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A separate detection of the vibration of each vocal fold by a new opto-electronic device.

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Abstract :

The existence of low-frequency modulations in some pathological vocal signals has already been reported by several authors. We have focused on the existence of these non-linear phenomena analysing the vibration of excised animal larynges submitted to asymmetrical situations. This work presents a laser beam device permitting to detect the vibration of each fold both simultaneously and separately. The first data are also proposed.

Introduction :

The existence of low-frequency modulations in some pathological vocal signals has already been reported by several authors [Herzel-94; Giovanni-in press]. These modulations are by nature non-linear phenomena and have been related to the numerous non-linearities present in the glottal function : the coupling of the air-flow and the vibratory mass of the vocal folds, the physical interaction between the folds in the closed phase of the cycle, etc. We have focused on the existence of such phenomena using an experimental device making it possible to study the vibration of excised animal larynges, in situation of tension asymmetry : the observed modulations had been related to the physical interactions between vocal folds presenting different vibratory characteristics [Berry-96, Ouaknine-98]. But the experimental demonstration of the interaction between the folds still requires a tool permitting to analyse the vibration of each fold both simultaneously and separately.

Up to now, the existing methods analysing the vibration of the vocal folds are : the high speed video and the videokymograph. The high speed video consists in filming the larynx at a speed of about 5000 pictures per second. The film is then projected at the normal speed of 24 pictures a second. Thus, a significant slow motion effect is obtained, which enables to analyse the motion of the free edge of the vocal folds and its overlapping of the median line. However, this device is very expensive to use and the information given (a picture) is not directly usable in a signal editor. The videokymograph [Schutte-96] is less expensive but gives quantifiable information on the glottal slit only and not on the asymmetries of the movements of each vocal fold. That's why we have decided to design a device which had to be rather cheap, have no physical contact with the vocal fold in order not to disrupt the vibration and which could be compared to the microphonic signal or the EGG signal. This study proposes to present a laser beam device allowing the simultaneous detection of the vibration of each fold and to state the first data.

Assembling of the device :

We chose to use an optical fiber reflectometer (OFR), with the following characteristics :

- It is based upon the emission of a laser ray through an optical fiber.

- It sends out a light ray towards the mucous membrane of the vocal fold, a ray which reflects on the target.
- The residual light is picked up by a photodetector which measures its intensity.
- The beam is uncollimated.
- The beam must be diverging, so that the density of the light is in inverse proportion to the distance d from the source to the target (=> The intensity of the reflected light is in inverse proportion to the squared distance from the source to the target.)

For small variations around the d distance (Taylor series formula), the signal which is recorded can be considered as proportional to the amplitude of these small variations (provided that d is long in comparison to with the amplitude of the vibrations.) The block diagram of the OFR is shown in figure 1.

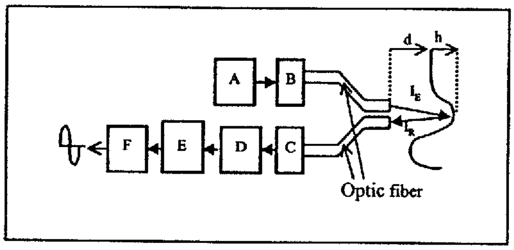


Figure. 1 Bloc diagram of the Opto-reflectometer
A – Pulse generator B- Laser diode C – Photo transistor D – Pulse amplifier E – Rectifier F – Low –Pass filter I_E – Light emitter intensity I_R – Light receiver intensity

$$I_R(d) = \frac{KI_E}{d^2}$$

$$\underset{h \to 0}{I_R}(d+h) = \frac{KI_E}{d^2} - \frac{2KI_E}{d^3}h$$

The coefficient K depend on the divergence solid angle of the source, absorption of the tissue, sensible area of the detector etc.

Experiment # 1 :

We first focused on the validation of this device as a means of recording the frequency of the glottal vibration by comparing it to EGG taken as a reference. We used the experimental device (figure 2) as previously described [Giovanni-in press] and analysed the emission of excised pork larynges.

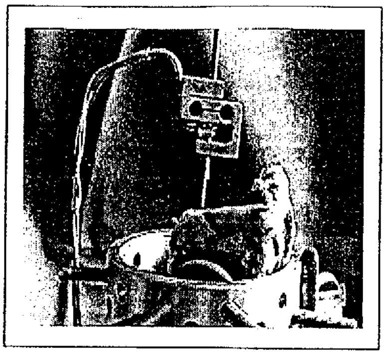


Figure 2: experimental device.

The device was equipped with a turbine generating air flows up to 10 l/s. The air flow was regulated by an electro-valve operated by a micro-computer. The air was maintained at 37°C and humidified. It was brought to the trachea thanks to a tracheostomy tube to ensure the air-tightness. The probe was fitted at the distal extremity of the trachea. Moreover, a micropositionor was fitted vertically on the ventricular floor, outside and a little ahead of the extremity of the vocal apophysis, on either side. The micropositionors were used to adjust the tension of the vocal muscle by shifting vertically. Two electrographic electrodes were brought into contact with the cartilage thyroïde. The study bore on 7 excised pork larynges analysed in symmetrical vibratory situation.

The OFR beam (figure 3) was directed into the glottal slit. The signal was thus at its maximum in the closed phase and at its minimum in the open phase of the glottal cycle. It made it possible to compare the OFR signal to the EGG signal by simply superimposing the two signals (figure 4).

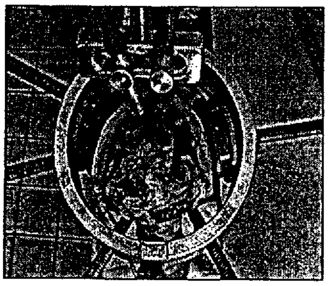


Figure 3 : Two OFR devices.

We then proceeded to measure the frequencies obtained from the 7 excised pork larynges, each of them undergoing 3 different flows (0,6 l/s, 0,7 l/s, 0,8 l/s). In fact, we recorded the EGG and OFR waves for several flows. From the lot performed for each larynx we picked the three in which the recording quality of the signal was the best and presented the fewest artefacts. We then compared the fundamental frequency shown by the EGG and the OFR for each larynx under each chosen situation.

	Difference (Hz)	% of difference
Mean difference between Fo EGG and Fo OFR	0,27	0,132
Standard deviation	0,59	0,22

Table 1: Comparison between the fundamental frequencies measured thanks to the EGG and the OFR.

The use of the laser beam device makes it possible to measure the glottal vibration. The spectral analysis of both types of signals also confirmed their correlation (figure 5). By using two separate OFR, we can propose to analyse the vibration of both the vocal folds simultaneously but separately.

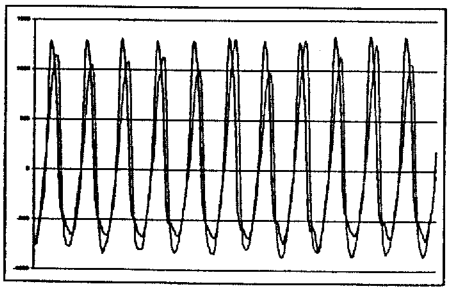


Figure 4 : Superimposition of the EGG signal and of the OFR signal.

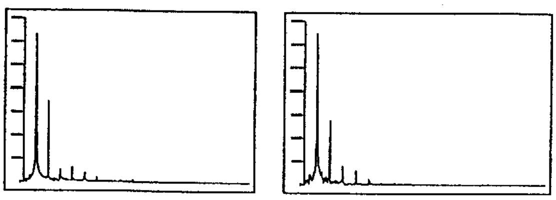


Figure 5 (left : EGG, right : OFR) : spectral analysis.

Experiment # 2 :

We then proceeded to use two identical OFR devices, calibrated beforehand to get the same response wave, and to analyse the emission of excised pork larynges presenting a tension asymmetry. Each opto-reflectometer emitted a light ray beam on a vocal fold mucous membrane. The study of the recorded waves made it possible to find a synchronisation between the vocal folds, which appears in the superimposition of the waves (figure 6) after an initial phase in which each vocal fold presents different vibratory characteristics (figure 7). This synchronisation cannot occur at random and confirms the notion of coupling.

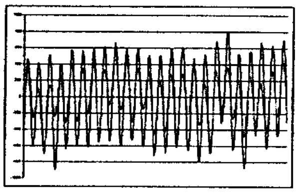


Figure 6

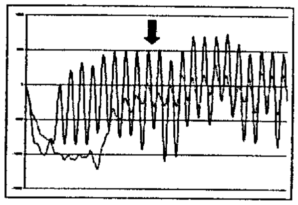
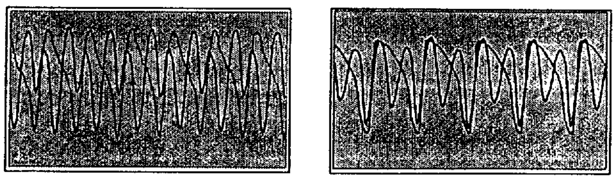


Figure 7
Arrow shows the beginning of the synchronization

In some cases, episodes of "period doubling" of one of the vocal folds were obtained, when the asymmetry was great enough. In fact, this phenomenon corresponded to vocal folds with very different vibratory characteristics, one of the vocal folds presenting a vibration which was about the double frequency of the other. During the vibration, there were times during which the closing phases coincided, permitting, so to speak, the re-synchronisation of the folds. An occurrence of this phenomenon is shown in figure 8. At the beginning of the vibratory cycle, they coincide. Then, one of them tends to its closing position, whereas the second is still in the opening phase. The first then resumes an opening position when the second gradually tends to the closing position. During the last stage of the vibratory cycle, both vocal folds reach the same point of the closing phase. In fact it appears that one of the vocal folds does not yield to coupling and presents a stage in which it vibrates freely in relation to the second. It however joins the other vocal fold's vibratory mode of thanks to coupling. The same case appears in figure 9.



Figures 8 and 9 : Episodes of period doubling of one of the vocal folds.

The simultaneous interpretation of the OFR and the EGG waves shows EGG cycles in which the vocal fold synchronisation is not obtained (figure 10). It can be thought that the vocal fold whose vibratory wave is closest to the EGG wave seems to be the one whose vibratory mode is master for the detection of the glottic vibration. A study of the characteristics of the EGG signal as compared to the OFR wave is being undertaken to find out if, with an appropriate coefficient (coupling coefficient) the EGG signal might be obtained by combining the separate OFR waves according to the diagram suggested by Steinecke [Steinecke-95] on mathematical modelisations of the glottal vibration.

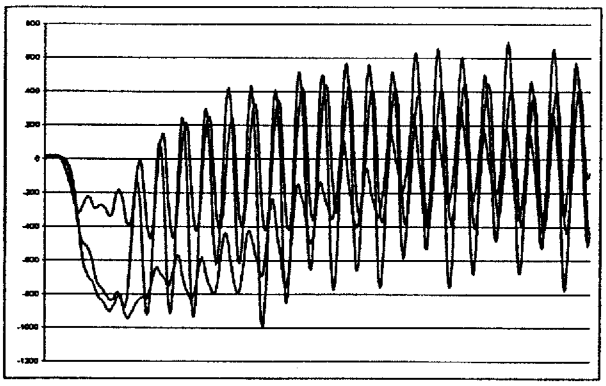


Figure 10 : superimposition of the 2 OFR waves and of the EGG signal during the vocal onset

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