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Effects of Frequency Band Manipulation on Perceptions of Infant Cries

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EFFECTS OF FREQUENCY BAND MANIPULATION ON PERCEPTIONS OF INFANT CRIES

by

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VITA

The author, Jerry W. Cleland, is the son of William E. and H. Louise Cleland. He was born June 22, 1954 in Belvidere, Illinois.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix Page

INTRODUCTION

The acoustic properties of human infant cries have been studied by researchers in a variety of disciplines. Research has been conducted to assess the relationship between eliciting stimuli and cry features, (e.g., Porter, Porges, and Marshall, 1988), the relationship of behavioral responses to the interactive manipulations of cry duration and caregivers' ability to stop the infants' cries (Gustafson, Cleland, and Harris, 1988), and the relationship between specific medical problems and cry features, (e.g., Golub and Corwin, 1982, 1985).

It has been well documented that the auditory signal emitted by a crying infant elicits caregiving behavior, e.g., Darwin (1855), Bowlby (1969), and Murray (1985). The cry is indicative of the highest state of infant arousal (Hopkins & Palthe, 1987) and is one of the loudest sounds humans ever make (Ringel & Kluppel, 1964). It is clear, however, that not all cries are equally effective elicitors of caregiving behaviors. Zeskind (1983) demonstrated that cries of high-risk infants elicit ratings by mothers indicating a greater likelihood of caregiving behavior than do those of low-risk infants. Murray (1979) reported that too much crying may exceed parental limits of tolerance and shift caregiver motivation from altruistic to egoistic. That is, when a cry, which typically elicits empathic responses, exceeds the limits of parental tolerance, nonempathic behaviors such as avoidant or even aggressive behavior may ensue. For Zeskind, the primary acoustic feature addressed was the power spectrum of the cry; for Murray, the primary acoustic feature addressed was cry duration. However, both suggest that the cry signal directly impacts caregiver-infant interactions by influencing parental perceptions of the infant.

Physioacoustic Cry Model

A physioacoustic model of cry production has been described by Golub and Corwin (1985), where cry production is divided into four components. The first component is responsible for developing pressure below the glottis. This subglottal system, consisting of the lungs and trachea, provides the force which drives the vocal folds. The second part of the model is the actual sound source, the vocal cords located at the larynx. The output from this part of the system can be either periodic, turbulent, or, most often, a combination of both. Truby and Lind (1965) refer to periodic output as phonated and turbulent output as dysphonated. Periodic sound is generally the result of unimpaired vocal cord vibration; turbulence is generally the result of forcing air through partially closed vocal cords. The authors reported that turbulence or dysphonation is often the result of excessive subglottal pressure, which overloads of the vocal cords and forces them apart, resulting in a nonperiodic signal.

The third component of the model includes the nasal and vocal tracts (pharynx), located directly above the larynx. The physical characteristics of these tracts determine the formant frequencies (see Appendix A for Glossary) which act to enhance or dampen particular frequencies generated by the vocal cords. This filtering function of the vocal and nasal tracts changes as the physical characteristics of the system components change. The end result is a dynamic sound system which has a frequency response that depends on the physical characteristics of the vocal tract. The fourth part of the physioacoustic model is simply any filtering or damping which takes place between the auditory output at the infant's mouth and some auditory receptor(s) (e.g., a microphone, ears, etc.). The interaction of these components, in conjunction with a knowledge of the eliciting stimuli, act to determine adult perceptions of the cry.

Cry Characteristics

It has been suggested that there are different types of cries, specific to the causal stimulus (e.g., pain, hunger, etc.). Wolff (1969) described three cry types which were presented as acoustically distinct in their initial phases: the hunger cry, which was the most frequent and rhythmic cry; the mad or anger cry, which was characterized by turbulence and forced breathing; and the pain cry, which was characterized by long duration and long pauses, or what might be described as wailing or moaning. Wasz-Höckert, Lind, Vourenkoski, Partanen, and Valanne (1968) described the melodic form of pain, hunger, birth, and pleasure cries. They described the pain cry melody as typically falling, rarely rising-falling. The hunger cry melody was described as a rising-falling form with the fundamental frequency (390-550 Hz) being somewhat lower than that of the pain cry (400-650 Hz). The birth cry melody, emitted in the first hours after birth, was reportedly flat or falling and had a fundamental frequency range of 450-550 Hz. The pleasure cry, emitted by a comfortable infant beginning at approximately three months of age, was described as having a flat form and, often, a nasal quality. The fundamental frequency range for these cries is approximately 360-650 Hz. The cries used for the present study were hunger cries because they represent the most common cry type and because they represent cries with the most commonly reported range of fundamental frequency.

Fundamental Frequency

Fundamental frequency (f_0) has been the primary focus of acoustic analyses of cry perception research for many years (Gustafson & Green, 1989). Early systematic measurement and description of infant cry parameters began with the use of the sound spectrograph, developed by Bell Laboratories in the late 1940's (e.g., Truby & Lind, 1965). For researchers using sound spectrographic analyses, fundamental frequency and relative power were visually displayed and could be interpreted quickly and easily. Comparisons of cries differing in mean f_0 provided an empirical basis of support for the assumption that variations in f_0 influence cry perception by adults (Boukydis, 1985).

Fundamental frequency is a characteristic of all periodic waveforms. It is defined as the number of times a waveform repeats itself in one second (Golub & Corwin, 1985) and, in the case of cries, it corresponds to the rate at which infants' vocal cords open and close per second (Green, Jones & Gustafson, 1987). Complex waveforms such as cries also contain harmonics, or multiples of the f_o. For an infant with a typical f_o of 400 Hz, the first harmonic (f_1) is 800 Hz, the second harmonic (f_2) is 1200 Hz, the third harmonic (f_3) is 1600 Hz, and so forth.

Fundamental Frequency and Vagal Tone

Shifts in the f_o of the cry have been hypothesized to reflect the physiological arousal of infants (Zeskind, Sale, Maio, Huntington, & Weiseman, 1985). The sound production centers are under the control of the vagus nerve (cranial nerve X), which innervates the pharynx, larynx, trachea, esophagus, and thoracic viscera as well as the cardiac and abdominal cavities (Reitan & Wolfson, 1985). The vagus nerve has both afferent and efferent components and is believed to play an important role in homeostasis (c.f., Porter, Porges, & Marshall, 1988). One measure of infant arousal is vagal tone, which is often assessed by measures of the amplitude of respiratory sinus arrythmia (Fox & Porges, 1985; Porges, 1983). The primary advantage of this measure is that researchers can track vagal activity in a non-invasive manner (Fouad, Tarazi, Ferrario, Fighaly, & Alicandri, 1984). As infant arousal increases, vagal tone decreases, resulting in increased laryngeal muscle tension and production of cries with higher f_o's.

Theoretically, f_o has been hypothesized to directly reflect the integrity and functioning of the central nervous system (Golub & Corwin, 1985; Zeskind & Lester, 1978). Porter, Porges, and Marshall (1988) demonstrated a direct relationship between f_0 and vagal tone as they tracked changes in infant cry frequency and vagal tone through each of eleven procedures in a routine circumcision. The authors simultaneously recorded cries and vagal tone at each procedure, which began with relatively non-invasive cleansing procedures and ended with a post-operative recording period. Infant cry f_0 directly reflected physiological trauma (i.e., degree of surgical invasiveness), but quickly returned to preoperative levels shortly after surgery. Similarly, neonates responded to sudden onset pain, a routine heel-lance procedure for PKU screening, with rapid increase in f_0 from a previous non-cry resting state (Grunau and Craig, 1987). As infant arousal increases, vagal tone decreases, causing increased laryngeal muscle tension and cries of higher f_0. Thus, f_0 tends to reflect physiological trauma for a given infant and, as a result, has been reported as an indicator of short-term infant arousal or long-term infant risk status.

Impact of Harmonic Structure

While normal infant cries vary, they tend to have a f_0 of approximately 400 Hz (range 300-500 Hz) and are approximately 82 dB SPL at 12 inches from their source (Ringel & Kluppel, 1964)[1]. Interestingly enough, pure tones in the frequency range containing the f_o must be played at an amplitude approximately 10-12 dB greater than frequencies in the 3000 Hz range to be perceived as equally loud (Kryter & Pearsons, 1963). While there can be little doubt that the f_o is a factor in aversiveness perceptions, there is reasonable doubt that acoustic energy in the vicinity of the f_o is <u>primarily</u> responsible for increased ratings of aversiveness (Gustafson, Green, & Jong, 1985). Unfortunately, the historical interest in f_o has sometimes created the impression that the most salient acoustic variable in infants cries was the f_o. Perhaps more important to ratings of overall pitch and aversiveness are the upper harmonics, which are a function of the f_o. In a recent study of sound annoyance, Halpern, Blake, and Hillenbrand (1986) described the perception of a "chilling noise" as having relatively greater energy at approximately 2.8 kHz and 5.6 kHz. The most aversive or chilling stimulus in their study was a three-pronged garden tool dragged across a piece of slate (the sound was reportedly similar to fingernails dragged across a blackboard). Fundamental frequency was not reported as the variable of primary interest; relative power differences at the harmonics, particularly increased power at 2.8 kHz and 5.6 kHz, was.

Infant Cry Components

The fundamental frequency, harmonic frequencies and combinations of those frequencies comprise the auditory stimulus generated by infant cries. The spectral profile of an infant cry depends, in part, on the acoustical properties of the vocal tract. Changes in the gross physical characteristics of the tract (e.g., cross-sectional area, length) result in modifications of its resonant characteristics. Resonances in the vocal tract are referred to as its formants and are usually independent of the f_0 and its harmonics (Golub & Corwin, 1985).

The human auditory system is most sensitive to frequencies at approximately 3 kHz (Békésy & Rosenblith, 1951), and energy in that region is perceived as louder than a similar concentration of energy in other ranges when relative amplitude was held constant across frequency ranges. Fletcher and Munson (1933) demonstrated that the human ear was most sensitive to frequencies near 3 kHz using equal loudness contours based on single tones across a range of amplitudes. Kryter and Pearsons (1963) reported that when power was held constant across a variety of natural and artificial sounds, perceived loudness of broadband noise was greatest at approximately 3 kHz.

Infant Cry Dynamics

While the f_0 contributes to perceptions of the infant cry, it is but a single component of a complex spectral profile. Those who listen to cry sounds hear the f_0 in conjunction with the entire range of harmonics, the amplitudes of which are modified by vocal tract formant frequency and respiratory pressure. Perceptions of cry pitch depend mainly on spectral content, but sound pressure and spectral variability within a given sound envelope also contribute to pitch perceptions. Since the cry is dynamic, the fundamental and harmonic frequencies change as tension on the vocal cords change. Vocal cord tension is modulated by contraction of the laryngeal muscles, which are innervated by both sympathetic and parasympathetic (vagal) input from the autonomic nervous system (Berne & Levy, 1983). Thus, the pitch of an infant's cry at a given point in time depends upon vocal cord tension, respiratory pressure, and vocal tract formant frequency.

Perception of Cries as Annoying

The notion that infant cries are perceived by adults as aversive is rarely disputed. Ostwald (1963), for example, has stated, "One can appreciate why the parent must interfere with the baby's cry: this sound is too annoying to be tolerated beyond a short period of time, particularly at close range" (p. 46). What is also rarely disputed is that the cries of some infants are more annoying than those of others. Several recent studies have addressed this issue by determining the relationship of specific acoustic variables with adult's ratings of infant cries.

After collecting adult ratings of infant cries, Zeskind and Marshall (1988) extracted three measures of fundamental frequency from pain cries of 16 newborn infants: mean fundamental frequency, standard deviation of the fundamental frequency, and peak fundamental frequency (the f_o with the greatest amplitude). The cry stimuli for this study were the first 10 seconds of crying which immediately followed a rubber-band snap to the neonate's heel. Each of the measures was found to be positively correlated with the four, seven-point Lickert-type rating scale items employed in the study: Urgent-Nonurgent, Distressing-Nondistressing, Arousing-Nonarousing, and Sick-Healthy. Multiple regression analyses revealed that the mean of the fundamental frequency accounted for the greatest variance in ratings of Urgency, Distress, and Arousal. Differences in standard deviation of the fundamental frequency accounted for the greatest variance in ratings of how Sick the infant sounded.

Another study which assessed the impact of fundamental frequency variables as well as relative amplitudes in 1000-Hz bandwidths on adult ratings of cries was reported by Gustafson and Green (1989). Twenty parents and 22 nonparent adult subjects rated 12, single-cry expirations (wails) that had been matched in mean and range to the duration, fundamental frequency and peak frequency to an initial pool of 100 single-cry expirations. Individual subjects judged each cry on two sets of ratings. One set included eight aversiveness items, each rated on a seven-point Lickert-type scale originally employed by Zeskind and Lester (1978): Urgent, Distressing, Sick, Arousing, Grating, Discomforting, Piercing, and Aversive. The other set included nine items from the semantic differential (Osgood, Suci, & Tannenbaum, 1957). Three items were selected from the activity, potency, and evaluation dimensions of the scale.

As in the Zeskind and Marshall (1988) study, Gustafson and Green (1989) assessed differences in the mean fundamental frequency and standard deviation of the fundamental frequency on ratings. In addition, peak frequency (the frequency with the greatest amplitude), the proportion of total power in each of five 1-kHz frequency bands from 0- to 5-kHz and amount of dysphonation (or irregular vocal cord activity, see

Truby & Lind, 1965) were assessed. The authors reported that cries which were perceived as most annoying were those that were longer in duration and more dysphonated, those that had less energy in the 0-1-kHz range, and those that had more energy in the 3-4-kHz range. These findings were stable, regardless of the ratings scales employed. Interestingly, mean fundamental frequency was not significantly correlated with any of the ratings. Further, even though the correlations of f_o were not significant, in each case the coefficient was in a negative direction. The findings in this study concur with those of a previous study (Gustafson, Green, & Tomic, 1984) which showed that relative power in the same 1000-Hz frequency ranges is an important characteristic for determining the identity of individual infants' cries.

Summary

Previous studies have suggested that cries of infants, particularly those who were distressed or those with pathologic conditions, displayed a higher overall f_o than cries of non-distressed infants. These cries were perceived as more annoying and subjects reported they would be more likely to intervene with caregiving behaviors. The focus of many of the studies was centered on the characteristics of fundamental frequency of the cry, although other variables such as duration of pauses between cries (Lounsbury & Bates, 1982) and relative energy differences in 1000-Hz frequency bands (Gustafson, Green, & Jong, 1985) have also been reported. Independent variables have been primarily limited to experimental subject characteristics such as amount of caregiving experience, effects of parity (i.e., primiparous, multiparous), and sex of subject (i.e., mother, father, nonparent female, etc.) (c.f., Papoušek, 1989). Differences between experimental cry stimuli have been a function of the medical status of the children (e.g., Thodén, Järvenpää, & Michelsson, K., 1985), of presumed cry types such as pain or hunger (Murry, 1980), or of mean differences of a variety of acoustic variables (Gustafson & Green, 1989).

None of these studies has directly manipulated the acoustic variables of the cry signal itself. This is due, in large part, to limitations of acoustic processing equipment. Many of the earlier studies employed the sound spectrograph. Traditional sound spectrographic analyses are quite limited in their ability to assess information of long duration and limited in their ability to provide detailed information about the component parts of broadband sound. Users of the sound spectrograph are able to sample auditory signals at only one of two durations and the sound spectrograph does not provide precise quantitative information about the spectral components (Green & Gustafson, 1987). The more recent employment of computer-aided digital-processing methods has increased the amount of information that can be extracted from spectral component analyses.

Rationale for the Present Study

The development of digital signal-processing techniques has enhanced the ability of experimenters to analyze acoustic waveforms, especially those with time-varying spectra. However, until very recently the acoustic variables that have been examined had not changed, although the analytic techniques have become increasingly sophisticated. Researchers have continued to measure mean fundamental frequency of cries, focusing on the effects of different pre- and post-natal conditions (e.g., low birth weight, malnutrition, endocrine abnormalities, etc.) and on the perceptual consequences of f_0 across different classes of experimental subjects (mothers, fathers, children, etc.).

While mean f_0 has played an important role in the study of infant cries, new digital signal-processing techniques allow for the analysis of a much wider range of acoustic variables. Furthermore, past research has relied on naturally-occurring, between-cry differences along some acoustic dimension, leaving differences along other dimensions uncontrolled. When one listens to cries from different infants who have been grouped together on the basis of some individual acoustic variable or set of acoustic variables, it is readily apparent that the cries are still quite distinct from one another. For example, pauses between cry expirations often vary between the cries of different infants, as does the overall rhythmicity of the cries. Perhaps the best way to determine the impact of these between-cry differences on ratings by adults, is to control them by manipulating specified acoustic parameters within individual cries. By directly manipulating specific acoustic features of infant cries and making within-cry comparisons, the effects of between-cry variations along other dimensions are eliminated and the effects of a particular variable can be isolated.

Recent studies of ratings of infant cry annoyance have suggested that the spectral characteristics of cries directly contribute to adult ratings of annoyance. Gustafson and Green (1989) reported that naturally-emitted hunger cries with less energy in the 0-1-kHz range and more energy in the 3-4-kHz range were perceived as more aversive. Zeskind and Marshall (1988) reported that pain cries elicited by a rubber band snap to the heel were rated as more annoying as the fundamental frequency rose and as the variability of the fundamental increased.

The fundamental frequency is contained within the 0-1-kHz range, the range Gustafson and Green (1989) report contributes to perceptions of annoyance when there is less power relative to other frequency ranges. Perhaps less energy in this range effectively accentuates perceptions of other frequency ranges. While not inconsistent with reports of a positive relationship between increases in fundamental frequency and annoyance ratings, this finding clearly casts doubt on the role of the fundamental frequency as the primary acoustic variable contributing to those ratings. They also reported that more power in the 3-4-kHz range increases perceptions of annoyance. This is consistent with previous studies assessing the subjective loudness ratings of broadband noise (e.g., Kryter & Pearsons, 1963).

The goal of the present study was to test the effects of directly manipulating power in individual, 1000-Hz bandwidths within the cries emitted by four healthy, but hungry infants. This study is different from previous research in two important ways. First, the capability to perform the acoustic manipulations employed in this study has only recently become available. This technology allows for direct manipulation of time-varying spectra, an option not available to previous researchers. Second, subjects in the present study rated the cries on a single dimension (e.g., aversiveness, urgency, or infant health). Ratings in previous studies were performed across numerous dimensions, possibly introducing carry-over effects from ratings on one dimension to ratings on the next. If these within-cry manipulations have an effect on adult ratings of infant crying, it would provide stronger evidence of the contribution of specific acoustic parameters on the perception of infant cries.

METHOD

Subjects

Sixty undergraduate students who were enrolled in introductory psychology participated in the experiment to fulfill course requirements. Since subjects' gender was not hypothesized to have an effect on ratings, sex of subjects was not controlled in any experimental group. The 60 subjects (*M* age = 18.2 yrs., *SD* = 0.73 yrs.) composed three independent groups of 20 college students which included a total of 27 males (*M* age = 18.4 yrs., *SD* = 0.74 yrs.) and 33 females (*M* age = 18.1 yrs., *SD* = 0.71 yrs.).

Stimuli

Four infants cries were chosen from a set of 20 infant cries. All were approximately four minutes in duration and were from 30-day-old infants who were healthy and full-term, as reported by parents (see Gustafson & Green, 1983). Preliminary testing of 20 pilot subjects suggested that of the four cries chosen, two were the most aversive of the original 20 cries and two were representative of typical or average cries. Ratings made by the 60 subjects in the present study revealed one cry to be highly aversive, one cry to be nonaversive and two cries to be approximately neutral.

Cry segment selection. Four 10-second cry segments were digitally sampled from each of the infants' four-minute recorded cry. One 10-second sample was selected from a randomly determined starting point at each minute of each infant's original, four-minute cry. If the selected starting point fell beyond the beginning of a cry bout (where bout is defined as the voiced expiratory phase of a cry during a single exhalation), the audio-tape was rewound to the beginning of that bout and sampling of the selected segment began at that point. This standard procedure insured that all cry recordings would begin at the onset of a cry bout, not in the middle or at the end of a cry. This sampling procedure continued until four 10-second segments had been selected, one from each minute of a particular infant's four-minute cry recording. The procedure was carried out on four recorded cries, yielding 16, 10-second cry samples that served as the source from which digitally-manipulated cries were produced. Each of the selected segments was manipulated in eight ways.

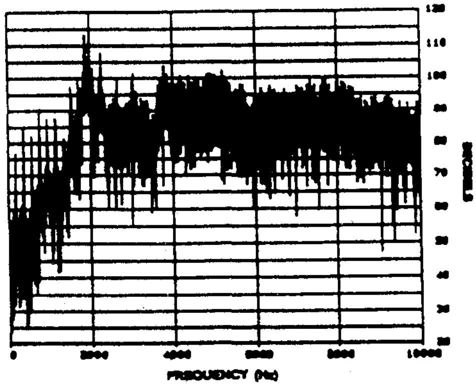
Digital manipulations. Cries were digitally manipulated with Interactive Laboratory Systems (ILS) software (Goletta, CA), run on a Masscomp 5450 minicomputer. The cries were sampled at 20 kHz for 10 seconds with 16-bit analogue-to-digital converters and then modified by ILS filtering routines. Sampling at 20 kHz allows a spectral analysis up to 10 kHz.

Cry segment increments. For each of the 16 sampled cry segments, the relative power was incremented in the 0-1-kHz range, in the 1-2-kHz range, in the 2-3-kHz range or in the 3-4-kHz range. The increment manipulation was accomplished in three steps. First, the cry segment was digitally band-pass filtered such that only frequencies in the desired range were passed. A fourth-order Butterworth filter, whose high frequency roll-off was 65 dB per octave and whose low frequency roll-off was 55 dB per octave, was utilized. The low- and high-pass cutoffs of the filter were set to the lower and upper ends of the desired 1000-Hz frequency range (e.g., 2000 Hz for the lower end and 3000 Hz for the upper end in the 2-3-kHz pass band). Second, spectral power in the selected frequency range was boosted by a factor of 10 (see cry bout recombination, below). Third, the boosted signal was added back to the original, unmanipulated signal, resulting in an 11:1 ratio in the boosted portion of the spectrum. This manipulation was completed once for each of the four 1000-Hz frequency ranges, for each of the 16 unmanipulated (control) segments. The result was to generate four manipulated cry segments from each control cry segment (see Figure 1). Since there were 16 unmanipulated segments, a total of 64 incremented 10-second segments were generated (see Appendix B). Once the cries had been properly manipulated, they were played through the digital-to-analogue converters at 20 kHz, low-pass filtered at 7.5 kHz for antialiasing, and recorded onto cassette tape with a ReVox B 215 Cassette Tape Deck (see Stimulus tape construction below).

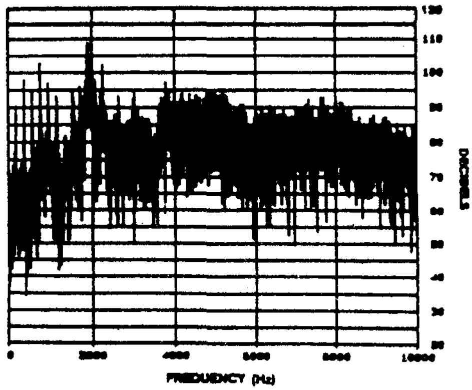
Cry segment decrements. For the decrements, the same previously selected control segments were employed, and manipulations were performed across the same frequency ranges. This time, however, the sampled segments were digitally band-reject filtered, eliminating a specific 1000-Hz frequency range. Again, a fourth-order Butterworth filter with the previously described characteristics was employed. As in the increment manipulation, the filtered cry was boosted by a factor of 10 and the filtered cry segment was added back to the original. The effect was to decrement the desired frequency range relative to all other frequency ranges, by boosting power in all but the band-rejected 1000-Hz range. As with the incremented cry segments, there were a total of 16 decremented segments for each of the four infants, resulting in a total of 64 decremented segments (Appendix B).

Cry bout recombination. Since the power in a

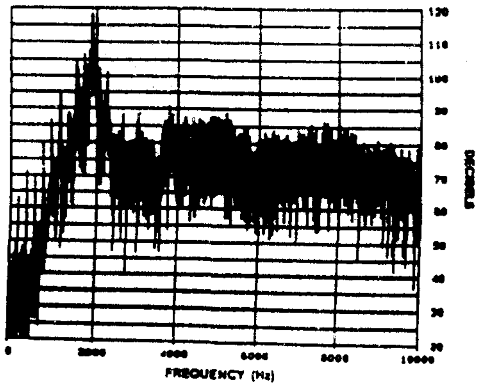
Figure 1. Frequency domain plots of a 300-ms sample cry bout which is unmanipulated and is incremented in 0-1-kHz, 1-2-kHz, 2-3-kHz, and 3-4-kHz frequency bands.



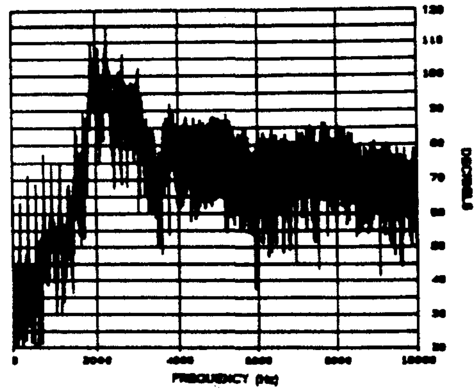
UNMANIPULATED CRY BOUT



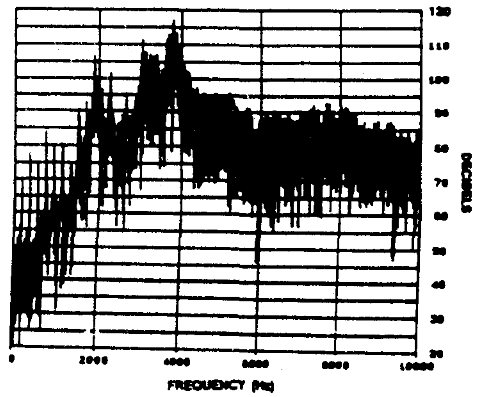
0-1-kHz INCREMENTED CRY BOUT



1-2-kHz INCREMENTED CRY BOUT



2-3-kHz INCREMENTED CRY BOUT



3-4-kHz INCREMENTED CRY BOUT

given spectral range varied across infants and across segments for each infant, a standard method for controlling power in each 10-second segment was necessary. Relative power of a cry signal can be manipulated in ILS by providing user-specified scaling values. While the actual scale values are arbitrary, they provide a method for increasing or decreasing power levels in the selected segments. The scaling values used in ILS for each paired member of the manipulated cries were determined by peak voltage of the combined cry pair. The digitized cries were first combined in ILS by scaling the original cry at 20 and the manipulated, filtered cry at 200 (a multiple of the previous ILS value). However, for some segments, recombination of the original and boosted segments proved to be too intense and, for some segments, not to be intense enough. As a result, the standard experimental procedure was to maintain the 11:1 ratio of the band-passed segment to the control segment, and specify those values such that the peak voltage of the combined signals was two volts.

For recombined cries whose peak pressure exceeded two volts, the scaled values of each paired member of the control and manipulated segments were decreased until peak sound pressure equaled two volts. An opposite procedure was employed for recombined cries whose peak pressure was less than two volts. As an example of the scaling procedure, one pair of combined segments exceeding two volts was recombined by scaling the control segment at 10 and the incremented segment at 100, while one pair of segments containing less than two volts was recombined by scaling the control segment at 60 and the incremented segment at 600 (see Appendix C, Scaling Factors).

<u>Stimulus Tape Construction</u>

The 16 control, 64 incremented, and 64 decremented 10-second segments provided 144 experimental cries. In addition, the 16 unmanipulated cries were again added as a check to determine the extent to which subjects rated cries similarly across the experiment. Thus, a total of 160, 10-second segments comprised the experimental stimulus tape.

Selection and order of cry segment assignment to the stimulus tape was performed in the following manner. For each minute of each infant's crying, nine 10-second segments were generated; four increments, four decrements, and one control segment (Appendix B). The first segment recorded onto the stimulus tape was randomly selected from one of the nine segments generated from the first minute of the cries of the first infant. Next, one of the nine segments from the second minute of the first infant's crying was randomly selected and recorded onto the stimulus tape. A segment from the third minute of crying was then selected, followed by a segment from the fourth minute of crying. The same procedure was followed for the second infant's cries, the third infant's cries, and the fourth infant's cries. When the first 16 segments had been selected and recorded onto the stimulus tape, the procedure began again with the eight remaining cries from the first minute of the first infant's cries, and so forth until all segments had been selected and recorded. The additional 16 unmanipulated segments were added at two points in the stimulus tape. They were the final eight segments in the first half of the stimulus tape, or cries 73 through 80 and were also the final eight segments of the second half of the stimulus tape or cries 153 through 160 (see Appendix D).

Amplitude manipulation. The stimulus-tape amplitude was controlled in an attempt to remove it as an experimental variable. The first step for controlling amplitude was described in the recombination procedure, where the manipulated and unmanipulated segments were combined at an 11:1 ratio, then controlled according to output voltage. The second step in equating amplitude was performed during the recording of each cry segment from ILS to the stimulus tape. Each of the 10-second segments was recorded onto the audio tape such that the peak amplitude for that segment was zero on the tape recorder VU meter (see Appendix C, dB change). The combination of these two manipulations resulted in experimental cry segments with only minimal, unsystematic variations in power levels.

Measurement of Fundamental Frequency

Fundamental frequency. Fundamental frequency was measured by selecting three, 25-ms samples of the cry from each of the four, 10-second cries. The 12 samples used to calculate mean f_o were selected by moving a cursor to a fully phonated section of an individual cry bout at the beginning, middle, and end of each of the 16 unmanipulated, 10-second cry segments.

Autocorrelation. The fundamental frequency for each 25-ms sample was determined by employing the autocorrelation routine from ILS (see also Okada, Murai, & Adachi, 1987). The ILS autocorrelation routine plots the output in a time domain format, where the Y-axis indicates the strength of the correlation and the X-axis indicates the time at which the waveform repeats. The repetition intervals are plotted as "spikes" in the graphic output. The first repetition represents the f_o, the second represents the first harmonic (f_1) and so forth. A perfectly repeating pure tone would show perfect correlation on the Y-axis at integer multiples of 1/f. However, when assessing infant cries, nonperiodic noise (e.g., dysphonation) is introduced into the cry. As a result, the magnitude of the correlations decrease, and the prominence of peaks at integer multiples of $1/f_o$ is reduced. As a result, only fully-phonated 25-ms sections of cry bouts were selected to determine the f_o.

To obtain the fundamental frequency, one need only to compute the reciprocal of the period of the first spike: fundamental frequency = 1/period. Thus, the frequency for a waveform that first repeats itself at 2.5^{-3} seconds is computed as follows: fundamental frequency = $1/2.5^{-3}$ = 400 Hz. A similar procedure can be employed for each of the harmonics, where the numerator for the first harmonic equals $2/f_o$, the numerator for the second harmonic equals $3/f_o$, and so forth.

Design

The study employed a repeated-measures within-subjects design, utilizing three independent groups of experimental subjects. Group assignment was determined by the order in which subjects volunteered for the experiment; all data were collected within one month. The first group of twenty subjects rated all 160, 10-second cry segments on a five-point scale of

Nonaversive-Aversive; the second group of twenty subjects rated the same cry segments on a five-point scale of Healthy-Sick; the third group of twenty subjects rated all cry segments on a five-point scale of Nonurgent-Urgent. Each group of subjects rated the cry segments on only one scale to eliminate carry-over effects. The three scales utilized in this study were selected from those employed by Zeskind and Lester (1978, 1982). The scales were chosen because they were hypothesized to represent separate, independent rating categories for the subjects in this study.

<u>Procedure</u>

The experimental stimuli were presented in a quiet room to groups of subjects ranging in number from two to six. Subjects in each group were informed of the purpose of the experiment, of the experimental procedure, and then asked to complete individual consent forms. Prior to the actual experimental cry ratings, four practice cries were played to familiarize subjects with the cry signals. The four practice cries were randomly selected, one from each of the four infants and were not included in the analyses. Having heard the practice cries, the subjects' task was to listen to each 10-second segment and, depending on group assignment, to rate each on the five-point scale assigned to that group: Nonaversive-Aversive, Healthy-

Sick, or Nonurgent-Urgent. Each subject was provided with a copy of the rating scale appropriate to his/her condition and a computer scan sheet.

Each cry segment was individually announced to subjects (e.g., "Cry number 1"), played for 10 seconds, and followed by a five-second pause during which subjects rated the cry segment. The stimulus tape was played to subjects through a Panasonic RX CD70 tape recorder. Experimental subjects listened to the cries through Realistic NOVA 33 headphones and marked a response on a computer scan sheet after each cry segment. Subjects rated the first 80 cry segments, took a brief rest, and then rated the final 80 cry segments. An experimental session took approximately 80 minutes.

RESULTS

Cry Characteristics

As shown in Appendix E, f_0 varied across each of the 10-second segments for each of the four infants' cries. The fundamental was assessed 12 times for the cry of each infant; mean f_0 and the SD of the f_0 were computed from these values. The mean f_0 did not vary significantly between the four cries; the SD differences were quite marked. It should be noted that the manipulations performed in this experiment did not affect the frequency of the fundamental, they affected only the relative power of 1000-Hz bandwidths, the lowest of which contained the fundamental. The mean duration of cry bouts was also assessed across each of the infants' cries; no significant differences were found (Appendix E).

Reliability of Ratings

Each of the 16 control segments was placed on the experimental cry tape twice. Correlations of those matched pairs of unmanipulated cries across all 60 subjects showed that 14 of 16 pairs were significantly correlated at $r = .32$ or greater (see Table 1).

Table 1

Correlations of Unmanipulated Cry Segments for Total Ratings, Aversive Ratings, Sick Ratings, and Urgent Ratings[1]

	Total ($\underline{n}$=60)		Aversive ($\underline{n}$=20)		Sick ($\underline{n}$=20)		Urgent ($\underline{n}$=20)	
Pair	r	p	r	p	r	p	r	p
1	.38	.002	.43	.029	.33	.079	.39	.004
2	.32	.007	.18	.218	.42	.034	.29	.110
3	.32	.007	.30	.102	.26	.135	.34	.074
4	.61	.000	.31	.094	.69	.000	.75	.000
5	.40	.001	.36	.061	.37	.054	.09	.345
6	.66	.000	.61	.002	.57	.005	.38	.050
7	.38	.002	.44	.026	.25	.142	.48	.016
8	.13	.171	-.07	.373	-.11	.326	.17	.232
9	.46	.000	.35	.066	.58	.004	.34	.073
10	.41	.001	.26	.137	.47	.018	.19	.210
11	.70	.000	.37	.053	.83	.000	.67	.001
12	.15	.122	.23	.167	.11	.315	.03	.444
13	.69	.000	.47	.019	.72	.000	.31	.090
14	.42	.000	.53	.010	.30	.101	.16	.254
15	.43	.000	.38	.056	.55	.006	.26	.135
16	.34	.004	.24	.153	.52	.009	.29	.106
$\underline{M}$ =	.43		.34		.43		.32	
SD =	.17		.16		.24		.19	

[1] Correlated data points are matched pairs of unmanipulated cry segments.

Overall, subjects' ratings on the three scales were consistent; only the correlations for pair number eight and pair number twelve were not significant, although it is unclear why those ratings were not correlated. Since both cries with nonsignificant correlations were taken from the last minute of the four minute cries, it may be that the signals were less distinctive than those of cry segments sampled earlier in the four-minute cry. That is, the cries may reflect decreased infant arousal, resulting in a cry signal with few distinctive features, or a relatively flat melodic form. Cries of this type may suggest some state not assessed by the rating scales in this study. For instance, subjects might have perceived the cries as "tired", but not aversive, sick, or urgent.

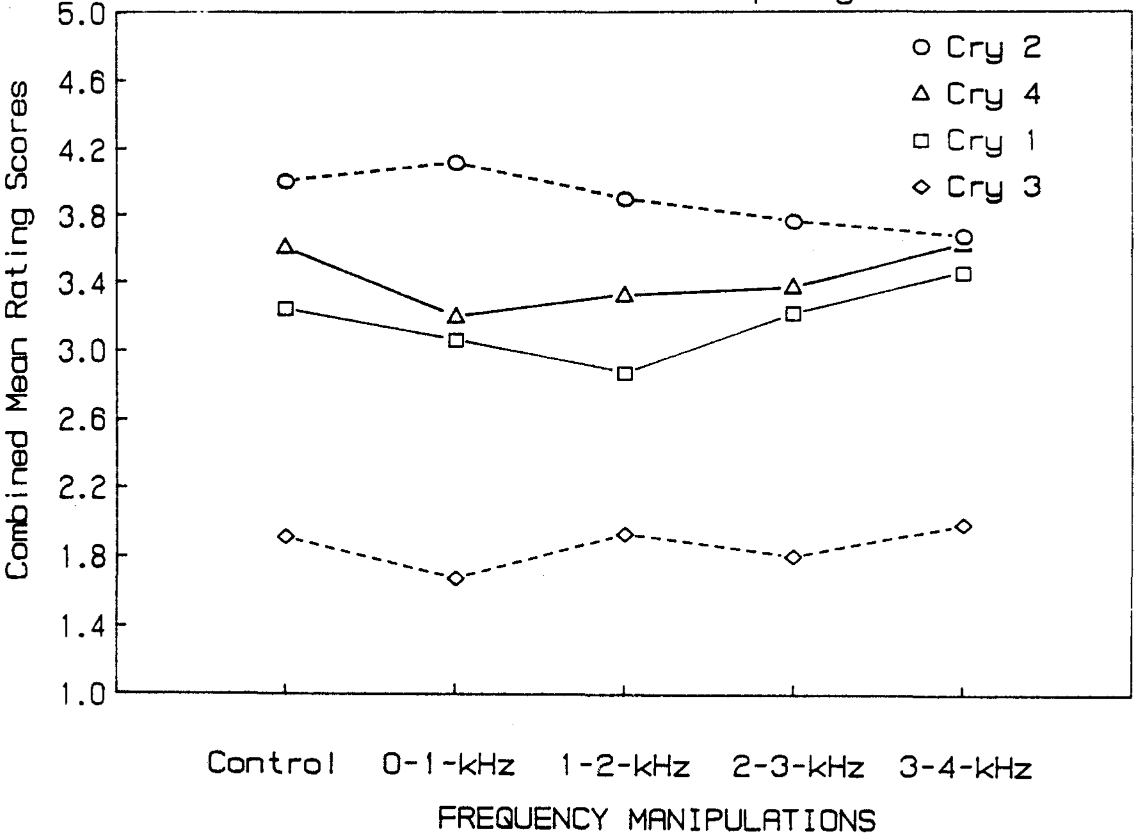
Overall Analyses

Effects of gender. As expected, sex of subject had no effect on the ratings by experimental participants.

Comparisons between infant cries. A comparison of the four infants' cries collapsed across rating scales and acoustic manipulations showed that subjects clearly differentiated between the cries themselves, $F(3, 177) = 194.43$, $p < .001$; those differences remained regardless of the dimension along which the cries were rated (see Figure 2), although the distinction was less

Figure 2. Summary of mean ratings for 10-second cries incremented in 1000-Hz frequency bands.

Summary of Mean Ratings for 10-Second
Cries Incremented in 1000-Hz Frequency Bands



clear on the Healthy-Sick scale. Cry 3 was rated as least aversive, most healthy, and least urgent (M = 1.93, SD = 0.52) while Cry 2 was rated as most aversive, most sick, and most urgent (M = 3.91, SD = 0.59). Cry 1 and Cry 4 fell between the two extremes (M = 3.23, SD = 0.51 and M = 3.52, SD = 0.51) respectively. Ratings of each cry were nearly identical to the pilot study ratings, which employed the Aversive scale.

Ceiling and floor effects. Since Cry 2 demonstrated a high percentage of ratings equal to or greater than 4.0 on a five-point scale across the three rating scales (M = 57.71%, SD = 10.65%) and Cry 3 had a high percentage of ratings equal to or less than 2.0 (M = 70.21%, SD = 8.28%), it appeared that ceiling and floor effects, respectively, were present. While these outcomes were disappointing, Cry 2 and Cry 3 were included in the study because they were believed to represent extremes of perceived aversiveness; this appears to have been the case. It is important that they were present in the stimulus set so that the other two cries could be judged in a context of cries whose ratings were more extreme. Since subjects employed a severely constrained range when rating Cry 2 and Cry 3, the two cries were eliminated from further analyses.

Within-Cry Analysis of Frequency Band Manipulations

Significant effects of incremented frequency band manipulations were apparent on the Aversiveness scale for Cry 1 and Cry 4 (see Table 2), and on the Urgent scale for Cry 4 (see Table 3); there were no effects on the Sick scale (see Table 4). A repeated-measures ANOVA performed across the unmanipulated and incremented Cry 1 and Cry 4 segments on the Aversiveness scale revealed a significant effect (Table 3). Likewise, the ANOVA showed an effect of incremented segments on the Urgent scale for cry 4 (Table 4). There were no significant effects for the decremented manipulations for either Cry 1 or Cry 4 on the Aversive, Urgent or Sick scales.

Planned Comparisons

Planned-comparison follow-up tests were employed to compare ratings of each of the four 1000-Hz incremented cry segments with ratings of the unmanipulated cry segments from which they were generated. The same comparisons were performed between the decremented segments and unmanipulated segments. All comparisons employed cry ratings that were collapsed across the four minutes of an individual infant's cries. Thus, for each of the overall Cry 1 and Cry 4 ratings demonstrating statistical significance, the unmanipulated cries were compared to

Table 2

Mean (Standard Deviation) Ratings on Aversiveness Scale[1]

	Incremented Cries						
Cry	Control	0-1kHz	1-2kHz	2-3kHz	3-4kHz	F(4,76)	p
1	3.35 (0.54)	2.81 (0.48)	2.33 (0.68)	3.03 (0.94)	3.75 (0.63)	19.17	.001
4	3.94 (0.68)	3.20 (0.57)	3.35 (0.59)	3.63 (0.47)	4.10 (0.56)	17.80	.001

	Decremented Cries						
Cry	Control	0-1kHz	1-2kHz	2-3kHz	3-4kHz	F(4,76)	p
1	3.35 (0.54)	3.40 (0.62)	3.30 (0.64)	3.36 (0.63)	3.29 (0.58)	0.23	n.s.
4	3.94 (0.68)	4.08 (0.62)	4.10 (0.61)	3.88 (0.64)	3.98 (0.58)	1.48	n.s.

[1] Ratings were entered such that lower values indicate decreased ratings of aversiveness.

Table 3

Mean (Standard Deviation) Ratings on Urgent Scale[1]

Cry	Control	Incremented Cries 0-1kHz	1-2kHz	2-3kHz	3-4kHz	F(4,76)	p
1	3.21 (0.70)	3.15 (0.85)	2.89 (0.67)	3.18 (0.73)	3.19 (0.80)	1.88	n.s.
4	3.55 (0.52)	3.13 (0.50)	3.16 (0.55)	3.28 (0.47)	3.40 (0.48)	4.70	.002

Cry	Control	Decremented Cries 0-1kHz	1-2kHz	2-3kHz	3-4kHz	F(4,76)	p
1	3.21 (0.70)	3.26 (0.63)	3.23 (0.80)	3.23 (0.72)	3.26 (0.63)	0.06	n.s.
4	3.55 (0.52)	3.61 (0.63)	3.64 (0.56)	3.56 (0.54)	3.70 (0.71)	0.53	n.s.

[1] Ratings were entered such that lower values indicate decreased ratings of urgency.

Table 4

Mean (Standard Deviation) Ratings on Sick-Healthy Scale[1]

Incremented Cries							
Cry	Control	0-1kHz	1-2kHz	2-3kHz	3-4kHz	F(4,76)	p
1	3.15 (0.75)	3.21 (0.84)	3.40 (0.50)	3.43 (0.72)	3.41 (0.70)	1.21	n.s.
4	3.35 (0.65)	3.26 (0.56)	3.46 (0.50)	3.20 (0.79)	3.36 (0.63)	1.16	n.s.

Decremented Cries							
Cry	Control	0-1kHz	1-2kHz	2-3kHz	3-4kHz	F(4,76)	p
1	3.15 (0.75)	3.41 (0.63)	3.34 (0.50)	3.35 (0.67)	3.38 (0.62)	0.89	n.s.
4	3.35 (0.65)	3.26 (0.70)	3.33 (0.67)	3.33 (0.65)	3.24 (0.45)	0.29	n.s.

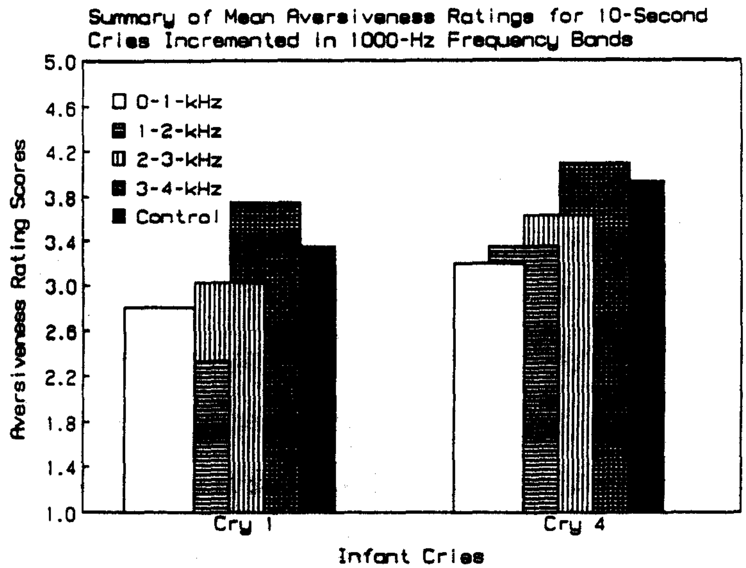
[1] Ratings were entered such that lower values indicate decreased ratings of sickness.

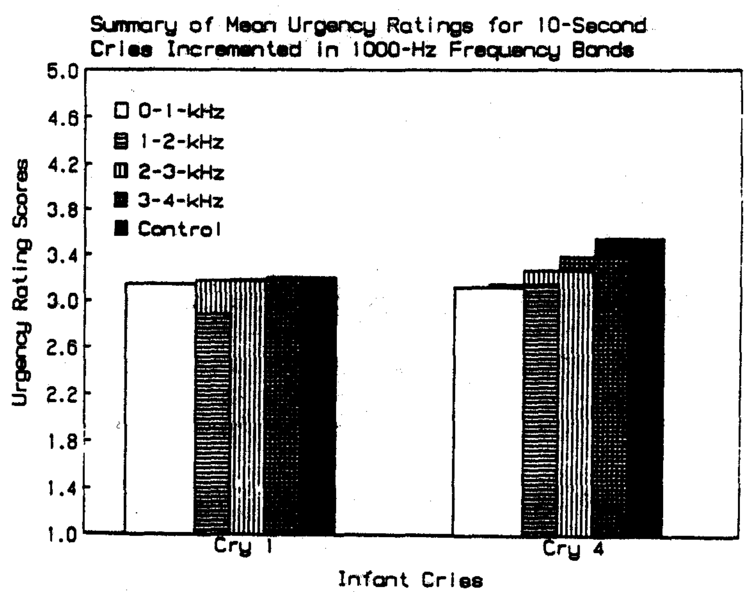
each of the four spectral manipulations.

Aversiveness scale. Ratings of Cry 1 on the Aversiveness scale revealed that, relative to the unmanipulated segments, increments in the 0-1-kHz range resulted in significantly lower ratings, $F(1, 95) = 10.00$, $p < .01$, as did ratings in the 1-2-kHz range, $F(1, 95) = 34.30$, $p < .001$. Conversely, increments in 3-4-kHz range resulted in significantly greater ratings of aversiveness, $F(1, 95) = 5.28$, $p < .025$. Similar comparisons of Cry 4 ratings revealed that increments resulted in significantly lower ratings of aversiveness in the 0-1-kHz range, $F(1, 95) = 33.72$, $p < .001$; in the 1-2-kHz range, $F(1, 95) = 21.43$, $p < .001$; and in the 2-3-kHz range, $F(1, 95) = 5.92$, $p < .025$. As was the case for Cry 1, ratings of aversiveness rose when the 3-4-kHz range was incremented, but the difference from the unmanipulated segments was not significant (see Figure 3).

Urgent scale. Planned comparisons for ratings of Cry 4 on the Urgent scale revealed similar significant differences. Lower ratings of urgency were found when cries were incremented in the 0-1-kHz range, $F(1, 95) = 13.57$, $p < .001$; in the 1-2-kHz range, $F(1, 95) = 11.70$, $p < .001$; and in the 2-3-kHz range, $F(1, 95) = 5.61$, $p < .025$ (Figure 3).

Figure 3. Aversiveness and Urgency ratings for 10-second cries incremented in 1000-Hz frequency bands.


Summary of Mean Aversiveness Ratings for 10-Second Cries Incremented in 1000-Hz Frequency Bands
5.0
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
Aversiveness Rating Scores
0-1-kHz
1-2-kHz
2-3-kHz
3-4-kHz
Control
Cry 1
Cry 4
Infant Cries


Summary of Mean Urgency Ratings for 10-Second Cries Incremented in 1000-Hz Frequency Bands
5.0
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
Urgency Rating Scores
0-1-kHz
1-2-kHz
2-3-kHz
3-4-kHz
Control
Cry 1
Cry 4
Infant Cries

Sick scale. There were no significant effects of the manipulations for Cry 1 or Cry 4 on subjects who employed the Healthy-Sick rating scale.

Between- vs. Within-Cry Variance

A multiple regression was performed to assess the amount of variance accounted for by overall between- and within-cry differences. Overall variance was assessed by forcing the between-cry ratings of Cry 1 and Cry 4 into the equation first, and then performing a stepwise comparison of the within-cry manipulations. The variance due to between-cry differences for Cry 1 and Cry 4 was quite high, $R^2 = .719$. After removing the variance of the between-cry comparisons, no within-cry manipulation accounted for a significant amount of variance. Thus, the within-cry manipulations in this study accounted for a small amount of variance, as compared to the pre-existing between-cry differences, yet subjects were consistently able to detect their presence and respond consistently.

DISCUSSION

The goal of this study was to manipulate power in individual, 1000-Hz bandwidths while controlling all other acoustic variables. Both peak amplitude and total power were controlled within each 10-second segment. Fundamental frequency and cry bout duration for the four cries were not significantly different, and temporal patterns and phonation type were controlled by maintaining them as constants throughout the experiment. In addition, unlike previous studies, independent groups of subjects rated all cries on one scale only, eliminating potential carry-over effects when cries are rated on more than one scale.

The results of this study indicate that within-cry manipulations which incremented 1000-Hz wide frequency bands affected adult perceptions of aversiveness and urgency in infant cries. However, ratings on each dimension were not identical.

It is interesting that subjects' ratings on the Urgent and Sick scales were unaffected by manipulations of the 3-4-kHz region. While increasing power in that range increases perceptions of cry aversiveness, it apparently has little effect on perceptions of the cry's urgency or on perceptions of the infant's health. Since this study employed an independent group of subjects for each rating scale, eliminating carry-over effects from ratings on one scale to the next, the present findings strongly suggest that differences in spectral power across 1000-Hz bandwidths are not relevant for the attributions of urgency or sickness to a cry.

Acoustic manipulations directly influenced subjects' perceptions of the infant cries, but only when power was added to 1000-Hz bands of 10-second cry segments. The most consistent finding for Cry 1 and Cry 4 was a decreased rating of Aversiveness and Urgency when power was added to the lower 1000-Hz frequency bands. An increased rating of Aversiveness resulted when power was added to the 3-4-kHz range.

From a psychoacoustic perspective, it is not surprising that cries with increased power in the 3-4-kHz range were perceived as more aversive. Since the human auditory system is most sensitive to frequencies at approximately 3 kHz (Békésy & Rosenblith, 1951), boosting spectral energy in that range would seem to increase the annoyance value of nearly any broadband sound. In fact, Kryter and Pearsons (1963) reported that across five bandwidths of noise (110 to 7500 Hz, 900 to 1060 Hz, 3120 to 3680 Hz, 625 to 1460 Hz, and

3120 to 7500 Hz), the best fitting line predicted that frequencies in the 3- to 5-kHz region were perceived as loudest.

More surprising are the lower ratings of aversiveness and urgency which resulted from spectral-energy increments in the lower frequency ranges. Unmanipulated control cries in the present study exhibited more energy at approximately 2 kHz than at any other frequency. Boosting energy across the 1000-Hz frequency ranges, particularly in the 0-1-kHz and 1-2-kHz ranges, may have de-emphasized the naturally occurring spectral contour, resulting in a "flattened" broadband spectrum. That is, when power was incremented, there was a much smaller difference in power for the 0-1-kHz range and overall power in the each of the other 1000-Hz ranges and, peak amplitude remained at approximately 2 kHz. Even when the 1-2-kHz and 2-3-kHz bands were incremented, the overall shape of the profile changed relatively little and the peak power remained at approximately 2 kHz. However, when the cry was incremented in the 3-4-kHz range, the peak power shifted from approximately 2 kHz to approximately 3.5 kHz. Since this is centered in the frequency range at which the ear maximally responds, that shift appeared to result in increased perceptions of cry aversiveness.

Although Cry 2 and Cry 3 were eliminated from the analyses, the following observations can be made. Except for the 0-1-kHz increment for Cry 3, ratings for the least aversive cry (3) were such that all manipulated segments (increments and decrements) were more aversive than the mean value of the unmanipulated segments. Conversely, for the most aversive cry (2), all manipulated segments were rated as less aversive than the mean value of the unmanipulated segments. Thus, for a nonaversive cry, nearly any change resulted in increased aversiveness, whereas for a highly aversive cry, each manipulation resulted in decreased aversiveness.

The cries chosen for this study were hunger cries, the type of cry most typical of infants. In general, prototypical hunger cries display a slow onset with a rising-falling melody form. As the cry continues, the onset becomes more abrupt, amplitude increases, and the melody changes to a falling and rarely rising-falling form. Cries following this transformation pattern become similar to prototypical pain cries, indicating a high level of arousal (Zeskind, Sale, Maio, Huntington, & Weiseman, 1985). Many previous studies have assessed the spectral content of pain cries, particularly the auditory output immediately following a painful stimulus (e.g., Zeskind

& Lester, 1978; Zeskind & Marshall, 1988) and then generalize the results across cry types and eliciting situations. Cries elicited by a painful stimulus are relatively uncommon and, therefore, are not the most representative experimental stimuli from which to generalize adult perceptions and ratings of infant cry signals.

The acoustic manipulations appeared to have differential effects, depending on the rating scale and cry employed. For Cry 1, incrementing power in the 3-4-kHz range resulted in higher ratings of aversiveness, but not of urgency or sickness. Cry 1 and Cry 4 power increments in the 0-1-kHz range, in the 1-2-kHz range, and, for Cry 4, in the 2-3-kHz range, resulted in lower ratings of aversiveness. The same manipulations in Cry 4 also resulted in lower ratings of urgency; there was no effect on urgency ratings when 1000-Hz bands were incremented in Cry 1.

These findings argue against the use of multiple rating scales when measuring subjects' perceptions of infant cries. The reported high correlations between acoustic features and perceptual dimensions (e.g., Zeskind & Marshall, 1988) seem most easily explained as experimental carry-over effects, rather than as valid, independent perceptions of infant cries. It seems more likely that subjects rating cries without the benefit of contextual cues (e.g., time since last feeding) would be most likely to categorize cry aversiveness, urgency, and so forth, along a single dimension of annoyance. That is, a cry which was rated as more aversive would seem likely to be rated as more urgent as well.

The cry segments used in this study were sampled across four minutes, rather than employing samples from shorter cries as done in other studies. This methodology, in conjunction with the use of hunger cries, would seem to increase the generalizability of the present results to actual caregiving situations. It is rare for actual infant cries to terminate after a few seconds, although infant cries which have been sampled across only a few seconds of the entire cry duration provide the stimuli for the majority of cry studies.

The findings of the present study differ, in part, from those of Gustafson and Green (1989) who reported that annoyance ratings increased as amount of energy decreased at lower frequencies, particularly in the 0-1-kHz range. Cry segments which were decremented in this study were not found to differ from control cries. However, the authors also reported that cries with greater energy in the 3-4-kHz range were perceived as more annoying. That result was replicated in the present study when employing the Aversiveness scale for Cry 1; there was a similar, but nonsignificant, trend for Cry 4. However, it should be noted that the experimental stimuli for the two studies were qualitatively different.

Gustafson and Green (1989) examined percent of relative power which was contained in each 1000-Hz frequency band. By definition, greater power in one frequency band requires that there be less in some other frequency band(s). In fact, correlation coefficients representing the relationship of eight Aversiveness scale items to percent power in 1000-Hz bandwidths showed nearly identical values for cries with a lower percent of energy in the 0-1-kHz range when compared to cries containing a higher percent of energy in the 3-4-kHz range. However, coefficient valences of the former were negative while those of the latter were positive. Similar outcomes were reported for the relationship between the same 1000-Hz frequency bands and ratings of nine Semantic Differential items (e.g., unpleasant, sharp, rugged, etc.).

The employment of digital-processing software allowed for direct manipulation of spectral power across the time-varying infant cries. Power in selected 1000-Hz bandwidths was manipulated while all other variables were controlled by maintaining them as constants. These manipulations allowed for a direct test of the impact of spectral power shifts across 1000-Hz frequency ranges in the broadband cry. In addition, the employment of independent groups of subjects, each of which rated cries on a single dimension, eliminated potential carry-over from ratings on one dimension to ratings on the next. As shown in this study, overall ratings on each dimension were clearly different, indicating that the findings of previous studies may need to be re-examined.

Future Studies

While the spectral power increments were shown to affect subjects' ratings of aversiveness and urgency of the cry signal, it is unclear how these differential perceptions of infant cries would translate into actual behavioral responses. One would suspect that caregivers might respond more quickly to hunger cries perceived as urgent or aversive. Murray (1985) reported that experienced caregivers responded with greater self-ratings of sympathy to hunger cries than to pain or birth cries. However, Frodi, Lamb, Leavitt, Donovan, Neff and Sherry (1978) suggested that infant cries may elicit maltreatment if they are perceived as particularly aversive by their parents.

In the above studies, subjects were not required to perform an actual caregiving task, only to rate how they might respond and/or how they perceived the infant. In addition, the subjects had no knowledge of the events preceding the cry (e.g., a painful stimulus or the time since last feeding). While perception of the cry signal is an important factor in caregiver-infant interactions, those perceptions do not translate directly into caregiver behavior.

A simulation paradigm has been developed which will allow experimenters to test actual caregiving behaviors while controlling the auditory stimulus and subjects' knowledge of events which preceded the cries. Gustafson and Harris (1990) reported that subjects who "babysat" for a life-like infant manikin behaved in a manner consistent with that expected when caring for a real infant. Subjects rocked the "baby", talked to it, checked its diaper, and gave it a pacifier. Given the perceptual outcomes of the present study, the next step should be an introduction of the modified cry stimuli into a caregiving simulation study. After all, the eventual goal of the majority of infant cry studies, including the present study, is to predict the impact of the cry signal on caregiver-infant interactions, and on the developmental implications of those interactions.

Endnotes:

1 In comparison to the cries of an infant, the f_0 of a middle C played on a piano is 256 Hz, and the mean amplitude of a subway train in 80 dB, while the amplitude of a city bus is 82 dB (Eldred, 1976).

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Appendix A

Glossary of Terms

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amplitude - a measure of the displacement of a vibrating medium from equilibrium. In general, as displacement increases, subjective estimates of loudness increase.

formant frequency - the frequency(s) at which a system will respond with maximum amplitude, sometimes termed the resonant frequency(s) of a system. Resonant frequencies depend on the physical properties of a system such as the diameter and length of the vocal tract.

frequency - a measure of the rate of vibration or oscillation, expressed in Hertz (Hz) or cycles per second (cps). In general, as frequency increases, subjective estimates of pitch increase.

fundamental frequency (f_o) - the lowest mode of vibration of a complex waveform.

harmonics - modes of vibration which are integer multiples of the fundamental frequency. For a tone which has a fundamental frequency of 400 Hz, the first harmonic (f_1) is 800 Hz, the second harmonic (f_2) is 1200 Hz, and so forth.

Hertz (Hz)- a unit of measure of the frequency of vibration which is synonymous with cycles per second.

peak frequency - the frequency in a spectral profile with the greatest amplitude.

pitch - a subjective property of sound which allows a listener to rank order auditory stimuli from highest to lowest. Typically, as frequency increases so do ratings of pitch.

spectral profile - the distribution of energy across the frequency domain, with pressure or power plotted as a function of frequency.

Appendix B

Table listing all Control (unmanipulated), Incremented, and Decremented 1000-Hz Bandwidth, 10-second Cry Segments[1].

Cry Segment Labels								
Control Segments	Manipulated Segments							
	Increments				Decrements			
	0-1k	1-2k	2-3k	3-4k	0-1k	1-2k	2-3k	3-4k
Cry 1								
1	101	102	103	104	105	106	107	108
2	201	202	203	204	205	206	207	208
3	301	302	303	304	305	306	307	308
4	401	402	403	404	405	406	407	408
Cry 2								
5	501	502	503	504	505	506	507	508
6	601	602	603	604	605	606	607	608
7	701	702	703	704	705	706	707	708
8	801	802	803	804	805	806	807	808
Cry 3								
9	901	902	903	904	905	906	907	908
10	1001	1002	1003	1004	1005	1006	1007	1008
11	1101	1102	1103	1104	1105	1106	1107	1108
12	1201	1202	1203	1204	1205	1206	1207	1208
Cry 4								
13	1301	1302	1303	1304	1305	1306	1307	1308
14	1401	1402	1403	1404	1405	1406	1407	1408
15	1501	1502	1503	1504	1505	1506	1507	1508
16	1601	1602	1603	1604	1605	1606	1607	1608

[1] Numbers in this table represent cry segment labels only. Segments numbered 1 through 16 are controls. Segments numbered 101 through 1608 are manipulated. Manipulated segments with ending values from 1-4 (e.g., 501-504) are incremented; those ending in 5-8 (e.g., 505-508) are decremented.

Appendix C

List of Stimulus-Tape Amplitude and ILS Scaling Factor Manipulations for Each Cry Segment

Cry Segments	Range in kHz	dB Change	Scaling Factors
1	0-10	+2	-- ---
101	0-1	-3	45, 450
102	1-2	-1	25, 250
103	2-3	-1	25, 250
104	3-4	-1	45, 450
105	0-1	+2	10, 100
106	1-2	+3	10, 100
107	2-3	+3	12, 120
108	3-4	-1	12, 120
2	0-10	+1	-- ---
201	0-1	-2	50, 500
202	1-2	-3	25, 250
203	2-3	-1	25, 250
204	3-4	+1	30, 300
205	0-1	0	12, 120
206	1-2	+3	12, 120
207	2-3	+2	12, 120
208	3-4	+2	10, 100
3	0-10	+3	-- ---
301	0-1	0	60, 600
302	1-2	0	25, 250
303	2-3	-1	25, 250
304	3-4	+1	30, 300
305	0-1	0	12, 120
306	1-2	+1	12, 120
307	2-3	+3	12, 120
308	3-4	+2	10, 100

Appendix C (continued)

Appendix C (continued)

Cry Segments	Range in kHz	dB Change	Scaling Factors
4	0-10	+2	-- ---
401	0-1	+1	60, 600
402	1-2	-1	25, 250
403	2-3	+3	20, 200
404	3-4	+1	25, 250
405	0-1	+1	10, 100
406	1-2	+3	10, 100
407	2-3	+3	10, 100
408	3-4	+2	10, 100
5	0-10	+1	-- ---
501	0-1	+3	60, 600
502	1-2	-1	35, 350
503	2-3	-1	20, 200
504	3-4	-1	50, 500
505	0-1	-1	15, 150
506	1-2	+1	10, 100
507	2-3	+3	10, 100
508	3-4	+1	10, 100
6	0-10	+2	-- ---
601	0-1	+3	60, 600
602	1-2	-1	30, 300
603	2-3	0	20, 200
604	3-4	+1	40, 400
605	0-1	+2	10, 100
606	1-2	+2	10, 100
607	2-3	+4	10, 100
608	3-4	+1	10, 100

Appendix C (continued)

Appendix C (continued)

Cry Segments	Range in kHz	dB Change	Scaling Factors
7	0-10	+1	-- ---
701	0-1	+2	60, 600
702	1-2	0	30, 300
703	2-3	-3	18, 180
704	3-4	-1	25, 250
705	0-1	-1	12, 120
706	1-2	0	12, 120
707	2-3	+4	10, 100
708	3-4	+1	10, 100
8	0-10	+4	-- ---
801	0-1	+3	70, 700
802	1-2	-1	50, 500
803	2-3	-1	25, 250
804	3-4	+1	10, 100
805	0-1	-1	15, 150
806	1-2	+1	15, 150
807	2-3	+3	15, 150
808	3-4	0	15, 150
9	0-10	+3	-- ---
901	0-1	-1	70, 700
902	1-2	0	50, 500
903	2-3	-2	35, 350
904	3-4	-2	35, 350
905	0-1	+1	12, 120
906	1-2	+2	12, 120
907	2-3	+3	12, 120
908	3-4	+2	12, 120

Appendix C (continued)

Appendix C (continued)

Cry Segments	Range in kHz	dB Change	Scaling Factors
10	0-10	+3	-- ---
1001	0-1	-2	50, 500
1002	1-2	+2	50, 500
1003	2-3	0	25, 250
1004	3-4	-1	50, 500
1005	0-1	0	15, 150
1006	1-2	0	15, 150
1007	2-3	+2	15, 150
1008	3-4	+2	12, 120
11	0-10	+2	-- ---
1101	0-1	-1	60, 600
1102	1-2	-1	50, 500
1103	2-3	-3	30, 300
1104	3-4	-2	40, 400
1105	0-1	0	12, 120
1106	1-2	+1	12, 120
1107	2-3	+3	12, 120
1108	3-4	+2	12, 120
12	0-10	+3	-- ---
1201	0-1	-2	50, 500
1202	1-2	+1	35, 350
1203	2-3	-2	25, 250
1204	3-4	-2	45, 450
1205	0-1	+1	12, 120
1206	1-2	+2	12, 120
1207	2-3	+3	12, 120
1208	3-4	+2	12, 120

Appendix C (continued)

Appendix C (continued)

Cry Segments	Range in kHz	dB Change	Scaling Factors
13	0-10	+1	-- ---
1301	0-1	-1	45, 450
1302	1-2	-1	45, 450
1303	2-3	0	30, 300
1304	3-4	0	30, 300
1305	0-1	+2	10, 100
1306	1-2	+2	10, 100
1307	2-3	+3	9, 90
1308	3-4	+2	9, 90
14	0-10	+1	-- ---
1401	0-1	-2	50, 500
1402	1-2	-1	50, 500
1403	2-3	-1	25, 250
1404	3-4	-1	40, 400
1405	0-1	+2	10, 100
1406	1-2	+3	10, 100
1407	2-3	+3	10, 100
1408	3-4	+2	10, 100
15	0-10	+2	-- ---
1501	0-1	+1	50, 500
1502	1-2	0	40, 400
1503	2-3	-1	30, 300
1504	3-4	-1	40, 400
1505	0-1	+1	10, 100
1506	1-2	+3	10, 100
1507	2-3	+3	10, 100
1508	3-4	+3	10, 100

Appendix C (continued)

Appendix C (continued)

Cry Segments	Range in kHz	dB Change	Scaling Factors
16	0-10	+2	-- ---
1601	0-1	-1	45, 450
1602	1-2	+1	40, 400
1603	2-3	0	30, 300
1604	3-4	0	35, 350
1605	0-1	+3	10, 100
1606	1-2	+1	10, 100
1607	2-3	+2	10, 100
1608	3-4	+2	10, 100

Appendix D

<u>Stimulus-tape order of block-randomized 10-second infant cry segments</u>[1].

<u>Order</u> <u>Segment</u> etc.

1	102	36	406	71	702	106	205	141	501
2	204	37	503	72	806	107	301	142	601
3	302	38	606	73	1	108	4	143	703
4	407	39	701	74	2	109	504	144	807
5	506	40	8	75	3	110	602	145	907
6	604	41	905	76	4	111	704	146	1001
7	708	42	1003	77	5	112	805	147	1103
8	804	43	1101	78	6	113	908	148	1205
9	901	44	1203	79	7	114	1007	149	13
10	10	45	1304	80	8	115	11	150	1403
11	1104	46	1402	81	902	116	1206	151	1507
12	12	47	1508	82	1004	117	1308	152	1608
13	1303	48	601	83	1105	118	1407	153	9
14	14	49	104	84	1204	119	15	154	10
15	1502	50	203	85	1301	120	1604	155	11
16	1602	51	307	86	1404	121	108	156	12
17	105	52	408	87	1504	122	2	157	13
18	208	53	508	88	1606	123	306	158	14
19	308	54	603	89	1	124	405	159	15
20	403	55	707	90	201	125	5	160	16
21	502	56	802	91	304	126	6		
22	607	57	906	92	402	127	705		
23	7	58	1005	93	507	128	803		
24	808	59	1102	94	608	129	903		
25	904	60	1202	95	706	130	1002		
26	1006	61	1305	96	801	131	1107		
27	1106	62	1406	97	9	132	1208		
28	1207	63	1501	98	1008	133	1302		
29	1307	64	1605	99	1108	134	1405		
30	1401	65	107	100	1201	135	1505		
31	1506	66	207	101	1306	136	16		
32	1607	67	3	102	1408	137	103		
33	106	68	404	103	1503	138	202		
34	206	69	505	104	1603	139	305		
35	303	70	605	105	101	140	401		

[1] The order of infant cry stimuli is followed by the cry segment labels listed in Appendix B.

Appendix E

Summary Table of Fundamental Frequency and Duration of the 16, 10-second Control (unmanipulated) Infant Cry Segments.

Cry Segment	Sample Number	Fundamental Frequency	Number of Bouts	*M* duration in sec.
Infant Cry 1				
1	1	370	7	.904 (.537)
	2	313		
	3	286		
2	1	313	5	1.664 (.928)
	2	303		
	3	323		
3	1	328	7	1.119 (.531)
	2	308		
	3	278		
4	1	345	7	.622 (.441)
	2	278		
	3	215		
	Mean	305.00		1.032
	SD	(39.01)		(.708)

Appendix E (continued)

Appendix E (continued)

Cry Segment	Sample Number	Fundamental Frequency	Number of Bouts	*M* duration in sec.
Infant Cry 2				
5	1	388	8	.997 (.396)
	2	426		
	3	426		
6	1	418	7	.940 (.141)
	2	429		
	3	403		
7	1	213	5	1.178 (.285)
	2	178		
	3	263		
8	1	370	11	.583 (.202)
	2	206		
	3	222		
	Mean *SD*	328.25 (102.05)		.858 (.343)

Appendix E (continued)

Appendix E (continued)

Cry Segment	Sample Number	Fundamental Frequency	Number of Bouts	*M* duration in sec.
Infant Cry 3				
9	1	333	8	.978 (.504)
	2	377		
	3	400		
10	1	417	7	1.348 (.408)
	2	400		
	3	267		
11	1	435	5	.737 (.431)
	2	270		
	3	333		
12	1	500	7	1.046 (.638)
	2	278		
	3	286		
	Mean *SD*	358.00 (75.27)		1.057 (.533)

Appendix E (continued)

Appendix E (continued)

Cry Segment	Sample Number	Fundamental Frequency	Number of Bouts	*M* duration in sec.
<u>Infant Cry 4</u>				
13	1	385	5	1.806 (.261)
	2	357		
	3	370		
14	1	351	7	1.258 (.248)
	2	345		
	3	353		
15	1	364	6	1.472 (.366)
	2	333		
	3	385		
16	1	323	6	1.233 (.521)
	2	351		
	3	345		
	Mean *SD*	355.17 (18.72)		1.419 (.423)

APPROVAL SHEET

The dissertation submitted by Jerry W. Cleland has been read and approved by the following committee:

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The final copies have been examined by the director of the dissertation and the signature which appears below verifies that fact that any necessary changes have been incorporated and the dissertation is now given final approval by the Committee with references to content and form.

The dissertation is therefore accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June 27, 1990 | Raymond H. Dye, Jr.
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