>
<tr>
<td>Highest frequency in area (Hz)</td>
<td>198.3 (30.60)</td>
<td>146.8</td>
<td>261.6</td>
<td>196.0</td>
<td>174.6, 220.0</td>
</tr>
<tr>
<td>Speaking frequency (ST)</td>
<td>1.9 (1.73)</td>
<td>–1.4</td>
<td>4.6</td>
<td>2.0</td>
<td>0.3, 3.4</td>
</tr>
<tr>
<td>Lowest frequency in area (ST)</td>
<td>–3.7 (2.30)</td>
<td>–7.0</td>
<td>0.0</td>
<td>–4.0</td>
<td>–6.0, –2.0</td>
</tr>
<tr>
<td>Highest frequency in area (ST)</td>
<td>10.0 (2.67)</td>
<td>5.0</td>
<td>15.0</td>
<td>10.0</td>
<td>8.00, 12.00</td>
</tr>
<tr>
<td>Speaking range (ST)</td>
<td>13.7 (2.69)</td>
<td>8.0</td>
<td>21.0</td>
<td>14.0</td>
<td>12.0, 15.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intensity measures</th>
<th>Mean (SD)</th>
<th>Min</th>
<th>Max</th>
<th>Median</th>
<th>25th, 75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speaking eq. level, Leq (dB)</td>
<td>72.2 (2.14)</td>
<td>67.7</td>
<td>77.6</td>
<td>72.2</td>
<td>70.7, 73.2</td>
</tr>
<tr>
<td>Lowest intensity in area (dB)</td>
<td>58.9 (2.46)</td>
<td>54.0</td>
<td>64.0</td>
<td>59.5</td>
<td>57.0, 60.2</td>
</tr>
<tr>
<td>Highest intensity in area (dB)</td>
<td>80.3 (2.52)</td>
<td>75.0</td>
<td>86.0</td>
<td>80.0</td>
<td>79.0, 82.0</td>
</tr>
<tr>
<td>Intensity range (dB)</td>
<td>21.4 (2.85)</td>
<td>17.0</td>
<td>26.0</td>
<td>21.0</td>
<td>19.0, 24.0</td>
</tr>
<tr>
<td>Area (ST$^\ast$dB)</td>
<td>142.0 (24.1)</td>
<td>99.0</td>
<td>197.0</td>
<td>139.0</td>
<td>126.5, 154.0</td>
</tr>
</tbody>
</table>
A stylized graph showing mean values from the VRPs and SRPs (in ST) is presented in Figure 4. The VRP figure was drawn from mean values of highest and lowest frequency and intensity (in ST and dB), and the mean maximum frequency range (in ST) was marked. A stylized SRP drawn from mean values of frequency ranges (ST) and intensity (dB) in area and average speaking frequency (F0) was then superimposed on the VRP figure.

During reading and narrating (for the SRP task), the subjects used on average 34% of their VRP frequency range (in ST). Mean speaking frequency was 21% of the mean of the total frequency range (measured from mean lowest frequency in the VRP in ST), that is, the average speaking frequency was in the lower part of the total frequency range.

Reliability. The VRPs for the three men who were recorded twice (test-retest) can be seen in Figure 5. When comparing the two recordings, the main finding was that the overall shapes of the individual VRPs were very similar. Small differences were seen mostly in the lower contour, i.e. in soft phonation, and in the falsetto register. These observations were confirmed in the correlation analyses. In particular, the correlation was high between the two recordings in area (ST∗dB), $r = 0.84$; and in intensity range (dB), $r = 0.99$; and somewhat lower for frequency range (ST), $r = 0.69$.

High correlations were also found between the two recordings for the SRP parameters: area (ST∗dB), $r = 0.99$; intensity range (dB), $r = 0.92$; frequency range (ST), $r = 0.98$; and F0 (ST), $r = 0.95$. 

Figure 3. Examples of variation in the vocally healthy male Voice Range Profiles (VRP) as recorded with a 15 cm mouth-to-microphone distance. a) A VRP with a large total F0 range and a large falsetto register. b) A VRP with a relatively narrow F0 range and a small falsetto register. The dark registrations in the right part of the contour reflect several tries in the subject’s effort to increase F0. In both a) and b) the register change occurred around 350–400 Hz.
Granuloma patients

Speech range profiles. Comparisons between the four granuloma patients’ individual data and the vocally healthy group data showed that two granuloma patients had SRP values that differed two standard deviations or more from the vocally healthy male SRP values presented in Table II (compared with mean values in ST, dB, and ST*dB). One of the patients (G2) had a SRP area which was considerably smaller (73 ST*dB) compared to the vocally healthy subjects and a reduced frequency range (7 ST). G1 had a low speaking frequency of 94.6 Hz. G3 and G4 did not exhibit any differences in SRP values (<2 SD) compared to mean values for the vocally healthy men. When comparing SRP values to VRP values, however, G3 had a higher speaking F0 in relation to his frequency range (30%) than found for the vocally healthy subjects (21%) (Figure 5).

Voice range profiles. Voice range profile data for the four granuloma patients are shown in Figure 6. Values for three patients differed 2 SD or more from the values of the vocally healthy subjects presented in Table III (compared with mean values in ST, dB, and ST*dB). G3 had a limited frequency range of 30 ST, a limited intensity range of 43 dB, and a small VRP area (818 ST*dB). G2 had a limited frequency range (31 ST) and a lowered maximum highest frequency (25 ST), and G1 had an increased lowest intensity (57 dB). All values for G4 differed less that 2 SD from the normal means.

Observations showed that the VRP for G3 (Figure 6c) differed from the vocally healthy subjects’
profiles in terms of contours and shape. Both the upper and the lower contours were more uneven, and a large area of vocal fry was also found in the low frequencies, below 70 Hz. Furthermore, G3 could hardly produce any falsetto tones.

**Recording and phonation times**

For the vocally healthy subjects, mean recording time for a VRP was 26:00 minutes (median 26:42; range 14:42–37:33) including instructions, short breaks, and questions. Mean phonation time was 7:16 minutes (median 7:17; range 3:43–9:46).

Mean total SRP recording time for the vocally healthy subjects was 1:07 minutes (median 1:04; range 0:51–2:16).

For the four patients, total VRP recording time varied between 17:43 and 27:05 minutes and the phonation time between 3:48 and 6:16 minutes. SRP recording time varied between 0:52 and 1:12 minutes for the patients.

**Discussion**

Voice handicap index data (VHI) have been reported for both vocally healthy subjects and for voice

| Table III. Voice range profile data for vocally healthy men (n = 30). Intensity is corrected for a 30 cm mouth-to-microphone distance in dB. Speaking frequency and highest and lowest frequency in area in ST values are relative to a 110 Hz reference value. |
|-----------------------------------------------|----------------|------|------|------|----------------|
|                                |        |      |      |       |                  |
| Frequency measures              | Mean (SD) | Min | Max  | Median | 25th, 75th percentile |
| Lowest frequency in area (Hz)   | 76.4 (12.33) | 51.9 | 110.0 | 77.8 | 65.4, 83.6 |
| Highest frequency in area (Hz)  | 811.3 (209.21) | 523.3 | 1396.9 | 784.0 | 650.1, 893.1 |
| Lowest frequency in area (ST)   | –6.5 (2.80) | –13.0 | 0.0 | –6.0 | –9.0, –4.8 |
| Highest frequency in area (ST)  | 34.1 (4.30) | 27.0 | 44.0 | 34.0 | 30.8, 36.2 |
| Frequency range (ST)            | 40.6 (4.41) | 33.0 | 51.0 | 40.5 | 37.0, 43.5 |
| Intensity measures              |          |      |      |       |                  |
| Lowest intensity in area (dB)   | 43.6 (3.65) | 39.0 | 53.0 | 43.0 | 40.8, 46.0 |
| Highest intensity in area (dB)  | 109.3 (1.77) | 105.0 | 111.0 | 110.0 | 108.0, 111.0 |
| Intensity range (dB)            | 65.7 (4.11) | 57.0 | 71.0 | 67.0 | 63.8, 69.0 |
| Area (ST*dB)                    | 1706.0 (340.3) | 1163.0 | 2499.0 | 1676.0 | 1470.0, 1895.3 |
patients. In an inter-European study of VHI data for different voice pathologies a mean total score of 30 was reported, averaged over all reported pathologies (44). For the Swedish VHI a total score of 20 has been suggested as the upper limit for a healthy voice (46). In the present study, VHI scores for the vocally healthy men fell within the normal range found in previous Swedish studies (1,45,47). The VHI scores for three of the four granuloma patients were above 20 and indicate that for these patients the vocal problems had a negative effect on their daily lives (46).

The repeated SRP and VRP recordings of the three vocally healthy subjects showed no big differences, and paired samples correlation analysis showed high correlations for all parameters except VRP frequency range, which showed a moderate correlation. The small test-retest differences in the SRPs suggest that the subjects used their natural speaking manner across the recordings. For the VRPs the small test-retest differences suggest that the recordings successfully captured the subjects’ maximum performances. The similarities in the VRP shapes across recordings seem to reflect that each person has his own unique VRP shape, most likely determined by physiological prerequisites. The differences across the VRP recordings were mostly found in the lower contour, i.e. in the soft voice, and in the high (falsetto) register.

Speaking frequency and intensity ranges for vocally healthy males have been reported previously (9,48). However, differences in speaking duration and speech material make comparisons among studies difficult. In the present study, mean speaking fundamental frequency was about one semitone higher than reported in previous studies for Swedish men (27,28). This difference may depend on differences in the recording material. In the present study speaking F0 values were based on both reading and narrating, whereas in the other studies F0 was measured over text reading only. In the present study superimposed recordings of both reading and narrating to pictures seemed to give a good representation of the speaking voice. The analysis in this study was based on speech samples of about 1:10 minutes on average.

Data for three of the four patients differed 2 SD or more from the vocally healthy means on one or more variables. The results exemplify how both quantitative and qualitative observations of SRPs and VRPs can provide clinical information. For example, for one of the patients the SRP frequency range was limited and the overall area was small, reflecting a monotonous voice, commonly found for contact granuloma patients (29–31,49). For another patient the VRP shape differed markedly from a normal shape, a finding also reflected in the measured values. Comparisons between SRP and VRP can provide useful information about the speaking voice, as for example a restricted and low-pitched speaking voice, clinically often called ‘talking in the bottom of the voice range’. In addition, the graphical information can be useful as visual feedback to the patients during voice therapy. Although small, the data sample from the patients can serve as an illustration of the clinical usefulness of SRP and VRP comparisons.

The vocally healthy subjects rarely increased the upper contour (loud voice) in the VRP when they tried to expand the area further from their first attempt. This finding suggests that a few attempts should be sufficient to reach the loud voice upper contour, which minimizes the risk for straining the voice and also saves time. In soft voice, however, the lower contour in the VRP was expanded (downwards) with as much as 5–10 dB in the subject’s second attempt for soft voice after his loud voice performance. This result emphasizes that repeated trials in the soft voice should be made, as also has been suggested previously (35,50). A possible explanation for the expansion of the lower contour is that the subjects became more comfortable with the recording situation, allowing them to experiment more with their voices. It may also be due to a physiological warming-up effect.

The change between the modal and falsetto registers is usually seen in the upper contour of the VRP as a ‘dip’ and is a normal pattern in a male VRP. Apart from the register dip, a majority of the vocally healthy subjects produced connected and often smooth VRP contours. An unbroken contour has been found to reflect a healthy voice (6,51). For one granuloma patient large ‘dips’ in both the upper and lower contours in the VRP reflected his notably deviant voice. However, uneven lower contours caused by single registrations in the low-intensity contour area were found also for a few of the vocally healthy subjects. These single registrations were likely due to the short registration time (25 ms).

An additional methodological issue is which registrations outside the SRP and VRP connected contours should be included in the analyses, if any. In the VRP analyses of the vocally healthy group we chose to omit the registrations from vocal fry and overtones. Such decisions were facilitated and based on thorough notes written down during the recordings. In the analyses of SRPs, single registrations more than 4 dB or 4 semitones outside the connected area were also omitted, because such registrations were not considered typical for the person’s speech. In clinical work, it is important to define and justify
defined as a 'musical range of phonation', and only allowed in the recording. For example, VRP was the VRP shape and size, as are the voice qualities used during the recording is an important factor for recording procedures. The amount of prompting differences are also likely due to differences in the present study was larger in comparison to area values found in other studies of vocally healthy males (4,10) and vocally healthy females (1,2,10). Apart from gender differences in VRP measures, differences are also likely due to differences in the recording procedures. The amount of prompting used during the recording is an important factor for the VRP shape and size, as are the voice qualities allowed in the recording. For example, VRP was defined as a 'musical range of phonation', and only 'high-quality' tones were accepted in the studies by Kotby et al. (10,11). In a study by Behrman et al. (6) the goal for the loudest phonation was determined as 'comfortable loud'. In the present study VRP phonations included shouts, /haha:/, to help expand the upper contour for loud voice. With the exception of avoiding excessively damaging pressed voice in loud phonation, no other demands on voice quality were set during the VRP recordings. These procedures enlarged the area. In clinical recordings of voice patients it can be difficult to monitor a patient's voice quality, and breathy phonation can result in as much as 15 dB lower intensity than non-breathy phonation (35). During recordings of patients' dysphonic voices all voice qualities must be allowed. Therefore, notes on voice qualitative observations are useful to support the recorded data. Valuable information could also be obtained using phonetogram systems in which acoustic parameters related to voice quality are included as proposed by Pabon et al. (15,16).

For one of the patients the VRP shape was clearly deviant, and his VRP parameters also differed from the normal values. However, care has to be taken in interpretation of patients' VRP data. Laryngostroboscopic examinations of the patients prior to the phonetogram recordings showed no interference between the granulomas and the vocal fold vibrations, which demonstrates that there is no simple one-to-one relationship between these patients' pathology and their voice function. Compensatory factors, for example increased subglottal pressure, may help to establish a close-to-normal vibration pattern.

For the VRP recordings both glissando tones and sustained phonations were allowed to help maximum performance. Both the subjects and the instructor preferred glissandi to pre-determined isolated tones since glissando phonations simplified the recording procedure. For vocally untrained subjects, glissando phonation eliminates possible difficulties in finding specific tones. For untrained subjects increased intensity is naturally accompanied by increased frequency, and it is often difficult to vary intensity for a sustained tone without also varying the fundamental frequency (52). For vocally trained subjects glissandi do not encourage the use of 'the singing voice' as much as do isolated tones (7). One problem with glissandi recordings is the difficulty to control the amount of jaw opening and the quality of the vowel. During glissandi in the present study, it was observed that the subjects' articulation sometimes changed, and this may have affected the final size of the VRP (40,53). However, it has also been shown that untrained subjects vary their jaw opening more randomly in comparison with voice-trained individuals, who use their jaw opening to maximize their voice intensity (35,54). The investigator should be observant on vowel changes during VRP recordings and remind the subject to use an /a:/ vowel, if needed.

In the SRP and VRP analyses, the parameters area, highest and lowest intensity in area, intensity range, highest and lowest frequency in area, and frequency range were chosen as relevant and straightforward...
measures of the voice. In previous studies those parameters have distinguished between vocally healthy and patient groups (4,11). In addition pitch and loudness have been found to change after laryngeal surgery in a clinical study of a mixed group of patients (6). Furthermore, increased VRP area after voice therapy has been reported for patients with non-organic voice disorders (1) and chronic dysphonia (22). The large VRP area variation for the vocally healthy subjects in the present study was mostly due to differences in the size of the falsetto register and consequently in the highest frequency in the area. Separation of the VRP into different registers during the recording could perhaps reduce the variation and also provide valuable supplemental information about the voice function. However, such separation is probably difficult for subjects without vocal training. In previous studies, recorded VRPs have been divided into different registers (55) and into low–high frequency regions (56). It is important that the clinician is observant of the patient’s modal and falsetto registers during the recording, as well as of the register change, so that such information is considered when interpreting the area values.

During the recordings of the VRPs in the present study great effort was made to reach each subject’s frequency and intensity maximums. For both patients and the vocally healthy subjects the recording procedure of the VRP was time-consuming. However, if the allocated time for the VRP recording does not allow for explanations and repeated phonations to assure the subject’s maximum vocal performance, parameter values as well as inter- and intra-subject variation will be difficult to interpret. The recording time varied largely among the vocally healthy subjects, and was somewhat shorter for the patients. The shorter time for the patients can be due to that they avoided excessively loud phonation in order not to add to their voice problem. Based on the experiences in the present study, it is suggested that no less than 30 minutes should be allocated for a VRP recording. However, for some patient groups recordings of only specific parts of the VRP may suffice. For example, the lower or upper contours alone may be indicative of the pathology.

**Limitations in the present study and suggestions for future studies**

The age distribution in the vocally healthy group in this study was relatively large. Because there are well recognized vocal changes with age, it is recommended that in future studies for normative data the subject groups are larger and divided into age-matched subgroups.

An important issue for future studies is the effect of the computer software registration time, an issue that has been discussed by Lamarche (14).

Acoustic measures related to voice quality were not included in the analyses of the SRPs and VRPs. The intensity and frequency values obtained are perhaps very useful in the voice clinic. However, in future studies it would be valuable to include additional acoustic information of voice quality aspects to the frequency and intensity measures in SRPs and VRPs.

**Conclusions**

The test-retest data suggest that SRP and VRP recordings can be made in a reliable way.

The following order is suggested for the VRP recording: 1) soft voice lower contour, 2) loud voice upper contour, 3) connect the upper and lower contours, 4) expand the loud voice upper contour even more, 5) expand the soft voice lower contour even more, 6) try to increase the area even more, making sure that all contours have been expanded as much as possible. Since the soft voice contour in the VRP was considerably lowered at the second attempt, several trials for soft voice after the loud voice contour is needed for reliable results.

To a large extent the inter-subject VRP variation was caused by differences in the falsetto register. Complementary qualitative observations of the falsetto register are therefore informative and necessary for interpretation of VRP data.

Reliable and valid VRP results are dependent on sufficient recording time. Results from this study suggest that 30 minutes should be allocated.

**Acknowledgements**

The authors want to thank Hans Larsson for technical support, Sten Ternström for advice on interpretation and presentation of results, Sharon L. Weinberg for advice on statistical analyses, and two reviewers for comments on a previous version of the manuscript.

**Declaration of interest:** The authors report no conflicts of interest.

**References**


Male voice and speech range profiles and VHI


