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INFANT CRY ANNOYANCE SCALE AND INDEXES

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ABSTRACT

Noise-induced annoyance methodology is applied to infant cry to gauge which of the three acoustic determinants of cries frequency in Hz, intensity in dBA, and duration in hours, minutes, or milliseconds is/are the most annoying to parents and caregivers. The main finding is that in cries, as in many other annoying noises, intensity in dBA is the most aversive correlate. The path leading to this finding is not linear, but rather a tortuous one because many issues and definitions had to be discussed first. In so doing, the smallest unit of a cry had to be established. This led subsequently to the discussions of cycles of cries, cry bouts, cry bioacoustics, noise, annoyance scale, and more. The cries that trigger Shaken Baby Syndrome (SBS) and Abusive Head Trauma (AHT) are described impressionistically by Barr (2014) as those modified by seven adjectives, namely "prolonged, hard-to-soothe, unpredictable, unexplained, uncontrollable, alarming, and inconsolable cries." These impressionistic labels are translated into measurable intensity indexes on a four-point annoyance scale. Future technological and practical mitigation solutions that can help reduce incidences of SBS and AHT are discussed.

Keywords: Cry Annoyance, Infant Cry, Cry Bioacoustics, Cry Bouts, Cry Cycles, Cry Indexes, Cry Noise, Intermittence Penalty, Nocturnal Penalty, Equal Energy Hypothesis

1.0 Introduction

The paper investigates infant cry in order to discover reliable thresholds of annoyance. This is achieved by dividing the paper into three installments. The first provides definitions of key terms such as "infant," "bioacoustics," and "cry." Definitions such as these are necessary because infant cry research lacks a standardized methodology, which makes comparisons between research difficult. The second installment applies noise-induced annoyance terminology and methodology to study the noises that infants make when they cry. This implies that I subscribe to the view that infant cry evokes varying levels of annoyance responses from parents and caregivers. I'm justified in holding this view because, according to Barr (2014), infant cry is the main trigger of Shaken Baby Syndrome (SBS) and Abusive Head Trauma (AHT). The third installment provides a rationale for devising a four-point annoyance scale that can be used to elicit hearers' responses to cry stimuli. The indexes on the scale are predicated on the fact that intensity as measured in dBA has been found to be the best predictor of annoyance in a wide variety of noise-related studies.[2]

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[1] **Dr. Benjamin Witts**, an applied behavior analyst, is the one who first interested me in Infant Cry research. Since then, we have had several meetings to discuss various aspects of this research project, have agreed on the nomenclature to be used for the cry annoyance scale, and on the socio-acoustic survey instrument that will be used to elicit participants' reactions to four cry samples. We have also attended one professional conference together. I'm grateful to him for insightful perspectives and illuminating conversations, for publications that he has sent my way, and look forward to working with him on various aspects of this project. I also acknowledge the support that I have received from my graduate assistant, **Ms. Megan Dell'Acqua**, who extracted the measurements used in this publication. This aspect of the Infant Cry research is funded by two grants that Dr. Witts and I received from the Office of Sponsored Programs of St. Cloud State University.

[2] Most noise annoyance studies do not include infants as a noise source. The most commonly noise sources listed by WHO (1980:22-24) are industry, road traffic, rail traffic, air traffic, sonic booms, construction and public works,

1.1 Definition of "Infant"

The state of Minnesota where this research is being conducted defines an infant as a person whose age is from birth to two years (*Minnesota's Child Maltreatment Report* 2019, p. 17). This is the population whose cries are investigated in this paper. I'm particularly interested in infants who are two to three months old because, according to Sparks et al. (2012:6) "the majority of victims are under 2 years of age and the peak of incidence is typically found from 2-3 months." They also report that "deaths due to abusive head trauma also peak at 1 to 2 months of age, most likely due to higher physiologic vulnerability during early infancy." They explain that "Infants who have assault-related head injuries at 3-4 months of age or older may be more resilient and more likely to survive their injuries." The cry of an infant, Baby 1F, a participant in the study, is used to illustrate the data in this paper because she fits the demographics of highly vulnerable infants. She was only five weeks old at the time of the recording. Her parents observed that she cried a lot during her first three weeks of life. They sought help from a healthcare professional because of her cries. The mother took some allergy tests, and it was determined that some ingredients in her diet upset Baby 1F. She eliminated those elements from her diet. By the time of the recording, the parents reported that Baby 1F's crying had lessened. They provided me with a cry bout of 23 minutes. Baby 1F's parents have three other children, which makes her their fourth child.

1.2 Infant Cry as "Bioacoustics"

The phrase "infant cry bioacoustics" was first encountered in Soltis (2004:448). The word "bioacoustics" is generally reserved for non-human vocalization. However, it is appropriate to use it to describe infant cry because the cries do not resemble anything of the language that the infants will start acquiring after their second birthday. Considering infant cry as bioacoustics is appropriate for another reason. Small insects such as cicadas manage to emit the loudest of noises by contorting their bodies. Infants also are small, yet they emit some of the most strident sounds that the human vocal apparatus can produce. In fact, as they grow out of infancy, they lose the ability to produce the piercing cry noises. The annoyance levels in an infant cry have a lot to do with how babies contort their bodies when crying. For this reason, Bosma (1965:63) contends that cries consist of two crucial elements: the **cry sound** and the **cry act**. He describes the latter as follows:

> The general pattern of an infant's arousal response is that of exaggerated surging expiration. These surges are signaled by his cries and demonstrated also by tensing of neck and trunk, opening of mouth, and flexion of limbs. Essentially the infant's whole motor expression is gathered about his succession of cries … Infant cry is a complex physical phenomenon: act plus sound. As act, the cry of the newborn infant is a patterned motor performance peculiar to this particular stage of neurological development. Cry occurs with the infant's arousal and is accompanied by successive surges of effort in which the infant's generalized actions are scheduled about his cry-adapted expirations. (Bosma 1965:63, 65, 66,89)

Cry acts are not explicitly referred to in the remainder of the paper, but they are implied all throughout. It is precisely because of the "surges of efforts" which involves the flailing of their

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indoor, outer, and miscellaneous noises. To the best of my knowledge, this is the first publication that considers infants as a noise source.

arms, the tensing of their legs, the arching of their backs, and the pushing out of air molecules with great velocity that infants manage to emit the cry noises that parents and caregivers consider annoying.

1.3 Daily Crying Cycles and the Nocturnal Penalty

Barr et al. (1996:348) studied 35 parents' cry diaries which documented their infants' crying and fussing patterns over a 24-hour cycle. Their notes provided Barr et al. with invaluable insights into cry behaviors. Barr and colleagues divided the diaries into three distinct periods: day, from 8:00 AM to 4:00 PM, evening, from 4:00 PM to 12:00 AM, and night, from 12:00 AM to 8:00 AM. Generally, parents and caregivers report that they find infant cries more annoying during the early evening and nighttime hours. For this reason, the three daily cycles can be lumped together into two main cycles, the diurnal and the nocturnal cries, as shown in Figure 1:

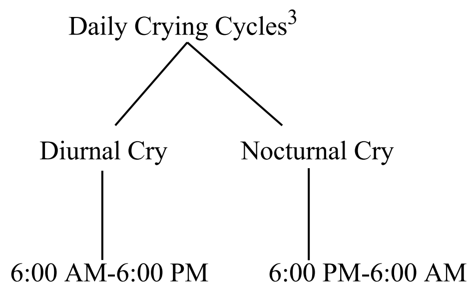

Figure 1: Daily Cry Cycle

That parents and caregivers deem nocturnal cries more annoying is not a coincidence. Noise annoyance studies have found that nighttime noises carry a penalty of 10 dBA (Fidell 2015:30). In other words, if a diurnal cry is 70 dBA, when parents and caregivers hear that same cry at night, they perceive it as though the infant is crying at a level of 80 dBA. The World Health Organization (WHO, 1980:12) notes in its noise annoyance report that most people are not annoyed by daytime noises with intensity levels lower or equal to 55 dBA. For nighttime, the noise tolerance level is 45 dBA or less, hence the penalty of 10 dBA for nocturnal annoyance.

1.4 Peak Daily Cry Cycles

Barr et al. (1996) gathered other important insights from their study of parents' diaries. For example, crying peaks during the first six weeks of life. During that time, 25% of infants cried for a little over 1h 30. Another 25% cried over 5 hours a day. The remaining 50% of infants cried between 2 and 3 hours (Barr 2014:560). Figure 2 displays these cycles, as follows:

[3] Daylight saving is not taken into account.

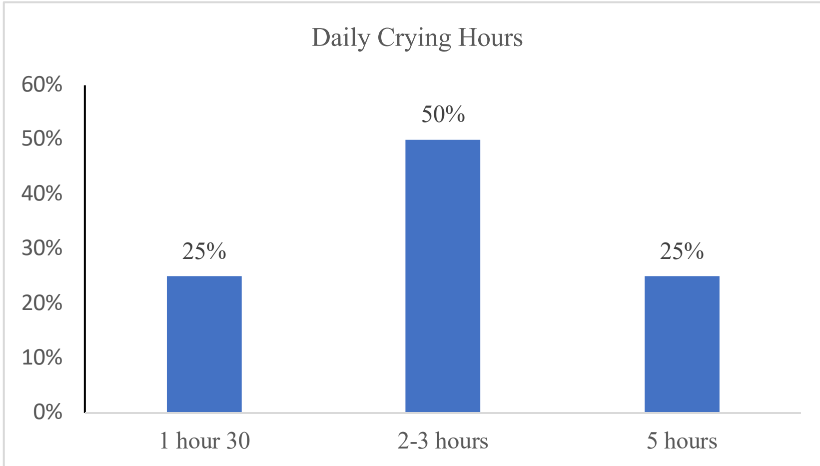

Figure 2: Daily Crying Hours

1.5 A Minimalist Approach to Cry Research

Up until now, the discussions have dealt with definitions and cry cycles. Now, we turn our attention to the internal structure of the cries.[4] Doing so can prove valuable and illuminating. Figure 3 allows us to peer into the internal hierarchical structure of cries:

Cry Bouts: ± 40 minutes
↓ ↑
Cry Periods: 10-15 seconds
↓ ↑
Rhythmic Groups: ± 500 msec
↓ ↑
Cry Signals: F0, Intensity, Duration

Figure 3: Cry Units

The bidirectional arrows mean that cries can be examined from a top-down or a bottom-up perspective. We prefer to study cries from the bottom up. The smallest unit on which all cries are based is the **cry signals** that the infants emit. Acoustically, these signals can be decomposed into **frequency spectra**, but more importantly into their fundamental frequency **(F0)** as measured in Hz, into **intensity** as measured in dBA, and into **duration** as measured in hours, minutes, seconds, or milliseconds. In acoustics, the three correlates that make up every cry signal are independent from each other and yet fully interdependent on each other. They are so inextricably bound that one cannot perceive one without perceiving the other two, and vice versa.

Cry signals combine with each other into a larger unit called **rhythmic group** (RG). The rhythmical nature of infant cry has been acknowledged by almost every cry researcher. Ji et al. (2021:5, 6) provide the following insights about the internal structure of cries: "It is shown that

[4] No effort is made to differentiate between "pathological cries" and "normal cries." See Ji et al. (2021:17) and Manigault et al. (2022:7) for a list of potential pathologies that have been diagnosed simply by analyzing cry signals. The current research examines all cries so long as they can cause annoyance.

infant cry signal is rhythmic and has cyclic changes due to the natural interruption and breath. … Infant cry is made of four types of sound: one coming from the expiration phase, a brief pause, and a sound coming from the inspiration phase followed by another pause. Variations in intensity, fundamental frequency (F0), formants, and duration are typical acoustic cues that carry prosodic information about infant cry." This characterization of cries underscores the importance of the RG as a unit of cry analysis.[5] Figure 4 taken from Koffi (2022:8) provides a spectrographic display of RGs and highlights their importance in the acoustic phonetic analysis of cries.

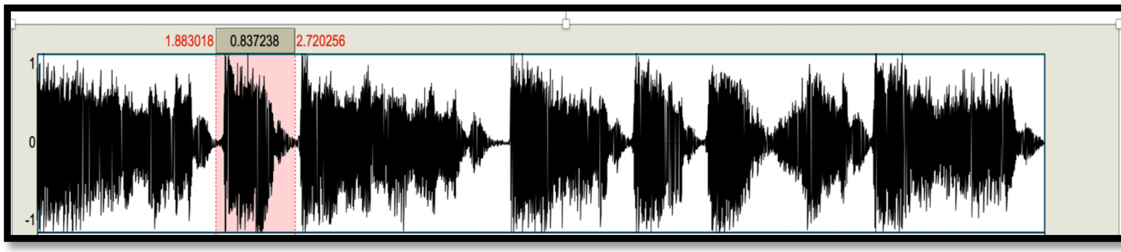

Figure 4: Display of RGs

For a formal definition of the RG, we turn to Manigault et al. (2022:4) who describe it as an **expiratory phase of respiration**. This means that when infants cry, they pause to inhale a little bit of air before crying again. The acts of inhaling and exhaling constitute one RG. Manigault et al. (2022) differentiate between **short** and **long** RGs. The former last less than 500 msec, while the latter last 500 msec or longer. By this definition, Baby 1F produced mostly short RGs, except for RG 17 which is 571 msec long.

Baby 1F			
Cry Episode 1	**F0 in Hz**	**Intensity in dBA**	**Duration in msec**
RG1	373	68	374
RG2	305	73	204
RG3	447	68	224
RG4	387	65	354
RG5	386	70	130
RG6	472	69	191
RG7	261	83	284
RG8	390	77	162
RG9	387	73	202
RG10	421	75	171
Cry Episode 2			
RG11	212	83	187
RG12	483	73	187
RG13	287	85	289

[5] In natural sciences, isolating the basic building block is key to a deeper understanding of what is being studied. In phonology, it is the phoneme. In phonetics, it is the phone. In biology, it is the cell. In chemistry and physics, it is the atom, etc. The RG is taken to be the basic building block of cries.

RG14	296	78	345
RG15	265	85	493
RG16	465	83	399
RG17	409	77	571
RG18	404	68	120
RG19	442	74	279
RG20	372	67	337

Table 1: Rhythmic Group Analysis[6]

Taking the RG as the minimal unit of cry analysis is important because it speaks directly to the **intermittent** nature of infant cry. Noise annoyance researchers report that intermittent noises are deemed more annoying than steady noises because they carry a penalty of 5 dBA. As noted in 1.2, when infants cry, there are moments of surges of effort and moments of diminution of effort. The interplay between greater and lesser effort contributes to the intermittence of cries. This explains the variability between the RGs in Table 1.

RGs combine with other RGs to form a larger unit of cry known as a **cry episode**. Reference to cry episodes abound in the cry acoustics literature. There is a long list of publications that have explicitly alluded to cry episodes as segments that last **10** to **15 seconds** (see Koffi 2022:5). Table 1 contains two cry episodes, RGs 1 to 10 and RGs 11 to 20.

Cry episodes also combine with one another into the largest unit that Barr et al. (1996:348) call a **cry bout**. According to them, a cry bout "describes a cluster of cry events or cycles, occurring on the order of 2 to many minutes, which are the typical units of measurement in diary studies. A new bout is counted only after absence of crying for at least 5 minutes." In his 2014 paper, Barr provides additional refinements to the concept of cry bout, as follows:

> … these crying bouts last longer than at any other time in the infant's life, and often average 40 min in duration, while individual bouts may go on for 1–2 h before stopping. Finally, although these bouts may happen at any time of the day or night, they typically cluster in the late afternoon or evening. (Barr 2014:560).

The notion of cry bout is a very important analytical construct. It is particularly useful because it shows that duration is an important acoustic determinant of annoyance. All things being equal, a cry bout that is long is likely to be judged more annoying than one that is short. The average duration of a cry bout is **40 minutes**. Some are shorter, and others are longer. For example, Baby 1F's cry bout used in this paper lasted only 23 minutes. If we take the average duration of 40 minutes, we can calculate the number of cry bouts within a 24-hour cycle. The 25% of infants who cry for 1hour 30 have 2.25 bouts. The 50% of infants who cry between 2 to 3 hours have 3.75 bouts a day, while the 25% of infants who cry 5 hours a day have 7.5 bouts. Fortunately for parents and caregivers, Barr also found that the duration of bouts goes diminishing from 40

[6] This data represents only the first 20 RGs of 2,231 RGs. All the data is extracted using Praat, Version 6.2.13 of May 18, 2022.

minutes to 34 minutes by the time infants reach 12 weeks, and 30 minutes thereafter. Cry bouts keep diminishing until the infant grows past the "terrible twos."

2.0 Definitions of Noise and Annoyance

The astute reader will have noticed by now that I have used the terms **"noise"** and **"annoyance"** without defining them. The time has come to do so. Yet, the definitions of these two terms are not as simple as one would think. Fidell (2015:29) notes that before a sound can be considered an annoying noise, researchers must answer two basic but very important questions:

1. How much is too much?
2. How can you tell?

The first question addresses annoyance directly, while the second question compels researchers to dig deeper and not rely solely on impressionistic evaluations because, as noted by Baken and Orlikoff (2000:1-2), the ear is easily fooled.

2.1 Subclassification of Noises

In the noise annoyance acoustic literature, noise is defined as an "unpleasant sound." This is a subjective definition because what is unpleasant to one person may not be to another. Yet, noise researchers have found a threshold for when a sound/noise turns into annoyance. Schnitta (2016:55) defines as annoying any sound that is 5 dBA higher than expected. This means that if a parent or caregiver expects an infant to cry at 65 dBA, if they cry at 70 dBA, their crying becomes annoying. The penalty of 5 dBA is very important for gauging levels of noise-induced annoyance. For example, what is simply a normal cry during the daytime hours can be perceived as annoyance at nighttime. WHO recommends 45 dBA or less as an adequate environmental noise level that is conducive to sleep. If an infant cries at 50 dBA at night, the cry becomes annoyance because of various penalties associated with nocturnal noises. Yet, during daytime hours, a cry of 50 dBA will not be considered annoying. Researchers have subdivided noises into four types:

1. Steady/continuous
2. Intermittent regular
3. Intermittent irregular
4. Impulse

Steady noises are those that have a sustained intensity level for a defined period. Here is an example. I live in Minnesota where the winter months are cold. Before leaving my house, I turn my car on and lets it run for 15 minutes. During this time, the engine in my Chevy Impala produces a steady noise of 48 dBA. This is an example of a steady/continuous noise. Intermittent noises on the other hand are very brief. Dornic and Laaksonen (1989:12,13) make a distinction between them. Some are intermittent regular noises, while others are intermittent irregular noises. The former are noises in which the start and stop times occur at predictable intervals. Fire alarms are a perfect example of intermittent regular noise because the alarm turns on and off at predetermined intervals. As for intermittent irregular noises, they have haphazard start and end times. For all intents and purposes, an infant cry qualifies as an intermittent irregular noise because the RGs are not of equal duration, as is exemplified in the next paragraph. Henderson and Hamernick (1986:569) define impulse noises as those caused by military operations or industry. They are a category of their own because for a noise to qualify as impulse, its intensity levels must be equal to or greater than 100 dBA. Henderson and Hamernick (1986:579) indicate that "increasing the number of impulses increases the number of acoustic traumas." This can also be said of intermittent noises in general, and of infants' cries in particular.

As Table 1 shows, Baby 1F's cry is an intermittent irregular noise because consecutive RGs have different durations. The durational distances between them are higher than 10 msec, except for RGs 11 and 12. The naked ear can detect a durational difference of 10 msec or more. The intermittence nature of infants' cries carries a penalty because, as noted in 2.2, all intermittent noises penalize the hearer. However, experts do not agree on the severity of the penalty. Qui et al. (2020:39) report that there has been a back-and-forth debate about the severity of the penalty on animal models. Some estimate the penalty to be as high as 10 dBA, others propose a penalty level of 5 dBA, while others are simply unsure about the severity of the penalty. Yet, the scholarly consensus is that there is a penalty though its severity has not been established beyond doubt. Koffi (2022) opted for the smaller penalty of 5 dBA. Since we take infant cry to be an intermittent irregular noise, a penalty of 5 dBA should be added to the loudness measurements of each RG in Table 1.

2.2 Definition of "Annoyance"

Annoyance is defined by Dornic and Laaksonen (1989:14) as the psychological response to noise. However, we turn to WHO (1980:12) for a more elaborate definition:

> Noise annoyance may be defined as a feeling of displeasure evoked by a noise. The annoyance-inducing capacity of a noise depends upon many of its physical characteristics including its intensity, spectral characteristics, and variations of these with time. However, annoyance reactions are sensitive to many non-acoustic factors of a social, psychological, or economic nature and there are considerable differences in individual reactions to the same noise.

Researchers have conducted many socio-acoustic surveys in hopes of finding the most accurate way to assess annoyance. In 1993, the International Commission on the Biological Effects of Noise (ICBEN) convened a meeting and tasked Team 6 to come up with a standardized annoyance scale. Team 6 collected 21 modifiers to qualify and quantify levels of annoyance (Yano and Ma 2007:584-5, Masden and Yano 2004:591, Sato et al. 2004:610, Table 1). After many debates and deliberations, they harmonized their views and settled on two scales: a four-point scale and a five-point scale, as displayed in Table 3:[7]

No	Five-Point Annoyance Scale	Four-Point Annoyance Scale
1.	Not at all	Not at all
2.	Slightly	
3.	Moderately	Somewhat
4.	Very	Significantly
5.	Extremely	Extremely

Table 3: ICBEN's Annoyance Scales

[7] The adjective "annoying" is implied on each point on the scale.

Jaehwan et al. (2010:807) indicate that the five-point scale is the most widely used, while Seki et al. (2004:604) add that having a standardized scale makes it possible "To compare the rates of annoyed people in different districts, countries or surveys…. It is particularly important to make the degrees comparable among different languages." The experts on Team 6 put a lot of thought into every aspect of the scale, including the choice of modifiers, because as noted by Fields et al. (2001:647), "Seemingly innocuous differences in the wording can have dramatic effects on respondents' answers." Team 6 members debated long and hard about the pros and cons of various scales. They eventually settled on the four-point and the five-point scales for the following reasons:

> Verbal scales of six points or more were rejected because such long scales were judged to be too cumbersome for telephone interviews. Scales of three points were rejected as not providing a sufficient range of alternatives. On a 3-point scale there would only be two degrees of annoyance for those who were other than "not at all annoyed." In the absence of empirical data, the standard psychometric criteria of reliability and validity could not be used in selecting between 4- and 5-point scales. Although both scale lengths have been used in previous noise surveys, the effects of length cannot be evaluated with noise-annoyance data because scale length is confounded with other differences between surveys and with wording differences in the question stems. As a result, other criteria were considered, upon which 5-point scales were slightly better on two criteria and equivalent on the remaining three.

Since there is no empirical data suggesting that the five-point scale is inherently better than the four-point one, we have opted to use the latter in measuring the annoyance in infant cry. More will be said about this in 3.2.

2.3 The non-acoustic determinants of Annoyance

Noise experts make a distinction between the acoustic determinants of annoyance and the non-acoustic ones. Fidell (2015:30) cautions that "Assuming that noise exposure is the sole cause of annoyance ignores the obvious differences between people and sound level meters." Dornic and Laaksonen (1989:17) adds that there are "large individual differences in annoyance susceptibility, which are frequently reported in the literature." The same observation is made in WHO (1980:14). In other words, some individuals are more prone to annoyance than others. Section 4.0 provides additional comments on individual differences that can be captured by administering a socio-acoustic survey.

Cry bioacoustics researchers have provided a profile of perpetrators who are likely to be greatly annoyed by crying to the point of causing bodily harm to infants. The eight traits of perpetrators below have been compiled from various sources, Hennes et al. (2001:22), Lagasse et al. (2005), Showers (2001:351-2), among others.

1. Parents or caregivers with predispositions towards violence
2. Parents or caregivers with predispositions towards abrupt mood swings
3. Parents or caregivers with chronic health problems
4. Parents or caregivers who abuse drugs and/or alcohol
5. Parents or caregivers who are poorly educated
6. Parents or caregivers who are immature both in age and in behavior

7. Parents or caregivers who for a variety of reasons lack mental alertness
8. Parents or caregivers who self-identify as males[8]

These traits show that annoyance has multiple sources of causation. When these non-acoustic determinants occur in tandem with the acoustic ones, people tend to react negatively or harshly. Irrespective of the source(s) of causation, Fidell (2015:30) observes that "After all, airplanes fly over everyone: introverts and extroverts, young and old, male and female, and sensitive and insensitive." His study focused on annoyance caused by aircraft noise. Yet, his remarks can be paraphrased and applied to infant cry as, "After all, infants will cry whether their parents or caregivers are introverts or extroverts, young or old, male or female, and sensitive or insensitive," because "The most commonly proposed signal function of the infant cry is to alert caregivers to need," (Soltis 2004:444). Regardless of parents' and caregivers' predispositions to annoyance, they should know that their infants will cry. It, therefore, behooves pediatric scientists to discover the acoustic determinants of cries that cause annoyance.

2.4 The Acoustic Determinants of Annoyance

It was indicated in 1.2 that the smallest unit of cry analysis is the cry signal and that it is a composite of frequency, intensity, and duration correlates, as was shown in Table 1. Do all three correlates cause the same level of annoyance or is there one that causes the most annoyance? To answer this question, we turn to the **Equal Energy Hypothesis** (EEH). In noise annoyance studies, researchers often mentioned EEH (Fidell 2015:29, Qui et al. 2020:39). There is a very large consensus among experts that, all things being equal, intensity plays a greater role in causing annoyance than frequency and duration. Because of this, Koffi (2022) proposed the following cry annoyance hierarchy:

Intensity > Duration > F0

Past pediatric researchers have focused almost exclusively on F0 in an effort to gain insights into the acoustics of infant cry. However, their efforts have not borne as much fruit as expected because they have not availed themselves of the insights from noise annoyance research. They have also been misled by pronouncements by earlier researchers such as Fairbanks (1942) who claimed to have found F0 in cries as high as 800 Hz or even up to 1,000 Hz. Baken and Orlikoff (2000:180) have expressed skepticism about these findings, saying that measurements with "a mean F0 as high as 814 Hz casts doubts on the validity of his methods." Koffi (2022:6) attributes these extremely high F0 measurements to an octave error that went undetected. Soltis (2004:448) reports that the most common F0 values are between 200 Hz to 600 Hz. However, he also indicates on page 451 that "The fundamental frequencies of cries associated with severe pathology, on the other hand, are usually greater than 1000 Hz." Even this claim should be taken with a grain of salt and remains to be verified because Soltis is simply relaying claims made by previous researchers instead of providing fresh data. We note in passing that the highest F0

[8] WHO (1980:11) reports that differences in annoyance sensitivity based on gender is well known. The literature on SBS and AHT indicates that males have a higher propensity towards causing SBS and AHT than females. Also, more baby boys suffer SBS and AHT at the hands of males than baby girls. Lagasse et al. (2005:90) report that "Men rated cries as more aversive, as eliciting more irritation and anger, and rated infants as more spoiled than women. Mothers rated cries as more likely to evoke sympathy and evoke caregiving than fathers."

produced by Baby 1F is 472 Hz in RG 6 (see Table 1).[9] Finally, for the spectral considerations in general, Koffi (2022:11,15) showed that Center of Gravity (CoG) and dysphonia, two measurements that are based in the frequency domain, do not discriminate between "Intense" and "Regular" cries.

Saying that F0 ranks last is not the same as saying that it does not play any role at all. We address this potential misunderstanding by quoting WHO's definition of the intensity correlate as it relates to noise and annoyance:

> Sound is produced by the vibration of bodies or air molecules and is transmitted as a longitudinal wave motion. It is, therefore, a form of mechanical energy and is measured in energy-related units. The sound output of a source is measured in watts and the intensity of sound at a point in space is defined by the rate of energy flow per unit area, measured in watts per msec. Intensity is proportional to the mean square of the sound pressure and, as the range of this variable is so wide, it is usual to express its value in decibels. Because the effects of noise depend strongly upon frequency of sound pressure oscillation, **spectrum analysis is important in noise measurement** [emphasis added, not in original] (WHO 1980:7).

When it comes to infant cry, we already know that F0 oscillation is between 200 Hz to 600 Hz. This means that spectral information is already factored in the intensity the level of the cry. This is part of the A-weighting mechanism. Equipment used to measure noise levels take frequency into account. In the technical literature, annoyance measurements are always reported as dBA or dB(A) because it reflects as accurately as mathematically possible how the naked ear perceives all the correlates of sounds/noises.

Spectral impact notwithstanding, even a causal perusal of the noise annoyance literature leaves no doubt that intensity plays a more dominant role than frequency. Frequency in Hz is mentioned sparingly and only when the discussions center on the spectral bandwidth in which the noise test is administered. Infants' cries occur between the spectral range of 3,000 to 6,000 Hz. This covers a small portion of humans' spectral audibility range of 20-20,000 Hz. Usually, after publications have mentioned this sort of spectral information, they move on to focus on the intensity domain because it carries more weight in noise annoyance research.

Murphy and Kardous' (2012) report on noise in the workplace mentions spectral domain only on three pages (pages 5, 7, 16) in the 27-page document. By comparison, duration is mentioned on 10 pages, while intensity is virtually on every page. A European Union Commission Scientific Committee on Emerging and Newly Identified Health Risks (2008) study mentions intensity in dBA 48 times, while the spectral domain is mentioned only sparingly. In assessing aircraft noise annoyance, Fidell (2015) discusses intensity alone with no mention of frequency. Schnitta's (2016) and Roy and Siebein's (2019) publications on acoustic comfort discuss decibel levels only with no mention of frequency. Qui et al. (2020) do mention frequency, but in a very generic sense in regard to the human audibility range. Rogers and Maglieri's (2015) paper on Concord Booms and Lubert's (2018) publication on the acoustics of rocket launch do not say

[9] We are extracting 10 correlates from each RG. These correlates are: F0, F1, F2, F3, F4, CoG, Intensity, Duration, Shimmer, and Jitter. They are extracted within the parameters of the default settings in Praat.

anything specific about the frequency domain, except in a generic sense. Jaehwan et al. (2010:807) also mention frequency in a generic sense on two pages, while the rest of their paper deals with intensity. Finally, Baker (2016) mentions frequency only in passing, but he devotes most his attention to intensity levels of noises in his study of neighborhood noises in England. The role of intensity was suspected in Koffi (2022), but it is now abundantly and unmistakably clear that intensity as measured in dBA is the most important acoustic determinant of annoyance. This also applies to cry-induced annoyance.

3.0 Designing an Annoyance Scale and Indexes

Since intensity in dBA is the most important acoustic determinant of annoyance, it means that scales and indexes should be based on it. Focusing on it rather than on the spectral domain can help answer why infant cries are aversive to parents and caregivers. Yet, before dealing with the scale and indexes directly, we must take a brief detour to understand the nature of cries that trigger SBS and AHT.

3.1 Impressionistic Descriptions of Annoying Cries

Barr (2014:560) provides the following impressionistic description of cries that trigger abusive responses. These types of cries are modified by seven adjectives, as highlighted in bold in the quote below:

> Although all crying can be frustrating, recent work has increasingly focused on the **prolonged**, **hard-to-soothe**, **unpredictable** and **unexplained** bouts that make caregivers feel helpless and guilty in the face of **uncontrollable** crying in their infant. These **alarming inconsolable** crying bouts are almost unique to the first few months of life. They are much more strongly associated with caregiver frustration than are the overall frequency or duration per day of crying or fussing. Unfortunately, the evidence is robustly clear that these completely normal if frustrating characteristics of crying are exactly what contribute to the majority of cases of shaking and abusive head trauma in early infancy [emphasis added, not in original].

Barr is not claiming that cries that are modified by one or more of these adjectives automatically trigger SBS and AHT. Yet, he writes on page 562 that immature responses to these types of cries account for up to 40% of traumatic injury in infants less than two years old. Sadly, 10% more of these infants die (Reichert and Schmidt 2001:80). Across the USA, these types of cries account for 1,000 fatalities annually (Hennes et al. 2001:21). Many of these fatalities can be prevented if we gain a better understanding of the acoustic determinant that parents and caregivers find the most annoying.

3.2 Justification for the Preference for the Four-Point Scale

The experts at the International Commission on the Biological Effects of Noise proposed the four-point scale as a suitable alternative to the five-point scale. We know from Fields et al. (2001:647) that there is no empirical difference that one of the two scales discussed in 2.2, Table 3, is better than the other. Consequently, we are fully justified in using the four-point scale and adapting it to infant cry research. Additionally, we provide thresholds to translate intensity metrics and explain what the points on the scale mean.

No	Noise Annoyance Scale	Cry Annoyance Scale	Indexes in dBA
1.	Not at all	Tolerable	≤ 70 dBA[10]
2.	Somewhat	Annoying	71-75 dBA
3.	Significantly	Aggravating	76-80 dBA
4.	Extremely	Maddening	≥ 81 dBA[11]

Table 4: Cry Annoyance Scale and Indexes

ICBEN's "Not at all," is replaced by "Tolerable," because there is really no aspect of infant cry that qualifies as "Not at all" annoying. Even fussing can be annoying if it goes on for 20 minutes or more. "Somewhat" is replaced simply by "Annoying." The last two ICBEN indexes are replaced respectively by "Aggravating" and "Maddening." These are words that have been uttered by parents to describe degrees of annoyance in cries.

The last column containing the thresholds in dBA is an adaptation of Roy and Siebein's (2019) scale for measuring noise levels in restaurants and public venues. In their paper, intensity measurements that are below 70 dBA are deemed "quiet." They consider intensity levels between 71-75 dBA to be "moderately loud," those between 76-80 dBA to be "loud," and those equal to or greater than 81 dBA are deemed "very loud." We have kept these thresholds and correlated them with the four points on the infant cry annoyance scale. When this scale and these indexes are applied to Baby 1F's data in Table 5, we get the following results:

Baby 1F		
Cry Episode 1	**Intensity in dBA**	**Cry Annoyance Index**
RG1	68	Tolerable
RG2	73	Annoying
RG3	68	Tolerable
RG4	65	Tolerable
RG5	70	Tolerable
RG6	69	Tolerable
RG7	83	Maddening
RG8	77	Aggravating
RG9	73	Annoying
RG10	75	Annoying
Average	**72**	**Annoying**
Cry Episode 2		
RG11	83	Maddening
RG12	73	Aggravating

[10] WHO (1980:11) reports that sleep is disturbed for 60% of people when the noise level rises to 70 dBA, and subjects who ordinarily sleep well have a hard time falling asleep when the noise level reaches 50 dBA.
[11] Crying at or beyond 85 dBA is considered extremely loud. For example, The US Occupational Safety and Health Administration (OSHA) does not regulate noise exposure below 85 dBA. However, "Workers exposed to 85 dBA noise for 8 hours per day must be enrolled in a hearing conservation program and provided with hearing protection device." (Le Prell 2022:16)

RG13	85	Maddening
RG14	78	Aggravating
RG15	85	Maddening
RG16	83	Maddening
RG17	77	Aggravating
RG18	68	Tolerable
RG19	74	Aggravating
RG20	67	Tolerable
Average	**77**	**Aggravating**

Table 5: Annoyance Scale and Indexed of Baby 1F's Cry

The arithmetic means of Cry Episodes 1 and 2 are respectively 72 and 77 dBA. They translate into "Annoying" and "Aggravating" on the annoyance scale. This is what a Sound Level Meter will record. However, since infant cry qualifies as an irregular intermittent noise, it carries a penalty of 5 dBA. So, when these cries enter the Central Auditory Nervous System (CANS) of the parent or caregiver, they are perceived auditorily as Aggravating cry for Episode 1 and as Maddening cry for Episode 2. This is if Baby 1F cried during daytime hours. If the cry happened at night, it carries a nocturnal penalty of 10 dBA.

A cautionary note should be sounded here because intensity is not perceived by the naked ear on a linear (arithmetic) scale, but on a logarithmic one. So, adding 10 dBA of nocturnal penalty to 5 dBA of intermittence penalty does not yield an increase of 15 dBA, but rather of 7 dBA.[12] So, if Cry Episodes 1 and 2 were to occur at night, hearers will perceive them respectively 79 dBA (Aggravating) and 84 dBA (Maddening). The 7 dBA difference between Cry Episodes 1 and 2 is enormous because it amounts to an 87% increase in sound energy (Schnitta 2016:55).

3.3 Duration and Annoyance

The correlate hierarchy in 2.4 indicates that duration is the second most important acoustic determinant of annoyance. All things being equal, parents who are among the 25% whose infants cry only 1.30 hours a day are likely to be less annoyed than parents of 25% of infants who cry 5 hours a day or more. Furthermore, duration of cry bouts matters in gauging annoyance. If an average cry bout lasts 40 minutes, parents whose infants cry less than average are likely to be less annoyed than parents whose infants cry longer than the average bout. Lagasse et al. (1996) found that some cry bouts last longer than an hour. There is a glimmer of hope for parents because cry bouts become shorter and shorter after the first 12 weeks of an infant's life (refer back to 1.5).

3.4 Mitigation Solutions

Weeks of prolonged, hard-to-soothe, unpredictable, unexplained, uncontrollable, inconsolable, and alarming cries can easily put some inexperienced parents and caregivers on edge and cause them to lose control and injure their infants. This statement is not in defense of child abuse, but an unpleasant acoustic reality that has fatal consequences for some infants. Yet, understanding that intensity and duration are the leading causes of annoyance can help to devise

[12] Solution provided by https://www.mathway.com/Calculus on November 30, 2022.

technological and/or suggest practical mitigation solutions that can drastically reduce instances of SBS and AHT in this country and elsewhere.

Since we live in an age of smart devices, the information contained in this publication can help devise smart technology in the form of apps that can measure the annoyance level of cries in a matter of seconds.[13] While waiting for this smart technology idea to come to fruition, parents and caregivers can reduce the annoyance levels in cries by using inexpensive earplugs. Some of the cheapest ones have a noise reduction rate (NRR) of 32 dBA or more. I use them when I fly because I sit in economy class when I travel. More often than not, I sit in the vicinity of parents with infants. I put my earplugs in before sitting down because I know that, sooner or later, the infants will cry when the aircraft taxies off and lands. The differences in air pressure cause their sensitive ears to hurt during these maneuvers. Parents should be encouraged to use these practical and inexpensive mitigation solutions. The devices fit unobstructively inside the ears but do not completely mute cry signals. So, parents and caregivers can still interact meaningfully with their infants. Parents and caregivers should also make earplugs available to babysitters. The Center for Disease Control encourages parents and caregivers to "try calming a crying baby by rocking gently, swaddling in a blanket, offering a pacifier, holding your baby against your bare skin, singing or talking softly."[14] Wearing earplugs is not incompatible with implementing these soothing techniques, especially since these devices can help blunt the acoustic determinants in cries that are most annoying.

4.0 Summary

Now that an annoyance scale has been established and index thresholds have been made available, the next phase of the research is to use this information to gauge participants' reaction to four representative cry samples. The elicitation of cry reactions will be done in keeping with the following recommendation by WHO (1980:12):

> Whatever noise scale is used to express noise exposure, it must be recognized that, at any level of noise annoyance, reactions will **vary greatly because of psychosocial differences.** A useful technique for accommodating the possible extent of individual variation is the use of a criterion curve showing the percentage of persons who will be annoyed as a function of noise level [emphasis added, not in original].

Since individual susceptibility to noise annoyance varies greatly (see also discussions in 2.3), the goal is to collect data from a large pool of participants and to assess their annoyance levels on the four-point scale discussed in 3.2. The participants will be asked to listen to four cry samples and to rate their annoyance levels. The survey will provide answers to the following questions:

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[13] Our research team plans to develop an infant cry app and wearables. This is a project in the making. We are looking for additional grants to make it possible. Even if we are awarded a grant now, it will take some time to develop the app and make it available to consumers. We anticipate that with such a hand-held device, a parent or caregiver can monitor an infant cry in just 15 seconds (the average length of a cry episode) and determine its level of annoyance. They will know in a matter of seconds the level of annoyance of the cry and suggested practical steps to help them cope and avoid an abusive reaction.

[14] https://www.cdc.gov/violenceprevention/childabuseandneglect/Abusive-Head-Trauma.html, retrieved on December 11, 2022.

1. Percentage of participants who find infant cry "Tolerable," "Annoying," "Aggravating," or "Maddening" when the cry intensity levels are 65-70 dBA
2. Percentage of participants who find infant cry "Tolerable," "Annoying," "Aggravating," or "Maddening" when the cry intensity levels are 71-75 dBA
3. Percentage of participants who find infant cry "Tolerable," "Annoying," "Aggravating," or "Maddening" when the cry intensity levels are 76-80 dBA
4. Percentage of participants who find infant cry "Tolerable," "Annoying," "Aggravating," or "Maddening" when the cry intensity levels are ≥ 81 dBA

The survey contains participants' biometric information such as gender, age, parental, and caregiver experiences. Correlations between various datapoints will provide useful insights into the indexes that elicit the greatest levels of cry annoyance among specific demographics.

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