BLOOD OXYGENATION VS CRY IN PRETERM NEWBORN INFANTS

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Abstract: **Crying is a physiological action made by the infant to communicate and to draw attention. However, especially for a premature infant, this action requires great effort, which may even have an adverse impact on blood oxygenation. In this work we present first results concerning the evaluation of the distress occurring during cry, as related to possible decrease of cerebral oxygenation. A recording system has been developed, that allows synchronised monitoring of the central blood oxygenation and the audio recording of newborn infant's cry.**
A multi-purpose voice analysis tool (BioVoice), characterised by high resolution and tracking capabilities, is applied to new-born infant cries. For these signals, the tool provides also detailed statistics (min and max cry length, maximum energy, etc.), to help diagnosis. BioVoice is completely automatic, working with any sampling frequency and F_0, and does not need any manual setting of whatever option to be made by the user, thus being easily accessible also to non-experts.
Some examples are reported, concerning preterm new-born infants.
Keywords: newborn cry, blood oxygenation, voice analysis.

I. INTRODUCTION

Infant monitoring in neonatal critical care units is a common procedure in clinical practice. The cerebral blood flow in preterm and full-term newborn infants has been studied extensively, as newborn infants have an impaired auto regulation of the cerebral blood flow. Irregularities in the blood flow and pressure may adversely influence the growth of the child. Some studies have been performed in order to evaluate the blood flow and oxygenation in the newborn by Near Infrared Spectroscopy (NIRS), also as linked to other techniques [1]-[6].
In newborn infants, one of the most common events that may affect the respiratory flow is related to cry. Crying is a physiological action made by the infant to communicate and to draw attention. It involves coordinated actions of many muscles of abdomen, chest, throat and head. This apparatus is obviously controlled by the central nervous system (CNS).
Specifically, for a premature infant, crying requires great effort, which may cause distress. Also, preterm and/or low-birth-weight infants often present respiratory problems, ranging from insufficient ventilation to apnoea, and hence crying implies an effort which may have an adverse impact on blood oxygenation. Acoustic analysis of new-born infant cry signals is thus of importance, as a precocious aid to clinical evaluation of several CNS pathologies. Being easy to perform, cheap and completely non-invasive, it can be successfully applied in many circumstances [8]-[14]. A robust high-resolution software tool is proposed here, to track main acoustic parameters of newborn cry.
Possible relationship among some cry parameters and distress is investigated, as related to the decrease of cerebral oxygenation. To this aim, a new recording system has been developed, that allows synchronised monitoring of the central blood oxygenation and the audio recording of infant's cry emissions.
Preliminary results on a data set of 9 preterm infants indicate that in some cases the effort in crying is associated with a noticeably decrease in the oxygenation level during a cry episode.

II. METHODS

Central blood saturation has been measured with NIRS device (somasensors by INVOS 5100C Somanetics Corp.), that allows for acquiring 1 sample each 5s. A unidirectional microphone (Shure SM58), equipped with US-144 portable audio / MIDI interface (96 kHz / 24-bit recording) has been used to record cry emissions. Audio recording was performed using a multimedia notebook which acquired a single channel audio track, with a sampling rate of 44 kHz and 16 bit resolution.
Specific software has been designed and implemented, to allow synchronization with the NIRS device, using a digital output linking the laptop with the input of the NIRS instrument. The software performs a simultaneous recording of the audio channel trough the US-144 board and of the NIRS signal using a RS-232 connection. The NIRS signal is composed of up to four independent channels, each made up of two data, one containing the relative saturation of oxygen, and the other representing the quality of the signal, which can be useful to detect possible artifacts related to patient movement or poor contact of the sensor with the patient.
Due to different sampling rates for NIRS and for audio signals, the range for audio analysis is adjusted to the nearest second in the corresponding NIRS recording.
As for audio signal analysis, a multi-purpose voice

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analysis tool (BioVoice) allows for new-born infant cry analysis, performing F_0, noise and resonance frequencies tracking, on signal frames of varying length (even few ms), adaptively tailored to varying signal characteristics. Details are given below.

Fundamental frequency F_0 - Newborn infant cry is characterised by high fundamental frequency F_0 (>300Hz), with abrupt changes and voiced/unvoiced features of very short duration within a single utterance. For analysis, the signal is divided into short frames, whose length adaptively varies according to varying signal characteristics: the higher the F_0 the shorter the frame length (kept fixed to 3 pitch periods). A voiced/unvoiced (V/UV) separation algorithm is implemented, to avoid F_0 estimation on signal frames that have no harmonic content, where misleading results could be obtained [7].

F_0 tracking is achieved by means of a two-step procedure, based on well-established results: the AMDF approach is applied to a wavelet-smoothed SIFT estimation of F_0, with optimised and varying adaptive filter order [8]-[10].

Resonance frequencies F_i - Even if vowel frequencies cannot be found in newborn cry, RFs reflect important acoustical characteristics of the vocal tract of the infant. Robust and high-resolution RF estimation is implemented, based on parametric AutoRegressive (AR) PSD evaluation. The AR model order p is automatically selected by the program, according to the relationship: $p=2LF_s/c$, where: F_s=sampling frequency, L=vocal tract length, and c=sound speed [9].

The BioVoice tool is provided with a user-friendly interface (Fig. 1) that allows selecting age, sex and type of vocal emission for each patient, performing computations without any other requirement. The tool automatically adjusts internal settings for optimal frame length, frequency range of analysis and plots. Specifically, the interface allows for:

– selecting data (.wav files);
– choosing the voice type, ranging from high-pitched new-born and singers voices to adult voices: the overall allowed F_0 range is $40Hz<F_0<1300Hz$;
– selecting the kind of analysis: single audio file or two files (for comparison purposes).

A notice is added concerning computer time required: for long files (>5s) and high sampling frequency (>40 kHz) the total time could approach 5min in total. A moving bar shows the residual time during computations.

A number of ad hoc plots and tables is displayed and saved in printable format, for a visual comparison of results. Specifically, for infant cry, F_0, V/UV frames, spectrogram, resonance frequencies are plotted, all in coloured map. Some tables summarise mean, std, max, min values for F_0 and F_1-F_3, as well as cry length and the corresponding maximum energy. These parameters are in fact considered among the most meaningful in newborn cry analysis [8]-[12].

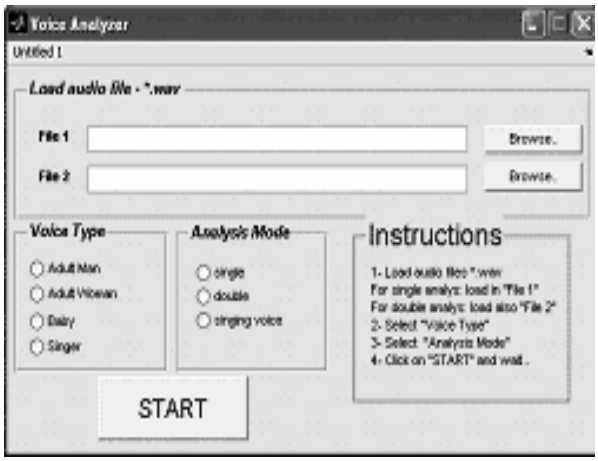


Figure 1 – The user interface for acoustic analysis

III RESULTS

Infants were selected by physicians among patients at the Critical Care Unit of the Children Hospital A.Meyer, in Firenze, Italy. The analysis has been carried out on a group of 9 preterm infants, having a pregnancy period ranging from 23 to 38 weeks and a weight at birth between 590g and 3020g. No relevant pathology was found among the analysed infants. An example is reported, concerning a newborn infant with pregnancy period of 38 weeks and a birth weight of 3020g. The birth was spontaneous. A suspected congenital cardiopathy has been pointed out by clinicians.

From our previous studies, the effect of crying seems much larger on central blood saturation than on peripheral saturation. Moreover, tracking the saturation level pointed out an increase of saturation after the episode, which means that the nervous system tries to compensate the loss of oxygen due to crying [14].

The example reported, though relative to an almost full-term newborn, allows pointing out possible distress due to crying, as evidenced by some voice parameters (mainly cry length, F0 melody and RFs), corresponding to a drop in oxygenation levels.

For printing reasons, we report here only a subset of the available figures, in a grey scale.

Figure 2 shows the plot of the NIRS values (% as referred to saturation) for about 27min of recording, extracted form a longer period. Actually, the new tool allows for simultaneous recording of both NIRS and cry on a range of several hours.

As shown in the figure, a remarkable decrease of RO2 occurs around the time instants 0:08:35, 0:15:35 and in the interval 0:21.15-0:24:15, all corresponding to cry episodes, automatically marked by the software. Specifically, the interval 0:23:01-0:23:04 is considered here, and indicated by the arrow in Fig.2. Fig. 3 shows the V/UV parts of the cry episode, as found by the BioVoice tool. An UV segment was found in the range (1.58s-2.3s).

Table 1 reports the information about V/UV segments of the cry that could be of relevance for diagnosis.

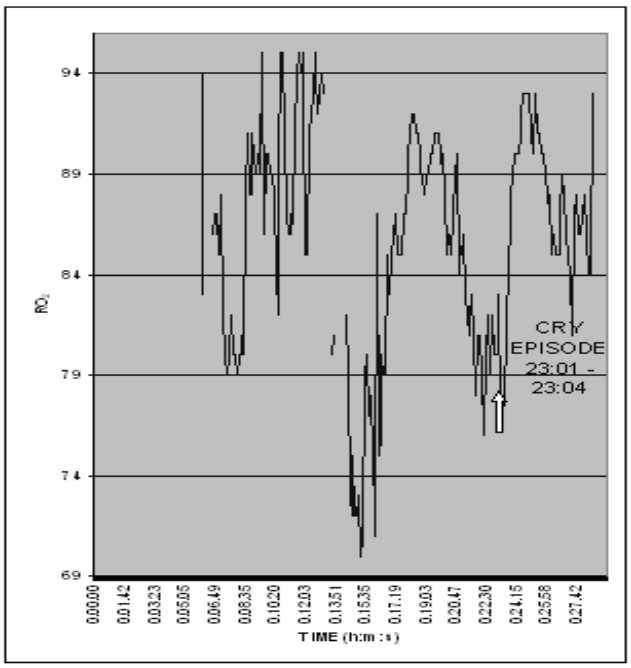


Figure 2 – NIRS tracking with a marker for the cry episode in the interval 0:23:01-0:23:04

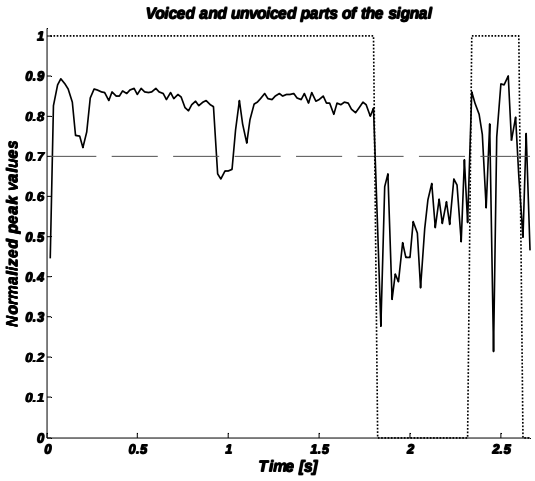


Figure 3 – V/UV parts of the cry signal

TABLE 1 – V/UV characteristics

*VOICED PARTS

Star	End	Total
0.020s	1.820s	1.800s
2.340s	2.620s	0.280s

Max duration = 1.800s ; Min duration = 0.280s ; Mean duration = 1.040s

Total duration = 2.080s ; Number Parts = 2

Fig. 4 shows F_0 tracking, performed on the voiced parts of the signal only. F_0 is characterized by almost regular rising and falling shape, typical of the newborn infant cry melody. However, notice shorter time duration of each utterance (<1s), and lower F0 mean value, as compared to healthy cry [9]-[14].

In Fig. 5, the spectrogram with the tracking of the first three RFs superimposed is displayed. Notice the almost irregular shape for the RFs, the 3rd one being almost unrecoverable. Moreover, RFs are set to lower frequencies with respect to the healthy cry [9]-[14], as shown in Table 2, where the maximum energy of the signal is also reported. This could be due to the still incomplete vocal tract structure in the newborn, as well as to his/her possible CNS dysfunction.

The analysis also suggests that physiological compensation systems are not able to maintain the level of blood oxygenation during crying episodes.

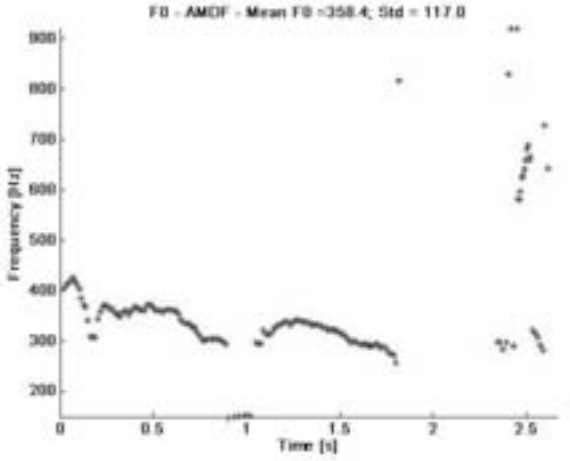


Figure 4 – Fundamental frequency tracking

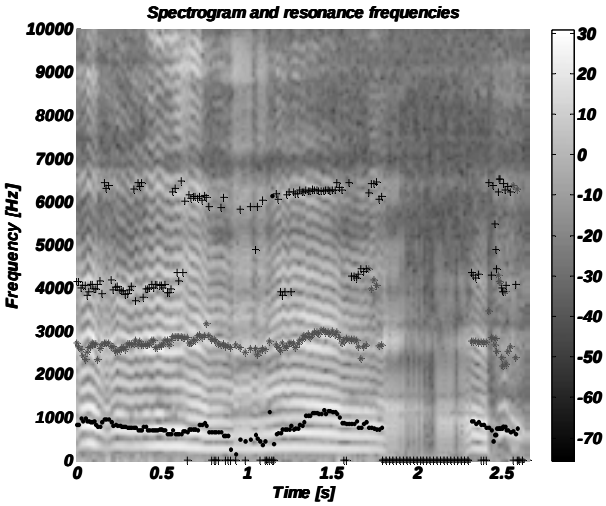
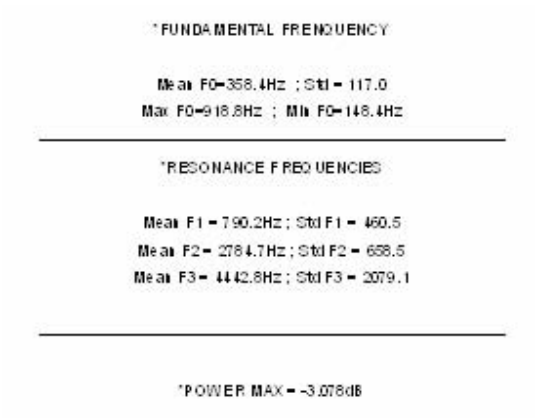


Figure 5 – Spectrogram and resonance frequencies F1-F3

TABLE 2 – Summary of main statistics of F_0 and for RFs F1-F3, along with maximum power.



IV FINAL REMARKS

First results have been presented, concerning the evaluation of the distress occurring during cry, as related to possible decrease of cerebral oxygenation. To this aim, the relationship among some cry parameters and the decrease of cerebral oxygenation is investigated. A synchronisation system has been developed, that allows simultaneously acquiring the central blood oxygenation and the audio recording of infant's cry emissions. A new robust tool for new-born infant cry analysis is presented. Being completely automatic, the proposed software can be successfully used in a wide range of applications, also in case of highly varying signals, without requiring any manual setting to be made by the user.

Preliminary results on a data set of 9 preterm infants indicate that in some cases the effort in crying is associated with a noticeably decrease in the oxygenation level during a cry episode and to abnormal cry parameters.

Future work will concern adding more parameters for audio signals analysis, as well as further optimising existing ones. A data base is under construction, in co-operation with the Children Hospital A. Meyer, Firenze, Italy, with the aim of searching for possible correlations also among other signals, such as ECG and peripherical blood oxygenation, as a non-invasive aid to diagnosis.

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