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Quantitative Assessment of Cry in Term and Preterm Infants: Long-Time Average Spectrum Analysis

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Abstract

Long-time average spectrum (LTAS) was used to analyze the cry utterance of 26 infants under four months old; 16 of them were full-term and the other 10 infants were preterm. The results of first spectral peak (FSP), mean spectral energy (MSE), spectral tilt (ST), high frequency energy (HFE) were used to compare the cry production between term and preterm infants. In addition, cry duration and percent phonation were also compared. According to previous studies, cry production of term and preterm infants show significant differences because immature neurological development of preterm infants. Major findings in this study are: 1) no significant difference in unedited cry duration across groups; 2) no significant difference in percentage of cry utterance across groups; 3) no significant difference in FSP across groups, and higher FSP in term infants; 4) no significant difference in MSE across groups, and a decrease of MSE in both groups over time; 5) no significant difference in ST across groups, and a quicker reduction of energy with larger ST in preterm infants over time; 6) no significant difference in HFE across groups, and a significant decline of HFE over time in both groups. Systematic characterization of infant cry can help to estimate health condition of infants in order to provide appropriate care.

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 cry production. If a set of distinctive measures can be identified, it might be possible to differentiate infant cries due to organic pathology and cries in the spectrum of normative behavior, including infant colic which is frequently found in infants

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younger than 4 months of age. The measures can thus be used to support doctors' diagnosis to identify if the unknown cries are caused by just infant colic or other more complicated factors in order to provide appropriate care. Cry utterances were analyzed with long-time average spectrum (LTAS) in two groups of newborn infants in this study. Non-partitioned cry episode and the 3 equal-length partitions (P1, P2, P3) were analyzed. First spectral peak, mean spectral energy, spectral tilt, and high frequency energy, as well as unedited cry duration and percent phonation 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 *etal*., 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 suggested that higher fundamental frequency and a larger percentage of dysphonation in cry could be found in the pain cries of infants who suffered from colic, no standard acoustic features in cry utterance of infants with colic was established (Zeskind & Barr, 1997). Long-time average spectrum might provide an option to investigate if there are any significant characteristics in the cries of infants with colic.

Though infants are not able to talk, they can express their feelings and emotions through cry, facial expression, and body movement. Diseases are able to be discovered by some characteristics in cry production (Radhika *et al*., 2012). For example, different pain stimuli would lead to different fundamental frequencies in infant cry utterance (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 cry production (Soltis, 2004). As for the way of eliciting cries, Johnston, Stevens, Craig, and Grunau (1993) proposed two different ways: the heel-stick procedure and injection. In this current study, injection was used as the only standard method to elicit cry to avoid any nuances that might caused by the different types of pain stimuli. However, even though there are measures to quantify 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 cry to arouse caregivers' attention, it can be expected that infants' cry utterance differs with and without their caregivers around them (Greenet *et al*., 1995). Usually, the responses from caregivers bring cry behavior to a halt (Green *et al*., 1995). Cry is thus a way of drawing others' attention to help infants get rid of the uncomfortable situation or meet their needs (LaGasse *et al*., 2005). Therefore, cry is not only an independent behavior but also plays an important role in social interactions between infants and their caretakers (Green *et al*., 1995).

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

The main objective of this current study is to find out how the cry production between term and preterm infants differs from each other. The findings might help in detecting infants' health conditions. Moreover, if the difference of the cry utterance can be systematically characterized, the measurements can be further applied to identify features in neonate cry 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 *et al.*, 2008). Therefore, gender was not controlled in this study. There were 26 infant participants; 16 were term infants and the other 10 were preterm infants. The infants were all under four months old for both 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 collecting cry utterance of both preterm and term infants, TASCAM wave recorder and RODE uni-directional microphone were used in audio recording. The microphone was held near the infants' mouth. All infants were in the supine position while receiving the injection. This can also avoid influence of different postures in acoustic properties, for example, fundamental frequency (Lin & Green, 2007). The cry production of both groups of infants was recorded during and after they received the injection in the hospital. The pain stimulus was thus the same in both groups of infants.

2.3 Acoustic Analysis

The analysis in this current study was mainly based on Goberman and Robb (1999). A cry episode of infants was defined as the duration of the continuous cry utterance, beginning with the first audible cry utterance after the pain stimulus, and an episode was completed as soon as the infants stopped cry. The non-voiced parts of a cry episode were first edited out in the cry utterance, making a “non-partitioned cry episode” (Goberman & Robb, 1999). In this current study, the inspiratory cry was eliminated, and 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 cry episode, respectively, corresponding to the attack, cruise, and subdual phases of a cry episode as suggested by Truby and Lind (1965). Unedited cry duration, percent phonation, first spectral peak, mean spectral energy, spectral tilt, and high frequency energy were measured.

- First spectral peak (FSP): the first amplitude peak across the LTAS display.
- Mean spectral energy (MSE): the mean amplitude value from 0 to 8000 Hz. Average energy from 0 to 8000 Hz - first peak energy
- Spectral tilt (ST): the ratio of energy between 0-1000 Hz, and 1000-5000 Hz. Average energy from 1000 to 5000 Hz / average energy from 0 to1000 Hz
- High frequency energy (HFE): the sum of amplitudes from 5000 to 8000 Hz. Average energy from 5000 to 8000 Hz *(8000-5000) / the bandwidth of LTAS

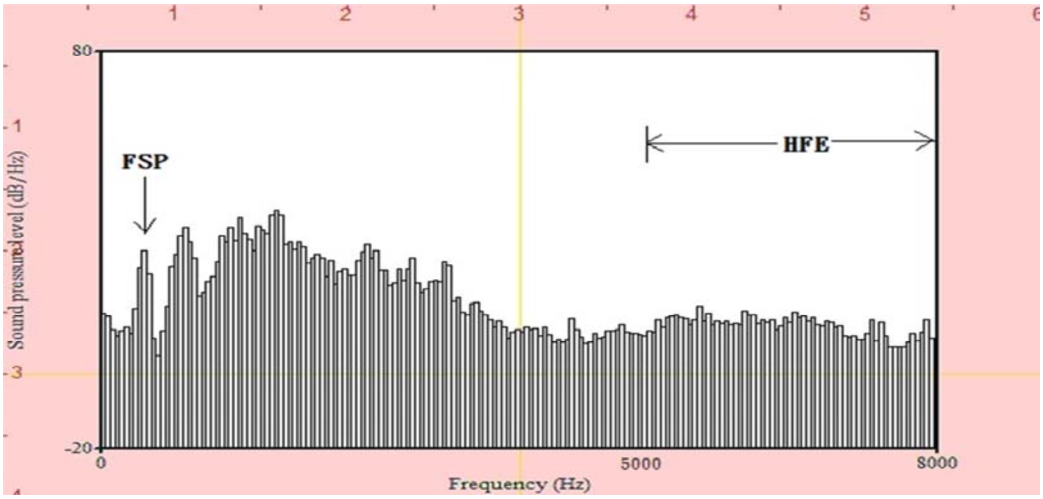

Figure 1. Typical LTAS display showing the location of the first spectral peak (FSP) and high frequency energy (HFE) between 5000Hz and 8000Hz.

3. Results & Discussion

3.1 Unedited Cry Duration

Cry duration reveals respiratory capability, and term infants were thus expected to have longer cry duration than preterm infants (Cacace *et al.*, 1995; Michelsson *et al.*, 1982; Thoden *et al.*, 1985). In this current study, the average duration of cry episodes for the 16 term infants was 42.27s (SD = 31.27s), and for the 10 preterm infants was 36.21s (SD = 30.93s). As expected, term infants had longer average duration of cry episodes. However, a t test was performed to examine whether cry duration differed statistically between these two groups, and indicated no significant difference between term and preterm infants, $t(24) = 0.48$, two-tailed, $p = 0.63$. The result is the same as that of Goberman and Robb (1999).

3.2 Percent Phonation

The amount of cries in term infants was reported to be larger than that in preterm infants (Cacace *et al.*, 1995; Michelsson *et al.*, 1982; Thoden *et al.*, 1985). The percentage of cry utterance in a long-term non-partitioned, unedited cry episode was calculated in this current study. However, no significant difference in percent phonation was found between these two groups in this current study. The average percent phonation across the cry episodes of the 16 term infants and the 10 preterm infants was 67.25% (SD = 17.04) and 67% (SD = 13.98) respectively. That is, 67% of the unedited cry episode contained cry production. Like what was found in Goberman and Robb (1999), there was no significant difference across groups in the percentage of cry utterance, $t(24) = 0.039$, two-tailed, $p = 0.97$.

3.3 First Spectral Peak (FSP)

The non-partitioned and partitioned first spectral peak values of the 16 term and the 10 preterm infants are listed in Table 1 and illustrated in Figure 2.

Table 1. First spectral peak from the non-partitioned episodes (NP) and three partitioned cry episodes with equal length (P1, P2, P3) in the term and preterm infants

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

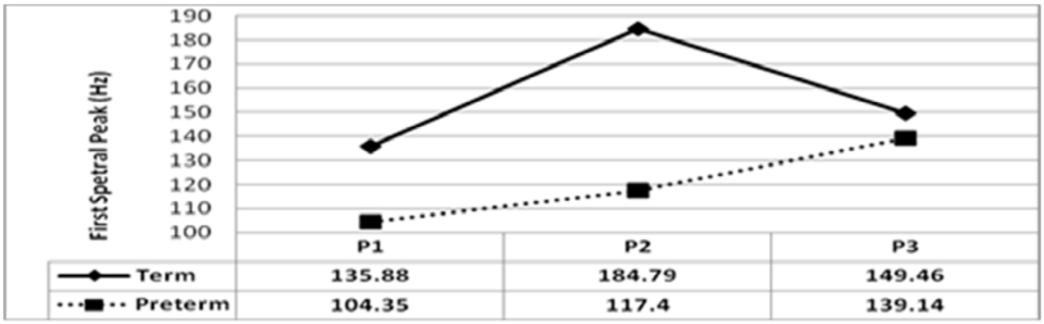

Figure 2. First spectral peak in term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned cry episodes.)

A two-way analysis of variance (ANOVA) was performed to calculate if there were significant differences in FSP values between the two groups (term factor), and whether there was significant variation between the three equal-length cry durations (P1, P2, P3) in each group (partition factor). The results indicated no significant term by partition interaction (p = 0.64), no significant main effect for term status (p = 0.17), and no significant main effect for partition (p = 0.56). Despite the fact that there was no significant difference in statistical tests, from overall observation, term infants demonstrated higher FSP in non-partitioned and the three partitioned episodes than that in preterm infants. Moreover, term and preterm infants displayed different trends of FSP in P1, P2, and P3. Term infants' cry episode involved more distinct phases with decrease of FSP in P3, whereas FSP kept increasing from P1 to P3 in preterm infants.

While the infants were receiving injections, the sharp pain stimulated them and all the infants burst out to cry. According to the previous studies (Johnston *et al*., 1993; Goberman & Robb, 1999), preterm infants were expected to have higher FSP because preterm infants were thought to be more sensitive and would react more intensely to pain. Intensive cry causes the increase of the subglottal pressure and the stiffness of the vocal folds. Premature infants, compared to term infants, were thus reported to have higher *fo* in their cry phonation due to tension of the larynx. However, this difference was not found in this current study. The mean FSP of the 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. Nevertheless, the difference between these two groups was not statistically significant as mentioned above. More data with controlled methodology in future studies can verify the discrepancy of the findings.

Another distinction between these two groups was the changes of FSP across three partitions. The trend of increase followed by decrease of FSP in term infants was not found in preterm infants. FSP kept increasing in preterm infants over time. This distinction was also found in Goberman and Robb (1999), in which FSP decreased significantly in term infants and there was no reduction of FSP in preterm infants.

3.4 Mean Spectral Energy (MSE)

The mean spectral energy values of non-partitioned and partitioned episodes of the 16 term and the 10 preterm infants are shown in Table 2 and Figure 3.

Table 2. Mean spectral energy from the non-partitioned episodes (NP) and three partitioned cry episodes with equal length (P1, P2, P3) in the term and preterm infants

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

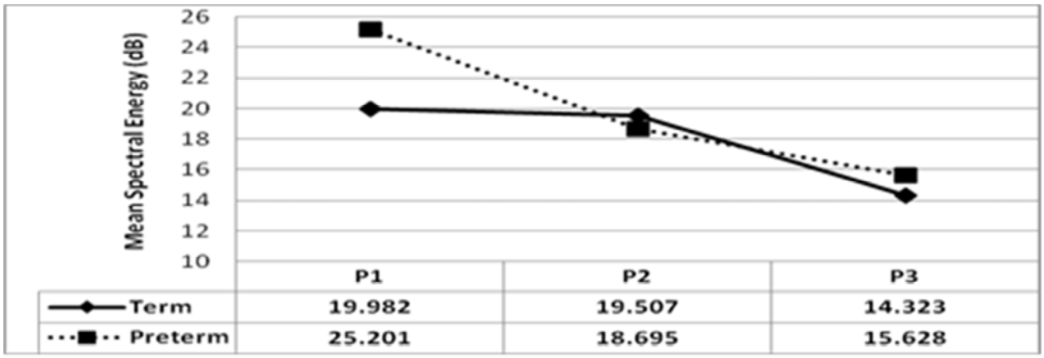

Figure 3. Mean spectral energy in term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned cry episodes.)

A two-way analysis of variance (ANOVA) was performed to investigate if there were significant differences between term and preterm infants (term factor), as well as across P1, P2, and P3 (partition factor) in each group. The results indicated no significant term by partition interaction (p = 0.36). There was a significant main effect for partition (F = 6.47, p = 0.003), yet there was no significant main effect for term, p = 0.52. One-way ANOVA tests were then performed in each group to check the changes of MSE in P1, P2, and P3. In term infants, P2 was significantly higher than P3 (p = 0.029). In preterm infants, P1 showed significantly higher energy than P2 (p =0.042) and P3 (p = 0.012).

MSE refers to the average energy in the frequency range of 0-8000 Hz, which was indicated to correspond to tension of the laryngeal musculature (Fuller & Horii, 1988). In this current study, although no significant difference could be identified, preterm infants showed higher MSE in non-partitioned episode and the three equidurational cry episodes. This shows that during the cry duration, the preterm infants' laryngeal muscles were tighter and they had a more severe reaction toward pain stimulus. The tighter laryngeal muscles suggested a more intense cry production. This finding was also indicated in Goberman and Robb (1999). Moreover, a decrease of MSE over time could be observed in both term and preterm infants. This might suggest that the laryngeal muscles of both groups of infants loosened by phase, especially in preterm infants. There was a sharper decrease of MSE from P1 to P3 in preterm infants. The trend seemed to correspond to the distinct phases in a cry episode indicated in Truby and Lind (1965) with the attack phase (high amplitude) and the cruising phase followed by the subdual phase (the lowest period of stress).

3.5 Spectral Tilt (ST)

The spectral tilt values of non-partitioned and partitioned cry episodes of the two groups are listed in Table 3 and displayed in Figure 4.

Table 3. Spectral tilt from the non-partitioned episodes (NP) and three partitioned cry episodes with equal length (P1, P2, P3) in the term and preterm infants

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

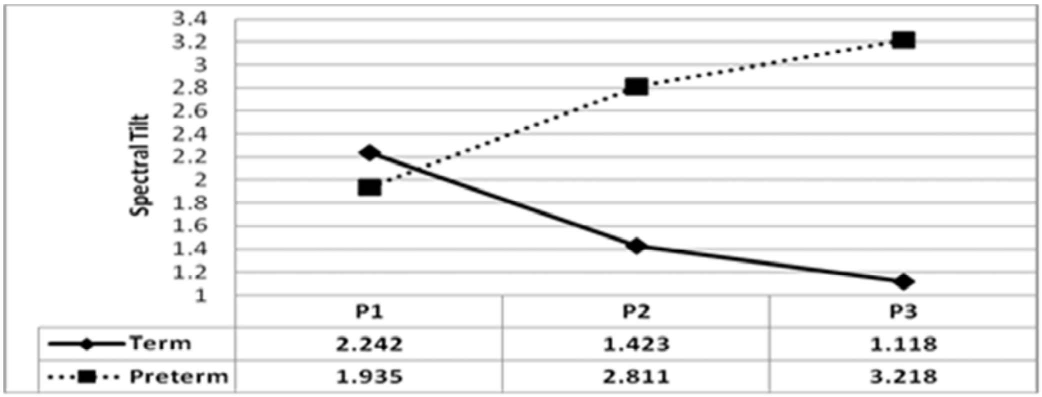

Figure 4. Spectral tilt in term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned cry episodes.)

In order to evaluate if there were significant differences of ST between the two groups and whether there were significant variations between the three equal-length cry durations (P1, P2, P3) in each group, a two-way analysis of variance (ANOVA) was performed. There was no significant term by partition interaction ($p = 0.223$), no significant main effect for partition ($p = 0.994$), and no significant main effect for term ($p = 0.123$). To investigate changes in ST across partitions within each group, separate one-way ANOVA tests were performed for term and preterm infant groups. In term infants, post hoc comparisons identified a significantly higher ST in P2 than in P3 ($p = 0.003$), but no significant difference in ST across partitions in the preterm infants.

Spectral tilt measures the ratio of low frequency energy and high frequency energy, revealing how quickly the energy declines over time. The quicker the decline is, the larger the ratio. Overall, the term infants showed higher ST values at the onset of cry production which decreased across partitions, whereas the preterm infants had lower ST values at the onset, which increased over time. That is, there was a quicker reduction of energy across partitions in preterm infants. The ST of term infants did not increase over time as mentioned in Goberman and Robb (1999), on the contrary, the increase of ST was found in preterm infants. A higher ST value was reported to be related to hypoadduction of the vocal folds, and a lower ST reflects a hyperadduction of the vocal folds (Mendoza *et al.*, 1996). In this current study, hyperadduction was observed in the decrease of ST in term infants, whereas hypoadduction was observed in the increase of ST in preterm infants.

3.6 High Frequency Energy (HFE)

The high frequency energy values of non-partitioned and partitioned cry episodes of the two groups are listed in Table 4 and illustrated in Figure 5.

Table 4. High frequency energy from the non-partitioned episodes (NP) and three partitioned cry episodes with equal length (P1, P2, P3) in the term and preterm infants

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

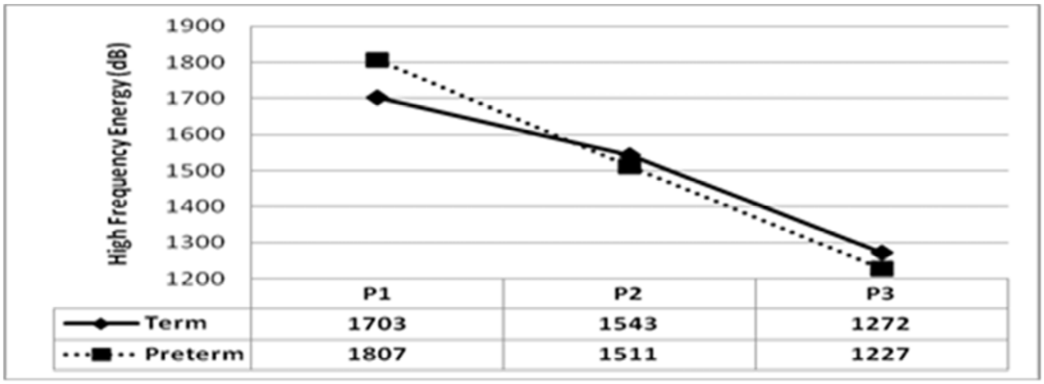

Figure 5. High frequency energy in term and preterm infants over time (P1, P2, and P3 are three equal-length partitioned cry episodes.)

In order to identify if there was significant variation of HFE between term and preterm infants, and whether there were significant variations 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 = 0.805) was found. Like in Goberman and Robb (1999), there was no main effect for term (p = 0.962). That is, there was no significant difference in HFE across the two groups. There was significant main effect for partitions (F = 8.29, p = 0.001). One-way ANOVA tests were then performed to check changes in HFE across partitions within each group. Significant differences in HFE were found across partitions for both term infants (F = 3.91, p = 0.031) and for preterm infants (F = 4.57, p = 0.025). There was a significantly higher P1 in HFE than P3 in both infant groups (p = 0.029 in term infants, and p = 0.02 in preterm infants). In both groups, HFE decreased over time. The HFE of term infants did not change drastically over time; however, in preterm infants, the HFE showed a steep descent, crossing from 1807 to 1227.

HFE measures the energy in the range of 5000-8000 Hz, which was indicated to be related to the noise elements in phonation (e.g., irregular cry utterance). It was reported that dysphonation in infant cry was very likely related to neurological disorders (Mende, Herzel, & Wermke, 1990). However, no significant difference of HFE between groups was found in this current study. Further studies with more data from both term and preterm infants might verify the correspondence of HFE and its physiological bases.

4. Summary and Suggestion for Future Studies

Cry productions of 16 term infants and 10 preterm infants under 4 months of age were analyzed with long-time average spectrum (LTAS). Major findings were:

1. There was no significant difference between term and preterm infants in cry duration. However, term infants had longer overall cry duration, which corresponded to better

respiratory capability to support phonation;

2. There was no significant difference across groups in the percentage of cry utterance although previous studies indicated that the amount of cries in term infants was larger than that in preterm infants;
3. No significant variation was found between these two groups in FSP. Term infants showed overall higher FSP, which is different from previous findings. Moreover, FSP in term infants involved more distinct phases across three partitions, declining toward the end of cry episode;
4. There was no significant difference of MSE between term and preterm infants. Overall, preterm infants showed higher MSE, which corresponded to tighter laryngeal muscle and intense cry production. A decrease of MSE was found in both groups over time;
5. No significant variation was found between these two groups in ST. There was a quicker reduction of energy with larger ST in preterm infants over time, which revealed hypoadduction of the vocal folds;
6. There was no significant difference in HFE between two groups, and there was a significant decline of HFE over time in both term and preterm infants.

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 cry from other infants. Once infant cry overlapped with adults' voice or cry from other infants, the partitions could no longer be used for further analysis. Second, all the infants receiving injections had their caregivers around. Both term and preterm infants might use more strength in cry, hoping their caretakers would alleviate their pain. This caused inevitable interaction between adults and infants, bringing unexpected disturbance to the results. Third, some caretakers tended to soothe the infants as soon as they started to cry, which would significantly change the natural cry episode since the soothing and consolation from the caretakers might influence their cry production. 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 environmental noise (e.g., from nurses, parents, and other infants around) should be controlled. Moreover, video recording should be implemented in order to identify whether the infants stopped crying spontaneously or their attention was drawn by things around. By controlling disturbance, future study can acquire sufficient data to identify systematic distinction in the pattern of cry production between term and preterm infants. Furthermore, LTAS analysis utilized in this study for cry analysis can be automatically processed and more features can be incorporated in the analysis in future studies.

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