FORENSIC ANALYSIS OF THE AUDIBILITY OF FEMALE SCREAMS

DURAND R. BEGAULT[1]

[1]*Audio Forensic Center, Charles M. Salter Associates, San Francisco, CA, USA*
Durand.Begault@cmsalter.com

Acoustical engineers and forensic acoustical experts are sometimes called upon to render opinions on the audibility of specific sounds at a given distance. Such sounds include speech, gunfire, warning signals such as fire alarms or locomotive horns, and in certain cases, human screaming. The audibility of female screaming has been questioned in several cases, where the expert can use both analytical and demonstrative techniques in order to form an opinion. The determination of audibility may be refined in terms of detection, discrimination and identification. This paper addresses measurement and typical levels of female screams, and reports on two different audibility analyses.

INTRODUCTION

"Voice projection" typically refers to a wilful emphasis of the speaking or singing voice to allow audibility at a great distance. It also refers to those techniques employed in public speaking to demand respect and attention, such as when a teacher is talking to the class, or simply to be heard clearly, as by actors in a theatre. Human screaming, particularly that which is effective in its role to alert others to a situation of calamity, shares characteristics with effective voice projection in singing. Voice projection is enhanced via air flowing from the expansion of the diaphragm, instead of air from the top of the lungs. Vocal resonance can be used to effect an increase in amplitude via the use of the 'head voice' by making use of the upper sinus cavities.

Acoustically, the scream is part of the vocal repertoire of many animals, and is differentiated between and even within one species. The exact acoustical mechanisms vary and can be quite complex, including the effect of large scale temporal patterns, turbulence and nonlinear acoustic effects, and complex spectral patterns including harmonic and inharmonic components (see for instance [1]). But for the acoustical engineer, the primary interest is in the over-all sound pressure level and its consequent implications for audibility.

Sometimes the question of audibility of a scream's sound pressure level relates to community disturbance and noise abatement; for example, reference [2] investigates 'pass-by' spectra of screams from multiple persons on a moving roller coaster. In forensic situations, the audibility of a scream is typically made with reference to the acoustics of sound production; sound propagation; and the psychoacoustics of a receiver who may have been a potential 'witness' to a crime [3]. In this paper, I will present data pertinent to each of these issues.

1 "HOW LOUD IS A SCREAM"

In acoustics, it is not unusual for someone from outside the field (e.g., an attorney) to question an expert about how 'loud' a particular sound source is, including screams. For instance, a world records book reportedly indicates 126.2 dB as the 'loudest scream'. After explaining the differences between loudness and sound pressure level, an expert must then attempt to explain the statistical variation and influence of the experimental design with respect to the measurement of a human-generated sound. One must also account for the means by which the level is measured, and for the specific frequency weighting and time averaging employed, since this can influence the outcome of any measurement [4]. Finally, care must be made for preventing distortion in the capture of these high-level signals.

Sound level measurements and recordings were made of female screaming at our parent firm Charles M. Salter Associates on two occasions. Calibrated 'Type 1' acoustical measurements were made in a sound-deadened room. Two sets of measurements from ten female subjects ranging in age from mid 20s to mid 40s were obtained. Each subject screamed three times, with instructions to "scream as loudly as possible, as if you had just been surprised by something very scary"; the data for the scream with the highest level was retained. The distance from the mouth of the subject to the microphone was 36 in.

In rank order, the data can be summarized for each participant in order from most to least intense: 123, 122, 122, 118, 115, 110, 109, 109, 108 and 102 decibels. The average level is 113.8 dB and the standard deviation is 7.3 dB. The values reported are the maximum A-weighted level using a fast (.125 ms) time integration ($L_{AF\text{-}MAX}$) to correspond to human perception.

A major source of variance involves individual physiology, the particular vocal characteristics of the subject, and subject ability to follow the experiment instructions. Another major source of variance is likely to be the inability of some subjects to "scream on demand" in a data-gathering exercise. It has been previously noted in studies of speech levels at various levels of effort, including shouting, that "the variability in voice level between talkers increased with voice effort" [5]. This is likely due to compound factors of experimental design (how well could the subject follow the 'instructions' of the experiment) as well as intra- and inter-speaker variability.

In these data, there was an apparent correlation of age and level; those subjects who produced the three screams with the highest levels were under 30 years of age. They also subjectively had the most 'convincing', or 'realistic' sound of a person screaming fearfully in accordance with the instructions to be 'surprised.' Additionally, the subject who produced the lowest-level 102 dB scream was the oldest subject, and later indicated having an 'allergy attack' during testing. Nevertheless, no attempt was made to exclude any of the data to prevent 'cherry picking' the results.

Figures 1-4 show data analysis of a 2.25 s specimen scream (the 'second highest' level scream). Figure 1 shows an overall downward frequency 'glide' with a diminished slope in the latter half of the time record. Comparing Figure 1 to Figure 4, the highest $L_{AF\text{-}MAX}$ level (121.8 B) correlates with greater frequency variance, and the average level corresponds to the steadier frequency components of the second half of the time record. Figure 2 shows a frequency 'warble' or vibrato that is coincident with the overall frequency glide.

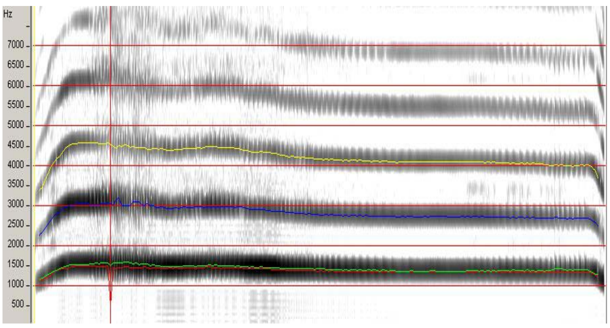

Figure 1. Spectrogram (0.5-8 kHz, 512 pt. FFT) of specimen scream (2.25 s). Energy is maximal in the first formant around 1.5 kHz. Note the overall downward glide in frequency.

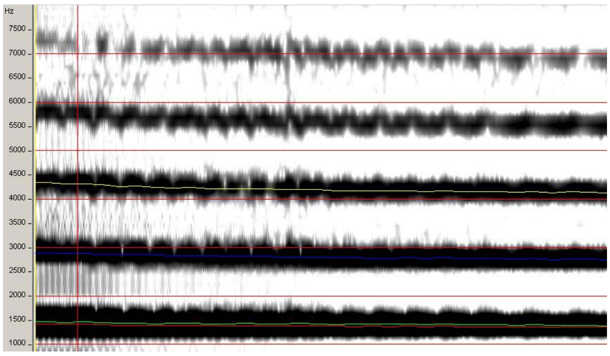

Figure 2. Spectrogram of same scream as in Figure 1, focusing on 1- 8 kHz over a period of 0.3 s. Note local frequency modulation ('warble' or 'vibrato').

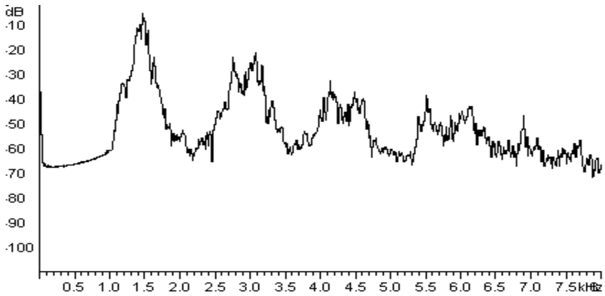

Figure 3. 4096-pt. Fast Fourier Transform: average across 2.25 s. "Smearing" of peaks results from the overall downward glide of frequency and warble effect.

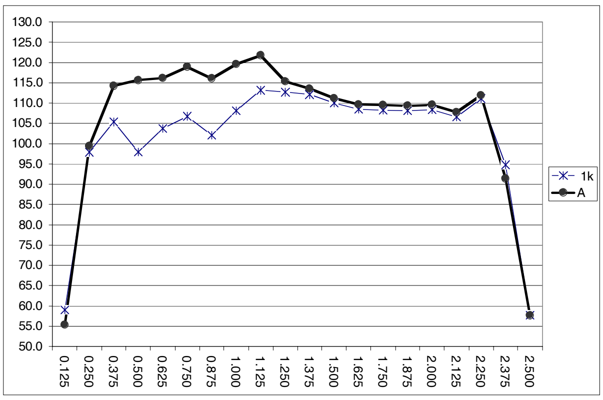

Figure 4. Overall A-weighted and 1 kHz octave band data for scream shown in Figure 1. The *x* axis indicates sound pressure level in dB; the *y* axis indicates time in 0.125 s increments. Note that the 1 kHz octave band drives the overall A-weighted level for the latter half of the scream. The average $L_{AF\text{-}MAX}$ is 121.8 dB, and the average A-weighted level is 115 dB.

2 FORENSIC ANALYSIS OF SCREAM AUDIBILITY: EXAMPLE CASE STUDY

The author was asked to determine audibility of human female screaming, from the location of an alleged incident (hereafter referred to as the 'source' location) to a residence in a nearby community ('receive' location). An acoustical testing protocol was developed involving loudspeaker playback of a recording of a human female screaming at a calibrated sound pressure level from the source location. This was felt to be more demonstrative than accomplishing the task via an acoustical model, with the advantage that the recordings could be played back for the Court. The specimen scream shown in Figures 1-4 was used for the testing.

Calibrated recordings and sound level measurements were made at potential locations outside the receive location (front, back and side yards) after calibrating a loudspeaker at the source position. The source-receiver distance was approximately 260-300 ft via a direct line-of-sight, depending on the specific receiver location. The source location was elevated relative to the receive location by approximately 50 feet, at a turn-off from a road located on the side of a hill. Between the source and receive location was a 25 foot wide river that provided a constant source of noise. Because of this configuration, there were no significant acoustical obstacles between the source and receive locations other than the residence itself.

An additional measurement was made inside the house with all windows and doors shut, under quiet indoor conditions. Both the screams and the background noise were recorded. The measurements occurred at the same time of day, the same day of the week, and with similar weather conditions (temperature, wind direction, wind speed (average and gusts) as on the date of the incident. No significant atmospheric absorption effects or wind direction effects would have resulted since the distance was less than 100 m [6].

Several factors are relevant to whether or not a resident in the vicinity of the receive location might have heard screaming from the source location. These include:

(1) the signal-noise ratio, both in terms of the overall frequency content and within a specific frequency band, the 2 kHz octave band;

(2) the duration of the signal;

(3) the degree to which the level of the test signal corresponds to other screams.

2.1 Signal-noise ratio

The signal-noise ratio refers to the measurement in decibels of the sound pressure of a signal (in this case, a scream) relative to the level of the background noise (in this case, traffic, wind in the trees, river noise, and other contributing community noises).

To determine the signal-noise ratio, the overall A-weighted and 2 kHz octave band levels were analyzed in a frequency region corresponding to the maximum acoustical energy of the scream. This was sensible since the frequency components of a scream have predominate energy in relatively higher frequencies whereas the background noise has its principal energy in low- and mid-band frequencies (1 kHz octave band and below).

The hypothesis tested by the measurement protocol was as follows: if a positive signal-noise ratio relative to the existing background noise at a particular receive location was measured (i.e., if the level of the signal was louder than the noise), the scream could have been audible at that location. A positive signal-noise ratio of 5 decibels can be considered a conservative estimate of audibility. This is a reasonable and scientific assumption based on the fact that noise can mask signals from being heard when the signal is lower in a concurrent frequency band. In addition, audibility can also be demonstrated empirically from playback of the recordings themselves.

Table I below summarizes the data from the measurements taken at receive location. The values reported are the maximum A-weighted level using a fast (.125 ms) time integration ($L_{AF\text{-}MAX}$) to correspond to human perception. (Similar signal-ratios were found by averaging over the duration of the sound).

LOCATION	Background level	Signal level	**Signal-noise ratio**
Back yard	**54.2** (46.9)	**79.4** (78.4)	**25.1** (31.5)
Side yard	**50.8** (41.2)	**77.5** (74.2)	**26.7** (33.0)
Front yard	**61.0** (53.9)	**68.6** (67.5)	**7.6** (13.6)
Indoors	**39.0** (30.2)	**43.1** (41.1)	**4.1** (11.0)

TABLE I. The A-weighted values for overall levels are indicated in **bold.** The levels within the 2 kHz octave band are indicated in parentheses.

The right column of Table I shows positive signal-noise ratios at all locations tested (all > 5 dB in the 2 kHz octave band). Indeed, the sound of the screams was clearly audible from all of the measurement positions, as well as at other more distant locations throughout the community. Police were summoned to investigate the test screams that were heard at two locations in town, one location indoors but with windows open, at approximately 500-700 feet distant, including on the opposite of a busy two-lane highway. Figure 5 indicates that the 2 kHz octave band frequency band of the scream was particularly effective at "penetrating" through background noise spectrum.

Table I also shows that with all doors and windows shut, the signal was audible inside of residence under quiet conditions with no household background noise present. With windows open towards the direction of the source, the level would *increase* the signal-noise ratio by at least 10 dB.

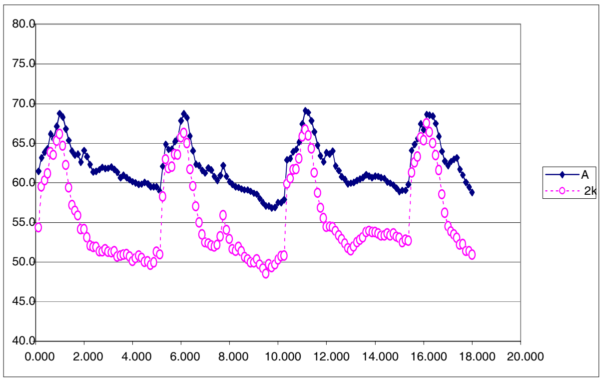

Figure 5. A-weighted (solid line, filled diamond) and 2 kHz octave band (dashed line, circles) sound pressure levels for four iterations of the scream**,** at the front yard of the residence (third row of Table I). The 2 kHz octave band level of the scream penetrates the *average* background noise level (indicated by the valleys) by about 14 dB.

2.2 Duration of the signal

The scream signal was 2.25 s duration, played four times with a brief interval of silence in-between. There were four iterations of this 8 second signal played for all of the receive locations, i.e., a total duration of 32 seconds of signal. The likelihood of audibility would increase as the duration of screaming over a given period of time increases, since there is greater statistical chance for persons to be outdoors, opening windows, or varying their background noise condition. The sound of screaming also has a distinct characteristic over time that allows it to be more noticeable compared to other co-existing sound in the environment. (During the incident, the screaming was alleged to have occurred repeatedly for close to an hour).

2.3 Correspondence of the test to other 'screams'

It is possible to adjust the signal-noise ratio to account for whether or not the *average* scream level of 114 dB found in Section 1 would have been heard, by lowering the signal level by 8 dB relative to the measured noise level. Table II indicates that the signal-noise ratio is positive in the 2 kHz octave band, where most of the acoustical energy of the scream is concentrated. For the least intense case, of a scream at 102 dB, the signal-noise ratio remains positive in the back and side yard locations, but is negative in the front yard location, due to the relative increase in the level of the background noise from the nearby highway. Note that the 102 dB level is outside of one standard deviation from the average and therefore is an "outlier" value relative to the other measured levels.

LOCATION	Signal-noise ratio for 122 dB Scream	Signal-noise ratio 114 dB Scream	Signal-noise ratio 102 dB Scream
Back yard	**25.1** (31.5)	**17.1** (23.5)	**5.1** (11.5)
Side yard	**26.7** (33.0)	**18.7** (25.0)	**6.7** (13.0)
Front yard	**7.6** (13.6)	**-0.4** (5.6)	**-12.4** (-6.4)
Indoors	**4.1** (11.0)	**-3.9** (3.0)	**-15.9** (-9.0)

TABLE II. The A-weighted values for overall levels are indicated in **bold.** The levels within the 2 kHz octave band are indicated in parentheses.

The directivity of the loudspeaker horn used in the testing roughly approximated the directionality of a human facing in the direction of the receiver locations. Had a person under 'worst case for audibility' conditions been facing 180 degrees relative to the direction tested, there would have been an overall drop in level of 3.5 dB [7]. The features of the location (dirt, rock) may act both as acoustic reflectors or absorbers. This reduction in level of 3.5 dB would not have been enough to eliminate audibility in the back and side yard locations at the 260-300 foot distances measured, for screaming at levels as low as 102 dB or as high as at 122 dB.

2.4 Outcome of the testing

Beyond the positive signal-noise ratios that have been presented so far, other factors increased the likelihood of audibility of a scream: (1) a large number of homes and other locations where people congregate, including a park, were proximate (300-500 feet) to the source location, (2) persons in the community have complained to the police about other noisy activities at this specific location, such as teenagers having a party, and (3) the reported duration of screaming during the incident was far longer than that used in the tests. Nevertheless, any outcome such as this must be ultimately evaluated with respect to the characteristics of the actual person screaming during the incident (who could not be tested) and any other acoustically relevant factors that were unknown during the testing.

3 SUMMARY

A scream is similar to a baby's cry; there is nearly a universally-understood agreement as to its meaning regarding human calamity, and its frequency content seems almost tailored to frequencies of maximal sensitivity on an equal-loudness contour. The level at which a scream might be discriminated from other types of sounds in most contexts is likely not much higher than the level at which it can be detected, due to its unique character. Forensic investigations may benefit from the use of acoustical measurements and simulations, provided that calibration is performed carefully and that consideration of potential variability in results is accounted for.

REFERENCES

[1] I. Tokuda, T. Riede, J. Neubauer, M. Owren and H. Herzel "Nonlinear analysis of irregular animal vocalizations" *Journal of the Acoustical Society of America,* vol. 111, no. 6, pp. 2908-2919 (2002).

[2] C. Menge, "Residential impact criteria and abatement strategies for roller coaster noise" *Proceedings of the 2002 International Congress and Exposition on Noise Control Engineering (Internoise 2002), Dearborn, MI* (2002).

[3] R. Peppin "The sounds of a murder" *Journal of the Acoustical Society of America,* vol. 114, no. 4, p. 2373 (2003).

[4] "Standard S1.4-1983 Specifications for Sound Level Meters." American National Standard ANSI Institute (1983).

[5] K. S. Pearsons, R. L. Bennett and S. Fidell, "Speech Levels in Various Noise Environments", United States Environmental Protection Agency report no. EPA-600/1-77-025 (1977).

[6] C. M. Harris, *Handbook of Acoustical Measurements and Noise Control* third edition McGraw Hill (1991).

[7] H. Fletcher, *Speech and Hearing in Communication* reprinted by the Acoustical Society of America (1995).