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Putting the Singing Voice on the Map

Towards Improving the Quantitative Evaluation of Voice Status
in Professional Female Singers

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Not Just Sound II: an Investigation of Singer patient Self-Perceptions Mapped into the Voice Range Profile.

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Abstract

Purpose: In aiming at higher specificity in clinical evaluations of the singing voice, singer perceptions were included and tested in conjunction with the voice range profile. **Method:** The use of a commercial phonetograph supplemented by a hand-held response button was clinically tested with 13 subjects presenting voice complaints. Singer patients were asked to press a button to indicate sensations of vocal discomfort or instability during phonation. Each press was registered at the actual position in the Voice Range Profile (VRP) so as to mark areas of difficulty. Consistency of button press behavior was assessed with a method developed previously. **Results:** In spite of their voice complaints, subjects did not press the button as much as healthy singers. Like healthy singers, the singer-patient group demonstrated consistent behavior but tended to press the button in completely different areas of the VRP space. The location of the presses was dominantly in the interior of the VRP and concentrated to a small fundamental frequency range. An extensive discussion examines carefully the reasons for such outcomes. **Conclusion:** The button augmented VRP could be a well needed resource for clinicians but requires further development and work.

Introduction

New perspectives on health definitions include both a growing awareness of the importance of the patient's self-perception of his/her problem, and the knowledge that a patient's treatment is very individually based. More and more effort is spent towards tailoring the clinical evaluation process to patient needs. Singers must meet high vocal demands, and have often high priority patient status in vocal clinics. They form a good example of a patient group with very specific needs. Several reports conclude that singers are at higher risk for voice disability and are prone to be impacted by these problems in a different way than are non-singers (Cohen, 2007; Morsomme, 2005; Phyland, 1999; Rosen, 2000).

Yet, there seems to be a discrepancy between what the literature reports on the one hand, and clinical approaches and practice concerning singer patients on the other. For example, it is only recently that voice-related quality-of-life instruments such as the Voice Handicap Index (VHI) have

been modified and adapted to meet the needs of singers (Cohen, 2007; Lamarche et al., in review; Morsomme, 2007; Murry, 2008). This discrepancy is perhaps related to the extent of resources available to clinicians. Clinicians are highly trained in recognizing, identifying and remediating phonatory failures in the spoken voice but might not be as well equipped in addressing the singing voice. Furthermore, since the voice problems of accomplished singers are often very specific and subtle, they might remain undetected by mainstream voice assessment protocols designed for speech (KayPENTAX, 2008). The Voice Range Profile (VRP) is often referred to as a tool that might be more sensitive to the subtleties of the singing voice, since it provides a map extending over the full vocal range. Thus the VRP, in comparison to isolated measures, is more likely to detect problems that occur only at certain effort levels and/or phonation frequencies.

In this light, a phonetograph augmented with a push-button was developed and tested with healthy singers (Lamarche, Ternström and Hertegård, 2008). This device superimposes subjective immediate self-perceptual information on the objective vocal measurements. By combining the self-perception of the singer during performance with a common clinical assessment, the VRP, the particular needs of the singer patient could be examined more closely. In a previous study (Lamarche *et al*. 2008), it was found that a singer's own perceptions could be used to produce a voice map containing acoustic as well as non-acoustic singer-relevant information. One outcome of this study was that healthy classical singers were consistent in using the button device. This led to the current question: will singer patients demonstrate more consistent button pressing than that found for healthy singers? Furthermore, will a particular pattern of button-device use emerge for this group or eventually even diagnosis groups? Indeed, it was expected that singer patients would press the button in the inner VRP areas rather than at VRP contour extreme limits as in the case of healthy singers.

The motivation for this paper was thus to examine how singer patients would use the button in the context of a VRP recording; and to explore how such VRP might further equip the clinician for the assessment of the singing voice status and facilitate the clinical evaluation process.

Methods

Signal Acquisition

A digital sound processing card (CAC Bullet II DSP) was used to run the computerized phonetograph, *Phog* (Version 2.00.10, Hitech Development AB, Sweden). The phonetograph was modified by author ST and Svante Granqvist to record simultaneously voice and presses of an external hand-held button.

The activation of the button device yielded pulses of 73 ms and this, regardless of how long the button was held down or of how hard it was pressed. The binary pulses were recorded in a vacant channel, in parallel with the phonetograph's fundamental frequency (F0), SPL, and voice quality parameters. Only button presses that were made during phonation were mapped into the VRP display, since their position would otherwise be undefined. For further detail, the reader is referred to Lamarche *et al*., 2008.

Recordings were conducted in a clinical environment. This imposed the choice of a headset cardioid microphone in order to reduce the influence of environmental, background noise and room reflections as well as allow more freedom to the singer while minimizing mouth to microphone distance changes (Cabrera, 2002; Lamarche *et al*., 2008). Prior to the recordings, a series of tests was performed on different kinds of headsets. It was found that the cardioid microphone recommended by the manufacturer for *Phog* and used by KayPentax (AKG model 420 headset) met the maximum level requirements (120-129 dB) for making VRPs of female classical singing. A low-noise microphone preamplifier was used (Line Audio Design model 2MP, Rinkaby, Sweden).

The phonetograph voicing thresholds were set to minimum 0.025 seconds for the accumulated time per cell, and maximum 75 cents for the F0-standard deviation over seven periods. The cell aspect ratio was 2/3 and the sampling rate was 16000 Hz. The calibration of SPL was performed for every subject. Microphone-to-mouth distance was measured from the front teeth to the boom and at this distance, a white noise calibration tone was played and measured at the microphone with a sound pressure meter (LA-210, Ono Sokki, Japan) using C-frequency-weighting. The mouth-to-microphone distance was then compensated for a distance of 30 cm using *Phog's* calibration settings.

Procedures

The investigator and the equipment were in the same room as the subject. By design, the patients could not see the computer screen. Subjects were asked to perform the tasks in a singing stance. Subjects used the phoneme /a:/ across all tasks. They were asked to use the button during each task to communicate feelings of discomfort or a loss of vocal control. Throughout the recording session, singers could break as they pleased, and were given freedom in structuring their performance (phrasing, breathing and pace). The following instructions were given to the patient-singers to guide their use of the button.

”As you sing, press the button whenever you feel vocal instability or discomfort.

Aim at communicating your sensations during your performance.”

These instructions were formulated so as to encourage the singer to focus on the effects of phonation rather than on the audio feedback and voice quality aspects. The task protocol was as follows.

Task 1

The subject was asked to make a description of their personal warm-up routine in a spontaneous speech task. Such a theme was considered to be neutral in content and easily accessible to all subjects. This task also included a counting exercise in which the subject used soft, comfortable speech as well as loud public speaking voice. Subjects spoke in their native tongue (either French or Dutch). The total duration of this task was 3 minutes. Task 1 had mainly a training nature where subjects could acquaint themselves with the instructions and the task at hand.

Task 2

A physiological VRP was performed. In this task, voice quality was completely disregarded and the singer was encouraged simply to phonate as softly and as loudly as possible. A descending *glissando* (a slow frequency sweep) followed by an ascending *glissando* exercise was used to obtain the softest and loudest possible phonation across the subject's range. Total task duration was approximately 6-8 minutes.

Task 3

A performance VRP was recorded for a discrete pitch exercise. A performance VRP entails the performance aspects of voice such as vibrato, relative stage vocal dynamics, musicality etc. A prompting pitch was played to the singer. The singer was then asked to sing this pitch in a *messa di voce* exercise (an increasing-decreasing tone on a stable pitch). Prompted intervals equivalent to the musical notes C-E-G-A were tested across the singer's range. The duration of the task was 6 minutes. This task was central to the experiment and importantly addressed the singing voice as it is typically used by the artist. Since singer patient's are inclined to have vocal complaints related to their singing voice, it was most interesting to assess how they would use the button device during performance.

Task 4

An excerpt from a typical audition piece was recorded. This task was performed only with the approval of the speech language pathologist (SLP). The task duration was 1 minute. The performance of a song served to break-up the repetition of Task 3, and to assess if button pressing behavior would change with increased performance context.

Task 5

The final task partly replicated Task 3. The regions previously marked by the button presses in Task 3 were used to select the parts of the task to be repeated. Subjects were oblivious to this decision. This procedure was chosen to minimize the use of the subject's voice. We felt it could be unethical with patients to subject them to additional loading in VRP areas where few or no button-press replications were to be expected. The task lasted 5 minutes.

Subjects

13 singers, 9 females and 4 males with a formal voice complaint were recorded. The group presented a variety of diagnoses: 6 cases of nodules, 5 of functional dysphonia, 1 of pharyngo laryngeal reflux and 1 complaint without diagnosis. All subjects had had vocal training. Singing levels and genres, however, were quite varied, extending from professional classical soloists and opera choristers to amateur gospel and ballad singers. Patients were recruited in a Belgian clinic. All subjects participating in this study were at the starting point of rehabilitation and had no prior knowledge or experience of

voice therapy. Data was collected at author DM's clinic, the Clinique Saint Luc, Centre d'Audio-Phonologie Saint Luc. Table 1 a) and b) presents a summary of the group demographics. An ethical vetting certificate was obtained from the *Regionala etikprövningsnämnden i Stockholm* (certificate 1358-31) and subjects all signed a consent form prior to the recording session. The VRP recording session was offered as a complement to regular evaluation.

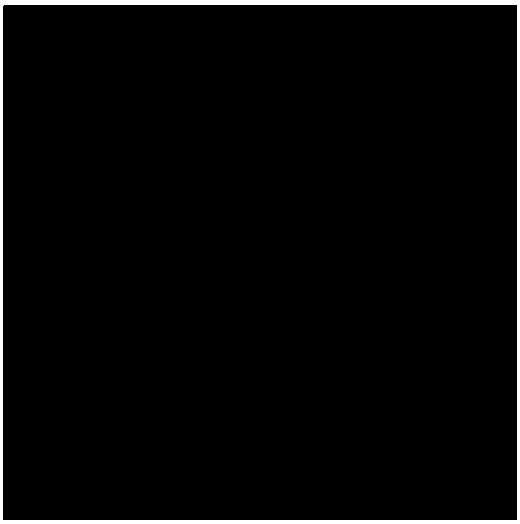

Table 1a) Singer-patient group data reporting age, sex, singing level and diagnosis (N=13). Functional dysphonia is reported accorded to the level scheme elaborated by Koufman (1982). Age data is missing for patients 8 and 12.

Table 1b) Voice status evaluation parameters for singer patients (N=13). The Voice Handicap Index adapted for singers is reported for the total score and the functional (F), emotional (E) and physical (P) subscales. Scores for the Dysphonia Severity Index (DSI) are also included. Unfortunately, information for patients 9, 12 and 13 was not available.

Post-task validation by the subjects

A post recording questionnaire (Appendix A) was distributed to all the participants involved in the project. Subjects graded with visual analogue scales (VAS) their current vocal status as well as their impressions of their use of the button in performance.[1] In addition, subjects described their motivations for pressing the button. The descriptive portion of subject answers was categorized and the frequency distribution of key words was tabulated. The questionnaire contained a total of nine questions. This type of post-task questionnaire was accompanied by a definition of the VRP and was answered in writing.

[1] The VAS consists of an horizontal 100 mm line which is accompanied by binary pole anchors.

During this evaluation, the subject could visually refer to the outcome of Task 3 and 5. The purpose of the questionnaire was to verify instruction comprehension and also carefully document the patient's experience of using the button.

Analysis

With the same instructions as above mentioned, previous work (Lamarche *et al*., 2008) had shown that healthy singers used the button consistently. These results motivated the formulation of one of the current study's expectations: since singer-patients suffer from a vocal problem, discomfort and the loss of control can be expected to occur more systematically and thus lead to a more consistent button-pressing behavior than that observed in healthy singers. In order to test this, the analysis protocol of the first study was somewhat modified.

Similarity

The analysis technique developed in previous work (Lamarche *et al.,* 2008) was repeated here. Similarity percentage scores were calculated to assess the consistency of the subject's behavior when pressing the button. Figure 1 gives an example of these first analysis steps taken in the previous study. Button presses were mapped to the VRP and each press was attributed a surrounding region. The overlap of the regions between Task 3 and Task 5 was determined and the degree of overlap defined the similarity score (this was labelled "original overlap" in reference to the actual collected button presses). The original number of presses was then redistributed randomly over the VRP area of Task 3. The degree of overlap was reassessed between the randomized button presses and the presses obtained in Task 5 (this was labelled as the "random overlap"). The probability that the original overlap occurred at higher than chance level was tested against a Poisson distribution (a discrete probability distribution that gives the probability of a number of events occurring in a fixed period of time, or, in this case, a fixed area) with an alpha of 0.05.

Specificity

Not only was it important to assess how individuals were consistent in using the button but equally how often they pressed. Since presumably a vocal disorder would provoke a systematic problem, it was hypothesised that patients would make greater use of the button than healthy singers. The distribution of the rate of pressing and the specificity of the information were examined in terms of repetition detection and color mapping to enable visualization of this information. The rate of button presses was compiled by retrieving the occurrence of the button-device pulses synchronised with the F_0 and SPL channels. This was then displayed on the VRP by mapping the rate to a set of 3 discrete color variations on the display. The display varied from the lightest shade of grey for a low rate to a darkest shade of grey for the highest rate.

Figure 2 illustrates how overlapping button presses and regions are identified by darker shades of gray.

Pooling

Finally, as it was important to assess the differences between the healthy group and the subjects, accumulated button presses were pooled into one Figure. Total press data was accumulated for the healthy group, for the overall subject group and for the two main diagnosis subgroups: nodules and functional dysphonia.Both males and females were included in the accumulated data since the aim was to examine the button pressing and the possible overall location trends. Naturally, in a VRP assessment, sexes would have to be grouped separately for a proper evaluation.

Questionnaire

Figure 3 and Table 2 a) and b) show the questionnaire results. The questionnaire itself is reproduced in Appendix A. The questionnaire responses generally confirmed our observations with the exception of results obtained for question 4. This will be further addressed in the discussion. The central item, a question in which the subjects were asked to rate the correspondence of the button press display to their singing experience, the average VAS ratings were 75 % of the total line length (standard deviation was 4.6). Figure 3 demonstrates the mean and standard deviations for all 5 questions answered with VAS ratings. In general, the singers found the button markings to be consistent with their recollections of their performance and demonstrated good comprehension of the task instructions. Table 2 tabulates the collected qualitative material in terms of a) the type of difficulty experienced in the recording, and the definition and description of the main reason for pressing the button device; and b) the effect of vocal effort on performance. Because responses for question 7 of the questionnaire were scarce, this question was excluded from qualitative reports.

Results

Overall, the similarity results attested to the group's consistent behavior. In a second elicitation of the task, the button was pressed at higher levels than chance. The similarity scores and *p*-values for thirteen button-VRP pairs are shown in Table 3. For 8 of the 13 subjects, 62 % of the group, the original button overlap percentages obtained were significantly higher than the ones obtained for the mean of 20 iterations of a randomized distribution of presses. Significance was determined with an alpha of 0.05. The average similarity score for the subject group was 10.9 % while in a previous study, results for a healthy group of female singers were 19.3 %. The data from this previous study (Lamarche *et al.*, 2008) are included in Table 4 to facilitate comparison. The healthy group of singers used here for comparison, included 16 healthy female opera singers, 19 to 35 years of age and with a minimum of 4 years of training,

Original button overlap percentages were often higher than the ones obtained for the mean random overlap, but with our criterion for non-randomness, not all of these differences were statistically significant. This applied for both healthy and patient groups. Exceptions could be noted for subjects 3 and 4 where the similarity percentages were lower (0 and 1 respectively) than the mean percentage

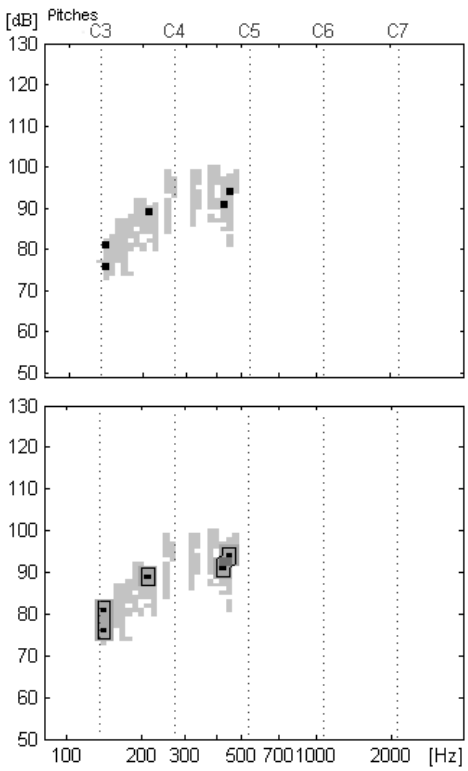

Figure 1. The performance VRP for one subject with the button presses (top) and including the zones mapped to each press (bottom). This VRP was obtained for patient 1, an amateur singer, singing mostly gospel and diagnosed with nodules. The vertical axis displays dB SPL @ 30 cm and the horizontal axis,logarithmic frequency in Hz.

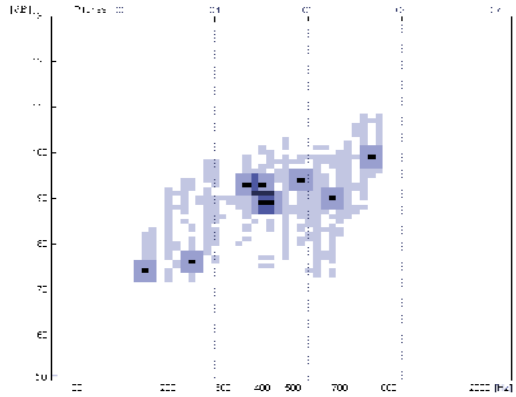

Figure 2. The merged VRPs for both Task 3 and 5, patient 4. The occurrence of button press zone overlap is depicted by darkening colors. In this way, the visualization of the button press overlap can help denote a particular area of concern. For this classical soprano diagnosed with nodules, the central region of the VRP seems especially problematic. Axes are defined as in Figure 1.

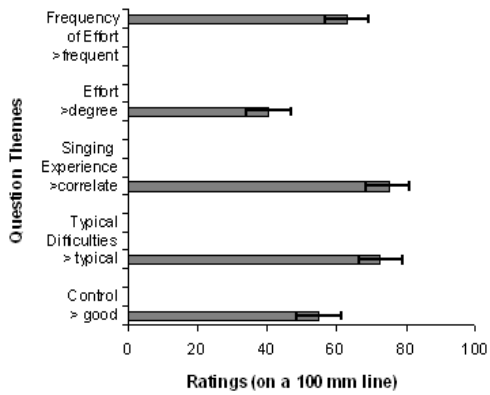

Figure 3. Post recording results of 5 questions as rated on a Visual Analogue Scale. Appendix A gives the details of the full questionnaire. Rating means and standard deviation are included for each theme. The main theme for each question is used as a category on the horizontal-axis and the semantic anchor that corresponded with the high extreme of the scale (in this case 100) is also included.

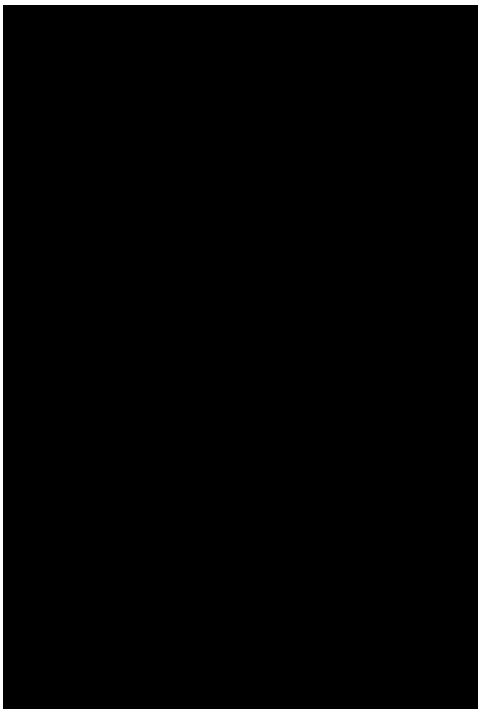

Table 2 a) Singer-patient descriptions of systematic difficulties relevant to the button pressing and descriptions of the main reason for pressing the button. Descriptions are grouped into thematic categories. Frequency of appearance for each statement is tabulated.

Table 2 b) Singer-patient responses concerning the impact of vocal effort on their performances. Statements are categorized per theme and frequency of appearance for each statement is included.

obtained for the random distribution of presses. Some exceptions had also previously been noted for subjects 9, 14 and 17 of the healthy group. These exceptions are associated with instances of insufficient sampling, i.e., where very few presses of the button were registered for either one of the tasks, thus increasing the risk of no overlap at all with the other task elicitation. When those limited presses were distributed randomly 20 times within the VRP space, the probability estimated as the mean overlap often became higher and therefore yielded the highest *p*-values for these cases.

Rate of Button Press

Healthy singers clearly had recourse to the button device more often than did singer patients. The bar graphs in Figure 4 a) and b) depict this unexpected trend. The overlap of button presses within a same task is depicted for the patient group in Figure 5 as well as parallel information retrieved from the previously studied healthy group (Lamarche *et al*., 2008). For both groups, results did not show any

signs of a warm-up effect; button press rates varied similarly in both elicitations and Task 3 and its replication, Task 5 yielded very similar VRP areas.

Pooling

Figure 6 shows the accumulated total of button presses of the 6 patients with nodules (all females) and Figure 7 displays the accumulated total of presses of the 5 patients (males and females) diagnosed with functional dysphonia. In a last step, button press information for Task 3 and 5 was merged to create a total density plot for the subjects and the healthy singers respectively. This type of plot is instrumental in depicting trends in a group's overall button press behavior. Figure 8 illustrates this information.

Subject	Original Overlap %	Mean Overlap %	*p*-values (α=0.05)
1	29	11.22	**<0.001**
2	9	7.66	0.242
3	0	2.03	0.869
4	1	5.60	0.975
5	7	0.31	**<0.001**
6	14	7.45	**0.010**
7	13	4.08	**<0.001**
8	0	0.0	------
9	5	1.51	**0.005**
10	24	6.29	**<0.001**
11	19	1.96	**<0.001**
12	7	5.66	0.211
13	14	0.47	**<0.001**

Table 3 Similarity results of trials for Task 3 and 5. Column 2 gives the "similarity score", the percentage of overlap of button regions for Task 3 and 5. The mean overlap with Task 5 from 20 iterations of presses from Task 3 randomly redistributed within the Task 3 contour (an estimate of a Poisson distribution parameter λ) is given in column 3. Column 4 gives the probability, assuming the Poisson distribution, of the observed button overlap being an outcome of a random process. Bolded *p*-values are significant at an alpha level of 0.05.

Subject	Original Overlap %	Rand Mean Overlap %	*p*-value (α=0.05)
1	28	14.3	**<0.001**
2	9	1.6	**<0.001**
3	10	6.8	**0.010**
4	30	14.1	**<0.001**
5	20	8.7	**<0.001**
6	9	4.8	**0.024**
7	15	5.1	**<0.001**
8	8	12.1	0.848
9	19	12.5	**0.030**
10	8	1.5	**<0.001**
11	20	7.3	**<0.001**
12	17	2.0	**<0.001**
13	35	28.9	0.110
14	8	3.6	**0.012**
15	51	8.0	**<0.001**

Table 4 The same analysis as in Table 3, but performed for a group of 15 healthy subjects. Bolded *p*-values are significant at an alpha level of 0.05.

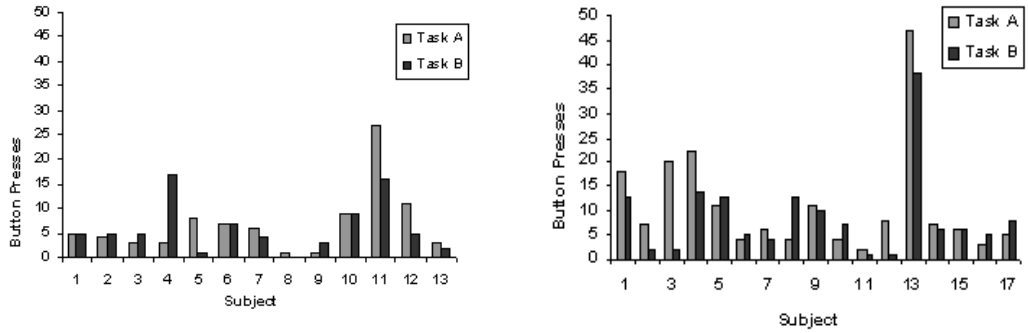

Figure 4a) Button press occurrences for singer patients in Task 3 and Task 5. **b)**. Results of button press occurrences for Task 3 and Task 5 for healthy singers.

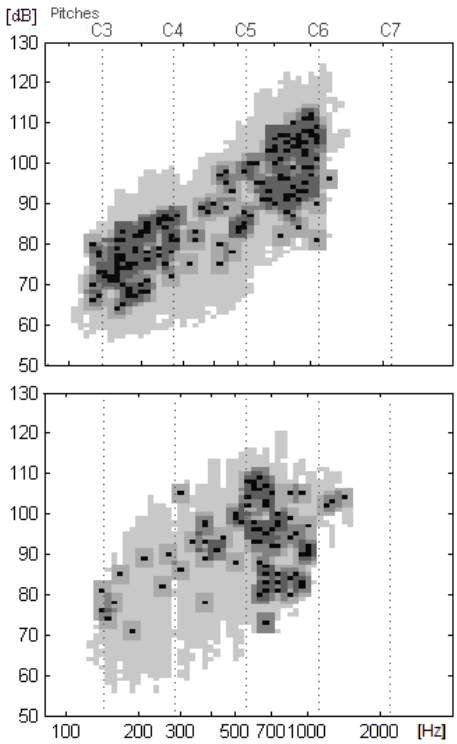

Figure 5. The accumulated button presses for a group of 15 female healthy singers (top) compared to a singer-patient group (bottom) of 9 females and 4 males. This averaging is performed only for Task 3 results. The darker the gray, the greater the button zone overlap. Axes as for Figure1.

Discussion

At the onset of this study it was expected that subjects would press more often, more consistently and depict different button pressing patterns than healthy singers. For the subject group, the locations of button presses within the VRP were expected to be concentrated in inner VRP areas as the fine motor control required in the messa di voce would be likely to pose problems in the presence of vocal disorder. In this way, the button presses could possibly elucidate new inner VRP areas of interest in concern to singer-patient voice assessment. Finally, it was also deemed interesting to examine the use of the button device and the location of press trends in relation to diagnosis groups; in this case nodules and functional dysphonia. However, due to the limited number of subjects, reliable and valid results could not be obtained.

Results partly differed from our expectations. The button press rate for singer patients was lower than that found for healthy singers.Furthermore, although conclusions of consistent behavior could be drawn for the singer-patient group, results were weaker than those found for the healthy group. Indeed, when tested across tasks, healthy singers had had comparable similarity scores to what was observed for the singer-patient group in the task replication. Some possible explanations for these somewhat weaker than expected results are suggested in what follows.

Indeed, when tested across tasks, healthy singers had had comparable similarity scores to what was observed for the singer-patient group in the task replication. Some possible explanations for these somewhat weaker than expected results are suggested in what follows.

Group Differences

The groups compared in this study represented very different populations of singers. The healthy singer group only included female professional opera singers, whereas the singer-patient group included both sexes and a variety of singing styles and levels. Professional classical singer-patient data proved to be practically impossible to collect within a reasonable timeframe and consequently, certain group criteria had to be relaxed or abandoned. The different nature of the groups could in itself be a possible underlying factor to the results obtained in this study.

The button enhanced VRP was not expected to create tasking issues given that the act of singing at a high level of performance also requires considerable multi-tasking. The singer must sing, attend to the accompaniment, play a role, dance and communicate with the audience. Consequently, adding the button device to VRP tasks for this population was not anticipated to cause task performance difficulties. However, the level of expertise of the singer might explain differences in the ability to manage multi-tasking such as required in a button VRP recording.

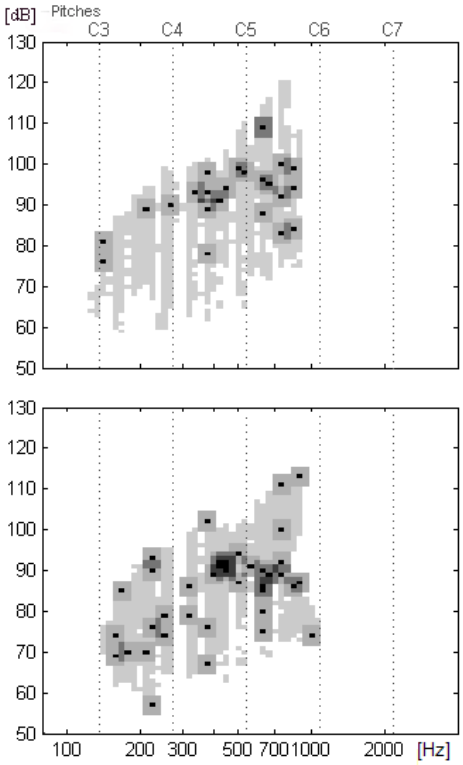

Figure 6. The accumulated button presses for 6 patients with nodules (all females) is compared for Tasks 3 (top) and 5 (bottom). Although pressing behavior changed a little between tasks, a tendency to press in the 400-450 Hz and 90 dB zone as well as just below 700 Hz in the range of 85-94 dB can be noted in both cases. Axes as for Figure 1.

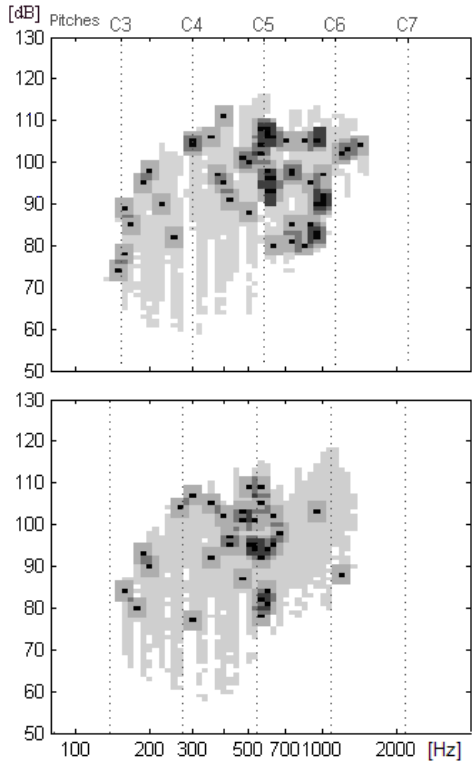

Figure 7. The accumulated button presses for 5 patients (3 females, 2 males) with functional dysphonia is compared for Tasks 3 (top) and 5 (bottom). Pressing occurs mostly at high SPL. Presses along the SPL extent for the frequency range 550-600 Hz was a recurring pattern for this group. Axes as for Figure 1.

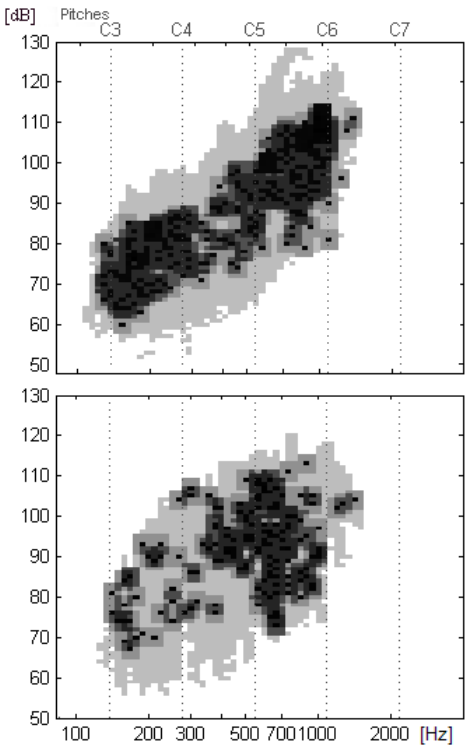

Figure 8. The total accumulated button press information for Tasks 3 and 5. The healthy group and the patient group exhibit clearly different patterns of button pressing. This outcome agrees with initial expectations that singer patients would press in inner VRP areas rather than at the VRP extremes. This trend is manifest despite the typical smoothing effects of averaging. Axes as for Figure 1.

The amateur or student singer may not have acquired a proper vocal gesture to enable their focus to shift to another task like the button pressing. Multi-tasking capabilities aside, the infrequent use of the button device observed for the patient-singer group could also be tied to the fact that these singers are not as aware of their vocal capabilities and limits as are professionals. Levels of self-confidence might also impact the use of the button and the frequency of pressing. It is more likely that professional singers were more self-confident in their vocal technique and performance and hence in using the button.

Load Effect

The proficiency of the singer might not be the only explanation for the observation of lower rates of button pressing and weaker consistent behavior. The greater difference between the two groups, the presence of a vocal complaint related to a voice disorder rather than level of training, can have greatly impacted the results of this study.

A certain vocal disorder load effect may come into play when singer patients are instructed to use the button device. The multi-tasking capabilities of the singer are then impaired by the presence of a disorder and the focus of the subject becomes more centred on the actual performance rather than on an internal analysis of events. The button tasks were perhaps requiring too much attention especially in the framework of a first voice status evaluation. Subject responses in the post-recording questionnaire seem to support this last interpretation. The most frequent responses to question 9 (see Table 2b) were emotional responses describing a heightened need for focus and concentration, loss of self-confidence and fear/insecurity related to phonation.

This load effect could have been potentially avoided with better training possibilities. A short training session had been designed in the context of the healthy group study but was not adopted for the singer-patient group experiment because of its additional vocal demands. Since another aim for these recordings was to collect singer-patient phonetographic data to compare to a recent normative study, tasks followed closely those used in the normative data collection (Lamarche *et al., in press*). We believed that instructing the subject in using the button for speech tasks and for the brief physiological VRP task, would provide sufficient experience in using the button device before the test. Healthy singer button press data in a previous study (Lamarche *et al*., 2008) had also demonstrated the singer's capability of generalising the button pressing across various tasks. For singer patients, however, the transition between the voice tasks and the performance tasks might be challenging enough to impede the generalisation of the button device training. Button pressing was scarce in the speech tasks (perhaps supporting the fact that these subjects had indeed *singing* voice complaints) while subjects pressed the button more often during the physiological VRP recordings. This task, due to its continuous and more rapid nature, was not intended for inclusion in the analysis but nonetheless could be used as an indicator that subjects understood the task at hand and could use the button device. Perhaps the load effect of the vocal disorder explicitly came into play when the singing voice was addressed.

With hindsight, and looking at past research in the field of motor theory, some explanation for the lack of generalisation can be found. Variable practice such as asking the subject to perform the button task in different voice modes typically diminishes training performance and rather improves long term learning (Titze & Verdolini, 2002).

Psychology of the singer

In this discussion of results, the subject's readiness to communicate problems must also be taken into account. Singers are often taught and drilled to hide imperfections, uncomfortable moments, errors and fatigue in order to keep a convincing and smooth performance. This is true for all stage artists, but for the singer, this becomes an intricate part of the act of singing. It is not uncommon, in the case of pathology or vocal problems and in contexts remote from the stage, for singers to shy away from revealing the problematic areas and to avoid or compensate for the problematic vocal gestures. This kind of behavior could consequently affect the way in which the subject presses the button. In a healthy state, when the singer is more self-confident and is relatively free from stress, button pressing could be more frequent without necessarily reflecting the totality of the singer's concerns. It would

follow that when the subject does push the button device, the importance of that button press is not negligible despite the lower rate of pressing.

In a similar line of thought, and in a more qualitative approach, it could be productive to address the subject's personality. For the singer, the impact of a vocal disorder is great and the button pressing could be heavily linked to the singer's coping strategy (i.e., either hiding and not pressing, or obsessing and pressing excessively).

Location of button presses

Expectations were met as to *where* in their VRP space subjects would press the button. This was a positive and central outcome of this study. Subjects did not press as often and as consistently as expected, but they did press the button in different regions of their VRP space in comparison to the healthy group. These different group tendencies were observable despite the effects of averaging. The total density plot averages for the healthy and the singer-patient group, Figure 8, clearly depicts the tendency of the singer patients to press in a latitudinal fashion, cutting through their VRP throughout the SPL extent of a 500 to 800 Hz frequency range. The healthy singers, on the other hand, tended to press at both extremes of their VRP. In Figure 8, the Gaussian (normal) character that results from the accumulation of any distributions has somewhat obscured this tendency to the extremes. However, we choose to present the data in this way, rather than to devise some scheme for VRP shape normalization. This outcome reveals the importance of examining the vocal dynamic capabilities of a voice and recording a full VRP rather than just a contour. The *messa di voce* exercise, for example, seems to be an ideal exercise for such an evaluation. The exercise indirectly gives information on the limitation and variation flexibility of the voice source. It would seem that problems or challenges are especially perceived along the full SPL extent of a voice in its higher range where control in general is more difficult and consequently extremely difficult in the case of a vocal disorder.

In Figure 6, the results representative of 6 subjects with nodules are illustrated. Nodules can be expected to impact the singing voice in terms of limitations of the upper range, onset delays in soft phonation (most particularly in the high range), reduction of the vocal endurance, a sense of increased effort and increased day-to-day voice variability. In the button press map, highlighted areas are mostly concentrated in the upper range and at the center-like part of the sound level extent. Three dominant areas can be noted: 1) a 450 to 550 Hz band in the top half of a 65 to 103 dB extent, 2) just below 700 Hz at the half point of a 72 to 110 dB extent and 3) the 850 Hz region at 10 to 15 db higher than the minimum of a 73 to 115 dB extent.

The functional dysphonia group exhibited a similar pattern (Figure 7). In both tasks, the subjects pressed mainly in the frequency region just above 523 Hz. The majority of button presses was found between 90 and 108 dB in Task 3 while somewhat lower, from 80 to 95 dB, in Task 5. In Task 3 there were also some highlighted regions in the higher range at approximately 880 Hz with similar SPL as found for the lower frequencies just mentioned. Button presses for the group with functional dysphonia were located slightly higher in frequency than what was observed for the group with nodules; however, with regard to SPL, the occurrence of these dominant button press regions was much the same. Interestingly, *mezzo forte* (an intermediate musical dynamic) in female singing is known to be approximately between 88-90 decibels. (Nawka et al., 1993, Lamarche et al, 2008) This

would mean that the dominant regions of button pressing corresponded approximately to the *mezzo forte* portion of the *messa di voce* exercise. Since this type of exercise requires very fine motricity involving gradual vocal fold adduction changes (Titze *et al*.,1999) subjects might feel particular control difficulties and even discomfort in the higher range of the voice (where the vocal folds are stretched and thin) as vocal fold mass must subtly, smoothly and gradually increase or decrease in order to regulate the resistance of the folds to the airflow. Furthermore, because the descending portion of a *messa di voce* can be anticipated to be particularly challenging, button presses were studied in relation to the audio signal. However, no specific timing trend with a particular ascending or descending gesture of the *messa di voce* could be discerned.

Further investigations including larger groups with better possibilities to categorize according to both diagnosis and voice category could assess more readily the kind of pressing pattern here observed. Clearly, singer-patient button presses reflect an extra dimension to the VRP recording since they convey information that is not necessarily available in the audio signal.

From the singer patient's point of view

Subject feedback concerning the relevance of button presses to their performance experience was generally affirmative. In the previous study, ratings like these were important for understanding the subject's experience of such a new device (Lamarche *et al*., 2008) This time, the questionnaire was used both as a tool to validate instruction comprehension and to identify the main motivations leading to button pressing. Both VAS ratings and qualitative data shown in Figure 3 and tabulated in Table 2 a) and b) contain valuable material in relation to the button VRP data. Every subject answered in the negative when asked if the difficulties coinciding with the button presses were momentaneous, of an incidental nature. Informally. patients sometimes mentioned that it was difficult to choose *when* to press since the difficulties were felt constantly. This difficulty of choosing the right time to press the button could also explain the reduced rate of button presses and the low scores obtained for question 6. It can also be concluded that when subjects did press the button, the button press in question was likely to be related to a heightened sensation of difficulty.

Since each recording session was filmed in order to ensure good methodological procedure coherence and to document calibrations, subject comments in the in-between task time could be noted. At times, the subject reported not pressing in specific places, or else wanting to immediately explain the presses. It was clear that there was a general tendency to forget to press the button even though the button device instructions were repeated at the onset of each task. These observations are consistent with the notion of a possible vocal disorder load. A subtle visual reminder placed in the vision field of the subject might be a small but helpful addition to the protocol and reduce memory load.

From the clinician's point of view

This type of enhanced VRP was developed and tested with the intention of improving evaluative possibilities for the clinician working with the singer patient. It was deemed important to integrate a clinical angle to the results presented above and to the overall experiment process.

implemented in order to achieve a deeper analysis level of button pressing similarities and information. As a proof of concept type of study, this work offers interesting possibilities for clinical applications as well as research.

The button-VRP could be an important documenting tool for pre-post vocal status. It could help objectify the assessment of change in voice status which is not necessarily only related to vocal range. Furthermore the assessment of pre and post interventions like surgery or rehabilitative therapy could be greatly supported by these button presses as they could directly attract attention to problem areas and in this way refine the course of the rehabilitative process. On the same lines, this kind of button enhanced VRP could even be of diagnostic interest. The button markings in the VRP could potentially map out interesting frequencies for closer laryngoscopic examination.

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References

Cabrera D, Davis P, Barnes J, Jacobs M, Bell D. Recording the operatic voice for acoustic analysis *Acoustics Australia / Australian Acoustical Society.* 2002; 30(3):103-108.

Cohen Seth M, Jacobson Barbara H, Garrett C Gaelyn, et al. Creation and validation of the Singing Voice Handicap Index. *The Annals of otology, rhinology, and laryngology.* 2007; 116 (6):420-6.

KayPENTAX. Voice range profile, model 4326. Retrieved 2008-08-06, (Last updated, September 15, 2008) from: **http://www.kayelemetrics.com/Product%20Info/CSL%20Options/4326/4326.htm**

Koufman JA, Blalock PD. Classification and approach to patients with functional voice disorders. *The Annals of otology, rhinology, and laryngology.* 1982; 91(4 Pt 1):372-7.

Lamarche A, Ternström S. An Exploration of Skin Acceleration Level as a Measure of Phonatory Function in Singing. *Journal of Voice.* 2008; 22(1):10-22.

Lamarche A, Ternström S, Hertegård S. Not just sound: supplementing the Voice Range Profile with the singer's own perceptions of vocal challenges. *Journal of Logopedics, phoniatrics, vocology.* 2008; 13:1-8. DOI:10.1080/14015430802239759

Morsomme D, Gaspar M, Jamart J, Remacle M, Verduyckt I. Adaptation du VoiceHandicap Index à la voix chantée. *Revue de laryngologie-otologie-rhinologie*. 2007; 128(5): 305-314.

Morsomme D, Simon C H, Jamart J, Remacle M, Verduyckt I. [A proposal to adapt the Voice Handicap Index to the singing voice]. *Revue de laryngologie - otologie - rhinologie.* 2005; 126: 305-313.

Murry T, Zschommler A, Prokop J. Voice Handicap in Singers. *Journal of Voice.* 2008. Jan 10. Doi:10.1016/j.jvoice.2007.10.013

Nawka, T, Seidner W, Cebulla M. Experiments on intentionally influencing the singer's vibrato *Proceedings of the Stockholm Music Acoustics Conference,* 1993 :221-228

Phyland DJ, Oates J, Greenwood KM. Self-reported voice problems among three groups of professional singers. *Journal of Voice.* 1999; 13(4):602-11.

Rosen C A, Murry T. Voice handicap index in singers. *Journal of Voice.* 2000; 14:370-7.

Schutte H K, Seidner W. Recommendation by the Union of European Phoniatricians (UEP): Standardizing Voice Area Measurements/Phonetography. *Folia Phoniatrica.*1994; 35:286-88.

Titze I.R., Verdolini, K. (in preperation) Vocology. 2002

Titze I R, Long R, Shirley, G I, Ramig, L O, Caroll, L M, Riley, W D. *Messa di voce*: An investigation of the symmetry of crescendo and decrescendo in a singing exercise. Journal of the Acoustical Society of America, 1999: 105(5) : 2933-2940.

Titze I R. Acoustic interpretation of the voice range profile (phonetogram). *Journal of Speech and Hearing Research.* 1992; 35: 21–34.

Appendix A

Questionnaire post enregistrement / Post recording Questionnaire

Cocher sur la ligne le grade perçu. Toujours faire le lien avec votre état vocal actuel.
Mark the line according to your perception. Always refer to your current voice status

1. **Impression globale de votre contrôle vocal tel que perçu aujourd'hui.**
   Indicate your overall impression of vocal control today.

Mauvais/Bad _____ **Bon**/Good

2. **Les zones identifiées pendant l'enregistrement représentent-elles vos difficultés habituelles ?**
   Are the highlighted portions of your phonetogram typical areas of difficulty or/and limits?

Atypique /Atypical _____ **Typique**/Typical

3. **Selon vous, les pressions exercées sur le bouton traduisent-elles correctement votre expérience vocale de ce jour ?**
   Do the button presses relate well to your singing experience today?

   Non/No _____ Oui/Yes

4. **Les pressions exercées sur le bouton correspondent à quelle sorte de difficultés vocales?**
   With which kind of vocal difficulties do the button presses coincide?

   Momentanées/Incidental _____ **Systematiques/**Systematic _____
   (Ex: phlegm on the vocal folds)

   Lesquelles/ Which ones

   _____
   _____
   _____

5. **Pouvez-vous brièvement décrire la raison principale qui vous a poussé à utiliser/activer le bouton?**
Can you explain the main reason for your use of the button?

_____
_____
_____
_____

6. **Évaluer de façon générale votre effort vocal en lien avec votre utilisation du bouton.**
Grade your general vocal effort at the times of button presses.

Aucun/None _____ E**xtrême**/Extreme

7. **Spécifiez en quelques mots clés ce qui décrit le mieux votre effort/inconfort vocal ?**
Which words best describe your vocal effort?

_____
_____
_____

8. **L'effort vocal ou l'inconfort vocal sont-ils fréquents lors de vos prestations vocales ?**
Is this type of effort frequent in your performance?

Non/No _____ **Oui**/Yes

9. **Si oui, comment influent-ils sur vos prestations vocales?**
In case of the affirmative, how does it influence your performance?

_____
_____
_____