DETECTION BY ADULTS OF DIFFERENCES IN THE DURATION
OF PAUSES IN INFANT CRIES

by

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Abstract

Crying is the primary source of distal communication through which newborn and young infants' needs are related to the caregiving environment and, as such, this social behavior is vital to the survival and development of the infant. Recently, a series of experimental studies has begun to isolate the effects of specific durational components of crying on adults' perceptions of infant cries. These studies have found the duration of pauses within and between cries to be perceptually salient features, however, the point at which adults were able to detect changes in the duration of the pauses was not addressed.

Seventy-five introductory psychology students participated in three experiments designed to determine Difference Thresholds for the point at which manipulations in the durations of pauses before and after the inspiration in infant cries were detectable by the adult listener. The Difference Threshold for the pause before the inspiration
(PBI) with the duration of the pause after the inspiration (PAI) held constant was an increase of 354.18% in the duration of the PBI. Difference Thresholds for increases and decreases in the duration of the PAI were 58.53% and -61.91%, respectively. For increases and decreases in the duration of the PAI with a perceptibly longer PBI, Difference Thresholds were 39.82% and -57.6%, respectively. The Difference Threshold for an increase in the duration of the PBI with a perceptibly shorter duration of the PAI was 420.06% and the Difference Threshold for a decrease in the duration of the PBI with a perceptibly longer duration of the PAI was 485.61%. Results provided the first known experimental evidence of the point at which changes in the durations of pauses before and after the inspiration in infant crying are detectable by adult listeners.
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Historical Overview of Research on Infant Crying

The study of infant crying may provide a window through which to view processes underlying early infant development (Zeskind, 1985). Physiologically, crying may contribute to the survival of the infant by closing the respiratory ducts, thus reorganizing the cardiorespiratory system. In addition, crying increases pulmonary capacity and aids the newborn infant in maintaining homeostasis. As a social behavior, crying, concurrently, serves to distally communicate the survival needs of infants to the caretaking environment. Several features of cries, such as their volume and their length and broadness in spectral characteristics make them ideal for communicating these needs over distances (Waser & Waser, 1977).

As a form of communication, crying carries information that is able to alter the behavioral response of the receiver. According to Hinde (1974), signals such as cries carry messages that result in an instantaneous response by the caregiver. Crying, as a form of early communication, contributes to infant development via its role in the bidirectional interaction between the infant and caregiving environment. For example, a wide range of studies shows how variations in cry sounds differentially affect the
perceptions, physiology, and responses of adult listeners, and how the responses of listeners feed-back to alter the behavior and development of the infant (Lester, 1984; Lester & Zeskind, 1982; Zeskind, 1985).

Recognizing the social value of infant crying, researchers have long explored the effect of variations in cry sounds on caregivers. One long-held assumption has been that cries are discrete signals which reflect the specific needs of the infant. This has led researchers to focus on whether adults can identify the eliciting stimulus of cries. In an early study, Sherman (1927) elicited crying in infants who ranged in age from three to seven days. Sherman used four conditions including hunger, elicitation of the Moro reflex, restraint of the infant’s head, and the prick of a needle to elicit supposedly different cry sounds. Subjects were mothers, nurses and graduate students. They were unable to identify the eliciting stimulus of the cry sounds. In fact, a wide range of possible emotions including colic, rage, hunger and organic brain emotion were proposed as causes of the cry sounds. Based on these data, Sherman concluded that cries cannot be perceptually associated with the eliciting stimulus and, more generally, that cries do not communicate specific information about their causes to the environment.

The attempt to examine whether adults are able to
identify the eliciting conditions of infant cry sounds has continued into the relatively recent past. Using a similar paradigm, Muller, Hollien and Murry (1974) presented tape-recorded cries to mothers of their own infants. These cries were elicited by 1) snapping the infant’s foot with a rubber band, 2) clapping large wooden blocks together behind the infant, and 3) halting a normal feeding a few seconds after onset. These stimuli were used to supposedly produce pain, startle and hunger cries, respectively. Because mothers were unable to accurately identify the evoking stimuli of cries, even of their own infants, Muller et al. (1974) concluded that cries do not communicate specific messages to the caregiving environment.

These two studies are examples of a research paradigm in which an underlying assumption is that cries elicited by any number of stimuli have idiographic sounds. However, the acoustic features of the cries used in the above studies were not measured to determine whether, in fact, the cries actually differed in sound. It may be that the conditions used to elicit supposedly different cries did not result in cries with different acoustic features. For example, measurement of the cry stimuli used by Muller et al. (1974) showed that there were no differences among cry sounds in fundamental frequency (Murry, Admunson & Hollien, 1977). Subsequent work has indicated that variations in the
fundamental frequency may be particularly salient in the process of perceptual differentiation (Freudenberg, Driscoll & Stern, 1978; Gustafson & Green, 1989; Zeskind & Collins, 1987; Zeskind & Lester, 1978; Zeskind & Marshall, 1988). These results may help explain why the earlier results showed that cries could not be identified by different eliciting stimuli.

In contrast to the previous paradigm, another research perspective has been to measure how specific acoustic features of cries are associated with different eliciting conditions. Wasz-Hockert, Lind, Vuorenkoski, Partanen and Valanne (1968), for example, described differences in a wide range of acoustic characteristics of cries that were associated with four eliciting conditions. The four cry types were categorized as 1) birth cries, recorded when the infant’s head was delivered; 2) pain cries, recorded during vaccinations or skin pinches; 3) hunger cries, which were collected four hours following a feeding when all other plausible causes of crying were eliminated; and 4) pleasure cries, defined as sounds made when the infant was comfortable with all possible distressing conditions eliminated. They then examined whether adults could perceptually differentiate these four cry sounds. In general, adults were able to differentiate among the various cry sounds, particularly if they had experience with
infants.

While this work provided pioneering analyses of the acoustic features of cries, the way in which categories of cries were defined may have been inappropriate. It has been argued that two of Wasz-Hockert’s categories of crying may not be valid as separate categorizations (Zeskind & Huntington, 1984). Pleasure cries were vocalizations of 7 to 9 month-old infants that were emitted when the infant was not distressed. These vocalizations consisted primarily of cooing and babbling and are not appropriate for most definitions of crying in newborn and young infants. In addition, the spectrographic characteristics of birth cries differ from pain cries only in that birth cries usually have greater amounts of turbulence or "noise". This acoustic feature is a consequence of the fluid still remaining in the infant’s respiratory system after the birth process. Thus, birth cries appear to be a variation of the pain cry rather than a distinct category of cries. In essence, this study indicates that cries associated with painful and hunger conditions can be perceptually differentiated.

In a parallel approach, Wolff (1967) examined differences among the temporal features of cries via use of the sound spectrograph. He systematically described the temporal components of infant crying as composed of four components; 1) the expiration, or actual cry sound, 2) a
short pause, 3) the inspiration, and finally, 4) a second pause, which is followed by the next expiration. By measuring the durations of these features in one infant, Wolff (1967) described the temporal morphology of cries associated with different conditions: a hunger or basic cry, a pain cry and a mad cry. Hunger (or basic) cries occurred shortly before an infant’s regularly scheduled feeding and were characterized by a rhythmical repetition of an expiratory sound, averaging approximately .62 sec., a pause before inspiration, averaging approximately .08 sec., an inspiration, averaging approximately .03 sec., and a final pause, averaging approximately .17 sec. The pain cry had longer initial expiratory sounds (up to six times longer than in the basic cry), inspirations and pause periods than the basic cry (mean duration of the expiratory sound = .62 sec.). The mad cry (expiratory sound mean duration = .69 sec.) was rhythmically similar to the hunger cry and was differentiated only by greater amounts of turbulence. Thus, differences in the durational features exist among cry sounds from different eliciting conditions.

Cries as Graded Signals

Another approach to the study of crying focuses on cries as graded signals (Murray, 1979; Zeskind, Sale, Maio, Huntington, & Weisman, 1985; Zeskind & Stern, 1975). Unlike discrete signals which operate in an on-off manner,
graded signals may vary along a continuum which expresses the motivational level of the communicator (Murray, 1979). Variations in that level are reflected in variations in the durations, frequency and intensity of the signal. Thus, according to Murray (1979), the meaning of graded signals is dependent on variations in acoustic cues which result from variations in the motivational level of the signaler. As such, Murray (1979) argued that it is not practical to separate cries by eliciting conditions. Instead, the acoustic features within the cries should be examined. Since cries reflect the motivational and arousal level of the infant, their relation to adult perceptions and the communication of specific needs of the infant to the environment should also be explored.

Zeskind et al. (1985) provided the first experimental evidence that cries function as graded signals and that changes in adults’ perceptions of cries are associated with the dynamic nature of these signals. The first, middle and last 10-second portions of pain and hunger cries were presented to subjects who were asked to rate them on 7-point Likert-type scale items which included items such as how aversive and arousing the cry sounded. Arousal, according to the authors, referred to the raters’ own perceived arousal. Subjects found the first two segments of the pain cry to be more aversive and arousing than the last segment.
They also found the hunger cry to be increasingly more aversive and arousing from the first to the middle to the final segments. These results were described in terms of a synchrony of arousal in which increases and decreases in the infants' level of arousal were reflected in changes in cry sounds which then resulted in synchronous changes in adults' perceptions of arousal. In other words, as the infant's level of arousal increased, related changes in cry sounds increased the level of arousal in adults. Importantly, these results showed that different portions of a cry in response to a single eliciting stimulus may communicate different messages to the caregiving environment.

**Role of Fundamental Frequency on Perceptions of Cries**

The view of cries as graded signals changed the focus of research from the categorization of cry types to the examination of specific acoustic features and their effect on adults' perceptions. Traditionally, the fundamental frequency (basic pitch) of cries has been the feature of choice in studies of adult perceptions (Wasz-Hockert et al., 1968; Zeskind & Lester, 1978). The role of the fundamental frequency has its roots in the study of infants who are at risk for nonoptimal development. Infants who show a wide range of prenatal (Lester & Dreher, 1989; Lester, Garcia-Coll, Valcarcel, Hoffman, & Brazelton, 1986; Zeskind, 1983b; Zeskind & Lester, 1981) and perinatal (Lester & Zeskind,
1978; Michelsson, 1971; Zeskind & Lester, 1978) conditions that place the infant at risk for nonoptimal development have cries characterized by a distinctive high-pitched sound. Studying adults' perceptions of these cries was instigated to examine the functional effect of these cries on the bidirectional interaction between infants and caregivers.

Research on the fundamental frequency of cries initially addressed whether adults can perceptually differentiate groups of cries from low- and high-risk infants. In general, cries with higher fundamental frequencies (1000-2000 Hz) are perceived as more aversive, urgent, arousing, and sick sounding than cries with a typical (350-550 Hz) fundamental frequency (Zeskind & Lester, 1978), and seem to elicit responses that promote contact between the infants and the caregivers (Zeskind, 1980). These perceptual responses to the cries of high-risk infants are also evident in mothers across several cultures (Zeskind, 1983a). Similarly, cries with a typical fundamental frequency are perceived as more urgent and aversive than cries with a lower, atypical fundamental frequency. A study by Freudenberg et al. (1978) showed that low fundamental frequencies in cry sounds affected adult perceptions. The fundamental frequency of the cries of infants with Down's syndrome is significantly lower (250 Hz)
than the cries of normal infants. Normal infants were perceived as needing more attention and their cries were rated as more unpleasant than the cries of the Down’s syndrome infants. Thus, these results suggest that lower pitched cries are not as urgent sounding or unpleasant as the cries of normal infants which have a somewhat higher fundamental frequency. Together, these results show that, along a continuum from atypically low to typical to atypically high fundamental frequencies, cries elicit increasingly urgent responses from caregivers.

The view of cries as graded signals has prompted recent studies to examine the continuum of gradations in specific acoustic features. In contrast to studying whether groups of cries can be perceptually differentiated, these studies examined the effects of gradations in acoustic features of cries on adults’ perceptions. Zeskind and Marshall (1988) examined the association between variations in three measures of pitch and adults’ perceptions. Results showed that increases in the peak, mean, and variability of the fundamental frequency were reliably related to increases in multiparous mothers’ ratings of how urgent, arousing, distressing, and sick the cry sounded. Whereas multiple regression analyses showed the mean fundamental frequency to be the best predictor of how urgent \( r^2 = 0.58 \), arousing
(r^2 = .56) and distressing (r^2 = .53) the cries were perceived, the variability of the fundamental frequency was the best predictor of how sick the infant sounded (r^2 = .63). According to these results, linear increases in several measures of the fundamental frequency were related to linear increases in the intensity of adult perceptions. Although much of the research investigating the effects of pitch on adults’ perceptions were based on the study of cries with atypical ranges of the fundamental frequency, other work has pointed to the linear relation between adults’ perceptions and variations in the fundamental frequency within a typical range of sound. Gustafson and Green (1989) found that adults’ ratings of cries of thirty-day-old infants within a fundamental frequency range of 340-470 Hz. were related to the fundamental frequency. As the fundamental frequency of cries within a normal frequency range increased, adults rated the cries as more urgent, distressing, arousing, sick, grating, discomforting, piercing and aversive.

Importantly, the linear relations between fundamental frequency and adults’ perceptions found in the laboratory have also been found in a more naturalistic setting. Zeskind and Collins (1987) observed the responses of day care workers to naturally occurring cries of infants in a
day care setting. Cries were tape-recorded from hanging microphones. The responses of caregivers were rated by naive observers as reliably more urgent to higher pitched cries than to lower pitched cries. The correlation between fundamental frequency and urgency was $r = .73$. Thus, even within a typical range of fundamental frequency, gradations in pitch were related to gradations of perceived distress.

While these studies have consistently found strong relations between the fundamental frequency of crying and adults’ perceptions, cries also differ in a wide range of other acoustic features that may affect adults’ perceptions. Other potentially salient features include dysphonation, dominant frequency, vibrato, gliding, amplitude, rise time and temporal features (Golub & Corwin, 1985). In order to determine whether the fundamental frequency directly affects adult perceptions of infant cries, studies must experimentally vary the acoustic feature while holding other features of the cries constant. In one such study, the effects of fundamental frequency on adults’ perceptions were examined (Bisping, Steingrueber, Oltmann, & Wenk, 1990). Fundamental frequency was manipulated by a decimation and interpolation procedure that resulted in cries ranging from 305 to 1220 Hz. Cries were played to listeners who were instructed to adjust the Sound Pressure Level (SPL) to a comfortable listening level for each cry. A significant
difference in the SPL was found between cries with higher fundamental frequencies and cries with lower fundamental frequencies, suggesting that cries with higher fundamental frequencies were more aversive to the listener than cries with lower fundamental frequencies. The experimental nature of this study indicates a direct relation between fundamental frequency and adults’ perceptions of infant crying and confirms similar findings in correlational studies.

Summary

Cries that are elicited from the same stimulus, but which vary in levels of fundamental frequency, communicate different messages to the environment. As such, the fundamental frequency may be one feature of cries that contributes to their being perceived as graded signals. As the pitch of the cry increases, even with other acoustical features held constant, perceptions of increased intensity and urgency are reported. Conversely, as pitch decreases, cries are perceived as less urgent and arousing. Thus, a range of studies have shown that pitch is a salient perceptual feature in the cries of newborn and young infants which can affect perceptions and the transmission of messages to the environment.

Role of Durational Features on Perceptions of Cries

While the fundamental frequency of crying has long been
the focus of research, increasing attention has been
directed to the study of the temporal characteristics of the
cry sound. Recall that Wolff (1967) described the temporal
morphology of crying as the rhythmical repetition of four
components: 1) an expiratory sound, 2) the pause before
inspiration, 3) an inspiration, and 4) the pause after
inspiration. Based on the analysis of one infant,
Rosenhouse (1980) separated cry sounds into three categories
based on the durations of these features. Short cries had
an expiration up to 600 msec in length, medium cries were
between 600 msec and 1.5 sec in duration and long cries were
over 1.5 sec. Pauses were classified into two categories -
inhalation pauses which average about 300 msec and allow the
intake of breath between cry bursts, and longer pauses which
occur between inhalations and the next cry burst. Cries
related to hunger and illness averaged from 660-1000 msec in
unit length (expirations and pauses), cries associated with
pain ranged from 600 to 830 msec and cries related to
fatigue averaged about 800 msec in length.

Variations in the durations of these temporal
components have been related to variations in adults’
perceptions. Gustafson, Green, and Tomic (1984) found that
durational features were salient cues for the recognition of
individual infants’ cries. Subjects heard 30 seconds of
crying from a target infant followed by 24 subsequent cries.
They were asked to decide (yes or no) whether or not each of the 24 cries was from their target infant. Cries with larger numbers of expirations and breaths per unit time were easier to identify than cries with fewer expirations per unit time. Easy-to-recognize infants averaged 10.5 expirations and 13.9 breaths per unit time to the 6.7 expirations and 10.5 breaths of difficult-to-recognize infants. Easy-to-recognize infants also had shorter breaths (1070.1 msec) and shorter pauses between cries (337.3 msec) in comparison to 1723.5 msec and 540.5 msec for the difficult-to-recognize infants, respectively. Easy-to-recognize cries were generally more rhythmical and shorter in duration. In another study, Gustafson and Green (1989) found that cries with longer durations were related to perceptions by parents and nonparents of being more aversive ($r^2 = .61$) than shorter cries. Although these results show that durational features of infant cries are related to adults' perceptions, the correlational nature of the work precludes making conclusions regarding the causal effects of temporal features. In addition, these studies do not indicate which temporal feature is the most influential in affecting adult perceptions of infant crying.

Experimental Manipulation of Durational Components

A series of studies has begun to explore experimentally
the effects of temporal features of infant crying on adult perceptions. In the first study, Zeskind, Klein, and Marshall (1992) modified the durations of all pauses and expirations in a 10-second segment of infant crying to explore the independent effects of these temporal components on adults' perceptions of infant crying. First, three cries were created by manipulating the durations of expirations: 1) the original cry, 2) a cry in which durations of expirations were increased by 50%, and 3) a cry in which durations of expirations were decreased by 50%. Each of these three cries then had both pauses decreased by 50% to make three additional cries. The pauses in the three cries with different expiration lengths were also increased by 50%. Thus, nine 10-second stimuli were created so that the effects of all possible combinations of short, original and long pauses and short, original and long expirations were studied.

Because previous interactions with their own infants may affect mothers' and fathers' ratings of infant cry sounds (Frodi & Lamb, 1980; Wiesenfeld, Malatesta & DeLoach, 1981; Zeskind & Shingler, 1991), nonparent adults without professional caregiving experience were chosen as subjects. Subjects rated the nine cries on scales that described how urgent, aversive, rhythmical, arousing, rough, normal and sick the cry sounded. These rating scale items have been
found to have correlations ranging from .73 to .91 which demonstrate a high degree of dependency between the eight scales (Zeskind & Lester, 1978). These scales have been used in various studies examining adult perceptions of infant cries (e.g. Boukydis & Burgess, 1982; Gustafson & Green, 1989; Zeskind & Marshall, 1988) and for different cultural groups (Zeskind, 1983a).

Results of this study showed a general monotonic effect for the duration of pauses. As the durations of both pauses increased, cries were perceived as increasingly less urgent, arousing, informative and aversive. For the perception of urgency, the monotonic effect of the durations of pauses also occurred as a function of the duration of the expiratory sound. Shorter pauses resulted in perceptions of increasing urgency in cries with short and long expirations. However, with an original expiration, cries with short and original pauses were not reliably different. In general, both long and short expirations with short pauses were perceived as more urgent than the original cry. These results support the view of cries as graded signals that are perceived differently as they gradually change along a continuum of acoustic features.

This study was replicated with mothers as subjects to determine whether the same results would be found in adults with caregiving experience (Zeskind, Wilhite, and Marshall,
1993). Using the same nine experimentally manipulated cry stimuli, the above results were almost identically replicated. A strong monotonic effect was found for the duration of both pauses showing that longer pauses are perceived as being less urgent than cries with shorter pauses. In addition, the same interaction as above was found between the durations of pauses and expiratory sounds such that the short pauses paired with short expirations were perceived as the most urgent. These results support previous findings that perceptual responses of non-parent adults and mothers with infants are similar on some perceptual measures of cries (Gustafson and Green, 1989; Zeskind and Lester, 1978). Although these results show that both pauses lengthened or shortened together by 50% are salient features in the perception of infant crying, there is no information as to the separate effects of the two pauses. Because both pauses were increased or decreased together, information regarding the communicative significance of the separate pauses could not be ascertained.

Some evidence suggests that the durations of the two pauses may change independently as a function of changes in infant arousal (Wolff, 1967). Whereas the durations of both pauses were simultaneously manipulated in the two studies mentioned above, the third study in the series began to
isolate the effects of these separate components of the cry sound on adults’ perceptions (Zeskind & Schuetze, in prep.). Using the cry sounds from the above studies, the durations of the pauses before and after the inspiratory sound were increased and decreased independently of one another. Cries were digitally manipulated so that all combinations of the pause before the inspiration (short, original, and long) and the pause after the inspiration (short, original, and long) were created for each expiratory sound (short, original, and long). Subjects were asked to rate each of the 27 cries on eight rating scale items. Preliminary analyses show strong main effects for the duration of the pause after inspiration, although its effect may be modulated by an interaction with the duration of the pause before inspiration.

Taken together, these studies indicate that the durations of pauses, especially the pause after inspiration, have a strong effect on adults’ perceptions of infant crying. Two important aspects of the methodology should be emphasized. First, the studies were conducted on manipulations of a 10-second segment of crying that contained multiple expiratory sounds and corresponding pauses so that the durations of components could be studied within the context of the natural rhythms underlying the sound of infant crying. Second, the standard proportion at
which durations of pauses were lengthened and shortened by was 50%, a rather arbitrary value derived from anecdotal information about the durations of pauses and expiratory sounds (Wolff, 1967). However, both of these methodological aspects leave unanswered the question at what point are changes in duration detectable by the adult listener. That is, how much of a difference makes a difference? Further, the perceptual threshold for one pause may not be the same as the threshold for the second pause due to the large difference in the durations of the two pauses.

Detection of Differences in Auditory Signals

Studies of psychophysical phenomena have typically defined the threshold of signal detection as the point at which some percentage, often 50%, of responses indicate that the comparison stimuli are different from the standard stimulus presented (Gescheider, 1985). Psychophysical studies have been conducted to determine differential thresholds for the intensity (Riesz, 1928) and frequency (Harris, 1952) of auditory stimuli. It is known that auditory thresholds are dependent on the period of time the stimulus is presented. Thresholds rise as the presentation time of the stimulus decreases (Hughes, 1946). However, little work has been done on adults' ability to detect changes in the length of silent inter-stimulus intervals.
One early study examined the ability of listeners to respond differentially to rates of interruption in white noise (Miller & Taylor, 1948). Using a sound-time fraction (portion of total time occupied by noise bursts) of 0.5, the point at which an interrupted noise is no longer distinguishable from a continuous noise was sought. In general, rates as high as 2000 interruptions per second were distinguished from continuous noise. However, this study did not directly explore the ability of adults to detect differences in the length of intervals between noise bursts. In addition, since these results were entirely based on a sound-time fraction of 0.5, it is not clear how adults would react to a higher sound-time fraction such as that occurring in a cry (e.g. - expiratory sound and pause).

In a more direct look at the role of the duration of silence between two noise pulses on the perceptions of adults, one study attempted to find the minimum silent interval between two pulses of white noise that can be perceived (Plomp, 1964). The time interval between two pulses of equal durations (200 msec) was varied in steps of .1 msec. The just-noticeable time interval between two noise pulses was dependent on the intensity level of the noise pulses. At an intensity level of 10 decibels, the just-noticeable time interval was approximately 30 msec, whereas the just-noticeable time interval at 70 decibels was
about 3 msec. These results indicate that the minimum
duration of silence between two bursts of noise that can be
detected by adult listeners is a function of the intensity
of the acoustic signal.

Although the methods of signal detection may be useful
in the study of infant crying, they may not be able to
provide the basis for hypotheses regarding detection of
differences in the cry sounds of newborn and young infants.
Infant cries differ from stimuli typically used in
psychophysical studies in two important ways. First, unlike
synthetic stimuli, infant cries are especially salient
social signals that function as a means of communication
between the infant and its environment. It is known that
even infants are able to perceptually and responsively
differentiate sounds made by infants and by other objects
and people. For instance, infants cry in response to their
own cries, but stop crying in response to the cry of another
infant, and calm infants do not respond at all to the cry of
a chimpanzee (Martin & Clark, 1982). It is also known that
infants cry significantly more in response to a tape
recorded cry than to white noise of the same intensity
(Simner, 1971). It appears that infants are not as aroused
by nonvocal properties, such as intensity and sudden onset,
etc., as they are to other infant vocalizations. As such,
the use of artificially produced white noise as a stimulus
in many psychophysical studies may affect the perceptions of adults in a different manner than a naturally occurring complex stimulus such as a cry.

A second difference between nonvocal stimuli and the cries of young infants is the rhythm of the auditory sequences. Both the sequences in the Miller and Taylor (1948) study which consisted of equal durations of sound and silence and the sequences in the Plomp (1964) study which consisted of silence bounded by noise bursts of equal duration differed from the typical rhythm of infant cries. In a typical cry occurring before an infant’s scheduled feeding, the first pause is bounded by an expiratory sound and a inspiration which is much shorter than the initial expiratory sound. The second pause, following the short inspiration, is then followed by another expiratory sound that may be shorter or longer than the initial expiratory sound. Thus, the duration of the components of a cry are not in the symmetrical form of the noise-silence sequences typically used in auditory studies and, as such, should have a correspondingly different effect on the perceptions of adults. As a result, direct comparisons between studies using pure tones or white noise as auditory signals and studies with cries as the auditory stimuli are difficult, but the methodology used in psychophysical studies may be useful in studies on the detection of differences in cry
Purpose of the Present Study

The purpose of the present study was to determine at what point manipulations in the durations of pauses before and after the inspiration in infant cries were detectable by the adult listener. To answer this question, three experiments were conducted using the Method of Constant Stimuli. This method has been used in a variety of perceptual studies to detect differences in acoustic signals (Gescheider, 1985). In Experiment I, Difference Thresholds were determined for both the pause before inspiration (PBI) and the pause after inspiration (PAI). Since a previous study found an interaction between the durations of the PBI and the PAI (Zeskind & Schuetze, in prep.), Difference Thresholds for each pause were determined as a function of the duration of the other pause. In Experiment II, the Difference Threshold for the PBI was determined in the context of the PAI. In other words, the durations of the PBI were manipulated while the durations of the PAI were held constant. In Experiment 3, a Difference Threshold for the PAI was similarly determined within the context of the PBI.

General Method

Method

Subjects. Subjects were female undergraduate students
who received course credit for participation. Thirty subjects were used in both Experiment I and Experiment III, and fifteen subjects participated in Experiment II.

**Stimuli.** The original stimulus was a segment of a naturally occurring crying bout of a thirty day-old female infant recorded in her home shortly before the regularly scheduled evening feeding. The infant had a gestational age of 35 weeks and a birthweight of 3210 grams and had no obstetric complications. In addition, the infant showed no abnormal signs on physical and neurological examinations. Figure 1 shows a spectrograph of the cry segment from this infant. The cry segment was selected for its rhythmical sound quality and apparent lack of atypical acoustic features such as an hyperphonated (high-pitched) or dysphonated (turbulence) acoustic structure.

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insert Figure 1 about here

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Measurement of the basic pitch and durational characteristics of the cry sound was determined by use of the acoustic analysis module of the MicroSystems Lab (MSL) computer program. The chosen cry sound was converted from analog to digital domains at 25,000 samples per second via the MSL program. Durations of the expiratory sound and pauses were determined by moving a cursor along an
oscilloscopic display with a resolution of 0.009 sec. The durations of the temporal components were 0.815 sec. for the first expiratory sound, 0.033 sec. for the pause before inspiration, 0.121 sec. for the inspiration, 0.261 sec. for the pause after inspiration, and 0.745 sec. for the second expiratory sound. The mean fundamental frequency of each expiratory sound was determined from a Fast Fourier Transform (spectrum analysis) of a 25 msec point at 5 equidistant locations in the cry segment. The mean fundamental frequency for these five points was 534.4 Hz in the initial expiratory sound and 530.2 Hz in the second expiratory sound. The characteristics of the durational features and fundamental frequency are well within the typical range of naturally occurring cries of one month old infants (Gustafson et al., 1984; Zeskind, Parker-Price, & Barr, 1993).

The MSL Edit module of the MSL program was used to digitally manipulate the individual pauses. Increases in the durations of pauses were made by adding "silent" time to the existing silent time within each pause. This was achieved by moving a cursor along the oscilloscopic display until the portion of silence marked was the length needed to increase the pause by the sufficient amount. The marked pause segment was then added to the existing pause. Conversely, decreases in the durations of pauses were made
by removing silent time from the existing duration of each pause.

First, the durations of the pause before inspiration (PBI) were manipulated. Durations of the manipulation of the PBI were based on pilot tests which indicated that differences in the cry sounds could be detected within a 1000% increase in duration. Pilot tests also indicated that decreases in the duration of the already short PBI were not detectable at a 100% change in duration. Thus, to establish the psychometric function, increases in the duration of the PBI were made at 200%, 400%, 600%, 800% and 1000%. Decreases in the duration of the PBI were made at 50% and 100%. At a decrease in the pause duration of 100%, the inspiration and the first expiratory sound are functionally joined and, thus, no further shortened manipulations were conducted. Using the same method, the durations of the relatively longer PAI were manipulated. Pilot tests indicated that 40% to 60% increases and decreases in the durations of this pause were detectable by adults. Thus, using the same original cry segment, the PAI was both increased and decreased by 20%, 40%, 60%, 80% and 100%. These manipulations created an additional ten cries.

Procedure. After obtaining written consent, subjects listened to tape-recorded instructions via headphones while they read along in a test booklet. All subjects were
individually tested in a testing room located in Derring Hall. The entire testing procedure lasted between 30 and 45 minutes.

Subjects listened to random order presentations of pairs of cry sounds. Each cry sound was presented at an intensity level of 68 dB measured via a sound-level meter at the headphones. In each experiment, subjects heard a pair consisting of the standard cry and either the standard cry presented again or one of several cries in which the durations of the pauses were manipulated. The number of cries and nature of the manipulations varied by experiment. Each pair of cry segments was repeated ten times in a random order. To counterbalance the order of presentation within each pair, half of the pairs for each duration of the pause of interest had the standard segment presented first while the other half had the manipulated segment presented first. The two cries in each pair were separated by a two second inter-cry-interval. After presentation of each pair, subjects were asked if the two cries in each pair sounded the "same" or "different". They had three seconds between the presentation of each pair of stimuli to mark their response in the test booklet.

In addition to determining the threshold at which subjects were able to perceptually differentiate cry sounds, subjects’ ability to identify the source of differences in
the sound of crying was of interest. Following the experiment, subjects were asked, in written form, "How were the cry sounds different when you thought there were differences between the two cry sounds in a pair?" The written responses of each subject were classified as correctly or incorrectly identifying the source of the differences in the cry sounds as changes in the duration of the pauses. "Correct" responses included statements such as "when the infant stops for a break", "the amount of time taken for a breath", "different patterns in breathing", "the pause between cries was longer", and "more time between the cries".

**Analyses.** The Method of Constant Stimuli was used to determine the Difference Threshold for each pause. This method uses the proportion of the ten times a subject indicated that the two cry segments within a given pair were perceived to be "different". A psychometric function was derived from the proportion of "different" responses given by each subject to each manipulated sound. Psychometric functions were derived separately for increases and decreases in the durations of pauses. The proportion of "different" responses was plotted on the ordinate and the manipulation percentage was plotted on the abscissa. See Figure 2 for an example of an expected psychometric function which is typically referred to as an empirical psychometric
function (Corso, 1962).

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insert Figure 2 about here

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The proportions of "different" responses were converted to $z$ scores for analysis (Gescheider, 1985) for each individual. The two halves of the psychometric function were analyzed separately for the threshold at which increases and decreases in the durations of pauses were detected. One Difference Threshold was calculated for the point at which adults could detect an increase in the duration of the pause of interest. The other Difference Threshold was calculated for the point at which adults could detect a decrease in the duration of the pause of interest. A linear regression was conducted on the $z$ scores of each subject to obtain an equation of the best fitting line through the $z$ scores. A linear $z$ score psychometric function, which is typically found in such psychophysical measures, indicates that data are in the form of the cumulative normal distribution.

The regression equation was then used to determine the Difference Threshold for each subject. First, the point along the linear regression that corresponded to the point at which 25% ($z$ score = -0.67) of the total responses indicated that the manipulated cry segment sounded
"different" from the original cry sound was entered into the regression equation. The equation provided the percentage of manipulation which corresponded to a \( z \) score of \(-0.67\). The point along the linear regression that corresponded to the point at which 75\% (\( z \) score = 0.67) of the total responses indicated that the manipulated cry sound was perceived as being "different" from the original cry sound was also entered into the regression equation. Again, the equation was solved to obtain the percentage of manipulation which corresponded to a \( z \) score of 0.67. The two values obtained from the regression equation were averaged to get the final Difference Threshold for that individual. The individual difference thresholds for each subject were then averaged to produce the final mean Difference Threshold. This final value represents the point at which subjects were able to detect differences in the durations of the respective pauses. The final mean Difference Thresholds were then computed for each group.

**Hypotheses.** Pilot work suggested that Difference Thresholds for the PAI would occur at manipulation values of approximately 50-60\% for a decreased duration of the PAI and at approximately 40\% for an increased duration of the PAI. The original duration of the PBI was too short (33 msec) for even a 100\% decrease to be detected, therefore, only a Difference Threshold for a lengthened PBI was examined. The
threshold at which adults perceive differences in an increase in the duration of the PAI is approximately 90 msec. Thus, the Difference Threshold for the PBI was hypothesized to occur between a 300-400% manipulation which corresponds to an increase of approximately 90 msec.

Experiment I:
Determining Difference Thresholds for the PBI and the PAI

The purpose of Experiment I was to determine the Difference Thresholds for the PBI and the PAI separately. A Difference Threshold for the point at which adults can determine increases in the durations of the PBI first was calculated. In addition, the points at which increases and decreases in the durations of the PAI become perceptible were then determined.

Method

Subjects. Thirty-four female undergraduate students were recruited from undergraduate Psychology classes to serve as subjects. Subjects were assigned to one of two groups until each group had 15 subjects. Four subjects were unable to detect differences in the duration of pauses as determined by the Method of Constant Stimuli. As standard practice in this research paradigm, these subjects’ data were excluded from further analyses. Four additional subjects were included in the study in order to maintain
groups of 15 subjects each.

Procedure. One group of 15 subjects heard the standard cry compared to the cries created from increasing the duration of the PBI by 200%, 400%, 600%, 800%, and 1000% and decreasing the duration of the PBI by 50% and 100% while holding the duration of the PAI constant. With the repeated presentation of each pair, subjects heard a total of 80 pairs of cry sounds. The second group heard the standard cry compared to cries created by increasing and decreasing the duration of the PAI by 20%, 40%, 60%, 80%, and 100% while holding the duration of the PBI constant. These subjects heard a total of 110 pairs of cry sounds. During a three second inter-pair-interval, subjects were asked to indicate whether the cries sounded the "same" or "different".

Results

The Difference Threshold at which an increase in the duration of the PBI could be detected was tested first. A linear regression was conducted on the z scores of each subject which corresponded to the proportion of times the manipulated cry was perceived to be "different" from the original cry. These regressions were used to calculate the slope and y intercept. Based on calculations obtained from the 15 individual regression equations, the mean Difference Threshold for detecting differences in increases in the
duration of the PBI occurred at 354.2% with a Standard Deviation of 313.5 (see Table 1). This corresponds to a mean increase of 0.117 sec. A regression analysis of the z scores averaged across the 15 subjects showed a significant linear trend ($r^2 = .89, p < .005$). Thus, the averaged psychometric function from which the averaged z scores were derived was based on the cumulative normal distribution. Figure 3 shows the psychometric function of detecting differences in an increase in the duration of PBI. The graph shows an increase in the proportion of times subjects perceived cry sounds to be "different" as the percentage of manipulation increases. As described earlier, the Difference Thresholds for decreases in the duration of the PBI were not examined because the durations of the PBI were initially very short.

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insert figure 3 about here

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Regression equations were then conducted on the z scores of the 15 subjects who heard manipulated cries in which the duration of the PAI was either increased or decreased. Separate regressions were calculated on responses to cries with an increased duration of the PAI and responses to cries with a decreased duration of the PAI.
Based on the calculations of the slope and y intercept from the regression equations, the mean Difference Threshold for the 15 subjects occurred at a decrease in the duration of the PAI at 61.9% with a Standard Deviation of 16.1 (see Table 1). This corresponds to a decrease in duration of 0.162 sec. The mean Difference Threshold for an increase in the duration of the PAI was 58.53% with a Standard Deviation of 30.87 (see Table 1) for the 15 subjects. This corresponds to an increase of 0.153 sec.

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insert Table 1 about here

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Regression analyses on the averaged z scores of the 15 subjects for both increases ($r^2=.96, p < .001$) and decreases ($r^2=.90, p < .004$) in the durations of the PAI both showed a significant linear trend. Results of these regressions indicated that the psychometric functions for increases and decreases in the duration of the PAI averaged across the 15 subjects were based on the normal distribution. Figure 4 shows the psychometric functions for increases and decreases in the durations of the PAI. The inverted bell-shaped graph shows that, as the manipulation percentages move away from zero, the proportion of times subjects perceived cry sounds to be different increased.
To determine whether the Difference Threshold for increases in the duration of the PAI (M=58.53, SD=30.87) differed from the Difference Threshold for decreases in the duration of the PAI (M=-61.9, SD=16.1), a paired $t$-test was conducted on the two mean Difference Thresholds. Results showed no reliable difference in the Difference Thresholds, $t(14) = -0.38$, $p < .71$. Because of the large within-group variability of the mean Difference Thresholds, a Wilcoxon Signed-ranks nonparametric test was also used to compare the Difference Thresholds. These results also showed no reliable differences between the Difference Thresholds for increases and decreases in the durations of the PAI, $z = -0.57$, $p < .57$.

In order to assess the ability of subjects to identify variations in the cry sounds, they were asked to write down what they believed to be the cause of the differences between cry sounds, if any difference was noticed. In a comparison between subjects who heard manipulations of the PBI and subjects who heard manipulations of the durations of the PAI, the distribution of subjects who indicated that changes in the durational components of the pauses were the source of the differences between cry sounds departed from
that expected by chance, $X^2(1)=3.7$, $p<.05$. Twelve of the 15 subjects who heard manipulations of the PBI were able to correctly identify the source of the differences between cries as changes in the durations of pauses. All 15 subjects who heard manipulations of the durations of the PAI, in addition to merely indicating differences between cries, were able to correctly identify the source of the differences as changes in the duration of the PAI (see Table 2).

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insert Table 2 about here

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Experiment 2:
Determining the Difference Threshold for the PAI as a function of the PBI.

**Method**

To examine the possible interaction-effect between the durations of the PBI and the PAI, a second experiment was conducted in which manipulations of the PAI were made with the duration of the PBI held constant. The mean Difference Threshold for an increase in the duration of the PBI was chosen as the new standard cry. This method enabled the examination of whether the Difference Threshold at the PAI varied as a function of the perceived difference in the
duration of the PBI. In other words, is the Difference Threshold for the PAI a function of the perceptible change in the duration of the PBI?

Subjects. Fifteen female undergraduate students who were recruited from undergraduate Psychology classes served as subjects. The data from three subjects were excluded from further analyses because they were not able to detect differences in the cry sounds as measured by the Method of Constant Stimuli. Three additional subjects were included in the experiment in order to keep a total of 15 subjects in each group.

Stimuli. The cry in which the duration of the PBI had been increased by 400% became the new standard cry. This cry was chosen because the duration of the PBI was longer than the perceptible duration of the PBI found in Experiment 1. The duration of the PBI in this new standard cry was 165 msec. Using this cry with the duration of the PBI held constant, the PAI was then both increased and decreased by 20%, 40%, 60%, 80%, and 100% following the procedure described in the General Method section.

Procedure. Subjects heard the new standard cry compared to itself and the ten cries created by manipulating the duration of the PAI while holding the duration of the PBI constant. These 11 pairs of cries were presented to subjects ten times each in random order. Thus, each subject
heard a total of 110 pairs of cries. During a three second inter-pair-interval, subjects were asked to indicate whether the cries sound the "same" or "different".

**Results**

The Difference Threshold at which increases in the duration of the PAI as a function of the PBI were detected was calculated first. Linear regressions were calculated on the z scores derived from the number of times each subject could detect differences in a pair of cries. Based on the calculations of the slope and y intercept from the regression equation derived for each subject, the point at which increases in the duration of the PAI with a perceptibly longer duration of the PBI could be detected was 39.82% with a Standard Deviation of 16.29 (see Table 1). This corresponds to an increase in the duration of the PAI of 0.104 sec.

The Difference Threshold for detecting decreases in the duration of the PAI with a perceptibly longer PBI was then calculated. A separate linear regression was calculated on responses given by each of the 15 subjects who heard cries in which the duration of the PAI had been decreased. Based on the calculations of the slope and y intercept from these regression equations, the mean point at which decreases in the duration of the PAI with the duration of the PBI held constant could be detected was -57.6% with a Standard
Deviation of 22.48 (see Table 1). This corresponds to a decrease of 0.150 sec.

Regression analyses conducted on the averaged z scores of the 15 subjects for increases ($r^2=.78$, $p < .02$) and decreases ($r^2=.95$, $p < .001$) in the duration of the PAI as a function of the PBI both showed a significant linear trend. Figure 5 shows the psychometric function of detecting differences for both increases and decreases in the duration of the PAI as a function of the PBI. The inverted bell-shaped graph shows that as the manipulation percentages moved away from zero, the proportion of times subjects perceived cry sounds to be different increased.

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insert figure 5 about here

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A paired t-test was then conducted to examine whether the Difference Threshold for an increased duration of the PAI when using a perceptibly longer PBI differed from the Difference Threshold for a decreased duration of the PAI when using a perceptibly longer PBI. Results showed that the percentage increase that was necessary for subjects to be able to perceive differences in the durations of the PAI with a perceptibly longer PBI ($M=39.82$, $SD=16.29$) was reliably smaller than the percentage decrease necessary for
detecting differences in the durations of the PAI with a perceptibly longer PBI ($M=-57.6$, $SD=22.48$), \(t(14) = -2.63, p < .02\). Because of the wide within-group variability, a Wilcoxon Matched-pairs Signed-ranks nonparametric test was also conducted. These results similarly showed that the two mean Difference Thresholds were reliably different, \(z = -2.39, p < .017\).

Between Experiments Analyses

An independent samples t-test was conducted to examine whether the percentage at which increases in the durations of the PAI could be detected, found in Experiment 1, differed from the percentage at which increases in the durations of the PAI when the duration of PBI was perceptibly longer in Experiment 2 could be detected. Separate variance estimates were used because variances of the two groups reliably differed, thus violating the assumption of homogeneity of variance ($F=3.59$, $p<.02$). Results showed that the Difference Threshold for increases in the durations of the PAI ($M=58.53$, $SD=30.87$) was reliably larger than the Difference Threshold for increases in the duration of the PAI with a perceptibly longer PBI ($M=39.82$, $SD=16.29$), \(t(28) = 2.08, p < .05\). Because of the wide within-group variability of the Difference Thresholds, a Mann Whitney \(U\) nonparametric test was conducted. These results also showed reliable differences between the
Difference Thresholds, $\bar{U} = 64.0$, $p < .04$. The results indicated that the Difference Threshold for increases in the durations of the PAI is larger than the Difference Threshold for increases in the duration of the PAI with a perceptibly longer PBI.

An independent samples $t$-test was also conducted on the Difference Threshold for decreases in the duration of the PAI ($M=-61.9$, $SD=16.1$) and the Difference Threshold for decreases in the duration of the PAI with a perceptibly longer duration of the PBI ($M=-57.6$, $SD=22.48$). Pooled variance estimates were used because variances of the two groups did not reliably differ ($F=1.96$, $p<.22$). Results showed no reliable differences between the two mean Difference Thresholds, $t(28) = .60$, $p < .551$. A comparison of the Difference Thresholds by a Mann Whitney $U$ nonparametric test also showed no reliable differences, $U=91.0$, $p < .37$. These results showed that the Difference Threshold for decreases in the duration of the PAI with a perceptibly longer PBI and the Difference Threshold for decreases in the duration of the PAI are not reliably different. Figure 6 shows a comparison of the psychometric functions for changes in the duration of the PAI with an original duration of the PBI and with a perceptibly longer duration of the PBI.
In response to questioning about the source of the differences between the cry sounds, 14 of the 15 subjects who heard increases and decreases in the duration of the PAI with a perceptibly longer PBI were able to correctly identify the source of the differences in the cries as changes in the duration of the pauses. Of the 30 total subjects who heard manipulations of the duration of the PAI, either alone or with a perceptibly longer duration of the PBI, 29 were able to pinpoint changes in the duration of pauses as the source of the differences between the various cry sounds.

Experiment 3:
Determining the Difference Threshold for the PBI as a function of the PAI.

Method
To examine the possible interaction-effect between the durations of the PBI and the PAI, a third experiment was conducted in which the detectability of changes in the duration of the PBI was examined as a function of the changes in the duration of the PAI. The mean Difference Threshold for an increase in the duration of the PAI was chosen as the new standard cry. This method enabled us to
examine whether the Difference Threshold of the PBI varied as a function of the perceived difference in the duration of the PAI. In other words, is the Difference Threshold for the PBI a function of the perceptible change in the duration of the PAI?

Subjects. Thirty-seven female undergraduate Psychology students were assigned to one of two groups. Data from seven subjects were excluded from analysis due to the inability of these subjects to detect differences in the durations of pauses as measured by the Method of Constant Stimuli. An additional seven subjects were included in the experiment in order to keep a total of 15 subjects in each group.

Stimuli. The cry in which the duration of the PAI had been increased by 60% became the new standard cry. This cry was chosen because the duration of the PAI was longer than the perceptible duration of the PAI found in Experiment 1. The duration of the PAI in this new standard cry was 411 msec. Durations of the PBI were then decreased by 50% and 100% and increased by 200%, 400%, 600%, 800% and 1000% while holding the duration of the PBI constant. The cry in which the duration of the PAI had been decreased by 60% was also chosen to be a new standard cry. This cry was selected because its duration of the PAI was similar to the perceptible duration of the PAI found in Experiment 1. The
new duration of the PAI was 103 msec. Again, the durations of the PBI were increased by 200%, 400%, 600%, 800%, and 1000% and decreased by 50% and 100% while holding the duration of the PAI constant.

Procedure. One group of subjects heard the standard cry with a longer duration of the PAI compared to itself and to seven cries with manipulated durations of the PBI. The other group of subjects heard the standard cry with a shorter duration of the PAI compared to itself and to seven cries with manipulated durations of the PBI. Each group of subjects was presented with eight pairs of cries ten times each in random order. Thus, each subject heard a total of 80 pairs of cries. During a 3 second inter-pair-interval, subjects were asked to indicate whether the two cries sounded the "same" or "different".

Results

The Difference Threshold at which increases in the duration of the PBI could be detected when the duration of the PAI was perceptibly shorter was calculated. A linear regression was conducted on the z scores of each subject based on the number of times the subject indicated that the stimuli within a pair of cries sounded different. Based on the calculations of the slope and y intercept from the regression equations, the point at which increases in the duration of the PBI with a perceptibly shorter duration of
the PAI could be detected was 420.06% with a Standard Deviation of 332.98 (see Table 1). This corresponds to an increase of 0.139 sec. in the duration of the PBI.

A regression analysis on the averaged z scores of the 15 subjects who heard increases in the duration of the PBI with a perceptibly shorter duration of the PAI showed a significant linear trend (r²=.92, p < .002). Thus, the psychometric function from which these averaged z scores were derived was a cumulative distribution function of the normal curve. Figure 7 shows the psychometric function of detecting differences in an increase in the duration of the PBI as a function of a shorter duration of the PAI. The graph shows an increase in the proportion of times subjects perceived cry sounds to be "different" as the percentage of manipulation increases.

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insert figure 7 about here

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The Difference Threshold at which increases in the durations of the PBI with a perceptibly longer PAI could be detected was then calculated. A separate linear regression was conducted on responses given by each of the 15 subjects who heard cries with a manipulated duration of the PBI based on a standard cry with a longer PAI. Based on the
calculations of the slope and y intercept from the regression equations, the Difference Threshold for increases in the duration of the PBI with a longer duration of the PAI held constant was found to be 485.61% with a Standard Deviation of 336.53 (see Table 1) which corresponds to an increase of 0.160 sec. in the duration of the PBI. A regression analysis conducted on the averaged z scores of the 15 subjects who heard increases in the duration of the PBI as a function of the longer PAI also showed a significant linear trend ($r^2=.97$, $p < .001$). Thus, the psychometric function for the duration of the PBI as a function of an increased duration of the PAI reflects a cumulative distribution function of the normal curve.

Figure 8 shows the psychometric function of detecting differences in an increase in the duration of the PBI as a function of the longer duration of the PAI. The graph shows an increase in the proportion of times subjects perceived cry sounds to be "different" as the percentage of manipulation increases.

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insert figure 8 about here
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A $t$-test on independent samples was conducted to examine whether the Difference Threshold for increases in
the duration of the PBI with a perceptibly shorter duration of the PAI (M=420.06, SD=332.98) was reliably different from the Difference Threshold for increases in the duration of the PBI with a perceptibly longer duration of the PAI (M=485.61, SD=336.53). Separate variance estimates were used because variances of the two groups reliably differed, thus violating the assumption of homogeneity of variance (F=1.02, p<.97). Results of this analysis showed no reliable differences between the two mean Difference Thresholds, t(28) = -.54, p < .60. Because of the wide within-group variability, a Mann Whitney U nonparametric tests was also conducted. These results also showed no reliable differences between the two mean Difference Thresholds, U = 112.0, p < .98. Figure 9 shows a comparison between the psychometric functions for increases in the duration of the PBI with either a perceptibly shorter or perceptibly longer duration of the PAI.

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insert Figure 9 about here

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Between Experiments Analyses

A t-test for independent samples was then conducted to compare the mean Difference Thresholds for increased durations of the PBI from Experiment 1 (M=354.2, SD=313.5) and for increased durations of the PBI with a perceptibly
shorter duration of the PAI (M=420.06, SD=332.98). Separate variance estimates were used because variances of the two groups reliably differed, thus violating the assumption of homogeneity of variance (F=1.13, p<.83). Results showed that there were no reliable differences between the two Difference Thresholds, t(28) = -.56, p < .58. Results of a Mann Whitney U nonparametric test also indicated that the means were not reliably different, U = 90.0, p < .35. Figure 9 shows a comparison between the psychometric functions for increases in the duration of the PBI with an original duration of the PAI and with a perceptibly shorter duration of the PAI.

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insert Figure 10 about here

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An independent samples t-test between the Difference Threshold of cries with increased durations of the PBI in Experiment 1 (M=354.2, SD=313.5) and the Difference Threshold of cries with an increased duration of the PBI with a perceptibly longer duration of the PAI (M=485.61, SD=336.53) was also conducted. Separate variance estimates were used because variances of the two groups reliably differed, thus violating the assumption of homogeneity of variance (F=1.15, p<.80). Results showed that the Difference Thresholds were not reliably different, t(28) =
-1.11, \( p < .28 \). In addition, a Mann Whitney \( U \) nonparametric test also indicated that the means were not significantly different, \( U = 87.0, p < .29 \). These results showed that the Difference Threshold for an increased duration of the PBI with a perceptibly longer PAI and the Difference Threshold for an increased duration of the PBI were not reliably different from each other. Figure 11 shows a comparison between the psychometric functions for increases in the durations of the PBI with either an original duration of the PAI or with a perceptibly longer duration of the PAI.

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insert Figure 11 about here

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In addition, Figure 12 shows comparisons of the psychometric functions for increases in the durations of the PBI with either an original duration of the PAI, perceptibly shorter duration of the PAI or perceptibly longer duration of the PAI.

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insert Figure 12 about here

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Following the presentation of the cry sounds, subjects were questioned about the nature of the differences between the cry sounds. In a comparison of correct responses by subjects who heard manipulations of the duration of the PBI
with a perceptibly shorter PAI, subjects who heard manipulated durations of the PBI with a perceptibly longer PAI and subjects who heard manipulation of the duration of the PAI with a perceptibly longer PBI, the distribution of subjects who indicated that changes in the durational components were the source of the difference departed from the distribution expected by chance, \( \chi^2(2) = 9.51, p < .009 \). 12 of the 15 subjects who heard increased durations of the PBI with a perceptibly shorter PAI correctly identified changes in the duration of pauses as the source of the differences between cries. Eight of the 15 subjects who heard manipulations of the PBI with a perceptibly longer duration of the PAI were able to identify the duration of pauses as the source of the differences between the cries (see Table 3), and all 15 subjects who heard manipulations in the durations of the PAI with a perceptibly longer PBI correctly identified the source of the differences between the cry sounds.

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insert Table 3 about here

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Correct responses were collapsed across subjects who heard manipulations in the durations of the PBI with either a perceptibly longer or shorter PAI. These responses were
then compared to the responses of subjects who heard manipulations of the durations of the PAI with a perceptibly longer PBI. The distribution of the number of subjects who indicated that variations in the durational components were the source departed from the distribution expected by chance, $X^2(1)=6.93, p<.009$. Twenty of the 30 subjects who heard manipulations of the durations of the PBI with a perceptibly longer or shorter PAI correctly identified the source of the differences between cry sounds. However, all 15 of the subjects who heard manipulations of the duration of the PAI with a perceptibly longer PBI correctly identified the source of the differences between cry sounds as changes in the durations of the pauses (see Table 4).

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insert Table 4 about here

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Discussion

Crying is a social signal through which newborns and young infants communicate their basic needs to the caregiving environment. A wide range of studies have now documented that variations in the acoustic characteristics of cries, in particular, the fundamental frequency, affect adults' perceptions of infant crying (Bisping et al., 1990; Boukydis & Burgess, 1982; Gustafson & Green, 1989; Gustafson
et al., 1984; Lounsbury & Bates, 1982; Zeskind & Lester, 1978; 1981; Zeskind & Marshall, 1988; Zeskind et al., 1985). Recent research also emphasized the role of the durations of pauses within and between cries as perceptually salient aspects of the cry sound (Boukydis & Burgess, 1982; Gustafson et al., 1984; Lounsbury & Bates, 1982; Zeskind et al., 1992; Zeskind et al., 1993; Zeskind & Schuetze, in prep.). Experimental work has shown that as the durations of pauses (particularly the pause following the inspiration) increase, the cry is perceived to be increasingly less urgent (Zeskind et al., 1992; Zeskind et al., 1993; Zeskind & Schuetze, in prep.). Results of the present study provide the first known experimental evidence which describes the point at which variations in the durations of pauses are perceptibly distinguishable by naive adults.

The results of Experiment 1 indicate that adults were able to perceptually differentiate between cries which differed in the duration of only one of their two pauses. Adults were first able to differentiate between cries in which the duration of the PBI had been increased by approximately 354%. This Difference Threshold was in the hypothesized range of a 300% to 400% increase in the duration of the PBI. Difference Thresholds for cries which differed only in the duration of the PAI occurred at an increase of approximately 59%, and at a decrease of
approximately 62%. Both of these values are similar to the hypothesized range of a 40% to 60% increase or decrease in the duration of the PAI.

The results of Experiment 2 showed the mean Difference Thresholds at which increases and decreases in the duration of the PAI were detected in the presence of a perceptibly longer duration of the PBI. The mean Difference Threshold for decreases in the duration of the PAI with a perceptibly longer PBI was approximately 58%. Adults could detect increases in the duration of the PAI with a perceptibly longer PBI at an increase of approximately 40%. These values, as hypothesized, were within or near the range of a 40% to 60% change in the duration of PAI.

Experiment 3 explored the possibility of an interaction between the durations of the PBI and the PAI by examining the point at which increases in the duration of the PBI could be detected with either a perceptibly longer or perceptibly shorter duration of the PAI. The Difference Threshold for detecting increases in the duration of the PBI with a perceptibly shorter PAI was approximately 420%. The point at which subjects were able to detect increases in the duration of the PBI with a perceptibly longer duration of the PAI was at an increase of approximately 486%.

An interesting finding was that several subjects appeared to be able to detect differences in cries in which
the duration of the PBI was decreased by the relatively small amount of 100%. Two of the subjects who heard manipulations of the duration of the PBI with a perceptibly longer duration of the PAI and five of the subjects who heard manipulations of the duration of the PBI with a perceptibly shorter duration of the PAI indicated that cries with a 100% decrease in the duration of the PBI sounded different than the original cry 50% of the time. Unfortunately, since it is impossible to decrease the duration of the PBI by more than 100%, it is impossible to determine a Difference Threshold for a decreased duration of the PBI using the Method of Constant Stimuli. One conclusion that can be drawn based on these data is that a small number of subjects who heard manipulations in the duration of the PBI were able to perceive changes in the duration of the PBI as small as a 100% decrease. Another conclusion that can be drawn is that these were "chance" responses made by subjects at a decrease of 100% in the duration of the PBI.

A comparison of the mean Difference Threshold for the PBI to the mean Difference Thresholds for the PAI showed large differences in the percentage values at which subjects were able to detect changes in the duration of pauses. A Difference Threshold of approximately 354% is a much larger percentage value than either 59% or 62%. However, closer
examination of the durations of the original pauses and of the pauses at which the Difference Threshold occurs reveals similarities between the Difference Thresholds of the PBI and the PAI. Since the original duration of the PBI was smaller relative to the original duration of the PAI, a much larger percentage value increase was needed to achieve durational increases of approximately the same amount. In other words, in order for the PBI to be increased by 0.117 sec., a large increase in the manipulation value was necessary. To achieve similar durational increases for the PAI, manipulation percentages of only 59% and 62% were needed to get similar durational differences of 0.153 sec. and 0.162 sec. Thus, the large difference between the percentage values of the Difference Thresholds was actually not a large difference when the durations of those Difference Thresholds are examined.

A comparison of the mean Difference Thresholds from Experiment 1 for the increased duration of the PAI to the decreased duration of the PAI showed that they were not significantly different. Statistical comparisons of the mean Difference Thresholds of an increased duration of the PAI with a perceptibly longer PBI to a decreased duration of the PAI with a perceptibly longer PBI found significant differences between the means. The mean Difference Threshold for an increased duration of the PAI with a
perceptibly longer duration of the PBI occurred at a smaller percentage change than the mean Difference Threshold for a decreased duration of PAI with a perceptibly longer duration of PBI. Thus, it appears that the amount of change necessary for adults to detect differences between cries is smaller when the duration of the PAI has been increased than when the duration of the PAI has been decreased.

Comparisons of the mean Difference Thresholds of the increased duration of the PAI from Experiment 1 and the increased duration of the PAI with a perceptibly longer duration of the PBI from Experiment 2 indicated that the means were reliably different. Subjects were able to detect differences between the original cry and cries with increased durations of the PAI at smaller increases when the manipulated PAI occurred in conjunction with a perceptibly longer duration of the PBI. In other words, the duration of the PBI had an effect on the Difference Threshold for an increased duration of the PAI.

Subjects apparently did not require as large an increase in the duration of the PAI to hear differences between a manipulated cry and the original cry if the duration of the PBI had also been increased. The longer duration of the PBI somehow facilitated the discrimination of increases in the PAI. As the duration of the PBI increased, the Difference Threshold for increases in the
duration of the PAI became smaller. These results are consistent with the finding of a PBI by PAI interaction-effect in a previous study (Zeskind & Schuetze, in prep.). In that study, ratings by adult listeners of cry sounds were found to be a function of both the PBI and the PAI. Thus, a PBI by PAI interaction-effect in this study would predict that changes in the duration of one pause would affect the point at which changes in the duration of the other pause became detectable by adults.

However, a comparison of the mean Difference Thresholds for a decreased duration of the PAI and a decreased duration of the PAI with a perceptibly longer duration of the PBI were not reliably different from each other. Thus, the mean Difference Threshold for a decreased duration of the PAI appears to remain fairly consistent independent of the duration of the PBI. This finding is not consistent with the PBI by the PAI interaction-effect found by Zeskind and Schuetze (in prep.). A PBI by PAI interaction-effect would predict a somewhat different mean Difference Threshold for the PAI with a perceptibly longer duration of the PBI than the mean Difference Threshold for the PAI. In other words, as the duration of the PBI changes, the Difference Threshold for the PAI should also change.

This difference between results of the present study and previous work may be attributable to different methods
by which responses to cries were measured. As detailed elsewhere, the methodologies employed in studies of adults' perceptions of infant crying greatly affect the pattern of results found (Zeskind & Huntington, 1984). Differences in methods that may impact findings include the contrasts used among cry stimuli and the manner in which subjects conduct their perceptual evaluation. In previous work, Zeskind and Schuetze (in prep.) found a PBI by PAI interaction in the ratings of adults on several 7-point Likert-type rating scale items. Rating scales require subjects to make a graded perceptual judgment rather than simply indicating whether two cries sound the "same" or "different". In the present study, subjects simply indicated whether two cries sounded the same or different. Thus, the fact that the current study did not replicate a PBI by PAI interaction-effect among cries with a decreased duration of the PAI may be a function of differences in the perceptual judgments made by subjects.

Comparisons of the Difference Thresholds for the PBI with a perceptibly shorter duration of the PAI to the PBI with a perceptibly longer duration of the PAI showed no reliable differences. Thus, the point at which increases in the PBI can be detected does not appear to change as a function of differences in the duration of the PAI. In addition, the Difference Threshold for increases in the
duration of the PBI from Experiment 1 is also not reliably different from either of the two Difference Thresholds for increases in the duration of the PBI with a perceptibly longer or perceptibly shorter duration of the PAI. Thus, Difference Thresholds for the PBI remain similar independent of the duration of the PAI. In other words, Difference Thresholds for increases in the duration of the PBI do not differ as a function of the duration of the PAI.

The importance of these findings can be found when cries are conceptualized as dynamic, graded signals. Graded signals vary along a continuum which expresses the motivational level of the signaler (Murray, 1979). Variations in the frequency, intensity and duration of the signals all contribute to variations in the motivational level of the receiver. According to this model of crying in newborn and young infants, the meaning of cries is a function of variations in their acoustic characteristics which result from variations in the motivational level of the crying infant. Wolff (1967) described the dynamic nature of the temporal features within a single infant's cry. For example, the shorter durations of the various components of a "pain" cry gradually increase as the infant's level of arousal increases until they resemble the durations of components of a "hunger" cry. Other work has experimentally demonstrated significant variations in
durational features within a single bout of crying (Zeskind et al., 1993). These results support the view of crying as a graded signal which changes over time (Murray, 1979). Since these graded signals reflect the arousal level of the infant, their relation to adult perceptions have been explored.

One experimental study has demonstrated that changes in adults’ perceptions of cries are associated with changes in these graded signals (Zeskind et al., 1985). As the arousal level of the infant increased, related changes in the cry sound increased the arousal level of the listener. These results showed that different segments of the same cry can communicate different messages to the caregiving environment.

Recent work has demonstrated that the duration of pauses is one of the important components in adults’ perceptions of infant crying (Boukydis & Burgess, 1982; Gustafson et al., 1984; Lounsbury & Bates, 1982; Zeskind et al., 1992; Zeskind et al., 1993; Zeskind & Schuetze, in prep.). In particular, the duration of pauses may be particularly salient in the perceived temperament of the crying infant (Boukydis & Burgess, 1982; Lounsbury & Bates, 1982). Recent experimental work showed that the durations of pauses both before and after the inspiration contain important perceptual information for nonparent adults.
(Zeskind et al., 1992) and mothers (Zeskind et al., 1993). In general, increasingly shorter pauses resulted in cries that were perceived as more arousing and urgent. Another study suggests that the PBI and the PAI independently act on adults' perceptions of crying (Zeskind & Schuetze, in prep.).

Finding Difference Thresholds of 58.53% and -61.91% suggest that the 50% manipulations used in previous studies on adults' perceptions of infant cries (Zeskind et al., 1992; Zeskind et al., 1993; Zeskind & Schuetze, in prep.) have a reasonable value for examining the effects that the PAI has on adults' perceptions of infant crying. Results of the present study also suggest, however, that larger manipulation values are needed before changes in the duration of the PBI become detectable to adults. Future work should use manipulation values of at least 500% to examine the effect that the PBI has on adults' perceptions of infant crying.

Subjects appeared to be quite accurate in their ability to identify the source of these perceptual discriminations. Overall, 61 of the 75 total subjects correctly identified variations in the duration of pauses as the source of acoustic differences. However, it appears that subjects were not able to recognize the differences in the PBI as readily when there was a longer duration of the PAI held
constant than when there was a shorter duration of the PAI held constant. In other words, changes in the duration of the PBI are not as easily identified when there is a perceptibly longer duration of the PAI. It appears that the longer duration of the PAI reduces the ability of subjects to recognize changes as stemming from the PBI but does not affect their ability to detect the point at which cry segments sound different from each other.

In addition, subjects who heard manipulated durations of the PBI in the context of the PAI were not as accurate in identifying the source of differences as subjects who heard manipulated durations of the PAI. A greater number of subjects who heard changes in the duration of the PAI than subjects who heard changes in the duration of the PBI correctly identified variations in the duration of pauses as the source of the difference between cries. This seems to be due, in part, to the initially shorter duration of the PBI. The location of the pause immediately before the low intensity, inspiratory sound within the cry may also make it perceptually less noticeable than the PAI which is located immediately before an expiratory sound.

The ability of subjects to identify the durations of pauses as the source of differences between cry sounds reinforces previous findings that the durations of pauses are perceptually salient to adult listeners (Lounsbury &
Bates, 1982; Zeskind et al., 1992; Zeskind et al., 1993; Zeskind & Schuetze, in prep.). Changes in the durations of pauses can not only affect the perceptions of adults as measured by rating scale items, but can also be readily identified by adult listeners as responsible for the variations between cry sounds.

It should be emphasized that the ability to detect differences in cry sounds showed wide individual differences among listeners. For example, the relatively large standard deviation of the Difference Threshold for detecting increases in the duration of the PBI indicates that the individual process may be colored by an individual’s previous personal experiences. One subject was not able to detect increases until the duration of the PBI had been increased by approximately 925% and another subject had a difference threshold and psychometric function which indicated that she was able to distinguish between the original cry and all of the comparison cries presented with manipulated durations of the PBI.

The mean Difference Threshold for increased durations of the PAI also showed a relatively large standard deviation of 30.87. Individual difference thresholds for cries with an increased duration of the PAI ranged from 14% to 138.46%. However, close examination of these individual difference thresholds indicated that, according to the criterion
established by the Method of Constant Stimuli, only one of the fifteen subjects was not able to hear a difference between the original cry and any of the cries presented with increased durations of the PAI. A relatively smaller standard deviation of 16.06 was found for the mean Difference Threshold for a decreased duration of the PAI. Individual difference thresholds ranged from -96.78% to -38.93%. Thus, all subjects seemed to be able to differentiate between some of the presented comparison cries and the original cry.

Interestingly, the range of the individual difference thresholds for the cries with an increased duration of the PAI was approximately 125% while the range of individual difference thresholds for cries with a decreased duration of the PAI was only 58%. Thus, it appears that subjects are able to differentiate between an original cry and cries with a decreased duration of the PAI more consistently than subjects are able to distinguish between an original cry and cries with an increased duration of the PAI.

Finding such wide individual differences in the ability of adults to discriminate among infant cry sounds is not unusual in studies of the perceptions of the cry of the newborn and young infants. The range of behavioral and perceptual responses by adult listeners is dependent on a wide range of factors such as cultural background (Zeskind,
1983a), gender (Boukydis & Burgess, 1982; Frodi, Lamb, Leavitt, Donovan, Neff, & Sherry, 1978; Wiesenfeld et al., 1981; Zeskind et al., 1985), parity of the mother (Boukydis & Burgess, 1982; Green et al., 1987; Gustafson & Harris, 1990; Zeskind, 1983a; Zeskind & Lester, 1978), attitudes about child-rearing (Crowe & Zeskind, 1992; Frodi & Lamb, 1980; Zeskind, 1987) or previous abusive interactions with infants (Frodi & Lamb, 1980; Zeskind & Shingler, 1991). Thus, the communicative significance of variations in the cry sounds of newborn and young infants may vary as a function of the characteristics of the adult listener.

Interactions between the characteristics of the infant and caregiving environment may provide the basis for the different probabilities underlying different developmental pathways. For example, experimental work has indicated that the intellectual and social development of infants who have differential cry sounds depend on the nature of the caregiving environment (Zeskind & Ramey, 1978; 1981). The relationship between infants and caregivers is a bidirectional process in which the caregiving responses elicited by the infant's cries may reorganize the successive behavior of the infant. For instance, if the caregiver responds to an hungry infant's cry by feeding the infant, the infant will cease crying, which in turn will increase the probability of such responding from the caregiver in the
future as well as affecting the immediate caregiving responses. Conversely, if the caregiver does not respond at all to an infant’s crying, the infant will continue to cry, becoming more aroused over time, which will have a very different effect on the caregiver. Thus, the meaning conveyed to the caregiving environment via an infant’s cry, may play an important role in the continued development of the infant. In order to fully appreciate this bidirectional, developmental process, it is important to understand how various components of infant crying affect the meaning of the cry.

Conclusion

There are several caveats that should be clarified about the significance of the findings of the present studies. It should be emphasized that the data from the present study do not provide information on the effect that perceptible changes in the durations of pauses have on adults’ ratings of the cries’ conveyance of meaning to adult listeners. Future work should examine the communicative significance that these perceptible variations in the durations of pauses convey to the caregiving environment.

Another limitation of the present study is that the reported Difference Thresholds for changes in the durations of pauses may change as other characteristics of the cry change. It is known that just noticeable differences (JND)
between two noise pulses change as a function of the intensity level of the noise pulses. At an intensity level of 10 dB, the JND is 30 msec and at an intensity level of 70 dB, the JND is 3 msec (Plomp, 1964). Thus, it may be that the intensity level of the expiratory sounds in infant cries will also affect the point at which adults can detect changes in the duration of pauses. In addition, other features, such as the pitch characteristics of expiratory sounds and the durations of other cry features, may affect the values of the Difference Thresholds for changes in the durations of pauses. Thus, it is important that future research examine the effect that various cry features have on the Difference Thresholds for increases and decreases in the durations of pauses. In particular, the effects of intensity and fundamental frequency of expiratory sounds on detectable changes in the durations of pauses should be examined.

Yet another limitation of the current study is that perceptible changes in the durations of only two pauses in a small segment of a crying bout were examined. The detectable change in the duration of pauses may change if a longer segment of a crying bout (or an entire crying bout) is examined. If the pauses are contained in a longer rhythmic sequence of expirations, pauses and inspirations, smaller changes in the durations of pauses may become more
difficult to detect. Thus, future research needs to examine how Difference Thresholds for detecting the changes in durations of pauses might change as function of the context in which they are included.

A legitimate question concerns whether cries resulting from other eliciting conditions would be perceived in the same manner. For instance, a "mad" cry, as defined by Wolff, initially has different temporal features than a basic cry. The initial expiratory sound of a "mad" cry described by Wolff (1967) is .78 sec. followed by a pause of .18 sec. The inspiration is .04 sec. and the second pause is .17 sec. long. In contrast, the durations of the components of a "basic" cry are .63 sec., .08 sec., .03 sec., and .17 sec., respectively. Perceptible changes in the durations of pauses in "mad" cries may differ greatly as a result of the initial duration. Thus, it is necessary to explore the effect that the arousal level of the infant and the resulting cry has on adults’ detections of differences in the durations of pauses.

Another question resulting from this study concerns the mechanisms which underly the differentiation of changes in cry sounds by adults. The results of the present study showed that reliably larger manipulation percentages of the PBI than for the PAI are necessary for adults to detect differences in the cry sounds. One possible explanation for
this is that the first expiratory sound is masking the relatively short PBI. Masking interferes with the perception of a signal (or silent interval) in the presence of the masking stimulus, which is nearby in time and space. In particular, forward masking consists of aftereffects which gradually die out after the termination of an auditory stimulus (Zwislocki, in Carterette & Friedman, 1978). The decay of aftereffects is faster with higher intensities of the masking stimulus, and usually disappear within 300 msec. (Stein, in Carterette & Friedman, 1978). Because the PBI is only 33 msec. long, adults may have difficulty detecting small changes in the duration of the pause, because the aftereffects of the initial expiratory sound have not sufficiently decayed or because of decreased sensitivity in the auditory system (Zwislocki, in Carterette and Friedman, 1978). The possibility of masking as one mechanism underlying the differentiation of cry sounds, in addition to other possible mechanisms, should be explored further in future research.
References


In L. Lipsiit (Ed.), *Advances in infant behavior and development*. (pp. 167-212). Norwood, NJ: Ablex.


Experimental modification of relative durations of pauses and expiratory sounds in infant cries alters adults' perceptions. *Developmental Psychology, 28,* 1153-1162.


Development, 52, 213-218.


Table 1

**Means and Standard Deviations of the Difference Thresholds**

<table>
<thead>
<tr>
<th>Pause manipulation</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased duration of the PBI</td>
<td>354.18%</td>
<td>313.54</td>
</tr>
<tr>
<td>Increased duration of the PAI</td>
<td>58.53%</td>
<td>30.87</td>
</tr>
<tr>
<td>Decreased duration of the PAI</td>
<td>-61.91%</td>
<td>16.06</td>
</tr>
<tr>
<td>Increased duration of the PBI with a perceptibly shorter PAI</td>
<td>420.06%</td>
<td>332.98</td>
</tr>
<tr>
<td>Increased duration of the PBI with a perceptibly longer PAI</td>
<td>485.61%</td>
<td>336.53</td>
</tr>
<tr>
<td>Increased duration of the PAI with a perceptibly longer PBI</td>
<td>39.82%</td>
<td>16.29</td>
</tr>
<tr>
<td>Decreased duration of the PAI with a perceptibly longer PBI</td>
<td>-57.60%</td>
<td>22.48</td>
</tr>
</tbody>
</table>
Table 2

Comparison of Subjects’ Reports on the Source of Differences Between Cry Sounds: Experiment 1

<table>
<thead>
<tr>
<th>Identification of the Source</th>
<th>Manipulated Pause</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PBI</td>
</tr>
<tr>
<td>Correct</td>
<td>12</td>
</tr>
<tr>
<td>Incorrect</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 3

Comparison of Subjects' Reports on the Source of Differences Between Cry Sounds: Experiments 2 and 3

<table>
<thead>
<tr>
<th>Identification of the Source</th>
<th>PBI with a perceptibly shorter PAI</th>
<th>PBI with a perceptibly longer PAI</th>
<th>PAI with a perceptibly longer PBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>12</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Incorrect</td>
<td>3</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 4
Comparison of Subjects’ Reports on the Source of Differences Between Cry Sounds: Collapsed across the PBI with the PAI versus the PAI with the PBI

<table>
<thead>
<tr>
<th>Identification of the Source of the PAI</th>
<th>PBI with perceptibly longer PBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>20</td>
</tr>
<tr>
<td>Incorrect</td>
<td>10</td>
</tr>
<tr>
<td>Correct</td>
<td>15</td>
</tr>
<tr>
<td>Incorrect</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 2. Empirical Psychometric Function: Proportion of Different Responses for Pause Duration.
Figure 3. Psychometric function of detecting differences in an manipulation percentages.

Increases in the PBL.
Figure 4. Psychometric function of detecting differences for increases and decreases in the durations of the PAl.

Manipulation Percentages

0 100 80 60 40 20 0

Z-scores

-1 -0.5 0 0.5 1 1.5
Figure 5. Psychometric function of detection differences for manipulation percentages.

With a perceptibly longer PBI, increases and decreases in the PAL...
Figure 6. Psychometric function of detecting differences for original and perceptibly longer PBI.

Increases and decreases in the durations of the PAl with an increase or decrease in the PAl.

Manipulation Percentages

-1.0 -0.5 0.0 0.5 1.0

Z-scores

0 20 40 60 80 100

-80 -60 -40 -20 0
Figure 7. Psychometric function of detecting differences for perceptibility of the shorter PAI.

Increases in the duration of the PAI as a function of a manipulation of the percentages of Z-scores.
Figure B. Perceptibility function of a Psychometric function of detecting differences for Manipulation Percentages.

Perceptibility Longer PaI.

Increases in the durations of the PaI as a function of a Manipulation Percentages.

Z-scores

-1.0

-0.5

0.0

0.5

1.0

1.5
Figure 9. Psychometric function of detecting differences for perceptible longer or shorter P41.

Increases in the durations of the PBI with a perceptibly longer or shorter P41.
Figure 10. Psychometric function of detecting differences for Original or Perceptibly Shorter PAl.

Increases in the durations of the PAl with an original or perceptibly shorter PAl.
Figure II. Psychometric function of detecting differences for perceptibility longer PAI.

Increases in the durations of the PAI with an original or long PAI can
increase in the PAI with an

Manipulation Percentages

93
Figure 12. Psychometric function of detecting differences for increases in the durations of the PBI with an original, perceptibly shorter or perceptibly longer PBI.

Manipulation Percentages

Z-scores

Original PBI
Perceptibly shorter
Perceptibly longer
Longer PBI
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