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Spectrum Analysis of Cry Sounds in Preterm and Full-Term Infants

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Abstract

Long-time average spectrum (LTAS) was used to analyze the cry phonations of 26 infants under four months old; 16 of them are full-term and the other 10 infants are preterm. The results of first spectral peak, mean spectral energy, spectral tilt, high frequency energy were used to compare the cry phonatory between full-term and preterm infants. In addition, cry duration and percent phonation is also compared. According to previous studies, full-term and preterm infants' crying behavior show significant differences because immature neurological development of preterm infants. Major findings in this study are: (1) There was no significant difference in unedited cry phonation across groups; (2) There was no significant difference in percent phonation across groups; (3) There was no significant difference in first spectral peak across groups, and no significant difference within groups could be found. However, full-term infants have higher first spectral peak than that of preterm infants; (4) There was no significant difference in mean spectral energy across groups, yet there was a significant main effect for partition; (5) There was no significant difference in spectral tilt across groups. Post hoc comparisons identified higher spectral tilt in P2 than in P3 in the full-term infants; (6) There was no significant difference in high frequency energy across groups. Significant differences were observed across partition, and in both groups, P1 had higher HFE than P3. The differences in the measures of crying behavior between full-term and preterm infants can help to estimate health condition of infants who are under 4 months old.

Keywords: Long-time average spectrum, Infant cry, Preterm infants

1. Introduction

Previous studies show that preterm infants are prone to immaturity of neurological development which leads to their sensitiveness toward pain stimulation, and the greater pain they suffer would reflect on crying behavior. If a set of distinctive measures can be identified, it might be possible to differentiate infant cries in the spectrum of normative behavior and cries due to organic pathology. The measures

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would be helpful for doctors and caregivers to identify if the unknown cries are caused by just infant colic or other more complicated factors. Long-time average spectrum (LTAS) of crying behavior were analyzed in two groups of newborn infants in this study. LTAS was used to analyze the infant's non-partitioned crying episode (NP), as well as the 3 equal-length partitions (P1, P2, P3). First spectral peak (FSP), mean spectral energy (MSE), spectral tilt (ST), and high frequency energy (HFE) were measured.

Colic strikes infants who are under four months old, and it makes the infants cry in the evening on a daily bases or at the moment of waking up (Lester, Boukydis, Gracia-Coll, & Hole, 1990). The cause of this pain is still unknown (Zeskind & Barr, 1997). Colic occurs when infants are around one month old and it often disappears without a reason when infants are older than three months (Clifford, 2002). It is a universal and commonly-seen phenomenon which is the cause for excessive cry behavior. Though previous studies have suggested that higher fundamental frequency and a larger percentage of dysphonation in crying behavior can be found in the pain cries of infants who suffer from colic, no standard acoustic features in cry vocalization of infants with colic was established (Zeskind & Barr, 1997). Long-time average spectrum might provide an option to see if there are any significant variations in the cries of infants with colic and those who are healthy from first spectral peak, mean spectral energy, spectral tilt, and high frequency energy.

Though infants are not able to talk, they can express their feelings and emotions through crying, facial expression, and body movements. Diseases are able to be discovered by some characteristics in crying behavior (Radhika, Chandralingam, Anjaneyulu, & Satyanarayana, 2012). For example, different pain stimuli would lead to different fundamental frequencies in infant cry vocalization (Radhika et al., 2012). If more specific characteristics are found in certain diseases, it would be more effective in prescribing and curing. Sometimes parents can differentiate why their babies cry by their various crying behavior (Soltis, 2004). As for the way of eliciting cries, Johnston, Stevens, Craig, & Grunau (1993) had proposed two different ways: the heel-stick procedure and injection. In this current study, injection was used as the only standard method of eliciting cries to avoid any nuances that might caused by the different types of pain stimuli. However, even though there are some scientific ways of detecting the pain intensity infants endure, the experience of pain is quite subjective and is not merely related to physiological but also psychological factors (Qiu, 2006). Moreover, since infants use crying to arouse caregivers' attention, it can be expected that infants' crying behavior differs with and without their caregivers around them (Green, Gustafson, Irwin, Kalinowski, & Wood, 1995). Usually, the responses from caregivers bring cry behaviors to a halt (Green et al., 1995). Thus, crying is regarded not only an independent behavior but also plays an important role in social interactions between infants and their caretakers (Green et al., 1995). Furthermore, crying is a way of drawing other people's attention to help infants get rid of the uncomfortable situation or meet their needs (LaGasse, Neal, & Lester, 2005).

Because of the immature development of nervous systems caused by premature birth, preterm infants' crying behavior is believed to reveal different characteristics from that of full-term infants whose nervous systems are comparatively well-developed (Goberman & Robb, 1999). Premature infants are reported to have higher *fo* in their cry phonation, and it might be due to the immature, shorter vocal folds (Johnston et al., 1993). Or as Zeskind (1983) stated that high-risk infants are not able to perfectly control their crying behavior and that they tend to react more intensely towards pain stimuli than low-risk infants. Infants react differently to the same stimulus pain whether they are healthy or born at risk. However, while some studies have shown that preterm infants are more sensitive to pain stimuli, others found that some premature infants have less intense reactions towards pain than normal infants (Qiu, 2006).

The main objective of this current study is to find out how the crying behavior between full-term and preterm infants differs from each other. The findings might help in detecting infants' health conditions. Moreover, if the differences of the crying behavior can be systematically characterized, the measurements can be further applied to identify features in neonate cries due to infant colic.

2. Method

2.1 Participants

Previous studies indicated that gender did not lead to significant differences in first spectral peak, mean spectral energy, spectral tilt, and high frequency energy (Goberman & Robb, 1999; Goberman, Johnson, Cannizzaro, & Robb, 2008). Therefore, gender was not controlled in this study. There were 26 infant participants; 16 were full-term infants and the other 10 were preterm infants. The infants were all under four months old for both full-term infants and preterm infants according to their gestational ages. All of the infants in this study were considered to have normal hearing according to interview with parents.

2.2 Data Collection

For data collection, TASCAM wave recorder and RODE uni-directinal microphone were used while recording the cry phonation of both preterm and full-term infants. The microphone was held near the infants' mouth. All infants were in the supine position while receiving the injection because acoustic properties (e.g. fundamental frequency) might be influenced by postures of infants (Lin & Green, 2007). Data were collected in the hospital. The cry phonation of both groups of infants was recorded during and after they receive the injection. The pain stimulus was the same in both groups of infants.

2.3 Acoustic Analysis

Based on Goberman and Robb (1999), a crying episode of infants was defined as the duration of the continuous crying activity, beginning with the first audible cry sound after the pain stimulus, and an episode was completed as soon as the infants stopped crying. The non-voiced parts of a crying episode were first edited out in the cry vocalization, making a “non-partitioned crying episode” (Goberman & Robb, 1999). In this current study, all the inspiratory cry was eliminated from pain stimulus, only the phonatory parts were analyzed. Then, a non-partitioned episode was divided into three partitions with the same length of durations (P1, P2, P3). P1, P2, P3 are regarded as the early, middle, and late sections of the crying episode, respectively, corresponding to the attack, cruise, and subdual phases of a crying episode as suggested by Truby and Lind (1965). First spectral peak, mean spectral energy, spectral tilt, and high frequency energy were measured. First spectral peak was identified as the first amplitude peak across the LTAS display. Mean spectral energy was measured with the mean amplitude value from 0 to 8000 Hz. Spectral tilt was the ratio of energy between 0-1000 Hz, and 1000-5000 Hz. High frequency energy was the sum of amplitudes from 5000 Hz to 8000 Hz.

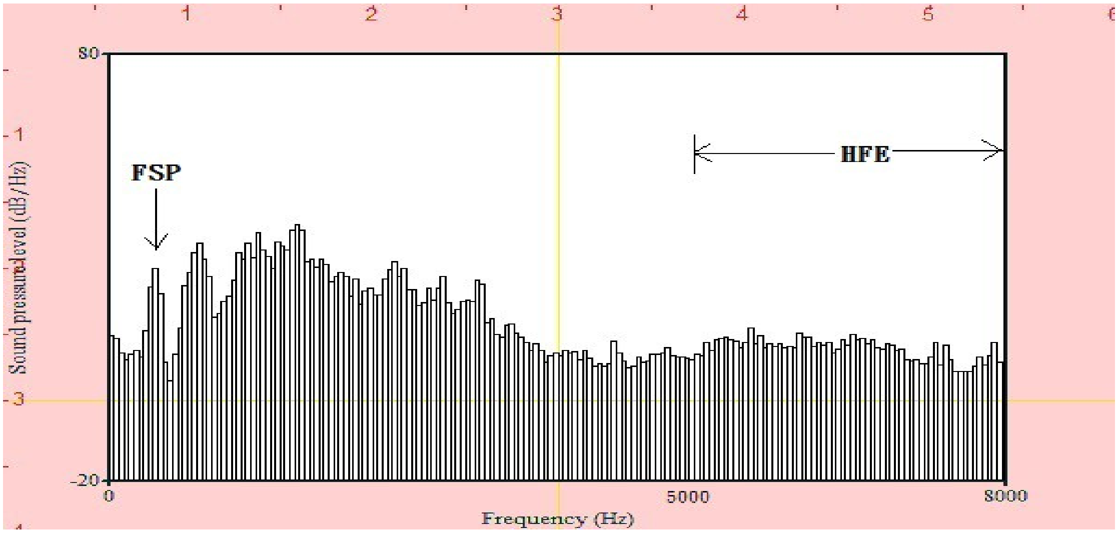

Figure 1. *Typical LTAS display showing the location of the first spectral peak (FSP) and high frequency energy (HFE) between 5000Hz and 8000Hz.*

3. Results & Discussion

3.1 Unedited Cry Duration

The average duration of crying episodes for the 16 full-term infants was 43.26s (SD=31.27), and for the 10 preterm infants was 36.21s (SD=30.93). Although full-term infants have longer average duration of crying episodes, there are no significant differences between the two groups, $t(24) = 0.48$, two-tailed, $p > .05$. The result is the same as that of Goberman and Robb (1999).

3.2 Percent Phonation

The percentage of cry phonation in a long-term non-partitioned, unedited crying episode was calculated. The average percent phonation across the crying episodes of the 16 full-term infants and the 10 preterm infants was 67% (SD=17.04) and 67% (SD=13.98) respectively. That is, 67% of the unedited crying episode contained cry phonation. Like what was found in Goberman and Robb (1999), there is no significant differences across groups in the percentage of cry phonation, $t(24) = 0.39$, two-tailed, $p > .05$.

3.3 First Spectral Peak (FSP)

The non-partitioned and partitioned first spectral peak values of the 16 full-term and the 10 preterm infants are listed in Table 1. A two-way analysis of variance (ANOVA) was performed to check if there were significant differences in FSP values between the two groups, and whether there was significant variation between the three equal-length cry durations (P1, P2, P3) in each group. The results indicated no significant term by partition interaction ($p > .05$), no significant main effect for term status ($p > .05$), and no significant main effect for partition ($p > .05$). Despite the fact that there were no significant differences in statistical tests, we found that full-term infants have higher non-partitioned FSP (182.07Hz) than that of preterm infants (130.44Hz). From overall observation, full-term infants demonstrated higher FSP in non-partitioned and the three partitioned episodes. Full-term and preterm infants displayed different trends of FSP in P1, P2, and P3.

While the infants were receiving injections, the sharp pain stimulated them and all the infants burst out crying. According to the previous studies (Johnston et al., 1993), preterm infants are expected to have higher FSP because preterm infants were thought to be more sensitive and would react more intensely to pain. Intensive crying behavior causes the increase of the subglottal pressure and the stiffness of the vocal folds. However, in this current study, the mean FSP of the full-term infants turned out to be higher than that of the preterm infants, in both the non-partitioned episode and the three equal-length episodes. Moreover, full-term infants' crying episode involved more distinct phases with decrease of FSP in P3. In preterm infants, FSP kept increasing from P1 to P3.

Table 1. *First spectral peak from the non-partitioned episodes (NP) and three partitioned crying episodes with equal length (P1, P2, P3) from the full-term and preterm groups of infants*

	FSP (Hz)				
Group		NP	P1	P2	P3
Full-term	M	182.07	135.88	184.79	149.46
	SD	139.06	113.24	142.45	119.31
Preterm	M	130.44	104.35	117.40	139.14
	SD	71.74	52.06	67.36	82.11

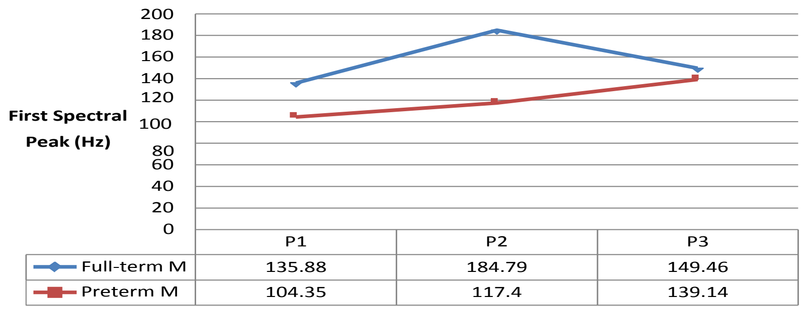

Figure 2. *First spectral peak of full-term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned crying episodes.)*

3.4 Mean Spectral Energy (MSE)

The mean spectral energy of non-partitioned and partitioned episodes of the 16 full-term and the 10 preterm infants are compared and listed in Table 2. A two-way analysis of variance (ANOVA) was performed to investigate if there was significant variation between the two groups, and whether there was significant variation between the three equal-length cry durations (P1, P2, P3) in each group. No significant term by partition interaction ($p > .05$) was found. There was a significant main effect for partition ($F = 6.47$, $p < .05$), yet there was no significant main effect for term, $p > .05$. One-way ANOVA tests were then performed in each group to check the changes in MSE (in P1, P2, P3). In full-term infants, P2 was significantly higher than P3. In preterm infants, P1 showed significantly higher energy than P2 and P3. The changes are illustrated in Figure 3.

Premature infants, compared to full-term infants, are reported to have higher *fo* in their cry phonation, and it might be due to tension of the larynx (Johnston et al., 1993). Greater pain stimulus makes laryngeal muscles tighten. In this current study, although no significant differences could be identified, preterm infants showed higher mean of MSE in non-partitioned episode and the three equidurational crying episodes. This shows that during the cry duration, the preterm infants' laryngeal muscles are tighter and they have a more severe reaction toward pain stimulus. The tighter laryngeal muscles suggest a more intense cry behavior. Moreover, a decrease in MSE could be observed in both full-term and preterm infants. This might suggest that the laryngeal muscles of both groups of infants loosen by phase, especially in preterm infants. There is sharper decrease of MSE from P1 to P3 in preterm infants.

Table 2. *Mean spectral energy from the non-partitioned episodes (NP) and three partitioned crying episodes with equal length (P1, P2, P3) from the full-term and preterm groups of infants*

		MSE (dB)			
Group		NP	P1	P2	P3
Full-term	M	19.368	19.982	19.507	14.323
	SD	9.627	9.523	11.158	11.266
Preterm	M	22.801	25.201	18.695	15.628
	SD	5.785	6.409	7.963	6.153

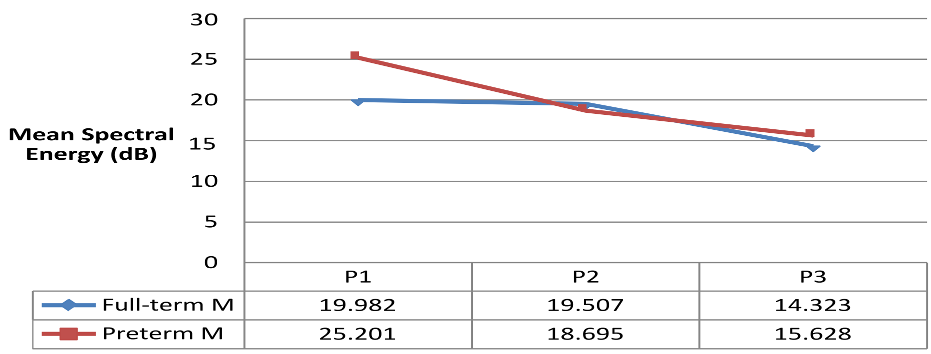

Figure 3. *Mean spectral energy of full-term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned crying episodes.)*

3.5 Spectral Tilt (ST)

The spectral tilt of non-partitioned and partitioned crying episodes of the two groups are compared and listed in Table 3. In order to identify if there was significant differences of ST between the two groups and whether there was significant variation between the three equal-length cry durations (P1, P2, P3) in each group, a two-way analysis of variance (ANOVA) was performed. There were no significant term by partition interaction ($p > .05$), no significant main effect for partition, and no significant main effect for term. To investigate changes in ST across partitions within each group, separate one-way ANOVA tests were performed for full-term and preterm infant groups. In full-term infants, post hoc comparisons identified a significantly higher ST for P2 than for P3 ($p < .05$), but no significant differences in ST across partitions for the preterm infants ($p > .05$). Overall, the full-term infants showed higher ST values at the onset of crying vocalization which decreased over time; whereas the preterm infants had lower ST values at the onset, which increased over time. The changes are demonstrated in Figure 4. For full-term infants, higher P2 than P3 in ST was observed. The ST of full-term infants does not increase over time as mentioned in Goberman and Robb (1999); on the contrary, the ST of full-term infants decreases over time. However, the increase of ST can be found in preterm infants.

The variation of ST of full-term and preterm infants is shown in table 3. Preterm infants have a slightly higher ST than full-term infants. ST refers to how quickly the amplitude of the harmonics decreases. A higher ST value was related to hypoadduction of the vocal folds (Mendoza, Munoz, & Naranjo, 1996). In this current study, hyperadduction is observed in the decrease ST of full-term infants, whereas, hypoadduction is observed in the increase ST of preterm infants.

Table 3. *Spectral tilt from the non-partitioned episodes (NP) and three partitioned crying episodes with equal length (P1, P2, P3) from the full-term and preterm groups of infants*

	ST				
Group		NP	P1	P2	P3
Full-term	M	1.381	2.242	1.423	1.118
	SD	0.307	3.207	0.387	0.300
Preterm	M	1.839	1.935	2.811	3.218
	SD	0.685	0.659	2.795	5.326

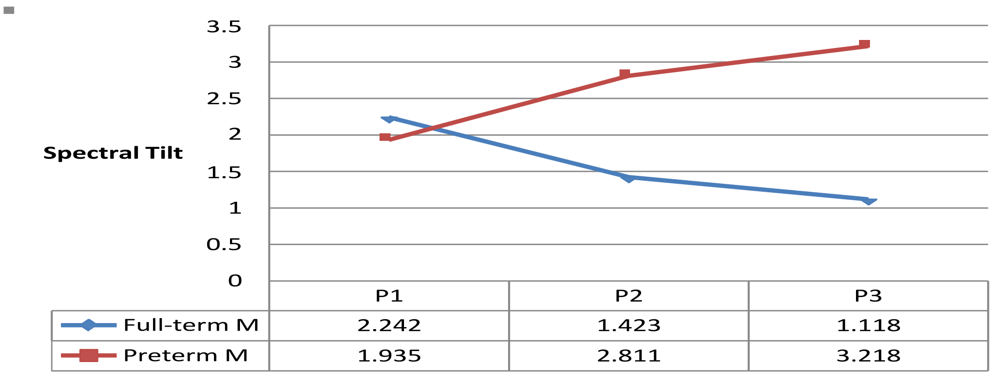

Figure 4*. Spectral tilt of full-term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned crying episodes.)*

3.6 High Frequency Energy (HFE)

The high frequency energy of non-partitioned and partitioned crying episodes of the two groups are compared and listed in Table 4. In order to identify if there was significant variation between the two groups, and whether there was significant variation between the three equal-length cry durations (P1, P2, P3) in each group, a two-way analysis of variance (ANOVA) was performed. No significant term by partition interaction (p > .05) was found. There was no main effect for term (p > .05), stating that there were no significant differences in HFE across the two groups. There was significant main effect for partitions (F = 8.29, p < .05). Furthermore, one-way ANOVA tests were performed to check changes in HFE across partition within each group. Significant differences in HFE were found across partition for both full-term infants (F = 3.91, $p < .05$) and for preterm infants (F = 4.57, $p < .05$). There was a significantly higher P1 in HFE than P3 in both infant groups ($p < .05$). In both groups, HFE decreases over time. The HFE of full-term infants does not change drastically over time; however, in preterm infants, the HFE shows a steep descent. The changes are demonstrated in Figure 5. HFE in both full-term infants and preterm infants decreases overtime. However, HFE of preterm infants has a wider range, crossing from 1225 to 1807, while the range HFE of full-term infants is about 300.

Table 4. *High frequency energy from the non-partitioned episodes (NP) and three partitioned crying episodes with equal length (P1, P2, P3) from the full-term and preterm groups of infants*

	HFE (dB)				
Group		NP	P1	P2	P3
Full-term	M	1672	1703	1543	1272
	SD	582	552	720	590
Preterm	M	1737	1807	1511	1227
	SD	469	514	546	509

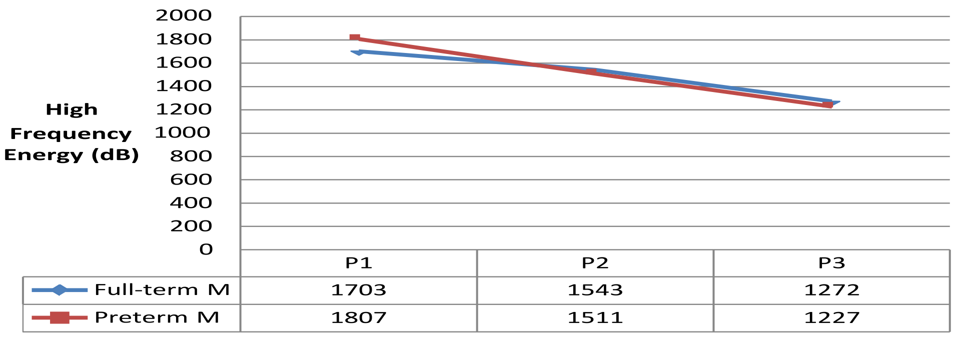

Figure 5*. High frequency energy of full-term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned crying episodes.)*

Some of the results in this current study did not match the findings in previous studies. The differences could be due to a few discerning variables. First, although the uni-directional microphone was used in this study, the environmental noises could not be completely controlled because the nurses were required to explain the procedure to the caregivers. Moreover, there was unavoidable overlapping from noises of other infants' cry sound. Once the infant's cry vocalization was overlapped with adults' voice or other infants' cry sound, the partition could no longer be used for further analysis. Second, all the infants receiving injections had their caregivers around them. This caused inevitable interaction between adults and infants, bringing unexpected nuances to the results. Both full-term and preterm infants might use more strength in crying, hoping their caretakers would alleviate their pain. Third, some caretakers tended to soothe the infants as soon as they started crying, which would significantly change the natural cry episode since the soothing and consolation from the caretakers might influence their cry phonation. The infants might feel safe and stopped crying. This might cause incomplete early, middle, and late sections in a cry episode, as Goberman and Robb (1999) mentioned. In further studies, the interaction of infants and their caregivers is probably one of the variables that should be strictly controlled. Moreover, video recording should be implemented in order to identify whether the infants stopped crying spontaneously or their attention was drawn by other things. Lacking complete three sections of cry episode might be the main reason of the discrepancy in the findings of this current study and previous studies.

4. Summary

Cry phonations of neonates from 16 full-term infants and 10 preterm infants were analyzed with long-time average spectrum (LTAS). Major findings were: (1) Full-term infants had higher first spectral peak than that of preterm infants; (2) Mean spectral energy in both groups of infants decreased over time; (3) Spectral tilt in full-term infants decreased, but increased in preterm infants over time; (4) High frequency energy in both full-term and preterm infants decreased over time. In further study, the environmental noise (e.g., from nurses, parents, and other infants around) should be controlled in order to acquire sufficient data to identify more systematic distinctions in the patterns of cry phonation between full-term and preterm infants.

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