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Twenty-Five Years of Scandinavian Cry Research

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1. SCANDINAVIAN CRY RESEARCH

1.1. Cry Studies in Scandinavia

The study of crying can be dealt with from many different perspectives: anatomical, physiological, psychological, phonetic, and pediatric. During the last two decades, the cry has also been an important factor in studies of mother–child interaction.

The first studies on infant cries were from the end of the last century. They were mainly based on auditory identification of the cry and its characteristics. Progress in cry research was maintained by the development of equipment for permanent recording of sound, from the graphophone and the gramophone almost a hundred years ago, to the development of tape recorders in the 1920s and the sound spectrograph

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in the 1940s. Now in the 1980s, computer analysis of various cry characteristics might become the most profitable mode to develop cry research for different disciplines.

As many other pediatricians before, one of the authors (Wasz-Höckert) had also been interested in the cry of newborns. Cries were demonstrated at the International Pediatric Congress in Montreal, 1959, by Karelitz from a tape with normal and Down's syndrome babies. By systematically employing the sound spectrographic method, cry research became an objective science in Finland in 1960. Through the research methods used in biology, Wasz-Höckert became familiar with the sonograph used at the Institute of Phonetics at the University of Helsinki. The first preliminary report by the original members of the cry research group was published in 1962 (Wasz-Höckert, Vuorenkoski, Valanne, & Michelsson). Another of the first reports (Wasz-Höckert, Valanne, Vuorenkoski, Michelsson, & Sovijarvi, 1963) dealt with four types of infant vocalization: the first birth cry, the hunger cry, the pain cry, and the pleasure cry. We found that these cry types could be distinguished from each other both auditorily and by means of sound spectrography (Wasz-Höckert, Partanen, Vuorenkoski, Valanne, & Michelsson, 1964a).

Another research group was founded in Stockholm to study the relationship between physiology and infant crying. The results were reported in the monograph *Newborn Infant Cry*, edited by Lind (1965).

In 1963, the research group headed by Wasz-Höckert joined the Lind group, and several cooperative research projects were reported. During the years of cry cooperation between Helsinki and Stockholm, the cry samples were mainly collected in Helsinki by Michelsson. The spectrograms were, however, made by Vuorenkoski in Stockholm at the Royal Technical Institute.

When we started with sound spectrographic cry analysis, no nomenclature existed of how and what to measure from the infant cries. In this respect, almost all the definitions and the nomenclature of the cry attributes had to be developed by the research group.

For several years, Scandinavian cry research was performed in three cities: Helsinki, Oulu, and Stockholm. Since 1972, the cry research laboratory in Helsinki has been the most active, enjoying the cooperation of visiting active scientists, such as Raes from Belgium, Makoi from Hungary, Fridman from Argentina, and Schukova and Syutkina from the USSR.

For the last 10 years we have mainly been interested in sound spectrographic cry analysis of infants with various diseases in the newborn period. Cry analysis can be an additional tool in the clinical diagnosis

of newborn infants. We have, therefore, analyzed cries of children with diseases that affect the central nervous system in order to evaluate in which respect these cries differ from the crying of healthy infants. Systematic analysis of the cries in various diseases in the newborn period have been performed. The first cry analyses were made on infants with chromosomal abnormalities (Vuorenkoski, Lind, Partanen, Lejeune, Lafourcade, & Wasz-Höckert, 1966). Also, infants with metabolic diseases such as hyperbilirubinemia and hypoglycemia have been analyzed (Koivisto, Michelsson, Sirvio, & Wasz-Höckert, 1974; Wasz-Höckert, Koivisto, Vuorenkoski, & Lind, 1971). Additionally, we have samples of cries of infants with diseases affecting the central nervous system, such as asphyxia (Michelsson, 1971; Michelsson, Sirvio, & Wasz-Höckert, 1977a) and meningitis (Michelsson, Sirvio, & Wasz-Höckert, 1977b). We have also studied cries of infants with disorders of the larynx and oral tract, such as cleft palate (Michelsson, Sirvio, Koivisto, Sovijarvi, & Wasz-Höckert, 1975), laryngitis and laryngeal malformation (Raes, Michelsson, & Despontin, 1980). It has been proved that the cry in laryngeal disorders differs significantly from cries obtained from infants with cerebral diseases (Raes, Michelsson, Dehaen, & Despontin, 1982). Additionally, we have noted that certain cry attributes, which are seldom seen in cries of healthy infants, occur more often in cries of infants with diseases involving the central nervous system (Michelsson *et al.*, 1977a, b).

1.2. Auditory Identification of Cry Types

Wasz-Höckert *et al.* (1964a) showed that the four basic cry types—birth, hunger, pain, and pleasure—could be identified auditorily. We investigated this with a tape with 24 selected short cry samples. It was found that the cries were recognized best by adults who had had previous experience with infant cries, such as nurses on pediatric wards and midwives. It was also found that training increased the ability to recognize different kinds of cries (Wasz-Höckert, Partanen, Vuorenkoski, Valanne, & Michelsson, 1964b). Valanne, Vuorenkoski, Partanen, Lind, and Wasz-Höckert (1967) found that mothers could recognize the cry of their own infant after they had listened to the cry of their own baby only once.

Partanen, Wasz-Höckert, Vuorenkoski, Theorell, Valanne, and Lind (1967) found that cries of sick infants could be distinguished auditorily from cries of healthy infants. The tape used in this research included cries of infants with asphyxia, brain damage, hyperbilirubinemia, and Down's syndrome. Training improved the ability to recognize the cries.

1.3. The Cry Analyzer

One of the results of the Finnish–Swedish cry research cooperation was the Cry Analyzer, which was manufactured by Special Instruments, Sweden, and constructed by a team consisting of Vuorenkoski, Kaunisto, Tjernlund, and Vesa (1971). It was originally intended for everyday use in clinical neonatal wards. The approach was to develop a screening device to collect cry samples from all babies on a newborn ward. A more detailed sound spectrographic analysis would be then done on cries of infants that differed from the normal.

The Cry Analyzer measures the number of cries with a pitch above and below 1000 Hz. The duration of the cry signals is also noted. Additionally, the frequency of heart and respiration rates can be measured. Objective evaluation of the analyser has indicated that the use in clinical practice is limited. Cries with a pitch over 1000 Hz with a duration of at least .4 sec in order to be registered are infrequent even in cries of sick infants.

1.4. Physiological Cry Studies

Investigations of the initiation of breathing in the newborn infant and also the cry motions and cry sounds were carried out at the Wenner-Gren Research Laboratory, Stockholm, by Truby, Bosma, and Lind in 1959–1965.

Normal newborn infants, 0 to 12 days old (gestational age 34 to 43 weeks), were, after pain stimulation (pinch), studied by the combined methods of cineradiography of the upper airways and sound spectrography and spirography or esophageal pressure recordings (Truby & Lind, 1965). The cry act that comprises intricate motor activity involving the upper respiratory tract was analyzed and correlated with the simultaneously registered cry sounds—the acoustic manifestations of the complex motor performances. The cry sound recording and analysis was considered useful in the clinical examination of the neonate. Permanent acoustic recording of the cry sound, which is similar to heart sound, could conceivably become a standard feature of the clinical record.

The cineradiographic studies of the cry motions (Bosma, Truby, & Lind, 1965) demonstrated that the cry actions of the pharynx and the oral cavity are relatively slow and incompletely integrated with the laryngeal action. Further, the integration is less complete in less mature infants. With increasing development, the whole organization of functioning is progressively integrated so that the discrepancies in coordination of respiratory motions of the larynx, pharynx, and thorax in infants are no longer discernible.

The study of the relation of cry sound to respiration (Bosma *et al.*, 1965) demonstrated a consistently similar pattern of respiratory volume displacement associated with the separate cry cycles in spite of the variations in intrathoracic pressure. This precise coordination between body wall compression and laryngeal valving is another of the remarkable motor achievements identified with cry.

1.5. Cry and Mother–Child Interaction

Improved standards of health among today's mothers have changed the nature of the service provided in maternity hospitals. Increased time has been devoted to psychological aspects of the care of "the newborn family." These developments have made possible a more individual care of the newborn. One precondition to carry out this individualized care is that one understands what the baby is trying to say when he or she cries. Parents are those who will best understand the needs of the neonate. Therefore, the introduction of "rooming in" right from birth meant a great improvement because in rooming-in wards babies cried less than half as often as babies in wards with no rooming-in facilities (Mooney & Lind, 1969).

The promotion of breast feeding has been important. Many investigations have demonstrated the medical and psychological benefits of breast feeding. The effect of infant cries on the breasts of the mother has been studied using thermography (Vuorenkoski, Wasz-Höckert, Koivisto, & Lind, 1969). It was found that cries rapidly increased the skin temperature over the breasts and that maximal skin temperature was reached within 3 to 5 minutes prior to feeding. The cries prepare the breasts, in a sense, for feeding.

1.6. Baby Carriers Increase the Contact between Parents and Children

In the fragile transition period after birth, it is important that every effort be made to make everything run as smoothly as possible. The baby must get used to a whole new way of life and to his or her parents. The parents must get used to the baby, learn to be parents, and become familiar with each other in this new role as parents. As a kind of extension of the intimate relationship during pregnancy, parents in many non-Western cultures carry their babies. In these cultures, the infants cry much less than in the Western world, where the crying of the young infant is one of the most serious problems of the new family. In one study, a group of parents were given a baby carrier at the maternity hospital and instructed on how to use it. Seventy-four of 83 mothers thought that the baby carrier promoted good contact with the baby when interviewed 3 months after delivery, and 69 out of 79 reported that the baby stopped crying when placed in the baby carrier (Brzokoupil, Fohrer, Lind, & Stensland-Junker, 1973).

1.7. Singing—An Aid to Parental Attachment

Infant crying initiates the search for causes. If the newborn is fed, properly dressed, and comfortably placed in his or her bed, why might he or she still cry? The child is born into a new strange world. One of the greatest changes for him/her after birth must be the loss of the rhythms of maternal heart sounds, breathing, voice and movements, which characterized life so completely within the uterus.

The mother's heart sounds become the unborn child's constant companion during the fetal period and constitute an important part of the fetal environment. Thus, it seems natural to imitate sounds, which are suggestive of heart sounds and which can be recognized by the child after birth. These sounds have a calming effect, creating a sense of security and comfort (Murooka, Machida, Sasaki, Iwasa, & Matumoto, 1978; Salk, 1973). Earlier generations in the Western world recognized the significance of rhythms, and infants were put in cradles, rocked, and songs were sung for them in order to calm and please them.

Music and rhythm bring joy to the listener and help develop feelings of communion. The musical interplay between parent and child increases their sense of belonging to each other. The experiences that we share when we sing, play instruments, or listen to each other become cornerstones of a stable foundation on which to build the family future. At Karolinska Hospital in Stockholm, it has been demonstrated that singing of lullabies for the unborn baby is a part of preparation for parenthood (Lind, 1980).

2. SOUND SPECTROGRAPHY

2.1. The Cry Characteristics

The nomenclature used for different cry characteristics in sound spectrographic cry analysis of newborn and small infants will now be explained. More clear and detailed information of the various cry characteristics is available in monographs by Wasz-Höckert, Lind, Vuorenkoski, Partanen, and Valanne (1968) and Michelsson (1971). Sirvio and

Michelsson (1976) and Michelsson (1980) have made detailed reviews of the various cry parameters measured. When studying the existing international literature on cry analysis, it is obvious that the terms used for the definitions of specific cry characteristics should be uniform before the results from different research centers can be precisely compared. Standardized methods for international use are urgently needed.

The following cry characteristics on the basis of sound spectrography, using the narrow band filter, have been measured by our research group. Some of these cry characteristics can probably be omitted in the future as less important when comparing cries of healthy and sick infants. When starting with cry analysis, there was no nomenclature available for sound spectrograpic cry studies; therefore many of the definitions of the cry characteristics were developed in the 1960s.

Some differences exist in the phonations in a cry sequence after the pain stimulus. Therefore, we have mainly used only the first phonation after the pain stimulus when comparing cries of healthy and sick infants. Lately, we have also evaluated the cry characteristics in the second and third phonation after the stimulus (Thoden & Koivisto, 1980).

2.1.1. *Latency*

The latency period, that is, the time between the pain stimulus and the onset of crying, has been measured in several studies. The cry has mainly been elicited by a pinch of the infant's arm or a snap on the ear.

The latency time is dependent not only on the infant's disease but also on the time since the last feeding as well as the wakefulness of the child at the time of the cry recording. Differences might also occur if the child at the time of the pain stimulus is deeply asleep or awake. The mean latency in cries of healthy infants was 1.2 sec in the study by Thodén and Koivisto (1980).

Fisichelli and Karelitz (1966) used a rubber band apparatus for eliciting the cry. They found a mean latency of 2.6 sec for children with brain damage and 1.6 sec for a normal group. In a study by Lester (1976) and Lester and Zeskind (1978) the latency was 1.4 to 1.6 sec.

2.1.2. *Duration of the Cries*

The duration of the cry signal after the pain stimulus is the time from the onset of crying to the end of the last phonation before inspiration, independently of whether the signal is continuous or consists of several short phonations. In the measurement of the duration of the second and third signals, all crying occurring between two inspirations was included. In interrupted signals, the duration of the total vocalization and the time of pauses between the signals has not yet been studied by us or by other research groups.

The mean duration of pain cries in our studies of healthy infants has varied between 2.6 sec (Wasz-Höckert *et al.*, 1968) and 5.2 sec (Thodén & Koivisto, 1980). In the first studies, however, very short phonations before or after the main signal were excluded. This made the duration shorter. The duration of the phonations has been shorter in cries of sick infants, for instance, a mean of 1.7 sec in infants with meningitis (Michelsson *et al.*, 1977b).

In cry analysis of the duration by different authors, variations have been noted between 1.0 to 6.5 sec (Gleiss & Hohn, 1968; Lester, 1976; Lester & Zeskind, 1978; Prescott, 1975; Ringel & Kluppel, 1964). Variations in the definitions of the cry sequence that have been measured do exist.

2.1.3. *Fundamental Frequency*

From the fundamental frequency, we have measured the maximum and the minimum pitchs. The maximum pitch is the highest voiced point of the fundamental frequency (F_0), and the minimum pitch is the lowest voiced point. However, if rapid changes in the fundamental frequency (shifts) have occurred, they have been measured separately. In recent studies we have made measurements of the maximum of the fundamental frequency both excluding and including shifts.

The mean maximum pitch of the fundamental frequency has, in our studies, varied between 570 to 680 Hz and the mean minimum pitch between 330 to 420 Hz (Michelsson, 1971; Thodén & Koivisto, 1980; Wasz-Höckert *et al.*, 1968). Ostwald, Phibbs, and Fox (1968) reported a mean maximum pitch of 540 Hz. Other investigations have usually reported a mean value for pitch based on the mean frequency of the whole cry. These values have varied between 308 to 606 Hz (Flatau & Gutzmann, 1906; Kittel & Hecht, 1977; Lester, 1976).

The fundamental frequency has been higher in cries of infants with diseases involving the central nervous system (Michelsson *et al.*, 1977a, b; Michelsson, Raes, Thodén, & Wasz-Höckert, 1982).

2.1.4. *Shift*

Shifts occur in almost every third pain cry of healthy infants, mostly at the beginning of the signals. Shifts can also occur at the end of the phonations or in the middle when a kind of double shift is seen. The shift is usually more high pitched than the fundamental; a maximum pitch of 1000 to 2000 Hz of the shift is common. High-pitched shifts occur in pain cries of infants with central nervous system disturbances.

2.1.5. *The Melody Type*

The melody type of the fundamental frequency has been classified as falling, rising/falling, rising, falling/rising, and flat. No melody type is detectable when the pitch is very unstable or voiceless. In cries of healthy newborn infants, both full-term and premature, the main melody type is falling or rising/falling. Especially rising and falling/rising types of melodies have been considered as pathological and are usually seen in cries of infants with central nervous system disorders (Michelsson *et al.*, 1977a, b; Michelsson, Raes, Thodén, & Wasz-Höckert, 1982). Flat signals are frequent in cries of infants with chromosomal abnormalities (Michelsson, Tuppurainen, & Aula, 1980).

Studies on the melody type are rare. Stark, Rose, and McLagen (1975) have reported on three types of pitch contour—flat, rise, and fall or a combination of these. Out of a total of 95 cries, they found a rising pitch in 11 signals and a falling pitch in 12 signals.

2.1.6. *Glottal Roll and Vibrato*

The glottal roll, or vocal fry, is a sound with a very low-pitched fundamental frequency. Glottal roll seems to be relatively common at the end of the phonations in cries of healthy infants; it was noted in 18% to 73% of cries (Michelsson, 1971; Stark *et al.*, 1975; Thodén & Koivisto, 1980; Wasz-Höckert *et al.*, 1968). Sometimes the glottal roll is preceded by a vibrato, which also can occur alone. The glottal roll is less common in sick infants who often have shorter cry signals that end abruptly (Michelsson *et al.*, 1977b; Michelsson, Raes, Thodén, & Wasz-Höckert, 1982).

2.1.7. *Double Harmonic Break and Biphonation*

The double harmonic break occurs on the sound spectrogram as parallel lines between the fundamental and its harmonics. The feature is not specific for any disease, and it occurs in 40 to 62% of pain cries of healthy infants (Wasz-Höckert *et al.*, 1968). On the contrary, biphonation is an important diagnostic feature when comparing cries of healthy and sick infants. This feature, which on the spectrogram is displayed as a double series of fundamental frequencies, does usually not occur in cries of healthy infants (Michelsson, 1971; Thodén & Koivisto, 1980). This feature has been present, especially in cries of infants with diseases that affect the central nervous system (Michelsson, 1971; Michelsson *et al.*, 1977a, b; Michelsson, Raes, Thodén, & Wasz-Höckert, 1982).

2.1.8. *Glide*

Glide is a very rapid change of the fundamental frequency of 600 Hz or more during a time of .1 sec. Glide has mainly been seen in crying of sick infants, and it also occurs in cries of symptomless prematures (Michelsson, 1971; Michelsson *et al.*, 1977a, b, Michelsson, Raes, Thodén, & Wasz-Höckert, 1982).

2.1.9. *Other Cry Characteristics*

In our cry studies we have determined if the signals are continuous or interrupted and if the cries are voiced, half voiced, or voiceless. Tonal pitch has, in some studies, been used to denote a rapid up-and-down movement of the fundamental frequency. Glottal plosives have been used to describe very short coughlike sounds. Furcation describes a split of the fundamental frequency into a series of fundamentals. This feature has been observed mainly in cries of infants with hyperbilirubinemia (Wasz-Höckert *et al.*, 1971). Noise concentration was introduced to denote a high energy peak at 2000 to 2500 Hz found in both voiced and voiceless parts of the signals. This feature has been observed especially in cries of infants with herpes virus encephalitis (Pettay, Donner, Michelsson, & Sirvio, 1977).

3. CRY IN NEWBORN INFANTS

3.1. Cry in Healthy Full-Term Infants

Analysis of pain cries from more than 300 healthy newborn infants has been analyzed by our research group (Michelsson, 1971; Wasz-Höckert *et al.*, 1963, 1964a, 1968). A recent study on normal infant crying by Thodén and Koivisto (1980) deals with a prospective analysis of cries of 38 infants from birth to 6 months of age and analyzes the first, second, and third phonation after the pain stimulus.

In all our cry studies on the pain cry of healthy full-term newborn infants, the mean maximum pitch of the fundamental frequency without shift has been about 650 Hz and the mean minimum pitch about 400 Hz. In 80% of the samples, the pain cry had a falling or rising/falling melody type with a stable pitch and a duration of approximately 2.5 sec. Shifts with a higher pitch occurred roughly in every third cry. The mean maximum pitch of shift was about 1200 Hz. The mean maximum pitch of the whole cry signal was about 800 Hz when the maximum pitch had been measured from the highest part of either the main fundamental frequency or the shift. The signals were voiced and continuous in about two-thirds of the cries. The occurrence of glottal roll was quite common, mainly at the end of the phonations. Vibrato occasionally preceded the glottal roll part. Biphonation, glide, furcation, and noise concentration were extremely rare in normal infant crying (Michelsson, 1971; Thodén & Koivisto, 1980; Wasz-Höckert *et al.*, 1968).

When comparing cries of healthy and sick infants we have mainly used the pain cry and in most of the studies the first cry signal after the pain stimulus. In order to investigate possible differences and standardize the cry characteristics of the second and the third cry signal in pain-induced cries, Thodén and Koivisto (1980) did a study on cries of 38 children. They found that the three first cry signals after the pinch did not differ much from each other. There was no significant difference in the maximum and minimum pitchs of the fundamental frequency in the three signals analyzed. Shifts were, however, seen more often in the first cry signal, even if the difference was not statistically significant. Because of the more frequent occurrence of shifts, the maximum pitch, including shift, was somewhat higher in the first cry signal. The second and third signals were significantly shorter and more often continuous than was the first signal. Glottal roll and vibrato were more common in the first signal.

Hunger, birth, and pleasure cries were analyzed by Wasz-Höckert *et al.* (1968). In 148 hunger cries, the mean maximum pitch was 550 Hz and mean minimum pitch 390 Hz. Shifts occurred in only 2% of the cries. The melody type was falling or rising/falling in 80%. Glottal roll occurred in 24%.

In 77 first birth cries, the mean maximum pitch was 550 Hz and mean minimum pitch 450 Hz. Shifts occurred in 18%. The cries were of short duration, mean 1.1 sec.

Pleasure cries had a mean maximum pitch of 650 Hz and mean minimum pitch of 360 Hz; shifts were seen in 19%; glottal roll in 26%. Flat signals were more common, occurring 46% of the time.

Thodén and Koivisto (1980) made a prospective study of cries of infants at 1 and 5 days of age and at 3 and 6 months. The only significant differences in the first cry signals at the age of 1 day, 5 days, 3 months, and 6 months were that the signals were less often continuous at the age of 3 months and that vibrato was less common at the age of 6 months.

The results indicate that there are few changes in the cry characteristics from 1 day of life up to the age of 6 months. The results showed, however, that there were differences in the cry characteristics, depending on whether or not we had analyzed the first, the second, or the third signal after the pain stimulus. The first signal was longer, more often interrupted, and ended more often in glottal roll than the second and the third signals. The maximum pitch of shift and the maximum pitch of the cry signal, including shift, were more high pitched in the first cry signal when compared to the third one at the ages of 1 and 5 days. According to these differences, the number of cries in a cry sequence should be stated in cry analysis. In the second and the third cry signals, there were no significant differences in these cry characteristics.

Studies by other authors concerning cries of healthy infants have mainly dealt with the duration and pitch of the cries and are in agreement with our studies (Kittel & Hecht, 1977; Lester & Zeskind, 1978; Murry, Amundson, & Hollien, 1977; Ostwald *et al.*, 1968; Prescott, 1975; Ringel & Kluppel, 1964).

3.2. Cry in Low-Birth-Weight Infants

The first cry study of low-birth-weight infants was by Michelsson (1971). The results showed that the cry of full-term infants who were small for gestational age did not differ considerably from the crying of full-term infants with normal birth weights. The cry results of the truly premature infants showed that the more premature the infant, the higher the fundamental frequency. The mean maximum pitch of the cry of prematures born at 35 to 37 weeks gestational age was 1010 Hz and of those born at 34 weeks or earlier, 1360 Hz. The mean minimum pitch was 480 Hz for the 35–37 gestational week group and 570 Hz. for the smaller prematures. Relatively large variations occurred in the fundamental frequencies in cries of very small prematures. These variations may be due to immaturity alone. However, pre- or perinatal complications might have changed the cry characteristics. In 1963–1967, when the cries were collected, attention was not paid to all complications affecting premature infants.

Cry analysis on prematures has been done by Thodén, Järvenpää, and Michelsson (1982) and Michelsson, Raes, Thodén, & Wasz-Höckert (1982). These results also showed that the more premature the infant was, the more the cry differed from the crying of healthy full-term infants. The cries were shorter and more high pitched.

The dominating melody type in cries of symptomless premature infants was falling or rising/falling, similar to that seen in the full-term controls. Both biphonation and glide occurred in cries of the prematures in 5% to 14% in the study by Michelsson (1971).

4. CRY IN VARIOUS DISEASES

4.1. Cry in Clinical Diagnostics

In order to evaluate how the cry changes in various diseases in newborn and small infants, systematic studies have been done to evaluate the sound spectrographic cry characteristics in sick infants. It has been found that it is not only the pitch but also other cry characteristics that change when the child is sick, and these changes are especially common in diseases in which the central nervous system is affected. Thus, cry analysis may be valuable in clinical diagnostics in order to evaluate whether the central nervous system is involved.

In a study by Michelsson, Raes, Thodén, & Wasz-Höckert (1982), the cries of 200 consecutive cases admitted to the newborn ward at the Children's Hospital were analyzed blindly. The results showed that the cries of infants with metabolic and neurological disturbances were more abnormal than cries of infants who were at the ward for observation or who had heart or lung diseases. The following cry characteristics were found to be useful in diagnosis when central nervous system involvement was expected: the maximum and minimum of the fundamental frequency increased, rising and falling/rising melody types became more common, and so did the occurrence of biphonation and glide.

4.2. Cry in Chromosomal Abnormalities

Our first study on cries of infants with chromosomal abnormalities was by Vuorenkoski *et al.* (1966), who analyzed the cries of infants with deletion of chromosome no. 5, the cri-du-chat syndrome. A general pitch of 860 Hz in 44 cries of 8 children was noted. Additionally, it was found that a flat melody type occurred in 36% and a rising melody type in 23% of the samples.

Michelsson *et al.* (1980) found approximately the same value of the fundamental frequency in two infants with cri-du-chat syndrome. Flat melody types were common. Luchsinger, Dubois, Vassella, Joss, Gloor, and Wiesmann (1967) and Bauer (1968) have also found that children with the cri-du-chat syndrome have cries with a pitch of 600 to 1000 Hz.

Lind, Vuorenkoski, Rosberg, Partanen, and Wasz-Höckert (1970) analyzed 120 cry samples of 30 infants with Down's syndrome, 0 to 8 months old. The vocalizations were often of long duration with a mean of 4.5 sec. The mean maximum pitch was 510 Hz, and the mean minimum pitch was 270 Hz. This was significantly less than in healthy controls. A flat melody type occurred in 63% of the cry samples.

Michelsson *et al.* (1980) have analyzed cry samples of 14 infants with various chromosomal abnormalities. In infants with 13- and 18-trisomy, the cries were, as in Down's syndrome, low pitched and monotonous whereas the cries were more high pitched in infants with abnormalities of chomosomes nos. 4 or 5. No biphonation was seen in the cries of the chromosomal abnormalities, and glide appeared only in 1 of the 135 cry samples studied.

We have found that the cry analysis is useful in clinical pediatrics when chromosomal abnormalities are expected. A cry analysis can give some guidance while waiting for the chromosomal estimation that takes several weeks.

4.3. Cry in Infants with Endocrine Disturbances

The cry in congenital hypothyroidism, studied in 40 cries of 4 infants by Michelsson and Sirvio (1976), was of lower pitch than usually seen in cries of healthy infants. The mean maximum pitch was 470 Hz and the mean minimum pitch 270 Hz. A low number of shifts, 7%, and a frequent occurrence of glottal roll, 57%, at the end of the phonations accentuated the audible impression of a hoarse low-pitched cry. The hoarse cry seems to be present for several months. Vuorenkoski, Vuorenkoski, and Anttolainen (1973) showed that even at the age of 8 months, a child who suffered from congenital hypothyroidism did not have any cries with a pitch above 1000 Hz.

4.4. Cries in Infants with Diseases and Malformations of the Orolaryngeal Tract

Sound spectrographic analysis of infants with cleft palate was reported by Michelsson *et al.* (1975); 52 cries from 13 infants with cleft palate were analyzed. When compared to cries of healthy neonates of the same age, no differences were observed with respect to the fundamental frequency. The mean maximum pitch was 710 Hz, the mean minimum pitch 360 Hz, and the melody type was falling or rising/falling in 88% of the cry samples. Glide occurred in 10% of cleft palate infants' cries. Biphonation was not seen.

Several cry characteristics that we have, according to our cry studies, connected with disturbances of the central nervous system were not seen in the cries of cleft palate infants. In studies by Raes *et al.* (1980) and Raes, Michelsson, Dehaeu, and Despontín (1982), these results were confirmed.

These cry results have clinical implications, especially when newborn infants are concerned. When the cry is audibly different, sound spectrography of the cries can reveal whether the cry characteristics have changed because of laryngeal or cerebral diseases.

4.5. Cry in Infants with Metabolic Disturbances

The cry of infants with neonatal hyperbilirubinemia was reported by Wasz-Höckert *et al.* (1971). The most abnormal cry signals were selected from 45 infants with hyperbilirubinemia. Both the maximum and minimum pitchs of the fundamental frequency were highly increased. The mean maximum pitch was 2120 Hz, and the mean minimum pitch was 960 Hz. Biphonation was common in 49% of the samples, as was furcation, in 42% of the samples. Furcation has been seen more commonly in pain cries of infants with hyperbilirubinemia than in cries of infants with any other disease.

Wasz-Höckert *et al.* (1971) noted also that the cries of some children with hyperbilirubinemia changed already 1 to 2 days prior to increased serum bilirubin values. The cry analysis method can thus enable early treatment with phototherapy or blood exchange.

A preliminary report on the crying of newborn infants with low blood sugar—hypoglycemia—was reported by Koivisto *et al.* (1974). Hypoglycemic infants with clinical symptoms are more likely to develop irreversible brain damage than those without symptoms (Koivisto, Blanco-Sequeiros, & Krause, 1972). Cry analysis can be one criterion in deciding which treatment is needed. In cries of 15 full-term infants with hypoglycemia and clinical symptoms, a mean maximum pitch of 1600 Hz was noted, with the highest part of the fundamental most often at the beginning of the cry signals. Vibrato and biphonation were seen in about two-thirds of the cries. Glides occurred in 3 of the 17 cries studied.

Cries of newborn infants to diabetic mothers have been studied by Thodén and Michelsson (1984). The mean maximum pitch, including shift, in cries of these infants was 1480 Hz. An interesting fact was that the pitch was still higher when the child also had hypoglycemia or hyperbilirubinemia, or both simultaneously. The maximum pitch rose to 1520 Hz (hypoglycemia), 1790 Hz (hyperbilirubinemia), and 1980 Hz (both). The minimum pitch was higher when the child had hypoglycemia, hyperbilirubinemia, or both. The study shows that both hyperbilirubinemia and hypoglycemia change the cry characteristics in the newborn period.

The results of cry analysis of infants with hyperbilirubinemia were confirmed by Michelsson, Raes, Thodén, and Wasz-Höckert (1982). These results showed that the cry characteristics changed whether the child was born full-term or premature.

4.6. Crying in Newborn Infants with Asphyxia

Michelsson (1971) collected cries from 250 asphyxiated infants during the first 3 days of life. All infants were born with Apgar scores of 7 or less at 1 or 5 minutes of age. The children were divided into two groups, depending on whether the child suffered from respiratory distresss (peripheral aphyxia) or had neurological symptoms in the newborn period (central asphyxia). The cry characteristics were compared to the crying of 50 healthy full-term and 75 premature infants, depending on whether the neonate with asphyxia was full term or premature. In both gestational-age groups, the cry was more abnormal in 125 children with central asphyxia than in 80 children with peripheral asphyxia. The cry was, however, different in both groups from a normal series of 50 infants. The mean maximum pitch, including shift, was 1460 Hz in the full-term neonates with central asphyxia, 1000 Hz in peripheral asphyxia, and 650 Hz in controls (Michelsson & Wasz-Höckert, 1980). Prematures with central asphyxia had a mean maximum pitch of 1950 Hz, including shift; the mean in peripheral asphyxia was 1610 Hz, and in symptomless prematures, 1520 Hz. Michelsson (1971) showed that biphonation occurred in more than 20% and glide in more than 10% of the samples of infants with asphyxia. Rising and falling/rising types of melody occurred in more than 30% of the signals. These changes in the cry characteristics were more marked the more severely the newborn had suffered from asphyxia.

The changes in cry characteristics in newborn infants with asphyxia were so obvious that we have a good reason to use the cry analysis as an additional tool in neonatal neurological examination. Michelsson (1971) found that if the cries became normal in a few days after asphyxia, the child was more likely to recover without neurological sequelae than if the cry characteristics remained abnormal during the hospitalization period. The prognostic value of cry analysis in asphyxia was confirmed in a follow-up study by Michelsson *et al.* (1977a). The results showed

that infants who at later checkup were found to be neurologically damaged had had more abnormal cries in the newborn period.

Syutkina, Michelsson, and Sirvio (1982) have, in animal studies, experimentally confirmed that asphyxia produces changes in the sounds produced. The study analyzed the utterances of Wistar rats in which asphyxia was experimentally caused by clamping the umbilical cord 2 to 4 days before birth. The cord was clamped until the fetal heart rate dropped to 50, which took about 15 to 20 minutes. Antenatal hypoxia was found to produce a significant increase of maximum pitch and decrease in the duration of the phonations. The mean maximum pitch was 4140 Hz in 61 pain-induced utterances of asphyxiated rats and 2890 Hz in 34 utterances of control rats.

4.7. Crying in Diseases of the Central Nervous System

The cry of 14 infants with bacterial meningitis was studied by Michelsson *et al.* (1977b). The cries of the 0–6-month-old infants were higher pitched, with a mean maximum pitch of 750 Hz in the 110 cries studied. The mean minimum pitch was 560 Hz. Rising and falling/rising melody types were more common (24%) than in control babies. Biphonation (49%) and glide (11%) occurred more frequently. Infants who at later checkup had neurological sequelae had more abnormal cry characteristics at the time of the disease. The results indicate that cry analysis has not only diagnostic but also prognostic value when analyzing cries of infants with meningitis.

In cries of infants with herpes simplex virus encephalitis (Pettay *et al.*, 1977), noise concentration occurred at the frequency region of 2000 to 3000 Hz. We have, therefore, used the cry analysis in clinical diagnostics when herpes encephalitis has been suspected. The cries were more high pitched. Both biphonation and glide were more common than in healthy controls.

A study on crying in children with hydrocephalus was done by Michelsson, Kaskinen, Aulanko, and Rinne (1984). The cry analysis of 248 cries—4 cries from each of 62 infants—were analyzed. The mean maximum pitch without shift was 750 Hz and the mean minimum pitch 430 Hz. When the infants with hydrocephalus were separated into groups according to etiology, the only significant difference in the maximum pitch when compared to controls was noted in infants who had congenital hydrocephalus present at birth. Flat types of melody were common, regardless of the cause of hydrocephalus. Biphonation occurred in 14% and glide in 8% in the whole material.

The cry results show that the cry is different from normal crying in diseases of the central nervous system. Biphonation was more common in meningitis than in encephalitis and hydrocephalus. Noise concentration occurred in herpes encephalitis. All groups of children had more high-pitched cries than controls. In infants with congenital abnormalities, such as Down's syndrome (Wasz-Höckert *et al.*, 1971), hypothyroidism (Michelsson & Sirvio, 1976), and congenitial syphilis (Kittel & Hecht, 1977), the cry was low pitched. Thus, it is obvious that the results of cry analysis are different in children with acquired and congenital disorders of the central nervous system.

4.8. Cries in Malnutrition

Cries of children with severe malnutrition were studied by Juntunen, Sirvio, and Michelsson (1978). In infants suffering from kwashiorkor, the cry characteristics did not differ from normal crying. The children often recover without sequelae. In marasmus, children can suffer from irreversible organic brain dysfunction (Stock & Smyth, 1967), and the cry is very high pitched and monotonous. The mean maximum pitch in the marasmic children was 1340 Hz; the mean minimum pitch 730 Hz.

4.9. Cry in Malformation Syndromes

In three cases with Krabbe's disease, the cry characteristics were analyzed and showed a higher mean maximum pitch (1120 Hz) and mean minimum pitch (590 Hz) than in controls (Thodén & Michelsson, 1979). Rising and falling/rising types of melody were seen significantly more often (27%) in the cries of these infants.

4.10. Cry in Twin Pairs

A study on cries in twins has been finished by Michelsson and Rinne (1984). The results showed that the cries in twin pairs who were both healthy were more equal than the cries in twin pairs in which one was healthy and the other was diseased. The study also confirmed previous results that the cries are more abnormal the more premature the infant is.

We have analyzed 90 cries from two pairs of Siamese twins (Michelsson, Raes, & Thodén, 1982). The results showed that the cries of the conjoined twins fell well into normal limits for crying. Cry features of a set of quadruplets was reported by Thodén, Raes, and Michelsson (1979).

5. SUMMARY

Scandinavian cry research has been ongoing since 1960. The first cry studies concerned both auditory identification and sound spectrographic analysis of various cry characteristics.

Lately, the main purpose of our cry research has been to show that cry analysis is an additional aid in making diagnoses in clinical pediatrics, especially in the newborn period and in diseases that have affected the central nervous system. For this purpose, systematic sound spectrographic analyses have been done on cries of newborn and small infants with various diseases.

When a child is sick and the cry changes from normal to abnormal, it can be caused by diseases or malformations affecting the central nervous system, the lungs or the larynx, or the oral cavities. We have, therefore, investigated by sound spectrogaphy, in which diseases the cry is similar to and in which diseases the cry is different from the crying of healthy infants. We have additionally evaluated whether there are some cry features that are specific for certain disorders. We believe that any method that can be useful for clinical assessment in the newborn period is valuable and should be developed further.

Classical pediatric textbooks have associated a high-pitched shrill cry with diseases affecting the central nervous system. We have proved that not only the pitch changes in diseases affecting the central nervous system but also other cry characteristics, such as the melody type and the occurrence of biphonation and glide. The cry signals have been more abnormal in severely sick infants. Cry analysis has been helpful not only in clinical diagnostics but also in estimating prognosis in diseases that have affected the central nervous system.

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