Abstract: With the increased survival of very preterm infants, there is a growing concern for their developmental outcomes. Infant cry characteristics reflect the development and possibly the integrity of the central nervous system. This study evaluates the distress occurring during cry in preterm newborn infants, as related to decrease of central blood oxygenation. A recording system has been developed, that allows synchronised, non-invasive monitoring of blood oxygenation and audio recordings of newborn infant’s cry. In the present work we evaluate the changes in the oxygen saturation levels in the central nervous system in full term and in preterm infants, and analyze possible differences between the two groups of patients. The method has been applied to preterm and full term newborns at the Intensive Care Unit, A.Meyer Children Hospital, Firenze, Italy and at Nuovo Ospedale S.Giovanni di Dio, Scandicci, Firenze, Italy. Results indicate that a similar decrease of central blood oxygenation occurs in both groups of patients, but the recovery time after the crying episode is more stable and faster in full term newborns than in preterm ones. Keywords: Oxygen saturation, preterm newborn, infant cry.

I. INTRODUCTION

With the increased survival of very preterm infants, there is a growing concern for their developmental and socio-emotional outcomes. Infant cry characteristics reflect the development and possibly the integrity of the central nervous system.

However, in preterm and/or low-birth-weight infants it could imply an effort which may have an adverse impact on blood oxygenation. In fact, preterm newborn infants have an impaired auto regulation of the cerebral blood flow [1-4]. Irregularities in the blood flow and pressure may adversely influence the development of the child [5-7]. Some studies have been performed to evaluate both cerebral and peripheral blood oxygenation in the newborn by Near InfraRed Spectroscopy (NIRS) and pulse oximetry, also as linked to other techniques [1-7].

Previous studies have shown that preterm infants and infants with neurological conditions have different cry characteristics when compared to healthy full-term infants. Research has been developed to study possible differences between full-term and preterm infants in their neuro-physiological maturity and the subsequent impact on their speech development [8]. Our previous results demonstrate that blood oxygenation level in preterm newborns is affected by stress caused by the effort required during crying [9-10]. These studies indicate that the distress effect of crying seems larger on central blood saturation than on peripheral saturation, hence here we will consider only central blood saturation as related to cry.

In this work, we extended previous studies to include a comparison of the results obtained in preterm and in full term infants.

II. METHODS

Monitoring has been performed by collecting data from two different sources: central blood saturation was measured with a NIRS device, and a microphone connected to a laptop has been used to record cry emissions.

A unidirectional microphone (Shure SM58), equipped with Tascam US-144 portable audio/MIDI interface (96 kHz/24-bit recording) has been used to record cry emissions. Audio recordings were stored on a multimedia laptop on a single channel audio track, with sampling rate Fs=44 kHz and 16 bit resolution.

Central blood saturation has been measured by means of a NIRS device (Somasensors by INVOS 5100C

Fig. 1: Experimental setup
Somanetics Corp.), with sampling rate of 0.6 samples/sec. 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, useful to detect possible artifacts related to patient movement or poor contact of the sensor with the patient.

Specific software has been designed and implemented to allow synchronization of the output of the two devices by means of a digital connection linking the laptop with the output of the NIRS device. The software implements simultaneous recording of the audio channel through the US-144 board and of the NIRS signal using a RS-232 connection. Moreover, the software allows for basic management of the patient database, allowing to record anamnesis data and to manage multiple recording sessions for the same patient. The overall setup used in the experiments is described in Fig. 1. Fig. 2 shows the block diagram of the whole recording and processing system.

All subjects were recorded in a quiet room, with low background noise and stable levels of illumination, according to the NIRS device requirements. Moreover, special care has been used to assure a good contact between sensors and patient’s skin thus avoiding artifacts caused by sudden movements.

Each recording lasts at least 15 min, in order to include several crying episodes, with a suitable amount of time both before and after each cry episode.

A preliminary analysis of the data indicates high variability of the baseline oxygenation level, both in full term and in preterm infants. The baseline oxygenation has been considered equal to the average oxygenation level during a convenient period of time when the child was awake and calm. On the whole test set we observed an oxygenation ranging from 65% to 85%. At the same time, the average variation in the oxygenation level during each recording is approximately of the same order of magnitude. Therefore, in order to assess the change in the oxygenation level during each recording, we considered the difference between the oxygenation level during and after the crying episode and the baseline oxygenation, measured in the time interval just before the episode.

As shown in our preliminary work [9], the recordings indicate a significant difference, in the preterm infants, of the oxygenation levels before the cry episode and during the episode. As it can be expected, the oxygenation level decreases during the cry, pointing out possible relationship between stress and cry (Fig. 3).

Starting from these results, the work has been extended to include a control group composed of full-term patients. The analysis has taken into account the recovery of oxygenation level when the crying episode is over and the infant is calm (either awake or sleeping).

Each recording has been manually analyzed, and three different crying episodes have been selected from it. Crying episodes have been selected of comparable length, and include a suitable period of rest (patient either sleeping or calm) both before and after the cry episode. Three parameters have been extracted from the oxygenation signal for each crying episode: the average saturation level before the episode (baseline level, $B$), the oxygenation level during the episode, and saturation after a reasonable recovery time. The baseline oxygenation level has been assumed equal to the average oxygenation over a period of 15 samples acquired before the beginning of cry. Then a “cry oxygenation” ($C$) has been evaluated using the average value over a time span of 18s.
approximately in the middle of the crying episode. A last reference value ($R$), related to the capability of the patient to recover the baseline oxygenation level, has been obtained by averaging the oxygenation level measured during 90s from the end of the cry episode.

Data have been analyzed in order to compare the oxygen saturation in basal condition (before the crying episode), in case of stress (during the episode), and the recovery capability of the newborn (90s after the episode). Comparison has been carried out, given the high differences in the absolute oxygenation levels, by comparing, on each episode, the variation of the oxygenation during and after the cry episode with the saturation before the episode:

$$\Delta C = C - B$$

$$\Delta O = R - B$$

We also evaluated the recovery of the oxygenation occurred during the recovery time:

$$\Delta R = R - C$$

The selected parameters have been evaluated separately on all episodes related to full term newborns and to preterm ones, and t-test has been applied to assess their statistical significance.

### III. RESULTS

The analysis has been carried out on a group of 20 preterm and/or low weight infants and 28 full term infants, having a pregnancy period ranging from 23 to 42 weeks and a weight at birth between 590g and 4250g, selected by physicians among patients at the Critical Care Unit of the Children Hospital A.Meyer, in Firenze, Italy and Nuovo Ospedale S.Giovanni di Dio, Scandicci, Firenze, Italy.

Full term newborns have been recorded a day after birth, while preterm newborns could be recorded only 20-30 days after birth, due to their long staying in the incubator.

Fig. 3 reports a sample extracted from the data set. In the upper part of the figure, the NIRS track is shown, while the bottom part of the figure shows the audio track acquired in the same period of time. The behavior shown in the figure is typical of full term newborns: during the cry episode, there is a clear decrease in the saturation level, which is promptly recovered when the crying episode is over.

We obtained about 150 cry episodes, which were analyzed by evaluating the difference between the values before, during, and after the cry episode using a paired t-test analysis. Results, summarized in Table 1, indicate there is a highly significant ($p<0.01$) difference in the oxygenation level before and during the cry episode, both in the full term and in the preterm groups. A different behavior can be noticed comparing the values measured during the cry episode and the values after the recovery time: in the full term group, the t-test indicates the presence of a highly significant difference, while in the preterm group the increase is less pronounced, and is not statistically significant. The same result is confirmed by the comparison of the saturation measured before the cry episode and after the recovery time. This difference is highly significant in the preterm group, indicating that the oxygenation after recovery is noticeably lower than before the crying episode, while in the full term group the difference is only marginally significant ($0.01 < p < 0.05$), suggesting that oxygenation has been recovered, although not completely.

### IV. CONCLUSION

The results of the experiments indicate that, both in the full term and in the preterm infants, a significant decrease of the oxygenation occurs during a cry episode. However, the two groups behave differently during the recovery time after the crying episode. Full term infants can recover almost completely the oxygenation levels before cry in less the 90s, while preterm infants need a longer period of time to achieve a full recovery of the oxygenation level.

### REFERENCES


