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Psychoacoustic Evaluation of Transmission Line Audible Noise: Building Attenuation Effects, Methodology Comparison, and Field Study Feasibility

MASTER

January 1, 1979 to December 31, 1979
Volume 1

Prepared for:

U. S. Department of Energy
Assistant Secretary for
Resource Applications
Office of Electric Energy Systems
Under Contract No. AT01-77ET29323

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Psychoacoustic Evaluation of Transmission Line Audible Noise: Building Attenuation Effects, Methodology Comparison, and Field Study Feasibility

January 1, 1979 to December 31, 1979
Volume 1

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EXECUTIVE SUMMARY

Increasing demand for electric energy necessitates the transmission of greater amounts of electricity from generation sites to consumers. Overhead high-voltage electric transmission lines are the primary means for distributing this energy over long distances. Historically, increased energy demand has been met by increasing transmission line voltages, thus minimizing expenditures on expensive materials and property rights-of-way. But one of the important factors limiting the development of new extra-high-voltage (EHV) and ultra-high-voltage (UHV) transmission technologies is the audible corona noise radiated by such lines under certain weather conditions. In evaluating new EHV and UHV technologies, both acoustical measurements of the noise being produced and psychoacoustic measurements of human response to this noise will play crucial roles.

The frequency spectrum and short-term temporal characteristics of transmission line audible noise are different from those of most other environmental noises. Therefore, traditional psychoacoustic measurement scales and environmental health and welfare noise criteria may not be appropriate for assessing the impact of transmission line noise. As a result, the Department of Energy (DoE) has sponsored a project at the National Bureau of Standards (NBS) to investigate human response to transmission line audible noise. This project is developing a psychoacoustic data base to determine the extent to which present measurement scales and human response criteria are appropriate for evaluating the environmental impact of transmission line audible noise and to suggest different scales and criteria if necessary.

In developing the necessary psychoacoustic data base, the DoE-NBS project has taken the following approach: (1) Samples of corona noise from transmission lines are recorded on magnetic tape in the field. (2) These samples are reproduced for human listeners in a simulated living room located at NBS. (3) The human response to corona noise is measured in the room. During the first year of the project (1977), the listening room was constructed and calibrated and psychoacoustic methodologies were tested for application to corona sounds.

During the second year (1978), an initial series of psychoacoustic experiments was conducted. Tentative conclusions from these experiments follow:

- 1) Despite its low sound level, corona noise is somewhat more aversive to people than might be expected on the basis of physical measurements of the sound.
- 2) Although all of the common frequency weighting scales underestimate the aversiveness of corona noise to some degree, A-weighted and D-weighted sound levels tend to minimize these underestimations.
- 3) Knowledge of the source of corona noise on the part of the listener does not affect its relative aversiveness. Thus feelings and attitudes toward power lines (e.g., fear) are not likely to be the sole determinants of the aversiveness of corona noise.
- 4) The high-frequency hissing and crackling components of corona noise are more aversive than the low-frequency humming and buzzing components. Therefore, engineering efforts should be directed toward reducing the high-frequency portion of the noise spectrum.
- 5) There are distinctly different kinds of corona noise which differ both in frequency spectrum and relative aversiveness. Consequently, long-term sampling of corona noise from different lines under different weather conditions may be needed to map out the range of human response to corona noise.

These conclusions should be regarded with some caution, however. Samples of corona noise were collected from only a few power lines under a limited set of weather conditions, and reproduction of the sounds in the listening room was at outdoor sound levels. This only represents the indoor case where a listener would be close to a large open window. The third year of the DoE-NBS project (1979) was directed at overcoming some of these limitations. In order to provide representative samples of the noise from a given power line, an automated magnetic tape recorder system was developed. This self-contained microprocessor-controlled system can remain unattended for long periods of time under a transmission line to collect samples of corona noise for psychoacoustic experiments. Volume II of the present report presents a full description of this tape recording system under separate cover.

NBS conducted further psychoacoustic experiments (1980) in order to investigate the effect of indoor listening conditions on the human response to corona noise. The experiments employed corona sounds that were electronically filtered to simulate the noise isolation afforded by two different kinds of homes. In addition, two different psychoacoustic methods were compared with respect to their effectiveness in experiments involving corona sounds. The following tentative conclusions were drawn from these two experiments:

- 1) Corona noise and other environmental noises are much less aversive when presented under indoor (closed windows) as opposed to outdoor conditions.
- 2) Corona noise, when presented so as to sound like it would in a house of "northern-type" construction, was less aversive than the same noise as it would sound in a house of "southern-type" construction.

- 3) Corona noise as it would sound in a northern house was indistinguishable in aversiveness from the ambient background noise in the listening room. Thus corona noise may not be a problem inside a northern-type house with the windows closed.
- 4) The data from two parallel but different psychoacoustic experiments showed that 83 percent of the variance in the data was accounted for with an "acoustic menu" procedure, while only 46 percent of the variance was accounted for by the acoustic stimuli with a "rating scale" procedure. Thus the "acoustic menu" procedure demonstrated superior experimental precision, although the rank ordering of the aversiveness of the stimuli was the same for both procedures.
- 5) The feasibility of collecting data from residents living near transmission lines was discussed. To achieve a statistically adequate sample of residents and their noise exposure would involve effort beyond the scope of the present DoE-NBS project.

Further experiments are needed in order to fill in and expand the present data base on the human response to corona sounds. They should be directed at 1) determining the extent to which different corona sounds differ in relative aversiveness when presented at natural levels, 2) assessing the aversive effects of corona noise as heard inside a house with open windows, 3) further testing the automated tape recorder system to collect representative samples of corona noise, and 4) developing a catalog of different types of corona sounds. Such data should prove useful to electric equipment manufacturers, operating electric utilities, land-use and urban planners, and architects and building designers in minimizing the environmental impact of electric transmission corridors.

INTRODUCTION

Extra-high-voltage (EHV) and ultra-high-voltage (UHV) overhead electric transmission lines often produce audible noise. The noise occurs primarily during moist weather for alternating current (ac) lines and primarily during clear dry weather for direct current (dc) lines. This sound, typically associated with corona discharge, is often referred to as "corona noise." To the degree that corona noise may be aversive to residents living near overhead electric transmission lines, it may represent a possible limitation to expanded use of this efficient means of transmitting electric energy. Therefore, in assessing environmental noise impact it is important to determine how aversive corona noise is, how human response to corona noise compares with the response to other environmental noises, and what the most appropriate way to measure corona noise is. Since exposure to corona noise in the environment occurs in a variety of outdoor and indoor listening situations, laboratory study of human response to this noise also should address these different exposure conditions.

In contrast to the scores of psychoacoustic studies conducted with transportation noise¹, there have been few investigations of human response to corona noise. Sforzini, Cortina, Sacerdote and Piazza² determined "loudness" balances with various samples of corona noise and found that A-weighted sound level correlated best with listeners' adjustments. Wells³ determined equal "annoyance" matches with corona noises and found that B-weighted sound level predicted the judgments of his participants most closely. Pearsons, Bennett and Fidell⁴ studied the annoyance reactions of people to both transformer noise and corona noise. They found that

many other noises were judged equally annoying to corona noise even though they were about 10 dB higher in A-weighted level. Some of the earlier experiments on human response to corona noise are summarized in a 1974 IEEE Psychoacoustics Workshop⁵.

As part of a project sponsored by the U. S. Department of Energy, Molino, Zerdy, Lerner and Harwood⁶ demonstrated the feasibility of using the "acoustic menu" procedure for evaluating human response to corona noise. The "acoustic menu" is a behavioral preference procedure developed by Zerdy and Molino⁷ that differs from verbally-based procedures commonly employed in psychoacoustic studies.¹ Molino et al.⁶ showed that various versions of the behavioral procedure produced consistent and reliable results, but their preliminary experiments did not permit a direct comparison of results obtained from the "acoustic menu" with results obtained from the more commonly-used procedures based upon verbal descriptions. The present study permits such a comparison.

Using the "acoustic menu" in an initial series of full-scale psychoacoustic experiments, Molino et al.⁸ demonstrated that all of the commonly used frequency weightings correlated very highly with people's reactions to corona and other noises. Although D-weighted sound level correlated best, A-weighted sound level predicted the listeners' responses nearly as well. They also observed⁹ that corona noise samples were equally preferred to a frequently studied reference noise (1000-Hz octave band) which was about 11 dB SPL higher than the corona noise. Equal preference judgments were also obtained with a collection of commonly heard environmental sounds which by

interpolation were found to be about 8 dB SPL higher than corona noises. Thus, the corona noise samples studied are more aversive acoustic stimuli than anticipated on the basis of their sound levels. Furthermore, the high-frequency (hissing and crackling) components of corona noise appear to contribute more to this aversiveness than do the low-frequency (humming and buzzing) components¹⁰.

The initial series of full-scale psychoacoustic experiments by Molino et al.⁸, also demonstrated that there are distinctly different kinds of corona sounds. These sounds differ both in physical frequency spectrum and in relative aversiveness. Therefore, in order to assess the environmental impact of audible noise from transmission lines, long-term sampling is needed of the noise produced by different transmission lines under various weather conditions. A special automated magnetic tape recording system was developed at NBS to provide long-term samples for psychoacoustic experiments. It is a self-contained, microprocessor-controlled system that can remain unattended for long periods of time under a transmission line. It includes a complete weather monitoring station and a Fast Fourier Transform spectrum analyzer to provide the microprocessor with information concerning climatic and acoustic conditions that might be favorable for making tape recordings of corona noise. Thus, "intelligent" decisions can be made in the field to collect representative tape-recorded samples of corona noise that would be suitable for presentation as stimuli in future psychoacoustic experiments. A full description of this automated tape recording system may be found in Volume II of the present report (under separate cover).

The initial experiments of Molino et al.⁸ reproduced corona noise samples and other environmental and artificial noises in a realistic listening room. Reproduction of the environmental sounds was at sound levels typical of outdoor exposures. This approximates the indoor case of a listener located near a large, open window. The present experiments employed some of the same outdoor acoustic stimuli, including corona noise samples, used in the earlier experiments. However, in the present study, these sounds were presented both as if they were heard outdoors and under various simulated indoor listening conditions. Thus, the present experiments, to a limited extent, tested the generalizability of some of the earlier findings for a wider range of listening conditions. They also evaluated how particular indoor listening conditions affected the relative aversiveness of corona noise. In addition, the use of a behavioral preference and a verbal category-scale procedure permitted the comparison of these two psychoacoustic techniques. This comparison was designed 1) to serve as a methodological bridge to facilitate comparison between the results of NBS menu experiments and the results of other researchers and 2) to evaluate the efficacy of the less time-consuming category-scale procedure in determining human response to corona noise. Finally, an evaluation was made of the feasibility of conducting field studies of the human response to corona noise.

METHOD

Two parallel experiments were conducted with 14 acoustic stimuli which were the same in spectrum and level, but which differed in duration. Experiment I employed the "acoustic menu" procedure. Research participants sat individually in a simulated living room. They chose between two available acoustic stimuli while engaged in casual reading of books. The participants were periodically forced to choose between the stimuli in a given pair, although the option of changing from one stimulus to the other could be exercised at any time. Each pair of stimuli was available for 5 minutes. Experiment II employed a paper-and-pencil "annoyance" rating scale. Participants sat in groups of four in the listening room and rated a series of acoustic stimuli, each stimulus lasting about 40 s in duration. Twenty-six different people participated in each experiment, for a total of 52 listeners.

Participants

Experiment I employed 25 females between 19 and 49 years of age (median age = 33 years) and 1 male, 18 years old. Experiment II employed 24 females between 18 and 46 years of age (median = 28) and 2 males, 18 and 19 years of age. All participants were paid volunteers recruited from the Gaithersburg, Maryland, area through local newspaper advertisements. The preponderance of female participants was due to recruitment conditions in the local area; earlier experiments⁸ had shown no significant effects of age or sex of the participant. The participants were screened to be audiologically normal as tested with pulsed pure tones on a Békésy audiometer. Thresholds were within 15 dB of the reference coupler sound pressure level for the normal hearing threshold¹¹.

Field Recordings

Six source spectra, listed in Table 1, were recorded on magnetic tape; microphone placement was 1.5 m (5 ft) above the ground (ear height). Outdoor recordings were always made with wind speeds of less than 13 km/hr (8 miles/hr). The measurement distance was that typical for a listener located just outside a transmission line right-of-way (see Apparatus and Calibration). No particular account was made for constructive and destructive interference patterns for tonal frequency components with regard to microphone placement. In the case of the three corona noise recordings, the procedure recommended in the IEEE Guide¹² was followed. A list of the recordings follows:

Apple Grove Corona. Audible noise from a test EHV (775 kV) ac transmission line located at Apple Grove, West Virginia, was recorded in the early morning after a heavy dew. The recording was made at a midspan position 15.2 m (50 ft) from the projection to the ground of the outer phase conductor of Line A, which was about 15 m (50 ft) high at this point (level ground). The A-weighted sound level was 54 dB (re 20 μ Pa). Some singing of birds could be heard in the background.

Roanoke Corona. Audible noise was recorded from an operating EHV (765 kV) ac transmission line located near Roanoke, Virginia. The recording was made during steady early-morning rain in a field at the base of a hill. The microphone was located 15.2 m (50 ft) from the projection to the ground of the outer phase conductor. However, the line was unusually high (about 46 m or 150 ft above the ground at midspan) because it traversed the hill at this point. The A-weighted sound level, including the rainfall sound which

Table 1
Stimuli in Experiments I and II
and A-weighted Sound Levels (dB)

Source Spectrum	Listening Conditions		
	Outdoors (O)	Southern House (S)	Northern House (N)
Apple Grove Corona	54	--	20
Roanoke Corona	61	35	28
Peru Corona	59	33	--
Lawnmower	66	44	--
Traffic	72	--	43
Octave Band	(45)	(75)	

served as a background, was 61 dB. Some slow amplitude modulations (2 to 3 Hz envelope-frequency) were present in the tonal components.

Peru Corona. The audible noise from an operating EHV (765 kV) ac transmission line located near Peru, Indiana, was recorded at night in a heavy fog. The average A-weighted sound level was 59 dB. The microphone was located 15.2 m (50 ft) from the projection to the ground of the outer phase of the line (level ground).

Traffic. Morning rush-hour traffic noise was recorded from a 6-lane interstate highway in Rockville, Maryland. The microphone was 22 m (72 ft) from the middle of the outer lane. The recording consisted of occasional truck passbys on an almost constant background of passing cars. The time-averaged A-weighted sound level of this sample was 72 dB.

Lawnmower. The noise from a stationary but operating 3 hp (2.2×10^3 watts) gasoline-powered lawnmower was recorded in a suburban backyard. The microphone was located at a distance of 15.2 m (50 ft) from the source, which produced an A-weighted sound level of 66 dB.

Octave Band. An octave band of white noise centered at 1000 Hz was recorded directly from a noise generator and filter. This artificial laboratory sound is a commonly employed psychoacoustic reference stimulus, and it permits the comparison of present results with those of other psychoacoustic experiments. It was presented at an A-weighted sound level of either 45 or 75 dB.

All of the above recordings of environmental noise must be regarded as isolated examples of the noise emitted by the particular source. No

attempt was made to sample statistically the noise from several different transmission lines under several different weather conditons in order to select a "typical" corona noise spectrum. Equipment for this purpose is presently being developed at NBS under the sponsorship of the U.S. Department of Energy. Thus, the transmission line audible noise spectra employed in the present experiments may not be representative of the most prevalent corona sounds heard in the environment, even for a given weather condition. The same is true for the tape-recorded sounds from the other environmental noise sources.

Apparatus and Calibration

Field recordings for 5 of the 6 source spectra (Octave Band excluded) were made with a portable system consisting of a condenser microphone with wind screen, a preamplifier and power supply, sound level meter, and magnetic tape recorder. A block diagram of the recording system is shown in Appendix A. For the 3 corona noise recordings, the microphone, preamplifier and power supply were housed in a grounded electrostatic shield made of wire-mesh. A polyurethane foam sphere (9 cm diameter, 800 pores/m) served as a wind screen for the microphone. All field recordings had calibration tones placed on them in the field by means of an acoustic calibrator. The artificial source spectrum, the Octave Band, was tape recorded on the same type of field recorder from a band-pass filter (24 dB/octave skirts) fed by a white noise generator.

The field recordings were edited to remove any spurious man-made sounds. Six samples of about 5 min of recorded sound for each source spectrum (5 environmental field recordings plus the Octave Band) were

prepared. They were then copied from the field tape recorder onto a 16-track studio tape recorder. In Experiment I, different pairs of tracks were automatically selected under computer control to generate the sequences of stimulus pairs used in the "acoustic menu" procedure. In Experiment II different single tracks were selected to generate random sequences of stimuli to be rated by the listeners. Additional tracks on the 16-track tape included timing signals for controlling stimulus sequences, and calibration signals for establishing system gain levels and for monitoring recorder equalization over repeated tape passes.

The acoustic spectra were gated by electronic switches with a rise/fall time of 0.5 s. In Experiment I, a pair of electronic switches was arranged so that only one spectrum was presented at any given time, with a 0.5 s silent interval between alternations from one spectrum to the other. In Experiment II, a single electronic switch gated selected 38 s samples of the 6 acoustic spectra, with an 8-s silent interval between each sample. Sound levels were controlled by programmable attenuators. Sound levels for the 5 environmental stimuli were established by reproducing in the listening room a recorded pink noise that had a true rms level equivalent to the level of the calibration tone on the particular field tape. The switched signal was fed through equalizers (both octave-band and parametric) and power amplifiers to 4 loudspeaker systems concealed above the acoustically transparent ceiling of the listening room. The gain for the two loudspeakers located above the windows of the room was 6 dB higher than the gain for the two loudspeakers located above the inside corners of the room to create the perception that the sounds were coming into the room through the windows.

Participants sat in a listening room furnished like a living room. The plaster-walled room was 4.8 by 6.5 m (16 by 22 ft). It had an acoustically permeable, but visually opaque, suspended ceiling 2.4 m (8 ft) above a wooden parquet floor, and an acoustically hard cement ceiling another 1.2 m (4 ft) above the suspended ceiling. The furniture in the room was chosen to be relatively reflective of sound. Carpets partially covered the floor, and drapes flanked the windows. The room was constructed to be semi-reverberant so that a relatively uniform sound field could be generated in the vicinity of the participant's head, minimizing sound exposure variations due to head movement.

Acoustic calibration of the listening room and the house filters (described below) and measurements of the band pressure levels of the stimuli reproduced in the room were based upon the room configuration used for Experiment I (menu). These measurements were achieved by a 9-microphone array that sampled the volume of the room likely to be occupied by a single participant's head. Thirty samples of 1 s each were averaged at each microphone position. The listening room conformed to the 1/3-octave band pink noise frequency response specifications (± 2 dB) for psychoacoustic tests stated in SAE AIR 1157¹³ over the entire frequency region from 40 Hz to 16 kHz. A similar frequency response was measured with the listening room configured as in Experiment II (ratings). The reading table was removed from the room and four of the five chairs in the room were arranged so that four participants could be seated simultaneously. In this instance, calibration was achieved by a single microphone

located in the position most likely to represent the center of the participant's head for a given chair. This microphone was moved from chair to chair while equalizing the room and measuring its frequency response. The 1/3-octave band frequency response across the four chairs (16 s integration time) was within ± 4 dB (in the worst case) over the frequency range from 40 Hz to 16 kHz. Typically it was within ± 2 dB. Further details on the construction and calibration of the listening room may be found in an earlier report⁶.

Listening Conditions

Environmental noise spectra (sounds other than the Octave Band) were presented in the listening room under one of three listening conditions (see Table 1).

Outdoors (0). The sounds were reproduced with spectra as recorded in the field -- that is, outdoors. In this condition, the stimuli represent the possible indoor exposure situation of a listener located near a large open window. The acoustic calibration of this condition was achieved by means of the pink noise spectrum used to calibrate the listening room. Four of the environmental stimuli in the Outdoors condition (Peru Corona excluded) had been employed in a similar earlier experiment⁹. The reproduced sound pressure levels in the present experiment were within ± 0.5 dB of those in the earlier experiment in all cases except Traffic (0), which was 2.4 dB lower. The 2.4 dB difference occurred because a somewhat different sample of a highly time-varying traffic noise recording was used in the earlier experiment than was used in the present experiment.

Southern House (S). The sounds were reproduced as they might be heard inside a room in a house of "southern" construction. The measured outdoor-to-indoor noise isolation of 21 houses of "warm-climate" construction was obtained from previously published data ^{14,15}. Octave band noise isolation data were averaged for these various houses, most of which were located in California or Florida. The average isolation was modelled by an analog electronic filter to produce the frequency-dependent attenuation, and an attenuator was used to produce the overall level shift. For this condition, the source spectra as recorded outdoors were reproduced on the studio tape recorder and passed through the "southern" house filter before being fed to the amplifiers and to the loudspeakers in the listening room. The frequency characteristic of the noise isolation afforded by the Southern House condition is shown in Figure 1.

Northern House (N). The sounds were reproduced as they might be heard inside a room in a house more typical of "northern" construction. In this case the outdoor-to-indoor noise isolation was measured for 9 houses located in the suburbs of Washington, D.C. While not of extreme "cold-climate" construction, these houses did possess many of the architectural features of houses designed to withstand colder winters than the southern houses. The 1/3-octave band noise isolation data from these 9 houses were averaged and electronically modelled by a filter and attenuator combination in a manner similar to the procedure employed for the Southern House condition. The frequency characteristic of the noise isolation afforded by this Northern House condition is shown in Figure 1.

Fig. 1. Noise Isolation for Simulated Indoor Listening Conditions.

Taken as a whole, the three listening conditions employed in the present experiments cover much of the range of exposures to corona noise that may occur inside a house located at the edge of a transmission line right-of-way. The Outdoor (O) condition represents a case of relatively high exposure level where the listener is sitting near a large open window. The Southern House (S) condition represents a case where the low-frequency components (below 100 Hz) are attenuated by about 15 dB and the high-frequency components (above 2000 Hz) are attenuated by about 25 dB. This would be the listening condition inside a house of low-to-moderate weight construction. The windows and doors would all be closed and sealed, however, and the house would probably have few thermal or acoustic leaks (i.e., it would have relatively good caulking and weatherstripping, for example). The Northern House (N) condition represents a case where the low-frequency components (below 100 Hz) are attenuated by about 15 dB, while the high-frequency components (above 2000 Hz) are attenuated by 35 dB. This would be the listening condition inside a house of moderate weight construction. Once again, the windows and doors would be well sealed, and there would be few thermal or acoustic leaks.

Thus, the two indoor conditions are examples of homes with good acoustic insulation. Older homes with poor maintenance or a poorly-constructed new home would be unlikely to achieve the degree of acoustic isolation modelled in the present experiments. In this sense, while much of the range of listening conditions of interest has been covered in the present study, the extent to which any of the specific listening conditions employed are typical for large segments of the population has

not been established. More information on the measurements, calculations, and modelling for the particular house filters chosen for the present experiments can be found in Donovan, Flynn, and Yaniv¹⁶.

The background noise in the listening room had an unweighted sound pressure level of 48 dB, corresponding to an A-weighted sound level of 40 dB. The frequency spectrum of the background noise, shown in Figure 3, was below the Preferred Noise Criterion (PNC-25) recommended for bedrooms and quiet residential areas¹⁷. It was similar to that used in other psychoacoustic studies¹ and to that measured inside suburban homes in the Gaithersburg, Maryland, area during non-rush hour periods of the day¹⁶. The background noise in the room interfered with physical measurements of the reproduced low-level stimuli, especially when presented under indoor listening conditions. Some of the frequency components of these stimuli were not measureable in the listening room with a 1/3-octave band analysis. Therefore, the frequency spectra of the acoustic stimuli were initially measured at higher levels than those presented during the experiment, so that the spectrum shapes would not be contaminated by the background noise of the listening room. The level of each stimulus was then attenuated so that the sound pressure levels in the listening room would be the same as those measured in the field (see Apparatus and Calibration). Thus, the band pressure levels reported in the present experiment represent the spectra of the stimuli that were actually added to the room ambient noise during the experiment.

The ambient noise in the listening room provided a more realistic background for the present psychoacoustic experiment than an anechoic

chamber, which might be unrealistically quiet. Although the room ambient noise did have a frequency spectrum above that of some of the indoor acoustic stimuli, particularly under the Northern House (N) condition, all of the stimuli were audible, although some just barely so.

Acoustic Stimuli

The five environmental source spectra were presented in the listening room under different listening conditions. Eleven of the 15 possible combinations of source spectrum and listening condition were employed in the present psychoacoustic experiments, as shown in Table 1. All 11 of the environmental stimuli were reproduced in the listening room at the realistic sound levels for the particular listening condition. The Octave Band stimulus was reproduced at two sound pressure levels: 45 dB and 75 dB. Another stimulus consisted only of the background ambient noise in the listening room (see Figure 3), i.e. no sound was delivered by the loudspeakers into the room. Thus a total of 14 different acoustic stimuli were employed in the present study.

The 13 acoustic spectra delivered over the loudspeakers were calibrated with the 9-microphone array described under Apparatus and Calibration for the menu experiment. Figure 2 shows the 1/3-octave band frequency spectra of the 3 corona noise samples under the outdoor condition, as measured in the listening room. Figure 3 shows the frequency spectra for the 2 non-corona environmental sounds under the outdoor condition and for the background ambient noise in the listening room. Standard deviations for individual 1/3-octave band levels in the above measurements ranged from

Fig. 2. 1/3-Octave Band Frequency Spectra of Corona Noise Samples as Heard Outdoors.

Fig. 3. 1/3-Octave Band Frequency Spectra of Non-Corona Environmental Noises as Heard Outdoors and of Listening Room Ambient.

0.3 dB to 5.6 dB BPL (most less than 3 dB BPL). These standard deviations, measured for the menu experiment, included both spatial variation near the participant's head and temporal variation. The corresponding standard deviations for the rating experiment were somewhat larger.

Various common frequency weightings and calculation procedures used to estimate human response were applied to transform the 1/3-octave band spectra for the 13 acoustic stimuli (excluding the Room Ambient stimulus). The transformed values are presented in Table 2. Equations and procedures for deriving these values may be found in Pearsons and Bennett¹⁷, with the exception of E-weighted sound level¹⁸ and Mark VII¹⁹. The acoustic stimuli were the same for Experiments I and II, although they differed in duration. In Experiment I (menu), a given pair of acoustic stimuli was available for 320 s (about 5 min). In Experiment II, a single acoustic stimulus was presented for 38 s, followed by an 8-s silent interval during which participants rated the previous stimulus. The various 38-s samples used in Experiment II were selected in randomized sequences from the entire 320-s tape recording used to generate the stimulus pairs in Experiment I.

Procedure

The most important difference between the two experiments consisted of the procedure employed to determine a listener's response to the sounds presented.

Experiment I: Acoustic Menu. Each participant chose between two available acoustic stimuli while engaged in casual reading of books. The participant was periodically forced to choose between the stimuli

Table 2
Scale Values Derived From
1/3-Octave Band Spectra
for 13 Stimuli

Scale	Corona A.G.(O)	Corona A.G.(N)	Corona R.(O)	Corona R.(S)	Corona R.(N)	Corona P.(O)	Corona P.(S)	Lawn- m.(O)	Lawn- m.(S)	Traf. (O)	Traf. (N)	Oct. (Lo)	Oct. (Hi)
Frequency Weightings													
A-Weighted _a	53.7	20.2	60.5	35.1	27.8	59.2	33.3	66.4	43.8	72.4	42.5	45.3	75.3
B-Weighted _a	53.5	25.9	60.6	38.0	34.6	58.3	33.5	70.3	50.0	74.7	50.0	45.1	75.1
C-Weighted _a	54.5	33.5	61.7	40.7	38.3	58.5	34.4	72.1	52.7	76.5	56.4	45.1	75.1
D-Weighted _a	60.9	27.8	67.8	42.3	35.7	66.4	40.2	72.6	50.4	77.2	49.8	47.6	77.6
E-Weighted _a	59.0	25.5	65.1	39.8	33.5	64.5	38.2	71.1	49.1	75.4	47.8	45.9	75.9
Unweighted _a	55.6	34.9	62.0	41.0	38.6	59.4	35.2	72.3	53.0	76.8	57.4	45.1	75.1
Calculation Procedures													
Mark VI _b	59.9	18.3*	74.4	44.9	24.6	74.3	45.4	80.8	58.4	84.4	57.3	53.5	81.8
Mark VII _a	62.3	12.3	67.2	42.0	30.5	66.4	40.8	73.4	52.6	76.5	50.9	46.4	73.1
Zwicker _c	73.9	29.6	79.9	53.3	43.1	78.2	50.4	86.6	63.3	90.4	62.2	57.0	86.1
PNL _d	66.4	14.5	73.5	45.2	32.4	71.4	42.5	79.6	55.3	84.1	53.6	50.5	81.4
PNLT _d	67.3	15.3	75.6	47.3	34.5	73.1	43.9	80.4	56.3	85.2	54.5	50.5	81.4
PSIL _d	46.4	13.1	53.0	28.0	19.7	51.1	26.0	59.2	34.4	65.2	32.8	33.2	63.2

Note: Frequency range used for computation:

a 25Hz-20kHz

b 50Hz-20kHz

c 25Hz-10kHz

d 50Hz-10kHz

c Zwicker loudness level was for free field case.

* Estimated value.

in a given pair, although the option of changing from one stimulus to the other could be exercised at any time. On the first day of the twelve-day experiment, the participant was allowed to select a book to read. The collection of available books included current best sellers and other popular light reading. The participant then read these specific instructions for the "acoustic menu" procedure (the full verbatim instructions may be found in Appendix B):

While you read at the desk, you will be hearing one member of a pair of sounds. Some of the sounds will be very faint. If you want, you may change which sound of the pair you hear by pressing on the telegraph key marked "CHANGE." Whenever the lamp on the desk goes off, you must press one of the two keys in front of you within 5 seconds. If you press the key marked "STAY," the sound you are hearing will stay on; if you press the key marked "CHANGE," you will hear the other sound. You must press either the "STAY" or "CHANGE" key whenever the lamp goes off. You are also free to change the sound you hear at any other time if you want.

In this procedure, a given pair of acoustic stimuli was available for approximately 5 min (320 s). During this period the participant was always exposed to one or the other member of the stimulus pair. The participant controlled which stimulus was heard at any time by means of the two telegraph keys. Every 32 s, one acoustic stimulus terminated, and immediately thereafter either the same or the alternative stimulus came on. At the same time the reading lamp mounted on the desk was extinguished for 5 s, during which time the participant was required to make a choice response. Each response initiated a 1 s refractory period during which time further responses were ineffective. The automatic termination of the stimulus that occurred every 32 s was followed half of the time by automatic onset of the same stimulus, and half of the time by onset of the alternative stimulus. The change to

the alternative member occurred every second time, so that an automatic stimulus changeover preceded the forced choice every 64 s.

During the menu experiment, each of the 14 acoustic stimuli was paired with every other stimulus. The 14 acoustic stimuli formed 182 possible ordered pairs, excluding pairings of stimuli with themselves. (Order within a pair was defined by the member of the pair that was automatically presented first at the beginning of the 320-s exposure for a given pair.) For each pair of sounds, one order of presentation was assigned to one participant, and the opposite order for that pair to another participant. This procedure grouped two participants with respect to order of presentation within stimulus pairs. A given participant thus received only one-half (91) of the 182 possible ordered pairs of stimuli. A yoked participant received the complementary half. The 13 yoked groups of two participants received independently randomized subsets of pairs. This procedure was devised to counterbalance order of stimulus onset while minimizing the number of stimuli presented. Each yoked participant's 91 pairs of sounds were then randomized individually, so the sequence of 91 stimulus pairs, as well as the pairs themselves, were different for all individuals.

A daily session (one hour long) consisted of 8 such pairs, presented in two blocks of 4 pairs, with the participant given a 5-min break between blocks. Additionally, eight selected pairs of stimuli were presented for training on the first day of the experiment. Thus the experiment lasted about 13 days. The participant was not informed of the original source of the sound recordings at any time during the experiment. After the experiment each participant was debriefed.

Experiment II: Rating Scale. Each participant sat in one of the four chairs in the listening room, and the participants rotated positions between sessions. Each participant was given a clipboard containing a rating sheet and printed instructions. The rating sheet had 28 numerical scales consisting of the integers from "0" to "10" (eleven point scale). The "0"-end of the scale was labelled "not at all annoying," while the "10"-end of the scale was labelled "extremely annoying." The use of this type of scale is discussed in Guilford (p. 265).²⁰ An example of the rating sheet may be found in Appendix C. The printed instructions contained the following description of the rating task:

You will be listening to a series of different sounds that will last about 40 seconds each. At the end of each 40-second period, the lamp on the television will light up for about 10 seconds. During this brief interval you should rate how ANNOYING you found the entire preceding 40 seconds of sound. Circle the number from 0 to 10 on your rating sheet that best describes your reaction to the entire period that the sound was on. For less annoying periods of sound, circle smaller numbers; for more annoying periods of sound, circle larger numbers. Circle a number on each line of the rating sheet in sequence for the 28 periods of sound you will be hearing.

Each day's session will consist of two segments of 28 periods of sound. For each period of sound, you should circle the number you assign to that entire period of sound in the appropriate place on the answer sheet. Be sure that you circle a number for each period of sound in the segment. You will be given a 5-minute break at the end of the first segment (in about 20 minutes). You may get up and move around during the break, but you must remain seated at all other times.

The 14 acoustic stimuli were presented for 40 s each, first in one random order and immediately thereafter in another random order to comprise the 28 periods of sound heard in each half of each session. A total of 12 such sequences of 14 stimuli were randomly formed and assigned to half-sessions and to the groups of participants. Thus, on a given day of the experiment, any

given group of participants heard each of the 14 stimuli four times in separately randomized orders. Immediately after each half-session the rating sheet for that half-session was collected from each participant. The experiment lasted for 3 days, i.e., 6 sessions or 12 presentations of each stimulus. The participant was not informed of the original source of the sound recordings at any time during the experiment. After the experiment each participant was debriefed.

RESULTS

Experiment I: Acoustical Menu

The amount of time spent listening to each of the 14 acoustic stimuli was recorded for each participant during presentation of the 91 pairs of stimuli. Each of the 14 stimuli was available as an alternative for choice for about 70 min throughout the entire experiment (320 s x 13). The time spent listening to a given stimulus, when that stimulus was available as an alternative, was summed across participants. The sums for the 14 stimuli were divided by the total time a stimulus was available to obtain the proportion of time spent by the participants in the presence of a particular stimulus. Data from the training sessions were excluded from all analyses.

Analysis of Variance. A one-way analysis of variance was performed on the proportions of available time spent in each stimulus using an arcsine transformation of the proportions for each of the 26 individual participants²¹. There was a significant effect of acoustic stimulus, $F(13, 325) = 128.52$, $p < 0.001$, $\omega^2 = 0.83$. (Omega-squared (ω^2) is an index of the degree of association between treatment category and score on the dependent variable.²²) As indicated by ω^2 , the type of acoustic stimulus accounted for approximately 83 percent of the variation in the time spent in the various stimuli.

Graphic Analysis. Figure 4 shows the mean proportions of available time spent in each stimulus, for the group of 26 participants, as a function of the sound pressure level of the stimulus. The vertical bands drawn through the data points represent plus and minus one standard error of the mean. The data

Fig. 4. Proportion of Time in Stimulus as a Function of Sound Pressure Level.

point for the Room Ambient stimulus has been plotted at the right-hand edge of the Figure because physical measurements in the listening room for this stimulus differed procedurally from those for the other stimuli. In the case of the other 13 stimuli, the physical measurements represent the acoustic signal added to the room ambient noise (see Apparatus and Calibration). The Room Ambient noise could not be measured in this way, and in some cases was higher in overall sound pressure level than the added acoustic signal (see Footnote b). The straight line drawn through the data points represents the least-squares fit derived from a regression analysis for the 11 environmental stimuli (those other than the Room Ambient and the Octave Band). For comparison, the same mean proportions of time spent in each of the stimuli were plotted as a function of the A-weighted and the D-weighted sound levels of each respective stimulus (not shown).

The sound level of the Octave Band required to achieve equal preference with the outdoor corona stimulus samples was estimated by linear interpolation (see Molino et al.⁶). An equal preference relationship can be estimated by the sound levels at which listeners would spend equivalent amounts of time in each stimulus, when presented with a given pair of acoustic stimuli as alternatives. In Figure 4, a straight-line segment (not shown) was drawn between the high- and the low-levels of the Octave Band. The horizontal intersections of the data points for the three samples of outdoor corona noise with the Octave Band line segment were projected onto the abscissa to estimate the sound pressure level of the octave band that would be equally preferred to each corona sample. The same procedure was followed to estimate the A-weighted and the D-weighted sound level of the Octave Band that would

be equally preferred to each outdoor corona sample. These results indicated that, in order to achieve equal preference with an outdoor corona sample, the Octave Band would have to be presented, on the average, at a sound pressure level approximately 7 dB higher than the particular corona noise sample. A-weighted sound level increased this average difference to about 9 dB, while D-weighted sound level reduced the average discrepancy to about 4 dB.

Post-Hoc Comparisons. Since there were a relatively large number of means (14) in the analysis of variance, the Newman-Keuls test²¹ was selected for post-hoc contrasts between all-possible pairs of means. In addition to mean differences that are obvious from inspection of Figure 4, the following statistical relationships among means for pairs of stimuli were observed at the 0.05 level:

- (1) Each outdoor corona stimulus was significantly less preferred than each of the indoor corona stimuli.
- (2) Although neither of the two Southern House (S) corona differed from either of the two Northern House (N) corona, the latter two corona stimuli both were preferred to (see Footnote a) the two indoor non-corona environmental stimuli, Traffic (N) or Lawnmower (S), while the Southern House (S) corona stimuli were not.
- (3) Each outdoor corona stimulus was significantly more preferred (see Footnote a) than Traffic (O); the Apple Grove Corona (O) was more preferred than either of the outdoor non-corona environmental stimuli, i.e. Traffic (O) or Lawnmower (O).
- (4) The two Northern House (N) corona noise samples did not differ from each other, nor did the two Southern House (S) corona noise samples. Moreover, the two indoor environmental stimuli did not differ from each other (i.e. Lawnmower (S) vs Traffic (N)).

In addition to the above pairwise comparisons, a number of contrasts involving multiple means were chosen for more selective (and powerful) post-

hoc evaluation using Scheffé's²³ S method. The Scheffé S method is capable of evaluating multiple means, a feature not found in the Newman-Keuls procedure. The following response relationships were significant at the 0.05 level:

- (1) The two Northern House (N) corona samples, taken together, were more preferred than the two Southern House (S) corona samples.
- (2) The collection of 4 indoor corona samples, including both (S) and (N) conditions, were more preferred than the collection of 3 outdoor corona samples.
- (3) The two Southern House (S) corona samples were more preferred than the Room Ambient, while the two Northern House (N) corona samples were not.
- (4) Peru Corona (O) and Roanoke Corona (O) were more preferred than Lawnmower (O) and Traffic (O).
- (5) Peru Corona (S) and Roanoke Corona (S) did not differ from Lawnmower (S) and Traffic (N).

Regression Analysis. Regression analyses were used to correlate the mean proportions of time spent in the 13 acoustic stimuli (Room Ambient excluded) with the transformed physical measurements for those stimuli, given in Table 2. Table 3 shows the Pearson product-moment correlation coefficient and the standard error of estimate for the regression of mean proportion of time in stimulus on transformed sound level. The greater the magnitude of the negative correlation coefficient and the smaller the standard error of estimate, the more successful is a weighting scale or calculation procedure at accounting for listeners' preference responses to physical differences among the stimuli. As shown in Table 3, the calculation procedures generally did not fit the data any more closely than did the frequency weightings. The PSIL scale yielded the largest negative correlation, followed by the D- and the E-weighted scales, while the Mark VII

Table 3

Regression Analysis for 13 Stimuli (Menu)

Scale	Correlation Coefficient	Standard Error of Estimate
Frequency Weightings		
A-Weighted	-0.970	0.059
B-Weighted	-0.965	0.065
C-Weighted	-0.950	0.075
D-Weighted	-0.981	0.047
E-Weighted	-0.980	0.048
Unweighted	-0.951	0.073
Calculation Procedures		
Mark VI	-0.950	0.076
Mark VII	-0.943	0.080
Zwicker (free field)	-0.969	0.060
PNL	-0.955	0.072
PNLT	-0.953	0.073
PSIL	-0.987	0.039

procedure yielded the lowest. Of the simple frequency weighting networks, the D- and E-scales produced the greatest negative correlation coefficients and the smallest corresponding standard errors of estimate. Rank ordering the various scales must be regarded with caution, however. All of the correlations are very high, and the commonly used statistical tests of differences between correlation coefficients require independent coefficients²⁴. Since every correlation included the same set of proportions (the dependent variable), the coefficients were not independent, and no formal inferential statistical analysis was attempted.

Regression analyses were also conducted with the Octave Band stimulus removed, since it represents an artificial laboratory sound. (The Room Ambient was also excluded; see Graphic Analysis.) Regression lines were fitted to the remaining 11 environmental stimuli for each of the 3 major frequency weighting scales. (The regression line for sound pressure level is shown in Figure 4.) The mean proportion of time spent in these 11 stimuli was well represented by a linear relationship. For sound pressure level, $r=-0.950$; for A-weighted sound level, $r=-0.988$; and for D-weighted sound level, $r=-0.985$.

Experiment II: Rating Scale

The numerical ratings for the last 8 presentations of the 14 acoustic stimuli were analyzed. The first 4 presentations were treated as practice and ignored. The average rating across participants and stimuli was within 0.5 scale units across the last 8 replications, showing no systematic trend as the experiment progressed. Therefore, the last 8 replications were assumed to represent stable rating responses.

Analysis of Variance. A one-way analysis of variance was performed on the ratings given to each stimulus by each of the 26 individual participants. This analysis disclosed a significant effect of acoustic stimulus, $F(13, 325) = 27.58$, $p < 0.001$, $\omega^2 = 0.46$. As shown by ω^2 , the type of acoustic stimulus accounted for approximately 46 percent of the variation in the average scale values assigned to the various stimuli. The grand mean was 4.53 scale units, indicating that relative to the scale mid-point (5.0), slightly more low ratings were used than high ratings.

Graphic Analysis. Figure 5 shows the transformed mean rating for each stimulus, for the group of 26 participants, as a function of the sound pressure level of the stimulus. A transform was applied to portray the results of Experiment II in a comparable manner (Figure 5) to the results of Experiment I (Figure 4). Since in Experiment I the mean proportion of time accorded to each stimulus was constrained to vary from 0 to 1.0, and since the more aversive stimuli were characterized by a participant spending less time listening to a stimulus, the following transformation was applied to the mean annoyance ratings in Experiment II: Each rating was divided by 10 and the resulting proportion was subtracted from 1.0. Thus, the data points in Figure 5 represent a scaled complement of the original mean rating value. The vertical bands drawn through the data points represent plus and minus one standard error of the transformed mean. The data point for the Room Ambient stimulus has been plotted at the right edge as in Figure 4. For the other 13 stimuli, the physical measurements represent the acoustic signal added to the room ambient noise. The straight line drawn through the data points represents the least-squares fit derived from a regression analysis for

Fig. 5. Transformed Rating as a Function of Sound Pressure Level.

the 11 environmental stimuli (those other than the Room Ambient and the Octave Band). For comparison, the same transformed mean annoyance scale value for each of the stimuli was plotted as a function of the A-weighted and of the D-weighted sound levels of the respective stimulus (not shown).

The sound level of the Octave Band required to achieve an equal transformed annoyance scale value with the outdoor corona stimulus samples was estimated by linear interpolation. As in Figure 4, a straight-line segment (not shown) was drawn between the high- and low-levels of the Octave Band in Figure 5, and the horizontal intersections were determined. The same procedure was followed to estimate the A-weighted and the D-weighted sound level value. These results indicated that, in order to achieve equal annoyance with an outdoor corona sample, the Octave Band would have to be presented, on the average, at a sound pressure level approximately 13 dB higher than the particular corona noise sample. A-weighted sound level increased this average difference to about 14 dB, while D-weighted sound level reduced the average discrepancy to about 8 dB.

Post-Hoc Comparisons. As in Experiment I, the Newman-Keuls test was used for post-hoc contrasts between all possible pairs of means. The following statistical relationships among mean annoyance ratings for pairs of stimuli that were not obviously significantly different were observed at the 0.05 level:

- (1) Each outdoor corona stimulus was rated significantly more annoying than each of the indoor corona stimuli.
- (2) The two of the three outdoor corona stimuli rated least annoying (Apple Grove and Peru) were rated significantly less annoying than the outdoor Traffic (0) stimulus, while the most annoying of the outdoor corona stimuli (Roanoke) was not.

- (3) Each of the indoor corona stimuli was rated significantly less annoying than either of the other indoor environmental stimuli, Lawnmower (S) or Traffic (N).
- (4) Neither of the two least annoying outdoor corona stimuli (Apple Grove or Peru) differed significantly from either of the indoor environmental stimuli (Traffic (N) or Lawnmower (S)), nor did they differ from the outdoor Lawnmower (O) stimulus.
- (5) The two Northern House (N) corona noise samples did not differ in annoyance from each other, nor did the two Southern House (S) corona noise samples. Moreover, the two indoor non-corona environmental stimuli did not differ from each other in annoyance (Lawnmower (S) vs Traffic (N)).

In addition to the pairwise comparisons presented above, as in Experiment I, a number of selected contrasts involving multiple means were examined using Scheffé's procedure. Of the five selected contrasts found to be statistically significant for Experiment I (menu), only the second contrast (2), which compares annoyance ratings of corona noises heard indoors with those heard outdoors, is significant in the case of Experiment II.

Regression Analysis. Regression analyses were used to correlate the transformed mean annoyance ratings for the 13 acoustic stimuli (Room Ambient excluded) with the transformed physical measurements for those stimuli, given in Table 2. Table 4 shows the Pearson product-moment correlation coefficients and the standard errors of estimate for the regression of the transformed mean annoyance ratings on measures derived from the physical sound spectrum. As was the case for Experiment I, the complex calculation procedures generally did not fit the data any more closely than did the simple frequency weightings. The Zwicker method yielded the highest negative correlation, followed by the D- and E-weighted scales, while the unweighted scale yielded the lowest. Of the simple frequency weighting networks, the D- and the E-scales produced

Table 4
Regression Analysis for 13 Stimuli (Rating)

Scale	Correlation Coefficient	Standard Error of Estimate
Frequency Weightings		
A-Weighted	-0.962	0.070
B-Weighted	-0.964	0.068
C-Weighted	-0.952	0.079
D-Weighted	-0.974	0.058
E-Weighted	-0.974	0.058
Unweighted	-0.953	0.078
Calculation Procedures		
Mark VI	-0.972	0.060
Mark VII	-0.966	0.066
Zwicker (free field)	-0.981	0.049
PNL	-0.970	0.062
PNLT	-0.968	0.064
PSIL	-0.973	0.059

the greatest negative correlation coefficients and the smallest standard errors of estimate. As in Experiment I, rank ordering the various scales must be regarded with caution, however.

Regression analyses were also conducted with the Octave Band stimulus removed. Regression lines were fitted to the remaining 11 environmental stimuli for each of the 3 major frequency weighting scales. (The regression line for sound pressure level is shown in Figure 5.) As in Experiment I, the transformed mean annoyance ratings for these 11 stimuli were well represented by a linear relationship. For sound pressure level, $\underline{r}=-0.971$; for A-weighted sound level, $\underline{r}=-0.990$; and for D-weighted sound level, $\underline{r}=-.990$.

DISCUSSION

The two experiments (menu and rating) employed a common set of 14 acoustic stimuli that differed only with respect to their durations (320 s vs. 40 s). Of particular interest were stimuli passed through electronic filters to simulate indoor noise exposures with two different types of house construction. Because many of these stimuli were relatively low in level (roughly 35 to 60 dB SPL) compared to those used in previous NBS studies of corona noise,^{6,8,9} many of the differences in relative aversiveness among the test stimuli were rather subtle. Although the "acoustic menu" method had been carefully pre-tested with levels corresponding to outdoor corona noise stimuli⁶ and had been used successfully in subsequent experiments,^{8,9} uncertainties in assessing the relative aversiveness of such low-level stimuli suggested also employing a widely-used "classical" psychophysical method. Thus the method of categorical scaling was used for comparison with the results of the menu experiment. The potentially greater cost-effectiveness of the rating method was also evaluated.

The results of the present experiments showed that, although the menu and the rating data are in general agreement, there are some important differences that yield different conclusions in some instances. The menu procedure demonstrated superior experimental precision. About 83 percent of the variance in the data for the menu procedure (Experiment I) was accounted for by the acoustic stimuli, comparing favorably in experimental precision to previous NBS studies of corona noise which also used the acoustic menu, but with stimuli of generally higher sound level. (The value of ω^2 averaged about 0.83 in four previous NBS studies.^{8,9}).

The rating procedure employed in Experiment II accounted for only about 46 percent of the variance in the data for the same set of acoustic stimuli. Furthermore, inspection of Figures 4 and 5 reveals more scatter or variability in the rating data than in the menu data. The average width of the standard error bands for the respective means in the rating experiment was 0.52; more than twice as wide as the corresponding average width in the menu experiment, 0.20.

A correlation coefficient was computed between the dependent variables of Experiments I and II (mean proportion of time in stimulus and mean transformed annoyance rating, respectively) across the 14 acoustic stimuli. A strong, positive and linear relationship was disclosed, $r(12 \text{ df}) = 0.977$, $p < 0.001$. Even though the rank ordering of the acoustic stimuli is practically the same in both experiments, there are differences in the spread or clustering of respective data points along the ordinates of the two regression lines for the two experiments (Figures 4 and 5). Many of these differences were substantiated in the post-hoc statistical comparisons. The different pattern of outcomes in the respective post-hoc analyses could be due to both differences in the central tendency for listener's responses as determined by the two experimental procedures and to the greater precision of the menu procedure (Experiment I).

Several important discrepancies between the outcomes of the menu and the rating experiments were disclosed by the post-hoc contrasts. More comparisons between stimulus conditions of primary interest were found to be statistically significant in the menu experiment than in the rating experiment. The most important specific discrepancy between the two experiments was the

finding of a significant difference in response between the two Northern House (N) corona samples and the two Southern House (S) corona samples in the menu experiment, but not in the rating experiment.

There were other discrepancies. The menu results also showed a significant difference between the two Southern House (S) corona samples and the Room Ambient stimulus. The rating experiment did not reveal such a difference. Furthermore, the menu results disclosed a significant difference between the two most aversive outdoor corona samples, Roanoke (O) and Peru (O), and the two other outdoor environmental stimuli, Lawnmower (O) and Traffic (O). This relationship did not hold for the results of the rating experiment. In only one instance of general interest did the rating experiment reveal a statistically significant relationship not found in the menu experiment. The rating results indicated that the two Southern House (S) corona stimuli differed from the two other indoor non-corona environmental stimuli, Lawnmower (S) and Traffic (N). The menu results did not indicate such a difference. (A statistical interpretation is suggested below.)

The results of the two present experiments suggest the superiority of the menu procedure over the rating procedure in terms of statistical precision for the particular ensemble of test stimuli employed. It is not clear, however, whether this difference in precision is inherent in the methods and procedures used or whether differences in experimental parameters played a major role. The most salient procedural differences between the two experiments include the following:

- (1) Different stimulus durations were employed; a particular stimulus could be as long as 5 min in the menu experiment but was always 40 s in the rating experiment.

- (2) Because of longer trial durations, 13 days were required for a participant to complete the menu experiment, while only 3 days were required to complete the rating experiment.
- (3) Listeners were run individually in the menu experiment and simultaneously in groups of four in the rating experiment.
- (4) Participants in the menu experiment read books as a background activity during the presentation of acoustic stimuli, while participants in the rating experiment had no particular assigned background activity.

Certain procedural differences were purposely incorporated into the design of the rating experiment for comparability with previous research and to evaluate the increased efficiency of the verbal category rating method. The stimulus duration (40 s) was a compromise in the direction of the stimulus durations used in other psychoacoustic studies of corona noise (2 to 20 s)^{2,3,4} and yet far shorter than the stimulus duration employed in the menu experiments (5 min). Nevertheless, the number of stimulus repetitions was approximately equal in both experiments (12 vs. 14). The rating experiment thus was considerably more efficient than the menu experiment, permitting an experiment to be completed in one-quarter of the time; but it was felt that the stimulus duration was not so short as to be considered a brief acoustic event for rating purposes. Further efficiency was added by having multiple listeners rate the sounds at the same time. A background activity was not incorporated into the rating experiment because such an activity was not employed either in previous psychoacoustic experiments conducted by others involving corona noise,^{3,4,5} or in the majority of annoyance rating experiments involving other experimental noise stimuli.¹ Nevertheless, these procedural differences between the rating and the

menu experiments could account for some of the lesser precision observed in the rating data.

A previous NBS study⁸ suggests that the greater precision of the menu procedure in the present study is not likely to be due strictly to the use of a longer stimulus duration, a different task, or single vs. multiple listeners. A rating experiment similar to the present one was conducted with groups of four or fewer participants run simultaneously (total sample size = 19). The stimuli in this earlier rating experiment were identical to those used in previous menu experiments^{8,9} in every way including duration (5 min). Other than group participation and the use of a numerical rating scale format, the only major difference from the menu experiments was the employment of different background activities. Television viewing was used in the earlier rating experiment rather than reading books as in the menu experiments. The part of the previous study most similar to the present study used a stimulus set which included differentially attenuated outdoor recordings of 5 corona noise samples. The proportion of variance accounted for (ω^2) was 0.84 for the menu data, while it was only 0.50 for the rating data. These amounts of explained variance are comparable to those found in the present study; 0.83 for menu, and 0.46 for rating, respectively. The differences in precision between methods also were similar in both studies; 0.34 for the earlier study, and 0.37 for the present one.

Since the majority of significant relationships of primary interest among the acoustic stimuli were found in the menu experiment, subsequent discussion will focus upon the results obtained with the acoustic menu

procedure. In general, the menu procedure provides a more extensive and reliable statistical definition of the observed preference structure than is the case for the rating scale procedure.

Figure 4 (menu data) suggests that preferences cluster, in decreasing order, into the following groups of stimuli: 1) Northern House (N) corona samples and Room Ambient; 2) Southern House (S) corona samples, Octave Band (Low), Lawnmower (S) and Traffic (N); 3) Outdoor (O) corona samples; and 4) Octave Band (High), Lawnmower (O) and Traffic (O). Different indoor listening conditions, (S) vs (N), had different effects on the aversiveness of the corona noise samples under study. The multiple comparisons for the results of the menu experiment indicated that the two Northern House (N) corona samples were preferred to the two Southern House (S) corona samples.

As described under Listening Conditions, the indoor conditions differed primarily in that more high-frequency components were present (less attenuated) in the Southern House (S) condition. This could account for the greater aversiveness or annoyance of the corona noise samples in the Southern House (S) condition relative to the Northern House (N) condition. A previous study¹⁰ indicates that the high-frequency components of corona noise contribute more toward its aversiveness than do the low-frequency components. The failure of the participants to show differential preference (menu) or annoyance ratings among the two corona samples in the Northern House (N) condition and the Room Ambient stimulus (no added acoustic signal) suggests that these corona noise stimuli were no more aversive than the background noise in the listening room. The participants in the menu experiment significantly preferred the Room Ambient stimulus to the two corona samples in

the Southern House (S) condition. The participants in the rating experiment showed no significant differences among ratings of these five stimuli.

Figure 4 shows that environmental stimuli (corona and otherwise) are considerably more preferred or less annoying when presented under indoor, as opposed to outdoor, listening conditions. Thus, possible environmental problems associated with corona noise exposure should be substantially reduced by the noise reduction afforded by a building shell with closed windows. Whether or not indoor exposure to corona noise is aversive or annoying enough to be consequential in terms of its effects on residents cannot be determined by the present experiment. In the case of the menu experiment no absolute measure of aversion could be derived. In the case of the rating experiment, the rating scale has some absolute scale properties, but the relatively large standard error bands of the rating data do not indicate any statistically significant discrimination between Room Ambient and the indoor corona noise stimuli.

Nevertheless, if certain types of building design (e.g., heavy outer walls, thick insulation) could minimize or possibly eliminate aversiveness to residents of affected dwellings, then, at least for those dwellings with closed windows, corona noise could be minimized as an environmental problem. This suggestion is based upon laboratory measurements, however, and may not generalize to field (environmental) situations where other factors (such as fear of transmission lines or objections to the effects of lines on the landscape) may affect response to corona noise exposure, as heard both indoors and outdoors. In addition, the indoor listening conditions of the present experiment represent the case where windows, doors, and partitions

are well-sealed, offering few acoustic leaks. Older homes in poor repair or mobile homes may not afford such acoustic isolation, even with closed windows and doors.

In the menu experiment, under outdoor listening conditions, the differences in preference between two of the corona samples, Peru Corona (O) and Roanoke Corona (O), and the two non-corona environmental stimuli, Lawnmower (O) and Traffic (O), were not only significant, but large in magnitude. The difference in the respective averages for these two sets of stimuli in terms of time spent listening to the stimuli was about 19 percent greater for the corona stimuli. This difference in preference is not surprising, since the two outdoor non-corona stimuli average about 14 dB SPL higher than these two particular outdoor corona stimuli. The difference in sound levels between these two respective sets of stimuli increases in the same direction to about 17 dB SPL under the indoor listening conditions. Notwithstanding this increased difference in levels, the difference in the average amount of time spent listening to these two respective sets of stimuli actually decreased to only about 9 percent greater for the corona stimuli.

These quantitative changes are substantiated for the menu data by the multiple-contrast analyses, which showed that, while the Peru Corona (O) and Roanoke Corona (O) differed significantly from Lawnmower (O) and Traffic (O), the Peru Corona (S) and the Roanoke Corona (S) did not differ significantly from Lawnmower (S) and Traffic (N). This shift in the degree of relative aversiveness between these two corona samples and the other environmental stimuli under indoor as opposed to outdoor listening conditions is unlikely to be the result of an artifact such as relative indifference at

the high end of the scale (that is, a "ceiling" effect). As demonstrated in the menu experiment, the Peru Corona (S) and Roanoke Corona (S) samples were significantly less preferred not only to the two Northern House (N) corona samples, but also to the Room Ambient stimulus.

However, the major discrepancies between the preference structures associated with the menu and with the rating procedures occur in regard to the above relationships. In direct contrast to the menu results, the rating data show a significant difference between each of the two Southern House (S) corona stimuli and the other two indoor non-corona environmental stimuli, Lawnmower (S) and Traffic (N). In the rating experiment these two indoor non-corona environmental stimuli also do not differ significantly from two of the three outdoor corona stimuli (Apple Grove (O) and Peru (O) corona), whereas the menu results show a clear and significant separation between all indoor and outdoor stimuli ($p < 0.05$ or less for all pairs of means). Furthermore, in the rating experiment, not only do the Apple Grove Corona (O) and the Peru Corona (O) not differ from the indoor Lawnmower (S) stimulus, but they also do not differ from the outdoor Lawnmower (O) stimulus. Comparison of Figures 4 and 5 indicates that, for the rating data, the indoor non-corona environmental stimuli tend to be ranked somewhere between the indoor and the outdoor corona stimuli, while for the menu data, they cluster in the vicinity of the Southern House (S) corona stimuli. Although this discrepancy cannot be resolved with the present data, the greater precision and consistency of the menu results suggest that they should be considered more accurate until contrary evidence is found.

In Experiment I, indoor listening conditions did not reduce the aversiveness of the corona noise samples as much as they did the aversiveness of some other non-corona environmental noises. This result may be potentially important for evaluating the impact of corona noise as heard indoors relative to the impact of other environmental noises as heard indoors. Some corona noise samples, which may be considerably less aversive than other common environmental noises when heard outdoors, may be of comparable aversiveness to these other noise sources when heard indoors. Thus, building shells may not afford as effective isolation for corona noises as for some other environmental sounds. This conclusion is tentative, however, because (1) only limited samples of both corona noise and environmental noise have been included in the present experiments; (2) only two indoor listening conditions were simulated; (3) the results of the two experimental procedures did not agree on this point; (4) conditions may differ in real life situations because of emotional factors for which an audible corona stimulus serves as a cue (e.g. fear).

Although no direct differences in preference were found among outdoor corona noise samples in the present experiments, indirect evidence for differences among corona sounds may be deduced. The Apple Grove Corona (0) sample was not significantly more preferred than the Roanoke Corona (0) and Peru Corona (0) samples under outdoor conditions. However, the Apple Grove Corona (0) sample was significantly preferred to the Lawnmower (0) and to the Octave (High) stimuli, while Roanoke (0) and Peru (0) corona were not. This result yields indirect support to previous NBS studies using similar corona noise samples^{8,9} where certain corona noise samples were signifi-

cantly preferred to other corona noise samples. The present data lend some support to the possibility of meaningful psychological heterogeneity among corona noise samples due to spectral differences resulting from either the transmission line configuration or climatological factors, or both. Thus, in order to assess environmental noise impact, long-term sampling of corona noise from different transmission lines is needed, as well as psychoacoustic data on more extensive samples of corona noises.

The Octave Band stimulus was included in the present experiments because it represents a commonly used reference sound for psychoacoustic investigations, and because it served as the reference sound in previous NBS studies. In the present menu experiment, the three outdoor corona noise samples were equally preferred, on the average, to an octave band about 7 dB higher in sound pressure level than the corona noises. For A-weighted sound level this average level difference for equally preferred stimuli increased to 9 dB, while for D-weighted sound level it diminished to 4 dB. Previous experiments conducted at NBS with the menu procedure showed that these three commonly used frequency weighting scales underestimated the aversiveness of corona noises relative to a 1000-Hz octave band in a similar manner. In one NBS study⁹, which presented a wide variety of environmental stimuli (two of which are included in the present experiments) only at outdoor sound levels, the following differences were obtained: sound pressure level, 11 dB; A-weighted sound level, 13 dB; and D-weighted sound level, 8 dB. In the annoyance rating portion of the present study similar differences were obtained by interpolating from transformed rating values: sound pressure level, 13 dB; A-weighted sound level, 14 dB; and D-weighted sound level, 8 dB. Although these estimates

differ somewhat among themselves, the discrepancies among the experiments are not large considering the precision of the data, and the rank ordering of the frequency weighting scales is identical in all cases. Further confirmation of these differences may be obtained from another NBS study⁶ and from an independent investigation by Pearsons et al.⁴ The NBS study showed an equal preference difference of about 10 dB for sound pressure level, while the Pearsons et al. investigation showed an equal annoyance difference of about 10 dB for A-weighted sound level. They also showed lower discrepancies for D-weighted sound level, as was the case in the present study. Analogous equal preference discrepancies between corona noise samples and a collection of other non-corona environmental sounds, as reported in an earlier NBS study⁸, could not be readily estimated from the present experiments. The present experiments did not employ a sufficient number of different non-corona environmental sounds.

Recommending an appropriate psychoacoustic measurement scale for corona noise should take two practical factors into account. First, the scale should be relatively simple to implement from physical measurements. This implies that the more complex calculation procedures given at the bottom of Table 2 are impractical. Second, instrumentation should be readily available, and the scale should be in relatively common use, for at least certain important applications, so as to facilitate comparisons among different studies. These considerations restrict the choice of scale to unweighted, A-weighted, or D-weighted sound level. Other factors being equal, then, the scale that correlates best with human response would be the recommended choice. The regression analyses of human response in the present experiments

(Tables 3 and 4) rank these scales, from best to worst, in the following order: D-weighted, A-weighted and unweighted sound level. This is the same rank order obtained by the above graphic analyses and in previous studies^{8,9}. Both D- and A-weighted sound levels also give good correlations with human response data.

Since the A-weighted scale is more commonly used, it would appear most appropriate for preliminary assessments, initial surveys and general applications involving measurements of corona noise. If slightly more precision is required from a simple frequency weighting scale, D-weighted sound level might be preferable, although the statistical support for this choice is not fully conclusive (see above). Examples of the latter instance might include evaluating slight alterations in the acoustic frequency spectrum as a result of changes in the design of transmission lines, or assessing environmental impact, where a possible difference of a few dB is important. Of course, as mentioned earlier, the correlation coefficients upon which these recommendations are based are not independent. Thus, judging the relative merits of the various scales in this manner must be regarded with caution.

The finding that D-weighted sound level showed the strongest correlation and the least discrepancy among the acoustic stimuli suggests that high-frequency components may contribute more to the aversiveness of corona noise than low-frequency components. Transmission line audible noise spectra are unusual in having a relatively flat frequency spectrum to 10 kHz and above, while most other environmental noise spectra contain relatively little energy at these high frequencies. The D-weighting scale gives more weight to high

frequencies than do the other common frequency weighting scales¹⁷. Furthermore, for the corona noise stimuli used in the present menu experiment, the Southern House (S) condition was more aversive than the Northern House (N) condition. The Southern House condition afforded less attenuation of the high-frequency components. This finding, that high-frequency components of certain samples of corona noise contribute more toward their aversiveness than low-frequency components, has been confirmed in other NBS experiments where the low- and high-frequency components were differentially attenuated¹⁰.

FEASIBILITY STUDY

The above two psychoacoustic experiments were part of a series of laboratory studies on the human response to corona noise conducted at NBS. These laboratory studies have reproduced corona noise in a simulated but realistic listening environment in order to determine the reactions of people to the noise. There are obvious limitations with this research approach, however. The present section explores the feasibility of conducting field studies on human response to corona noise generated by actual transmission lines.

One obvious difference between laboratory studies and field studies concerns the identification of the noise source. Unless explicitly told the source of corona noise, in laboratory experiments most participants who do not live near transmission lines know little or nothing about the nature of the noise source. On the other hand, unless attempts are made to assess people's reactions indirectly, the noise source will be familiar to most participants in field surveys.

In the context of laboratory psychoacoustic studies, the influence of knowledge of the sound source was investigated in a pair of earlier NBS experiments.⁸ These experiments suggested that the relative aversiveness of corona noise samples within an ensemble of test stimuli did not differ significantly whether the listeners were informed about the sources of the various environmental noises (including corona noise) or not. Participants in a "knowledge-of-source" group were trained before the experiment began to associate each sound with a color photograph of its source. Those in a "no-knowledge" group were provided with no information regarding the source

of the test stimuli prior to the start of the experiment. Statistical analysis of the averaged data for the 26 participants in each group showed nearly identical preference structures for the set of test stimuli. Furthermore, none of the participants in the "no-knowledge" group correctly identified the source of the corona noise on a post-test. Thus it may be concluded that corona noise is an inherently aversive stimulus acoustically, at least within the isolated context of a laboratory experiment.

The utility of laboratory studies of corona noise would be greatly enhanced if the responses of affected residents actually living near transmission lines could be determined accurately. Factors occur in the natural (field) environment which may be difficult or impossible to simulate in a laboratory setting. On the one hand, fear of transmission lines in terms of their physical effects or the degrading of the landscape or scenery may accentuate aversion to the corona noise. On the other hand, the perceived need for or dependence on electrical energy, especially in remote, isolated areas, may increase tolerance for corona noise. Thus such in situ factors may modify or modulate the adverse response to corona noise.

Until valid and generalizable data from people who actually live near transmission lines are obtained and synthesized systematically with laboratory data, laboratory findings alone can only be regarded as "best estimate" predictors. Valid and reliable field data would enhance the value of laboratory findings and place them in a better perspective.

The goals of the present evaluation are (1) to examine what is presently known about impacted residents near transmission lines, (2) to assess the outcomes and contributions of available field surveys on corona noise,

(3) to analyze the special problems which confront field-survey techniques applied to the study of corona noise, and (4) to examine the implications of this feasibility analysis for the DoE-NBS transmission line audible noise research program.

Available Field Observations

Environmental noise problems are most strongly brought to attention when affected residents register complaints to the parties responsible for the noise emissions, or to government agencies, community interest or environmental protection groups. Complaints concerning transmission lines have ranged from letters and phone calls of protest, to legal action, and even to violent demonstrations requiring police intervention.²⁵

Complaints are one of the most direct indications of adverse community response to noise, but they must be interpreted cautiously. For example, studies of morale in industry²⁶ frequently show that complaints against management or supervision are often inhibited and generalize to specific features of the job or of the workplace such as pay, benefits, lighting, heating, noise, etc. This displacement of complaints to relatively salient features of the non-personal work environment presumably arises from fear of reprisal or inability to express complex emotions in a simple, direct manner.²⁷ Likewise, overall dissatisfaction with one's community, neighborhood, or property may generalize to more salient features of the environment such as noise, public services, adequacy of roads, etc. Thus, with respect to complaints against transmission line noise, the above considerations must be weighed in order to determine to what extent the noise complaint

is due to intrinsic annoyance, and to what extent it may be symptomatic of an underlying and perhaps inexpressible dissatisfaction with some other aspect of the complainant's milieu.

Because of their directness and face validity, complaint data should be collected from a wide area and carefully analyzed. In view of possible divergence in the motivation for complaints from one locale to another, as discussed above, it is highly desirable to supplement an analysis of complaint protocols with an extensive and carefully designed field study of attitudes towards noise. Analysis of surveyed attitudes toward corona noise could provide some explanation of the motivation underlying complaints and may provide an estimate of the extent of annoyance experienced by affected residents who have not registered complaints.

The electric utility industry has been actively concerned for a considerable time about the potential problems of audible emissions from transmission lines. The psychoacoustic workshop on power-line noise, sponsored by the Power Engineering Society of the IEEE, and the publication of its Proceedings⁵, reflect the timeliness and extent of interest and concern among both industry representatives and other professionals. Although frequent references to complaints and annoyance due to corona noise are alluded to, no empirical data on noise effects upon residents are given in these Proceedings. Some empirical data are provided in the research by Bolt, Beranek and Newman conducted for the Electric Power Research Institute (EPRI).²⁸ One part of this research included a survey of community reaction to corona noise (discussed below).

Extensive discussion of the problems associated with corona noise is summarized in a report by DoE on hearings before the New York State Public Service Commission on the potential environmental effects of 765-kV transmission lines.²⁹ There was much controversy because of a lack of experimental results and survey data on the human response to corona noise. Most of the arguments were based on extrapolations or application of predictive algorithms derived from other sources of noise or from general noise surveys. Although many problems associated with corona noise such as annoyance, complaints, speech interference, effects on sleep, and community response were covered, the discussions were rarely based on actual human response data for corona noise stimuli.

As an outcome of the transmission line hearings conducted by the New York State Public Service Commission, the Power Authority of the State of New York was ordered to report all complaints about corona noise to the Commission. In fact, any such complaint from a household within 600 feet of the line which cannot be "resolved" satisfactorily can result in the Commission requiring the Power Authority either to move the house or to sell it. In the latter case, any prospective buyer would have to be informed of the conditions leading to the resale of the house.

Driscoll³⁰ reported that, as of January 4, 1980, the Power Authority of the State of New York forwarded complaint forms from 97 people to the Public Service Commission. The percentage of complaints by various items was as follows:

- (1) television interference -- 24 percent
- (2) radio interference -- 23 percent

(3)	transmission line noise	--	21 percent
(4)	shocks	--	6 percent
(5)	miscellaneous	--	6 percent

The group of 97 registered 160 complaints (many residents complained of more than one item). Although a few complaints were made by people who lived beyond 600 m (2000 ft) of the centerline, most of the noise complaints originated within 180 m (600 ft) of the centerline. Driscoll reports that since there were 99 residences in the impacted area that fell within 180 m (600 ft), the noise complaints received were about 15 percent of the possible complaints from households within that distance.

Thus some complaint data are being recorded in New York State, and it is likely that some electric power utility companies may have proprietary complaint data on file. Other states also may have records of complaints concerning corona noise, but the data base for such complaints is not likely to be very large, and what exists may be widely scattered.

Available Field Surveys

In 1974 Busby, Driscoll, and Washburn³¹ used a structured interview to obtain attitudes toward 765-kV transmission lines. The owners of 18 working farms in rural Ohio were questioned. Although 5 of the 18 spontaneously mentioned noise from the lines, none of the 18 said they were "bothered" by the noise when specifically asked about it. Some of the farmers did report that they were bothered by mild shocks (from touching large, metallic objects near the line), but were able to adjust to these shocks. Drainage and soil compaction problems resulting from the construction of the line were among

the major complaints. D. Driscoll (personal communication)²⁹ suggested, however, that the findings of the Busby et al. survey could possibly be quite different for non-farming residents in rural areas, many of whom choose to live there for recreation or "peace and quiet."

Bolt, Beranek, and Newman (BBN) conducted a survey of the human response to the noise from both transformers and transmission lines.²⁸ The community reaction portion of the research was based upon Fidell's Nationwide Urban Noise Survey,³² with many of the noise-related questions modified to mention transformer and corona noise. The corona noise portion of the study included 183 residents along a 230-kV transmission line and 87 residents along a 500-kV line (total sample size = 270). The dwellings sampled were along the transmission line right-of-way. A "purposive" sampling plan was used; that is, dwellings were selected by site requirements rather than by demographic variables. The dwellings were relatively free from heavy street traffic and located at the edge of the right-of-way.

A-weighted sound level measurements were taken at the edge of the right-of-way during quiet periods of the night. The average level for the six sites along the 230-kV line was about 44 dB and the corresponding average level for the three 500-kV sites was about 50 dB. Fourteen dB were added to transform these nighttime measurements to estimate the L_{dn} values over the entire day, yielding 58 dB and 64 dB, respectively. A social survey revealed that about 19 percent of the residents living along the 230-kV line reported being "highly annoyed" and about 23 percent of the people living near the 500-kV line gave the same report.

Using an equation derived from Shultz's worldwide social survey data,³³ the investigators estimated "that noise from power lines would have to be on the order of 10 dB lower in level than that of other low-level noise sources to annoy equivalent percentages of people to the same degree" (p. 20). On this basis they conclude that "reaction to urban exposure to noise from 500-kV power transmission lines is more widespread than reaction to lower voltage transmission lines, and more pervasive than would be expected on the basis of its acoustic level alone" (p. 20). Yet earlier (p.17) they state "perhaps the clearest finding of this survey is the absence of strong opinions about the noise of transmission lines and transformers." The apparent discrepancy between these conclusions is clarified if the following results of the study are considered. Only 2 percent of the residents spontaneously mentioned electrical noise sources (power lines or transformers) as "other" noises heard in their neighborhood. When asked specifically whether or not they had heard corona noise, only about 40 percent of the sample living near transmission lines reported that they had ever heard the noise. Of the 113 respondents who reported having heard corona noise, 34 were unable to estimate how frequently they heard the noise and 30 reported hearing it "just a few times a year." Of the total sample (under the assumption that those who reported that they never noticed the line should not report any disruptive effects):

- (1) 98 percent indicated that corona noise did not interfere with listening to radio, TV, or records.
- (2) 96 percent reported no interference with sleep from corona noise.
- (3) 94 percent admitted no startle or fear of the lines.

In view of the small percentages of spontaneous references to electrical noises, the apparent widespread unfamiliarity with the occurrence of corona noise, and the very small percentages reporting disruption by corona noise, it is difficult to understand why 19 to 23 percent of the total sample reported being "highly annoyed" when directly asked. The DoE summary of the New York hearings on transmission line noise provides some observations that may shed some light on this issue.

In the testimony it was agreed that, with an overall L_{dn} of 55 dB, a percentage of the exposed population will be "highly annoyed" irrespective of the level of transmission line noise. This percentage varied between 17 percent and 10 percent depending upon the experts consulted, but it was agreed that at least "10 percent of the population (as determined from attitude surveys on other sources of noise) will be highly annoyed by their noise environments regardless of the actual noise levels" (p. 18). Since L_{dn} estimates of 58 dB (230-kV line) and 64 dB (500-kV line) were used in the Bolt, Beranek and Newman survey, the percentages given above for people "highly annoyed" are extrapolations based on estimated levels. Thus the percentages observed (19-23 percent) may be influenced by ambient noise to an undetermined extent. (For example, if the 17 percent estimate is assumed, only 2 percent of the 230-kV sample should be "highly annoyed.") The argument that corona noise would have to be about "10 dB lower" than other non-corona low-level sounds to obtain equivalent percentages of people annoyed becomes hard to justify from these results.

From a logistical viewpoint the BBN approach was limited by the great expense inherent in carrying out a corona noise field study. The use of an

urban setting, they point out, provided results limited in generality but which allowed a moderately large sample size at reasonable expense. Nonetheless, Bradley and Jonah,^{34,35,36} in a recent large-scale study of traffic noise, warn that their own results showed significant effects related to community size. They stated that "... it is unwise to extrapolate the results of large city noise studies to small communities and rural areas" (p. 409). The BBN study also was limited in its control for demographic variables by the use of "a purposive sampling plan" (see p. 3).²⁸ Yet Bradley and Jonah found significant effects of socio-economic status and of type of house in addition to size of community. Furthermore, the BBN study sampled transmission lines of much lower voltage (230-kV and 550kV), which are not as noisy as the 765-kV transmission lines that were debated in the New York State hearings. It may be difficult to generalize from conclusions drawn in the BBN study to higher-voltage EHV and UHV transmission lines. Thus it appears that field studies of human response to corona noise are currently inadequate for comparison with laboratory results.

Requirements for a Cost-Effective Social Survey

A sufficiently extensive and well-coordinated survey would be a difficult, time-consuming, and expensive undertaking. Attempts are usually made to site transmission lines (in the 765-kV range) in relatively sparsely populated areas. In these areas, dwellings are often widely separated, which could lead to high travel costs if personal interviews were used in the survey. In addition, the type of dwelling construction as well as the distance of houses from the line right-of-way usually vary substantially even along a single transmission line. Since the long-term characteristics of

corona noise are so closely tied to climatic variables, lines in widely spread geographic areas (most likely serviced by different power companies) would have to be surveyed to form an accurate composite of the national corona noise problem. Thus it appears that obtaining a representative, generalizable and statistically rigorous sample of sites for a corona-noise survey could be a considerably more extensive and expensive enterprise than is the case for many other sources of noise pollution.

Recently Bradley and Jonah^{34,35,36}, published a series of studies which describe a well-conceived field survey of the human response to traffic noise. They point out that, while up to 25 percent of the variance in responses has been explained as being attributable to noise level in the case of aircraft noise studies, "conventional" traffic noise surveys have been able to explain only about 10 or 11 percent of the variance. If the variance accounted for in a corona noise survey were comparable to that achieved by most work in traffic noise, it would be difficult to evaluate subtle differences among corona stimuli. By contrast, just such subtle differences have been discerned in earlier DoE-NBS laboratory studies where anywhere from 79 to 93 percent of the variance in responses has been accounted for using the "acoustic menu" procedure.⁸ By incorporating an improved survey scale based on the goal that a field study "... should be carried out as much as possible as a controlled experiment ..." (p. 590), Bradley and Jonah were able to account for about 21 percent of the response variance, thereby roughly doubling the precision obtained in the other field surveys of traffic noise which they cite.

Thus the Bradley and Jonah studies achieved considerable success, but, as is the case with most productive field studies, a relatively large-scale effort in terms of both time and expense was required. Careful selection of sampling sites was coupled with considerations of achieving a balance of physical measurement data on noise levels and human response data from surveys. Also the two types of data (physical and survey) were, as much as possible, coincident both spatially and temporally. Since it was not feasible to consider all site variables simultaneously, they were treated in limited combinations using factorial designs in three separate experiments. Their three experiments examined 48 site variable combinations, so that 1200 households were interviewed. Although this procedure suggests a substantial logistical problem, in the case of traffic noise it is feasible. For example, highways are numerous in many different populated geographical areas, houses can readily be found that are within the same locale and are at relatively uniform distance from the highway, climatic factors are not usually of great significance, and pockets of similar building construction can be found in neighborhoods of homogeneous socio-economic status. Many of these factors are generally not true of sampling sites along 765-kV transmission lines, as discussed above. Furthermore, beyond the site variables usually studied in connection with highway noise, there are additional site characteristics that are important for adequate sampling in measuring the effects of corona noise. These include: 1) line voltage, 2) line configuration, 3) type of line (ac or dc), 4) conductor diameter and bundle size, and 5) micro-climate (related to specific, qualitative differences in noise emissions characteristic of a given area).

Bradley and Jonah report that each of their interviews took about 35 minutes to administer. Thus to conduct a comparable corona noise survey using a modified interview (to focus on corona noise rather than traffic noise) would require at least 700 staff-hours just to administer, independent of travel time and time due to missed appointments, etc. Travel requirements between dwellings within the region of a single rural transmission line would be quite expensive in order to achieve enough interviews (i.e., 25) to satisfy a single site parameter. Although the personal interview is generally considered preferable, costs could be cut substantially by using telephone interviews and a detailed map of the transmission line. Once the logistics of conducting a survey incorporating several transmission lines, in different regions of the country, in conjunction with several other site or line variables, are entertained, the cost of the enterprise can be readily appreciated.

A shortcoming which Bradley and Jonah attribute to many previous, small-scale noise surveys is the use of a simplistic response criterion of annoyance. Some studies simply tabulate the percentage of people annoyed, disturbed, complaining, etc., and correlate this with a measure of noise levels. Improvements in the response criterion can often be achieved by use of a noise rating scale. Current studies increasingly use rating scales whose development is based on psychometrically sophisticated techniques. Rather than using a simple descriptor of noise such as "annoyance," the instruments developed by Bradley and Jonah attempt to describe the human response to noise simultaneously along several dimensions, such as general annoyance, sleep disturbance, speech interference, and activity or concentration distraction. In order to select items, 80 survey responses were factor

analyzed using a principal components solution. Thus considerable effort and time was invested by Bradley and Jonah in the development of a questionnaire, in addition to site selection, sampling, and administration of the final survey.

Implications for DoE-NBS Research

In reviewing the few small-scale social surveys on corona noise which are available, it seems likely that further corona noise surveys of similar effort and range could provide useful answers to specific questions. However, the authors believe that a cost-effective corona noise social survey designed to answer questions about corona noise that can be generalized across geographic areas should follow, at a minimum, the procedures and techniques employed in the studies of Bradley and Jonah.^{34,35,36} Such a survey might be conducted for transmission line audible noise, but the effort and costs would be considerable. The benefits of such a well-designed, large-scale social survey would be great in view of the need to corroborate the results of laboratory psychoacoustic experiments. A narrow-range or "compromised" social survey, however, would not serve as an adequate substitute.

CONCLUSIONS

The following tentative conclusions are offered:

- 1) Corona noise and some other environmental noises are considerably more preferred (less aversive) when presented under indoor (closed windows) as opposed to outdoor conditions.
- 2) Corona noise as might be heard in a house of northern-type construction was more preferred (less aversive) than the same noise as might be heard in a house of southern-type construction.
- 3) Corona noise as might be heard in a northern house was indistinguishable in aversiveness from the ambient background noise in the listening room. Thus corona noise may not be a problem to residents inside a northern-type house with the windows closed.
- 4) The "acoustic menu" procedure demonstrated superior experimental precision over the "rating scale" procedure in two otherwise parallel psychoacoustic experiments. The rank ordering of the stimuli was the same for both procedures, however.
- 5) The feasibility of conducting a social survey of residents living near transmission lines, which would form a useful bridge between laboratory and field results, would likely be a difficult and expensive undertaking.

Conclusions drawn from the present DoE-NBS study must be regarded with certain cautions. Only a limited number of samples of corona noise and other environmental noise were employed in the present psychoacoustic experiments. Furthermore, the simulated indoor listening conditions only included an approximation to a "northern-type" house and a "southern-type" house (in each case, with all windows and doors closed). Thus, neither the corona noise samples nor the simulated listening conditions are necessarily representative of listening situations as encountered in the field. With regard to methodological comparisons, the "menu" experiment and the "rating" experiment employed different stimulus durations as well as different background activities.

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FOOTNOTES

- ^a The word "preference" as used in this context is hedonically neutral, i.e., it does not imply that acoustic stimuli are either aversive or not. Since some of the acoustic stimuli in the present study would probably be aversive to people, one could assume that a stimulus that is "more preferred" to another might be "less objectionable" or "less aversive" than that other stimulus. The present paper, however, employs the more conservative terminology, which does not assume any hedonic valence.
- ^b The fact that the sound pressure level of the added acoustic signal was below the sound pressure level of the ambient background noise in the room does not necessarily mean that the added acoustic signal was inaudible. The primary frequency components of the room ambient noise and of the added acoustic signal were often in quite different regions of the acoustic frequency spectrum. The human ear is highly frequency selective, whereas overall sound pressure level measurements are not. Moreover, the ear can detect certain signals whose levels are 10 dB or more below a masking noise, even when the signal and the noise are in the same frequency region.

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APPENDIX A. Block diagram of the apparatus.

APPENDIX B

INSTRUCTIONS

Select a book which you think you will enjoy. You may continue reading the book you have selected for as many days as you like. If you lose interest in a book you may select a different one the next day. On any given day, you may read only from one book.

Read at a comfortable speed. Although we are not interested in the amount you read, it is important that you keep reading and not daydream. At the end of the entire experiment we will ask you some questions about the material you have read.

While you read at the desk you will be hearing one member of a pair of sounds. Some of the sounds will be very faint. If you want, you may change which sound of the pair you hear by pressing on the telegraph key marked "CHANGE." Whenever the lamp on the desk goes off, you must press one of the two keys in front of you within 5 seconds. If you press the key marked "STAY," the sound you are hearing will stay on; if you press the key marked "CHANGE," you will hear the other sound. You must press either the "STAY" or "CHANGE" key whenever the lamp goes off. You are also free to change the sound you hear at any other time if you want.

Each day's hourly session will consist of eight 5-minute segments. Each segment contains a new pair of sounds. The first 4 segments will follow one another by a few seconds. Then we will give you a rest break of about 5 minutes before the final 4 segments. You may get up and move around during the rest-break, but you must remain seated at the desk at all other times.

NAME _____ DATE _____ SEGMENT 1 _____ 2 _____

APPENDIX C: RATING SHEET

SOUND

NUMBER RATING

1	NOT AT ALL ANNOYING	0	1	2	3	4	5	6	7	8	9	10	EXTREMELY ANNOYING
2		0	1	2	3	4	5	6	7	8	9	10	
3		0	1	2	3	4	5	6	7	8	9	10	
4		0	1	2	3	4	5	6	7	8	9	10	
5		0	1	2	3	4	5	6	7	8	9	10	
6		0	1	2	3	4	5	6	7	8	9	10	
7		0	1	2	3	4	5	6	7	8	9	10	
8	NOT AT ALL ANNOYING	0	1	2	3	4	5	6	7	8	9	10	EXTREMELY ANNOYING
9		0	1	2	3	4	5	6	7	8	9	10	
10		0	1	2	3	4	5	6	7	8	9	10	
11		0	1	2	3	4	5	6	7	8	9	10	
12		0	1	2	3	4	5	6	7	8	9	10	
13		0	1	2	3	4	5	6	7	8	9	10	
14		0	1	2	3	4	5	6	7	8	9	10	
15	NOT AT ALL ANNOYING	0	1	2	3	4	5	6	7	8	9	10	EXTREMELY ANNOYING
16		0	1	2	3	4	5	6	7	8	9	10	
17		0	1	2	3	4	5	6	7	8	9	10	
18		0	1	2	3	4	5	6	7	8	9	10	
19		0	1	2	3	4	5	6	7	8	9	10	
20		0	1	2	3	4	5	6	7	8	9	10	
21		0	1	2	3	4	5	6	7	8	9	10	
22	NOT AT ALL ANNOYING	0	1	2	3	4	5	6	7	8	9	10	EXTREMELY ANNOYING
23		0	1	2	3	4	5	6	7	8	9	10	
24		0	1	2	3	4	5	6	7	8	9	10	
25		0	1	2	3	4	5	6	7	8	9	10	
26		0	1	2	3	4	5	6	7	8	9	10	
27		0	1	2	3	4	5	6	7	8	9	10	
28		0	1	2	3	4	5	6	7	8	9	10	

Please remember to rate each sound for the entire 40-second period.

APPENDIX D
INSTRUCTIONS

Please have a seat in one of the chairs. Next time the experimenter will explain how you are to change chairs from session to session.

You will be listening to a series of different sounds that will last about 40 seconds each. At the end of each 40-second period, the lamp on the television will light up for about 10 seconds. During this brief interval you should rate how ANNOYING you found the entire preceding 40 seconds of sound. Circle the number from 0 to 10 on your rating sheet that best describes your reaction to the entire period that the sound was on. For less annoying periods of sound, circle smaller numbers; for more annoying periods of sound, circle larger numbers. Circle a number on each line of the rating sheet in sequence for the 28 periods of sound you will be hearing.

Each day's session will consist of two segments of 28 periods of sound. For each period of sound, you should circle the number you assign to that entire period of sound in the appropriate place on the answer sheet. Be sure that you circle a number for each period of sound in the segment. You will be given a 5-minute break at the end of the first segment (in about 20 minutes). You may get up and move around during the break, but you must remain seated at all other times.

It is very important that you refrain from talking or making any noise during the experiment (e.g., don't tap on your chair or shuffle your feet). Be careful not to move or to slide your chair from the position that you find it in. Please try to maintain concentration on the task of judging

the annoyance of the sounds on the basis of the annoyance due to the entire 40-second period. Do not look at other people's numbers because there are no right or wrong answers -- the ratings are entirely up to you. Try not to daydream or to be distracted by the activities of the other people in the room.

Some of the sounds may be faint so circle a number everytime the lamp comes on whether you heard the sound or not.

You may ask questions if you have any.