ANALYSES OF THE PREDICTABILITY OF NOISE-INDUCED SLEEP DISTURBANCE

BBN SYSTEMS AND TECHNOLOGIES CORPORATION
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This report provides a summary of the analyses performed on 21 studies concerning the effects of noise on sleep. The analyses were performed in the hope of developing a quantitative predictive model for assessing the effects of aircraft noise exposure on sleep. However, large discrepancies noted between laboratory and field studies precluded the development of such a model. The report includes a summary of the studies reviewed, the analyses undertaken, and various dose-effect relationships for awakening, and sleep stage change as a function of A-level and sound exposure level (SEL) in laboratory and field environments. The analyses include hierarchical multivariate regressions of the data of reviewed studies. Since a model for sleep disturbance could not be developed from available information, suggestions for studies to acquire the data are provided.

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This final report is the Analysis of the Predicability of Noise-Induced Sleep Disturbances. This report summarizes analyses performed on 21 published studies concerning the effects of noise on sleep. It is the best effort of the authors and is not intended to represent the final conclusions or recommendtions of the technical effort. It is for use as a source of information.

This report has been reviewed and is approved for publication.

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FOREWORD

This report was prepared under Contract F33615-86-C-0530 of the Noise and Sonic Boom Impact Technology (NSBIT) program. The NSBIT program is conducted by the United States Air Force Systems Command, Human Systems Division, under direction of Captain Robert Kull, Program Manager. Mr. Lawrence Finegold served as the contract monitor for this effort.

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EXECUTIVE SUMMARY

This report summarizes analyses performed on 21 published studies concerning the effects of noise on sleep. The analyses were performed in the hope of developing a quantitative predictive model for assessing the effects of aircraft noise exposure on sleep. However, a lack of appropriate field studies, combined with large discrepancies between laboratory and field studies, precluded development of such a model. The report includes a summary of the studies reviewed, the analyses undertaken, and various dose-effect relationships for awakening, and sleep stage change as a function of A-level and sound exposure level (SEL) in laboratory and field environments. The analyses include hierarchical multivariate regressions of the data of reviewed studies. Since a model for sleep disturbance could not be developed from available information. suggestions for studies to acquire the data are provided.

1 INTRODUCTION

Research on effects of noise on sleep has provided information for the development of a model of sleep disturbance. Such a model is currently employed by the Noise and Sonic Boom Impact Technology (NSBIT) Advanced Development Program Office in its Assessment System for Aircraft Noise (ASAN) program. The model is included in one of ASANs effects modules which are portions of the system devoted to particular noise effects (e.g., hearing damage, annoyance, sleep disturbance). However, its use by United States Air Force (USAF) environmental planners is limited by several deficiencies, including great variability in response, lack of appropriate aircraft noise sources, and information on the effects of realistic environments. We hoped that a reanalysis of the early data, coupled with an analysis of more recent information, would provide an improved lationship between noise and sleep disturbance.

The purpose of the current effort was to develop an improved predictive model for assessing the effects of military aircraft noise exposure on sleep. Predicting sleep disturbance due to aircraft operations near Military Training Routes (MTRs) and Military Operating Areas (MOAs) was of special concern. As aircraft equipped with night vision and advanced navigation systems enter service in increasing numbers in the near future, the numbers of nighttime training missions may be expected to increase correspondingly. Thus, environmental planners need an adequate quantitative model to predict the effect of these flights on sleep.

Information from which the desired predictive model could be constructed was to be btained from published reports of effects on sleep of noise of different (primarily transportation) sources. Information derived from 53 published studies of sleep disturbance under both laboratory and field conditions was assembled and analyzed in an effort to synthesize a quantitative dosage-effect relationship.

Analyses of these sleep studies revealed large discrepancies between findings reported in laboratory studies and findings of more realistic field studies. These discrepancies were so great

as to preclude the derivation of a dosage-effect relationship useful for current purposes. Since the discrepancies could not be resolved with available information, efforts to develop a predictive model ceased in favor of preparation of a report summarizing the analyses already completed. This report also suggests studies which can help to resolve the discrepancy between laboratory and field findings about sleep disturbance while providing the necessary information for developing an adequate sleep disturbance model.

2 BACKGROUND

2.1 Classification of Sleep Stages

Although the effects of noise on sleep have been extensively studied, relatively little is known in a quantitative fashion that would permit confident prediction of amounts of noise exposure that disturb sleep. Sleep quality is often studied electrophysiologically, by means of recordings obtained through standard percutaneous electrode placements on the head. Brainwave patterns (electroencephalograms, or EEGs) are generally reproduced in graphical form (on strip-chart recorders) and classified into several "stages" of sleep.

Even though agreement on the definition of sleep stages is not universal, commonly accepted classification systems incorporate stages thought to represent light sleep, deep sleep, and sleep associated with dreaming. Light sleep is often designated as stage 1. The greatest amount of time during the night is normally spent between light and deep sleep, in what is termed stage 2. Deep sleep is designated as stages 3 and 4. Stages 3 and 4 are also frequently combined into a Delta wave stage. A stage known as rapid eye movement (REM), often associated with dreams, completes the list of sleep stages. It is not clear whether REM is more closely aligned with stage 1 or stage 4. People normally cycle through the various sleep stages more or less periodically several times throughout the night.

2.2 Prior Reviews of the Noise Effects Literature

Two major reviews of the literature on noise-induced sleep disturbance are discussed below in the following paragraphs (2.2.1 and 2.2.2).

2.2.1 Lukas - 1975

A major review of the effects of noise on sleep was conducted by Lukas in 1975 and later reported in 2 separate publications (Lukas, 1975 and Lukas, 1977). Lukas reviewed 26 sleep studies, 13 of which eventually contributed data to reported analyses. Only studies conducted under laboratory conditions (in which all noise exposure was under experimental control) were considered. The principal sleep disturbance metrics in these studies were awakening (or "arousal") and "no sleep disruption." Awakening was defined behaviorally, either through a button push or a verbal confirmation. Arousal was defined as an indication of an awake state derived from EEG records. "No sleep disruption" was defined as "the failure to shift to at least 1 lighter stage of sleep within 1 min of stimulus termination." "No sleep disruption" should not be confused with "no awakening," since one can have their sleep disrupted by changing stages without actually waking up. The studies Lukas reviewed presented a variety of noise signals to test subjects, but concentrated on transportation sources (either aircraft or vehicular traffic). Sonic booms were also included in several of the studies, especially those conducted by Lukas himself. Lukas also conducted tests using aircraft flyover noises as stimuli.

Lukas evaluated 4 noise metrics for use as independent variables in his efforts to develop a dosage-effect relationship between noise exposure and sleep disruption. The 4 highly correlated metrics examined were: (1) maximum A-level, (2) "effective" (Duration Corrected) A-level, (3) Effective Perceived Noise Level (EPNL), and (4) Single Event Noise Exposure Level (SENEL).

Lukas concluded from the relative strengths of the correlations between these metrics and observed sleep disruption that duration corrected noise metrics were superior to most metrics based on maximum noise level alone. He, therefore, adopted EPNL as the independent variable for the dosage-effect relationship he derived. His final dose-response relationships for awakening and no sleep disruption are presented later in this report and are shown graphically in Figs. 4-9 and 4-10.

Lukas also formulated a measure which he called "composite sleep quality" in an effort to define a dependent variable sensitive to an entire night's "sleep quality." The data analyzed to develop this composite sleep quality scale were obtained from morning after questionnaires administered to test subjects. The key elements of "composite sleep quality" were: (1) feelings of well being on arousal, (2) feelings about the general quality of sleep, and (3) an estimate of how long it took to fall asleep the preceding night.

Lukas used information about as many of these factors as possible, in different studies, to create a total sleep quality score for nights with and without noise exposure. Lukas then used change in composite sleep quality between nights with noise exposure and nights without noise exposure as his dependent variable. Unfortunately, composite sleep quality data were based principally on questionnaire results for sonic booms or clicks. Lukas had only a single datum for composite sleep quality associated with subsonic aircraft flyover noise exposure.

Noise metrics for this portion of Lukas's review included: (1) Composite Noise Rating (CNR), (2) Equivalent Noise Level During 7.5 Nighttime Hours (L_{eq}), and (3) Noise and Number Index (NNI). Lukas did not directly measure values for these independent variables, but instead estimated them from maximum noise levels. The resulting values were lower than the background noise levels, suggesting that these types of measures may not be suitable for situations in which cumulative noise exposure is dominated by relatively few high level noise intrusions.

Within this rather circumscribed data set, all independent variables considered provided reasonable predictions of composite sleep quality.

2.2.2 Griefahn - 1980

Another major review of the effects of noise on sleep was conducted by Griefahn in 1976. The review, with co-authors Jansen and Klosterkotter, was originally published in German (Griefahn et al., 1976). An English language version appeared 4 years later (Griefahn, 1980). The review listed 76 references, 54 of which were in English. Griefahn, like Lukas, adopted awakening and no sleep disruption as her dependent variables, designating the latter as "0-reactions" in her analyses.

Griefahn used only maximum level as an independent variable for predicting sleep disturbance. The relationships she derived with this predictor variable from the data of 10 studies are described later and presented graphically in Figs. 4-9 and 4-10. In addition to the awakening and 0-reaction dose-response relations, Griefahn also analyzed total sleep time and time spent in various sleep stages, comparing results obtained on nights with and without noise exposure. The sounds presented to test subjects in studies Griefahn analyzed included samples of aircraft, trains, white noise, tones, and road traffic. The levels at which these sounds were presented ranged in A-level from 55 to 100 dB.

Based on data from 13 papers, Griefahn was unable to document any meaningful change in total sleep time, stage 2 sleep, or the sum of stage 1 and REM sleep as a function of noise exposure. She did, however, notice more time awake and less time in stages 3 and 4 on nights during which noise exposure occurred. The differences were small but statistically significant ($p < .001$) according to Griefahn.

Griefahn also noticed some evidence of habituation to noise exposure in her review. For example, a level of noise exposure between 40-86 dB that awakened half of the test subjects on the 1st night of a 12-night test would awaken only about one-third of the test subjects by the 7th through 12th nights. Zero reactions behaved in a similar fashion. Starting at 50% the 1st night, the frequency of reaction would increase until about the 7th night, when the percentage of 0-reactions occurring would increase to 70%, at which level it would remain until the 12th night.

Griefahn noticed a similar effect for awakenings from multiple signal presentations throughout the night. Levels of the presentations ranged from 58-87 dBA. As the number of signal presentations increases from 0 to 35 per night, awakenings increase to about 3.5 per night by 30 signal presentations. At this point, further increases in the number of signal presentations do not increase the number of awakenings.

Clearly, habituation plays a role in the awakening results whether over a series of nights or the number of events occurring during a single night. This behavior may be attributable in part to some unconscious effort to ignore noise which has no particular meaning or is of no great importance to the person subjected to the noise.

However, 0-reactions do not seem to adapt as the number of stimuli per night increase. The relation between no sleep disruption and noise exposure maintains a constant increase as the signal presentations increase from 0 to 35. For example, if 5 stimuli were presented per night, 4 were accompanied by 0-reactions. If 20 stimuli were presented per night, 10 were accompanied by 0-reactions. Each increase of 5 stimuli per night was accompanied by an increase of about 2 0-reactions or no sleep disruptions (40% of the increase in stimuli).

Apparently, 0-reactions are not as subject to habituation as awakenings are. Whether this behavior is true in a longer term situation remains to be seen. Also, the influence of stimulus level on habituation of either 0-reactions or awakenings is lacking.

Griefahn also commented on associations among sex, age, awakenings, and 0-reactions. No clear relationship was observed between the sex of test subjects and sensitivity to noise-induced sleep disturbance. Griefahn notes, however, that the sleep of older people (both numbers of awakenings and 0-reactions) is more readily disturbed by noise than that of younger people.

2.2.3 More Recent Studies

Besides the studies reviewed by Lukas and Griefahn, some more recent studies are included in the current investigation. These studies include Horonjeff et al. (1979), Ohrstrom (1983), Ohrstrom et al. (1988), Pearsons et al. (1973), Stevenson et al. (1989), Vallet et al. (1980), and Vernet (1979). All but 1 of these studies (Ohrstrom, 1983) were conducted in the field; this differentiates them from all of the studies reviewed by Lukas, and from most of the studies reviewed by Griefahn. Further information on these studies is contained in Appendix A.

2.3 Summary of Individual and Cumulative Measures of Sleep Disturbance

Individual responses are those for which there is a single response for a single event. Cumulative responses differ in that each represents a single response to a group of noise stimuli occurring over the entire night. Of course, the individual responses themselves could be combined to form a cumulative response, but cumulative responses cannot be reduced to individual responses. Most published sleep studies concern individual responses. Certainly the bulk of the previous reviews by Lukas and Griefahn deal with awakening and arousal or no sleep disruption which fall in the individual response category. Metrics of individual responses include:

1. Awakening or Arousal
2. Sleep Stage Change
3. Heart Rate Change
4. Body Movement

Metrics which fall exclusively in the cumulative response category include:

1. Sleep Latency
2. Total Sleep Time
3. Total Time in Sleep Stage
4. Sleep Quality (Self Report)
    a. number of times awakened
    b. time to fall asleep
    c. feeling of well being on arousal
    d. length of sleep time
5. Performance Test Scores

One difficulty of interpretation of sleep disturbance metrics of the cumulative type is that they are highly susceptible to influences other than noise. Also, it can be difficult to avoid bias in collection of subjective measures such as self report. However, cumulative responses can be sensitive to annoyance attributed to noise-induced sleep interference. Cumulative response metrics should therefore be considered in future sleep investigations involving disturbance due to noise exposure.

2.4 Sleep Disturbance Metrics

Sleep disturbance metrics other than those examined by Lukas have also been studied by other investigators. For example, relationships between total amounts of time throughout the night spent in various sleep stages and noise exposure have been investigated, as discussed by Griefahn (1980) and noted in Section 2.2.2. Such metrics are of little interest for our purposes for 2 reasons: (1) total time spent in different sleep stages is not particularly sensitive to noise exposure (Griefahn, 1980; Kramer et al., 1971; Lukas and Dobbs, 1972; Pearsons et al., 1974), and (2) total time spent in different sleep stages does not lend itself to analysis of the effects of individual noise intrusions (such as low altitude, high speed nocturnal overflights) on sleep quality.

Sleep latency, or the time required to fall asleep, is another metric discussed later whose relationship to noise exposure has been investigated. Sleep latency is another inappropriate dependent variable for our purposes, since latency is difficult to associate with single events. Furthermore, studies of the association between sleep latency and noise exposure commonly use steady state sound sources. Sleep latency is also a poor choice of a dependent variable for our purposes because it is easily confounded by both habituation and general physical condition.

Two additional indices of sleep disturbance are gross body movement and heart rate (Osada, 1975; Vallet et al., 1983; Ohrstrom et al., 1988(2); Griefahn, 1989). Gross body movement, derived from 1 or more accelerometers attached to beds, has been recorded in studies of the effects of sonic booms on sleep (Rylander, 1972). Although heart rate has been observed to increase somewhat in the presence of some noises, it is unclear whether the increase can be interpreted as an indication of anything other than normal physiological activity. One reported feature of heart rate as a noise metric is its apparent lack of habituation.

Self-reported sleep quality is a subjective metric that could in principle serve as an index of noise-induced sleep disturbance. Although limited data and lack of standardized responses make it difficult to develop a dosage-response relationship from self-report information (as discussed in Section 3.4), self-report could be a reasonable metric of sleep disturbance in future studies. However, self-judged sleep quality has been solicited in so many nonuniform ways that there are no straightforward ways of making consistent interpretations of information from different studies.

For example, a common way to collect subjective sleep quality reports is through absolute judgments on arbitrary numeric scales in response to a question of the sort, "How well did you sleep last night?" Self-reports of sleep quality have also been solicited by means of very different questions, such as "Did noise wake you up last night?" and "How disturbing is noise to your sleep?" Although these and other questions have been used to solicit self-reports of sleep quality in experimental studies, responses do not usually provide information susceptible to quantitative statistical analyses.

2.5 Noise Metrics

Metrics used to quantify noise exposure in sleep research fall into 2 categories: (1) those which characterize a single event, and (2) those which characterize a group of events or an entire night or day. Metrics which characterize a single event include: (1) Maximum A-level (AL_{max}), (2) Perceived Noise Level (PNL), (3) Sound Exposure Level (SEL), (4) Effective Perceived Noise Level (EPNL), and (5) C-level (CL).

All of these measures either express sound pressure at a single point in time (AL, CL, and PNL), or sum the energy of the event and combine it with a transformation of its duration

(SEL or EPNL). The effect of duration is apparent in the following approximation to SEL based on Maximum AL and duration:

$$SEL = AL_{max} + 10 \log D \tag{2-1}$$

where D is the effective duration in seconds.

For a noise event with a triangular time history, D = 0.43 times the duration at 10 dB down points.

A final difference among the measures is the emphasis accorded to different parts of the frequency spectrum of sounds.

Sound metrics which characterize the noise of a group of events or an entire night or 24-h day include (1) Equivalent Noise Level (L_{eq}), (2) Composite Noise Level (CNL), (3) Day-Night Average Level (L_{dn}), (4) Community Noise Equivalent Level (CNEL), and (5) Cumulative Distribution Levels ($L_{\%}$).

The L_{eq} is simply the energy average over a specified length of time such as an hour, an 8-h period or a 24-h day. An energy average is calculated by averaging squared sound pressure levels which are proportional to the energy during the specified time interval. The Cumulative Distribution Levels indicate the sound pressure level exceeded a certain percentage of the time. For example, L_{10} represents the level that is exceeded 10% of the time during a specified time period. The remaining measures are all used to characterize the level in communities for a 24-h period. Because of the assumption that people are more sensitive to noise during nighttime hours (10 p.m. to 7 a.m.) some penalty is also applied in these metrics. The magnitude of the penalty is usually 10 dB. In the case of CNEL an additional penalty of 5 dB is added to noise levels occurring during the evening hours of 7 p.m. to 10 p.m.

For purposes of this report, the analysis will use only single-event measures since the dose-response relationships are available primarily for single-event stimuli. Originally, we anticipated that EPNL would be included. However, since AL was used in the majority of recent studies, SEL was selected, along with AL_{max}, as the measures for statistical analyses.

3 REANALYSIS OF DATA FROM SLEEP STUDIES

3.1 Published Research

Assembly of material for this review was guided initially by the earlier reviews of Lukas and Griefahn. Additional material was obtained by examining indices of recent periodicals, primarily *The Journal of the Acoustical Society of America* and *The Journal of Sound and Vibration*. Other sources were identified from references cited in publications located by this procedure. Some information was located through examination of library searches completed using the NSBIT citation database on the effects of noise on humans. Information was also provided by the NSBIT program office. Presentations made at the 1978, 1983, and 1988 international conferences on "Noise as a Public Health Problem" provided additional sources. Finally, some information was obtained through contact with researchers who had conducted previous published work in the area of the effects of noise on sleep. All of the 53 studies which were reviewed are included in the Reference section of this report. Further details of all the 21 studies which were included in the analysis are also presented in tabular form in Appendix A.

3.2 Awakening/Arousal

Twenty studies contained information on self-reported awakening and EEG-defined arousal. This information was not always in a form convenient for dosage-effect analyses. Ideally, the information should include the percentage of subjects awakened or aroused when presented with a noise stimulus of known noise level. In some cases this information was not available. When possible this information was estimated from whatever data were available. This was true for both the sleep responses and the noise measurements.

3.3 No Sleep Disruption

Twelve studies contained information on "no sleep disruption" (as defined previously), but not necessarily in a form convenient for dosage-effect analyses. Reported information sometimes indicated the percentage of all subjects, but sometimes indicated only the percentage of time for 1 subject that no change of sleep stage occurred within 1 min of the occurrence of a noise stimulus. The inverse of "no sleep disruption" is the preferred metric for current purposes, so that responses increase rather than decrease with increased noise exposure. Thus, for example, sleep stage change (which includes all changes of sleep stage to a lighter stage, including awakening) is used in the present analyses in lieu of "no sleep disruption."

3.4 Sleep Quality

Self reports of subjective sleep quality have been collected in a number of studies, 9 of which were laboratory (including quasi-lab), and 3 were field surveys (Collins and Iampietro, 1973; Eberhardt et al., 1987; Eberhardt and Akselsson, 1987; Fidell and Jones, 1975; Griefahn and Gros, 1986; Herbert and Wilkinson, 1973; Johnson, 1973; Ludlow and Morgan, 1972; Lukas et al., 1971; Lukas et al., 1972; Schneider, 1973; Griefahn and Muzet, 1978). The importance of quality of sleep to health remains unclear. However, it is thought that an important component of sleep quality is how rested a person feels in the morning (Johnson, 1973). The quality of sleep is usually reported as lower on noisy nights. Ohrstrom et al. (1982) and Griefahn and Gros (1978) note that higher noise levels are often associated with poorer sleep quality and that continuous noise has significantly less of an effect on sleep quality than does intermittent noise. Although the aforementioned studies do mention sleep quality, in general, the actual reported data are scanty and wide disparity exists in the scaling of the sleep quality metric. It is not, therefore, possible to infer a quantitative dosage-effect relationship between subjectively reported sleep quality and noise exposure at this time.

3.5 Sleep Latency

Studies investigating the effects of noise on the amount of time it takes to fall asleep (Johnson, 1973; Langdon and Buller, 1976; Muzet, 1973; Thiessen and Lapointe, 1983) are far fewer in number than those reporting the effects of sleep quality. The general expectation in these studies is that the latency of sleep onset increases on noisy nights. Muzet et al. (1973) concluded that sleep latency was longest on the 1 "disturbed" night of 3 experimental nights. However, Thiessen and Lapointe (1983) report that sleep latency shows adaptation very similar to the awakening response, and that sleep onset is not affected by noise although there are strong individual differences.

The amount of sleep latency adaptation that occurs and how long it persists after the noise source is removed or changed is not clear at this time and should be examined in future studies.

4 DOSE-RESPONSE RELATIONSHIPS

An analysis of the effects of noise on sleep in prior research was conducted using data from the experiments reviewed by Lukas in 1975, augmented by studies conducted from 1975 to date. While all of the studies reviewed by Lukas consisted of experiments conducted under laboratory conditions with experimenter-controlled stimuli, some of the subsequent studies reviewed were conducted in the field. For our purposes, field studies are those with natural noise sources conducted in the field. Quasi-laboratory studies are those conducted in the field, but in which an experimenter controlled the sound source.

4.1 Method

Fifty-three studies in all were reviewed, of which 21 provided usable data for these analyses. The remaining 32 studies were unusable for a variety of reasons, some of which were: (1) nonquantifiable information, (2) duplication of data over reports, (3) lack of information on individual event levels, or (4) sleep or noise data presented in incompatible formats. Some studies provided a single data point while others provided several points. As a result, all analyses combine data collected from the same and from different subjects under different conditions.

The 2 major dependent variables examined were percentage of test subjects awakened or aroused and percentage of sleep disruption (including change to a lighter level of sleep as measured by EEG). Some studies reported results in terms of both measures, while others reported only 1 or the other measure of sleep disturbance. There were 136 data points available for arousal/awakening, and 83 for sleep disruption.

Two forms of the major independent variable were used: noise level as measured in AL_{max} and SEL. Both noise level types were measured in decibels (dB) re 20 micropascals. Estimates of SEL were made for studies that reported only AL_{max}.

The SEL estimates were made from the relation given in Section 2.5. Since most of the noise stimuli are either aircraft flyovers with a triangular time pattern, or steady sounds with a rectangular time pattern, the relation reduces to the following equations:

$$SEL = AL_{max} + 10\log D_{10} - 3.7 \quad \text{(triangular time pattern)} \tag{4-1}$$

$$SEL = AL_{max} + 10\log D_{10} \quad \text{(rectangular time pattern)} \tag{4-2}$$

where D_{10} is the duration as measured while the noise is within 10 dB of the maximum level (10-dB-down duration). Values used in estimating SEL from maximum AL_{max} are given in Table A-1. The constant 3.7 is derived by integration of the energy contained within a triangular time pattern in accordance with the following formula:

$$SEL = 10\log \left(\int 10^{AL(t)/10}\, dt \right) \tag{4-3}$$

where AL(t) is the A-level at each instant in time.

Choices of additional predictor variables depended on availability rather than theoretical rationale. For example, apparently age and the interaction between age and sex influence the relationship between noise and sleep disturbance (Griefahn, 1980). However, the reviewed studies reported age ranges so great that any measure of central tendency would have been meaningless. The only available variables that could be coded with reasonable reliability were sex of test subjects, location of the study (laboratory or field), type of noise intrusion, a crude measure of level of background noise, and number of nights subjects spent in a noisy environment as a coarse measure of habituation.

4.1.1 Coding and Transformations of Variables

Background noise in AL_{max} was coded into 3 levels: less than 30, 31 to 49, and 50 or more. This 3-level variable, BACKGRD, was treated as continuous.

Location was classified into 3 categories: laboratory, field, and contrived field or quasi-lab (located in the field but using nonnatural noise intrusions). From this, 2 dummy coded variables were created: laboratory vs. nonlaboratory (LAB) and true field vs. other locations (FIELD).

Sex originally had 3 categories, necessitated by the lack of precise information in some of the reported studies: male only, female only, and mixed male and female. The 2 dummy coded variables used in the multiple regression analyses were all male vs. other (MALE) and all female vs. other (FEMALE).

The length of the study in terms of number of nights in a noisy environment was coded as a continuous variable, LENGTH. This variable served as a very rough measure of habituation, since some individual data points produced early in a long-term study would be considered part of the long duration data.

The type of noise produced was originally classified into 10 categories: jet aircraft, sonic boom, truck, traffic, pink noise, white noise, train, tone, transmission line noise (including simulated transformer, air conditioner, distant traffic, and test transmission line), and ping (roughly a half-second sonar-like sound in the 3-4 kHz region). For purposes of multiple regression analysis, 3 dummy coded variables were formed: jet aircraft vs. other (JET), sonic boom vs. other (BOOM), and traffic (including truck) vs. other (TRAFFIC).

Preliminary analyses were performed with a normal probability (probit) transformation of the 2 dependent variables (awakening and sleep disruption). Since results were not affected by the transformation, only those analyses with untransformed dependent variables are reported.

4.1.2 Data Analyses

Four separate bivariate regression analyses were performed, for each combination of 2 major dependent variables (arousal/awakening and sleep disturbance), and the 2 independent variables (noise measured in AL_{max} and SEL). Bivariate regressions were also calculated separately for laboratory and field studies.

Four separate hierarchical multiple regression analyses were also performed for the same combination of the two dependent variables, and two major independent variables just described.

In each of the hierarchical regression analyses, order of entry of variables was the same. First entered were variables based on subject characteristics, MALE and FEMALE. At the second step of the hierarchy were variables reflecting type of noise intrusion, JET, BOOM, and TRAFFIC. The third step included characteristics of the study: location (LAB and FIELD), BACKGRD noise level, and LENGTH of time subjects spent in the study. The final variable entered was noise level, measured either in AL_{max} or SEL. Some SELs were converted from AL_{max}s. Each such conversion was treated on an individual basis, taking duration into account.

Hierarchical analysis allows evaluation, at each step of the hierarchy, of the contribution of independent variables to prediction of the dependent measure (sleep disruption), over and above the contribution of variables previously entered into the regression equation. Thus, at the last step one may see how much noise level affects sleep, after accounting for sleep disruption attributable to subject characteristics, type of noise, and study characteristics. Appendix B reviews hierarchical regression analyses.

4.2 Results

Preliminary screening of variables (see Appendix B) revealed no cause for alarm concerning violation of such assumptions of multiple regression analysis as multivariate normality, linearity, and multicollinearity. There were no unduly influential cases when using sleep disruption as a dependent variable. However, in the data predicting arousal/awakening, the 3 cases with sonar-like pings as a noise source were significantly deviant from the remaining cases ($p < .001$ using Mahalanobis distance as a criterion). These 3 data points consisted of male participants in a contrived field study, with high background noise (greater than 50 dBA) and for especially long duration (30 days) relative to the remaining studies. These 3 data points were eliminated from further analyses. When using arousal/awakening as a dependent variable, there is far greater variance in number of awakenings at high noise levels than at low noise levels, producing notable heteroscedasticity. The net effect is likely to be an underestimate of the influence of noise level on probability of awakening.

4.2.1 Bivariate Relationships Between Noise and Sleep

In the prediction of awakening by AL_{max} alone, Figs. 4-1 and 4-2 show bivariate regressions separately for laboratory (including quasi-lab) and field data points. Both laboratory and field studies show a reliable relationship between AL_{max} and awakening, $r_{113} = .47$, $p < .01$; and $r_{19} =$ .J, $p < .01$, respectively.

In the bivariate regressions between awakening and noise level as measured by SEL, both lab and field studies again show reliable relationships: $r_{113} = .62$ and $r_{19} = .70$, $p < .01$, respectively, as seen in Figs. 4-3 and 4-4.

Using noise intrusion measured in AL_{max}, bivariate predictions of sleep disruption are strong and statistically reliable, $p < .01$, for lab data, $r_{57} = 0.80$, as well as for field data, $r_{22} = .83$ (Figs. 4-5 and 4-6, respectively).

Using noise intrusion measured in SEL as a predictor, Figs. 4-7 and 4-8 show that bivariate gression remains strong, $p < .01$, for both lab data, $r_{57} = 0.79$ and field data, $r_{22} = 0.78$.

4.2.2 Laboratory vs. Field Studies

Only 3 of the studies were designated quasi-lab--conducted in the field, but with operator-induced noise intrusions. Since this is too small a number for purposes of statistical analysis, these studies were combined with those actually conducted in the laboratory.

For all 4 combinations of noise and disruption, highly discrepant results are produced for laboratory (including quasi-laboratory) vs. field studies, as is evident from Figs. 4-1 through 4-8. In all cases, greater responsiveness to increasing noise (steeper slopes) is seen for the laboratory results compared with field results, although the field studies tend to produce more reliable regressions (narrower confidence intervals). Using the AL_{max} measure of noise to predict awakening, regression coefficients for laboratory (B = 0.57) and field (B = 0.12) were significantly different, $F_{2, 132} = 17.96$, $p < .01$. Regression coefficients for laboratory (B = 0.82) and field (B = 0.14) were also reliably different when using the SEL measure of noise to predict awakening, $F_{2, 132} = 17.85$, $p < .01$.

Predicting sleep disruption by AL_{max} measure of noise, reliable differences in regression coefficients were found between laboratory (B = 1.21) and field (B = 0.77) studies, $F_{2, 79} = 10.99$, $p < .01$. Using the SEL measure of noise for prediction of sleep disruption, significantly different regression coefficients were again produced by laboratory (B = 1.17) and field (B = 0.71) studies, $F_{2, 79} = 18.64$, $p < .01$.

4.2.3 Comparison with Prior Reviews

Figure 4-9 illustrates the results of the current reviews as well as those conducted by Lukas (1977) and Griefahn (1980) for predicting arousal or awakening using SEL as a measure of noise level. Figure 4-10 compares results for predicting sleep disruption by that same noise metric. Note that the slope of the relationship increases from a low produced by field studies, to laboratory studies reviewed in the current analysis, to results reported by Lukas, to a high produced by results reported by Griefahn.

The results of the field studies agree reasonably well with the results of the Lukas review. However, the results of the review by Griefahn suggest that awakening occurs for noises about 15 dB higher than those of Lukas. Further, the slope of the relationship is greater for both awakening and sleep disruption as shown in Figs. 4-9 and 4-10. Part of the reason for the

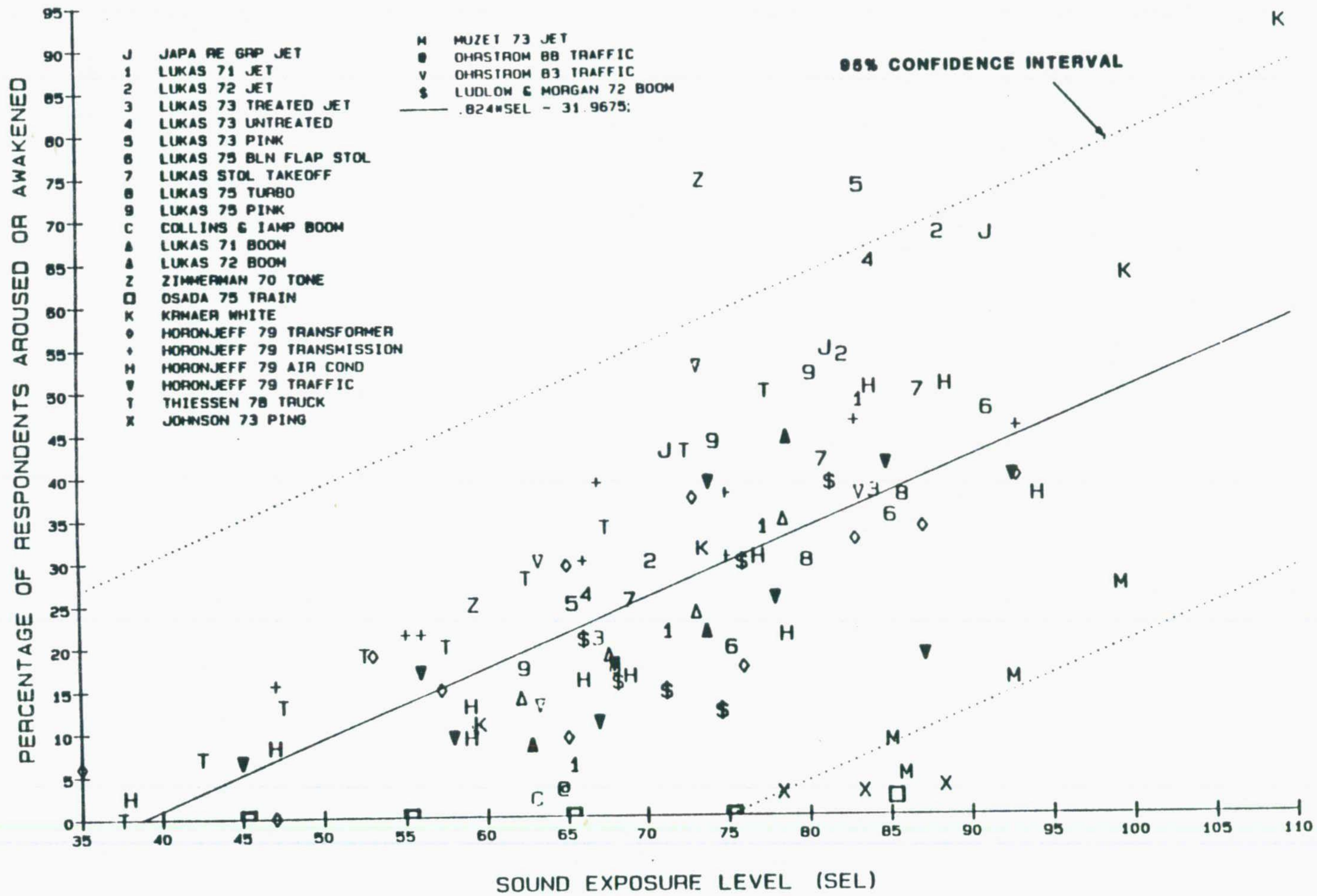

Figure 4-3. Summary of Laboratory Studies Showing Awakening or Arousal for Various Sound Exposure Levels.

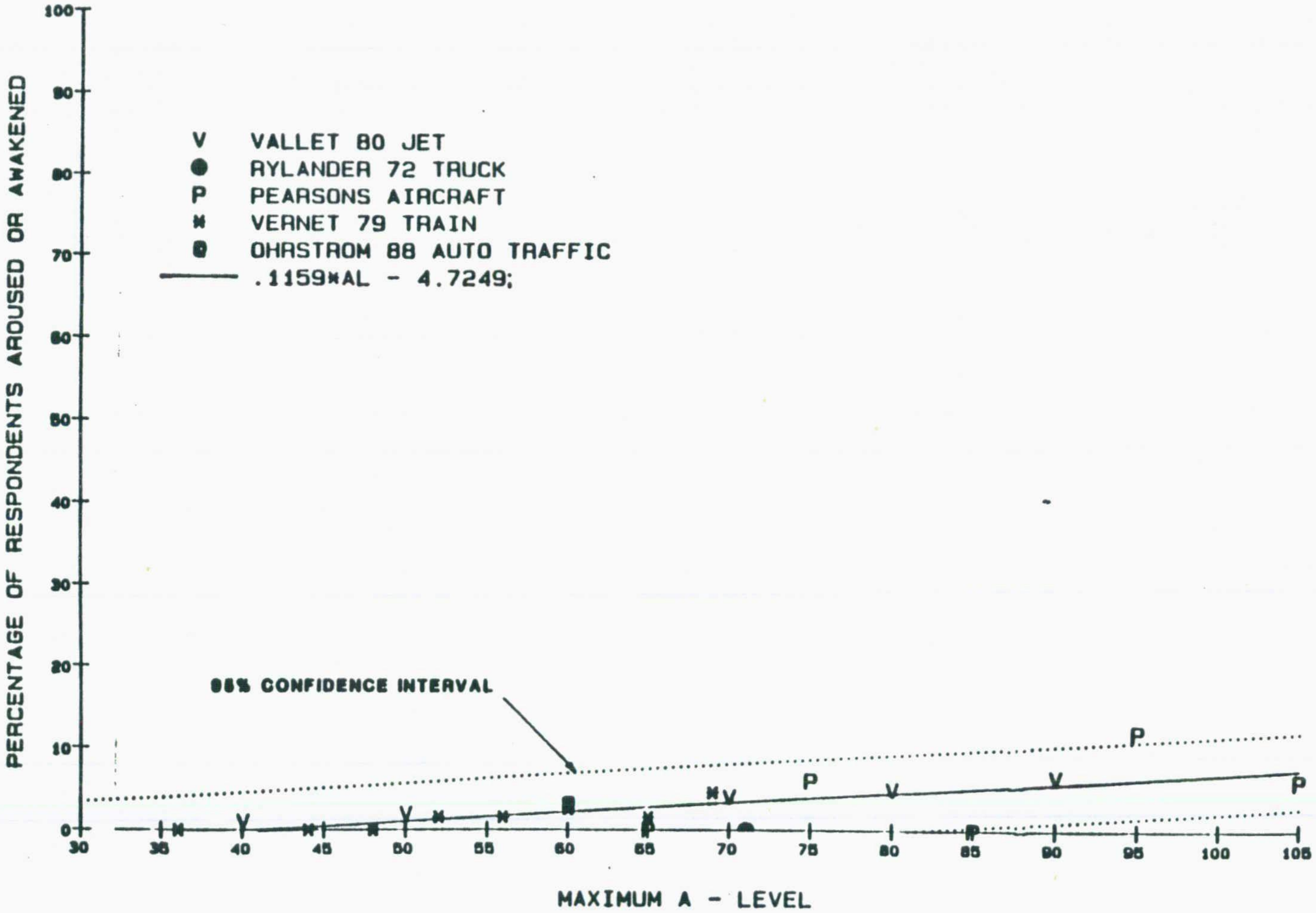

Figure 4-2. Summary of Field Studies Showing Awakening or Arousal for Various Maximum A-Levels.

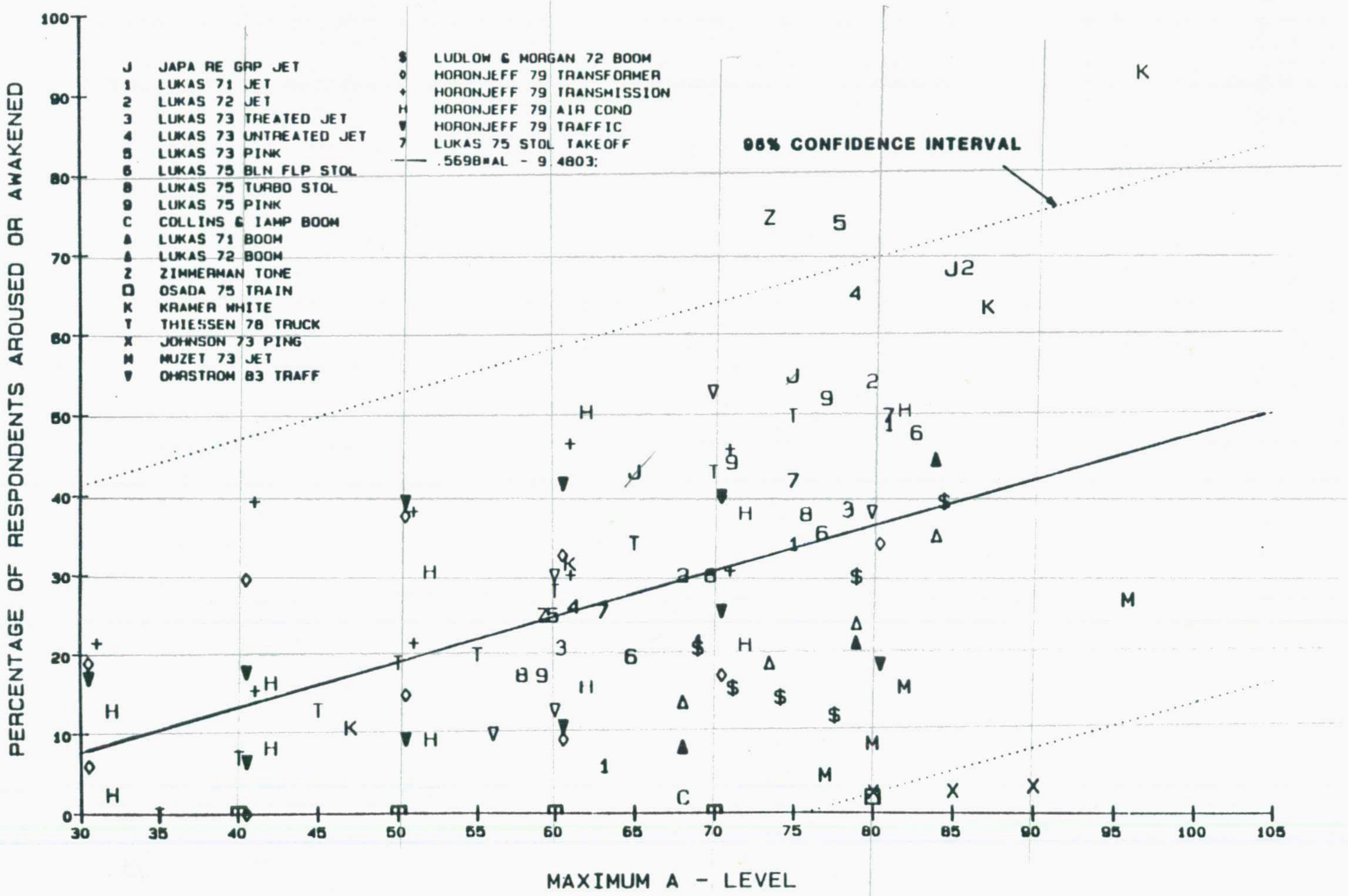

Figure 4-1. Summary of Laboratory Studies Showing Awakening or Arousal for Various Maximum A-Levels.

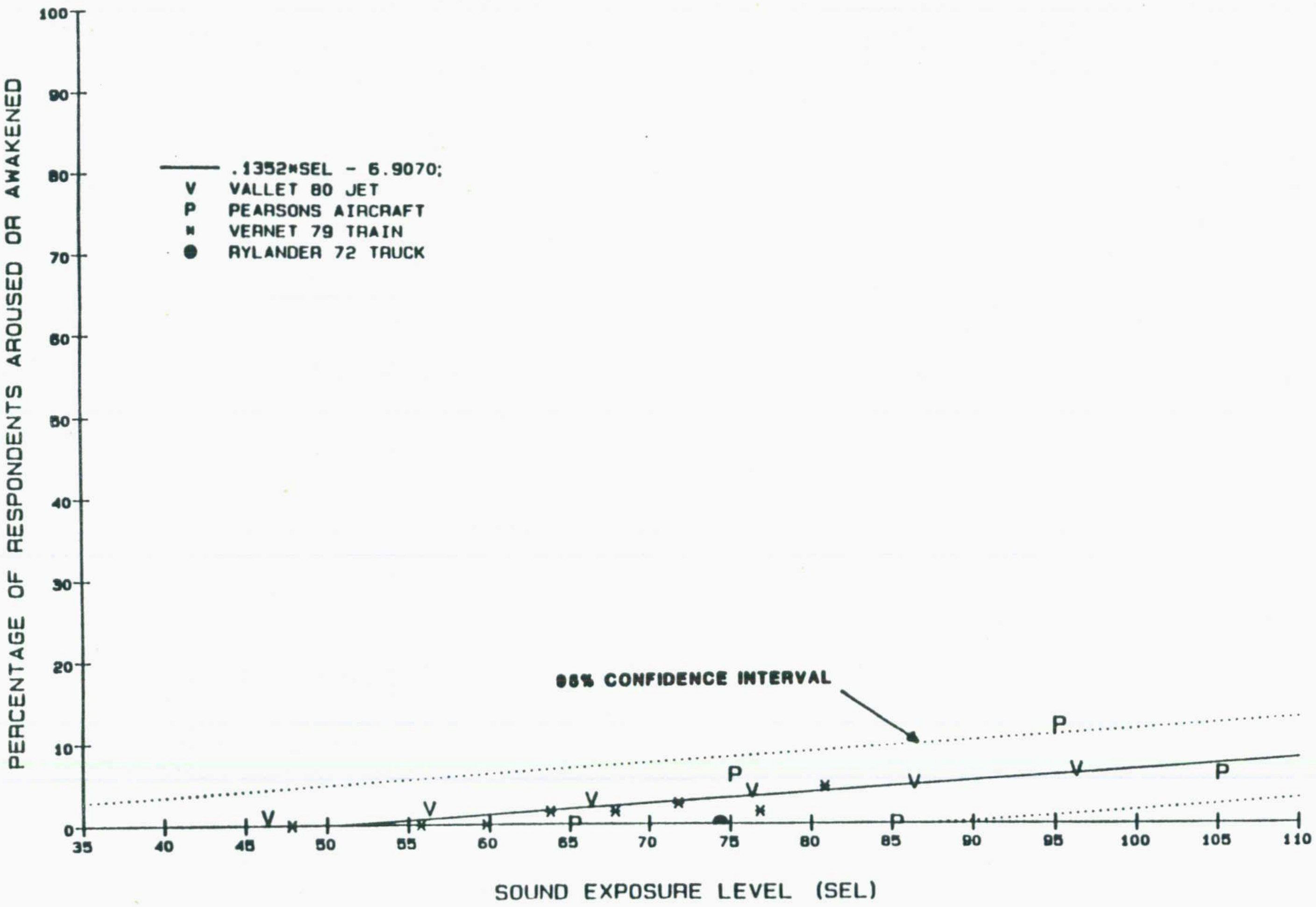

Figure 4-4. Summary of Field Studies Showing Awakening or Arousal for Various Sound Exposure Levels.

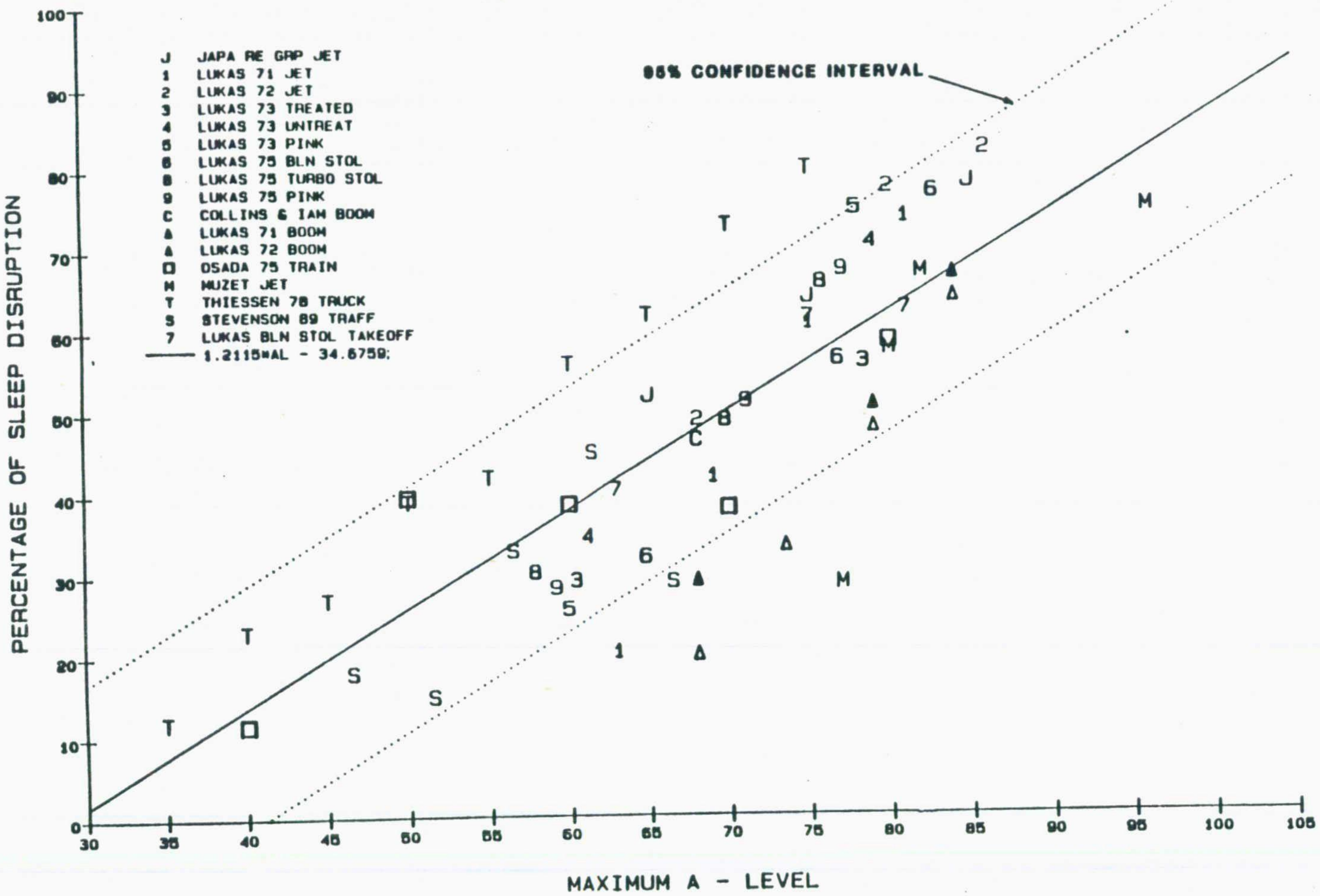

Figure 4-5. Summary of Laboratory Studies Showing Some Sleep Disruption (Sleep Stage Change or Awakening) for Various Maximum A-Levels.

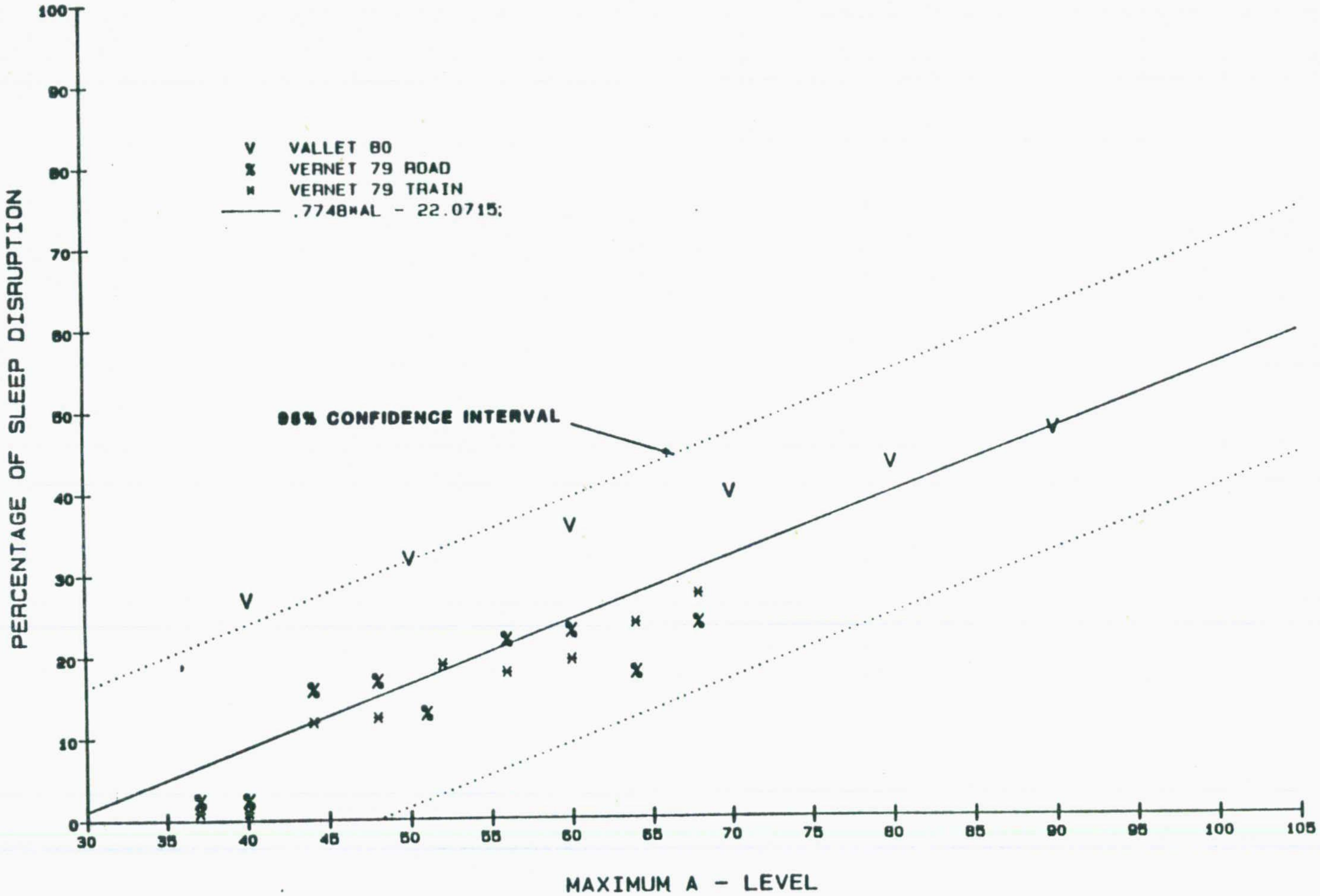

Figure 4-6. Summary of Field Studies Showing Some Sleep Disruption (Sleep Stage Change or Awakening) for Various Maximum A-Levels.

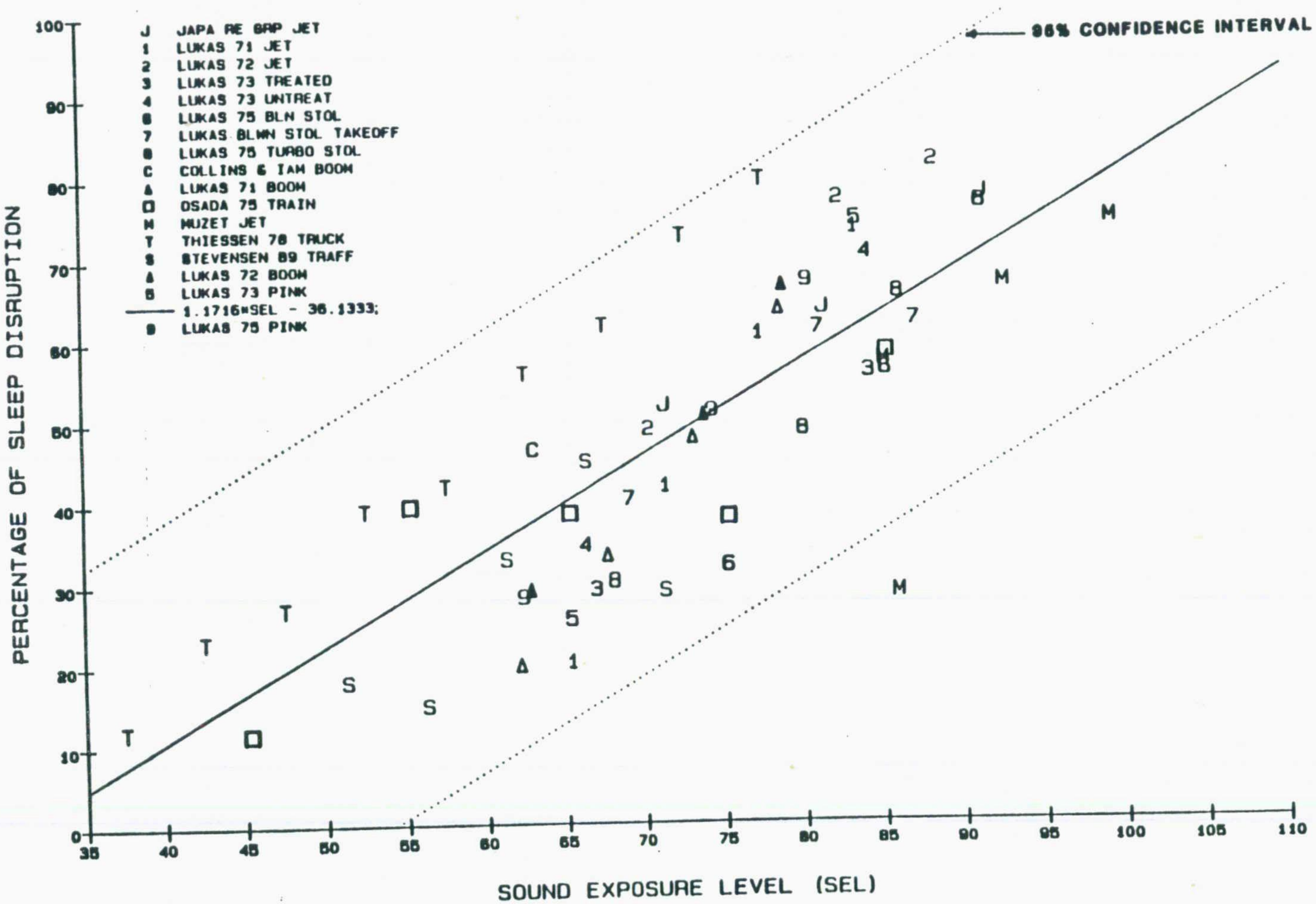

Figure 4-7. Summary of Laboratory Studies Showing Some Sleep Disruption (Sleep Stage Change or Awakening) for Various Sound Exposure Levels.

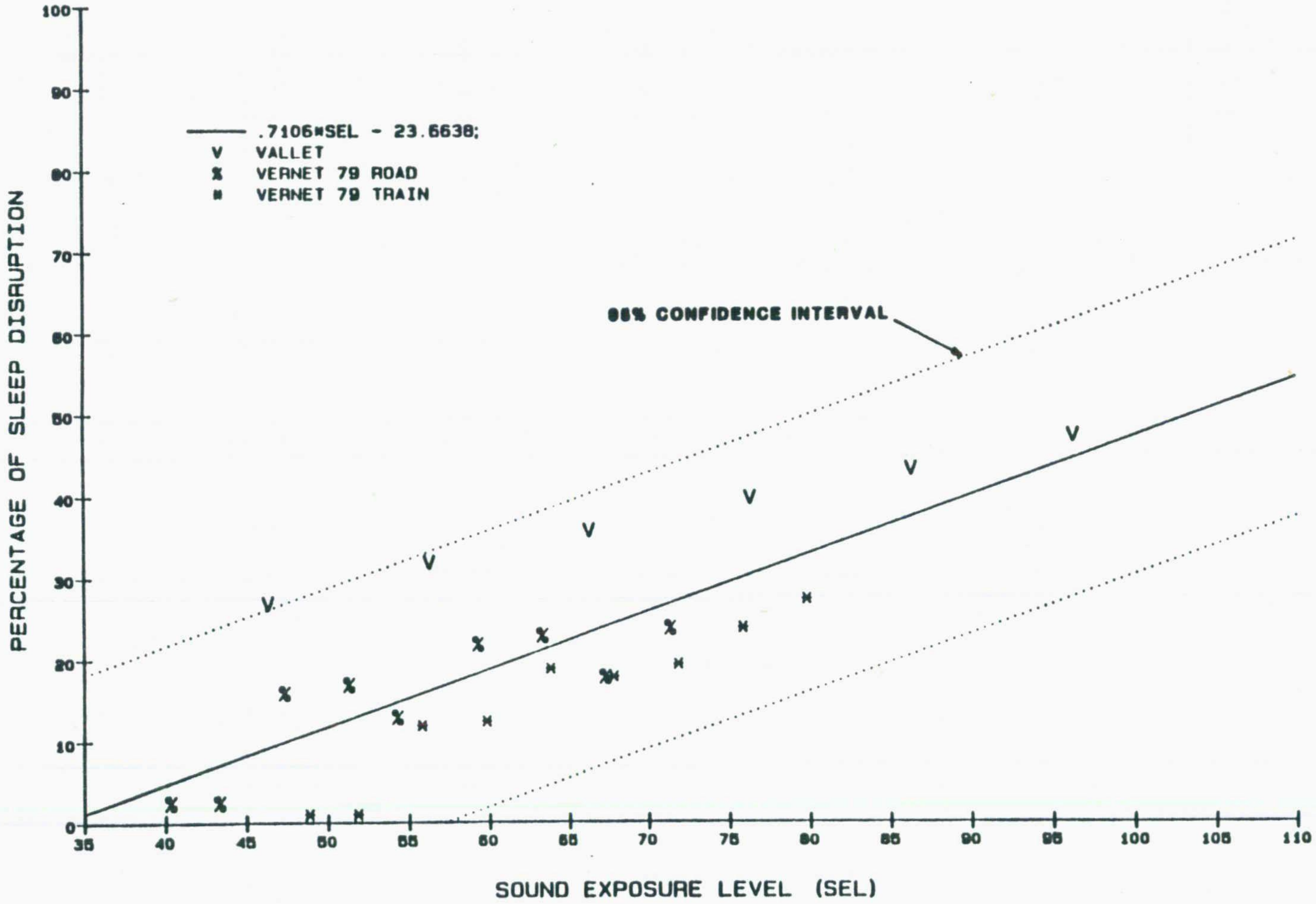

Figure 4-8. Summary of Field Studies Showing Some Sleep Disruption (Sleep Stage or Awakening) for Various Sound Exposure Levels.

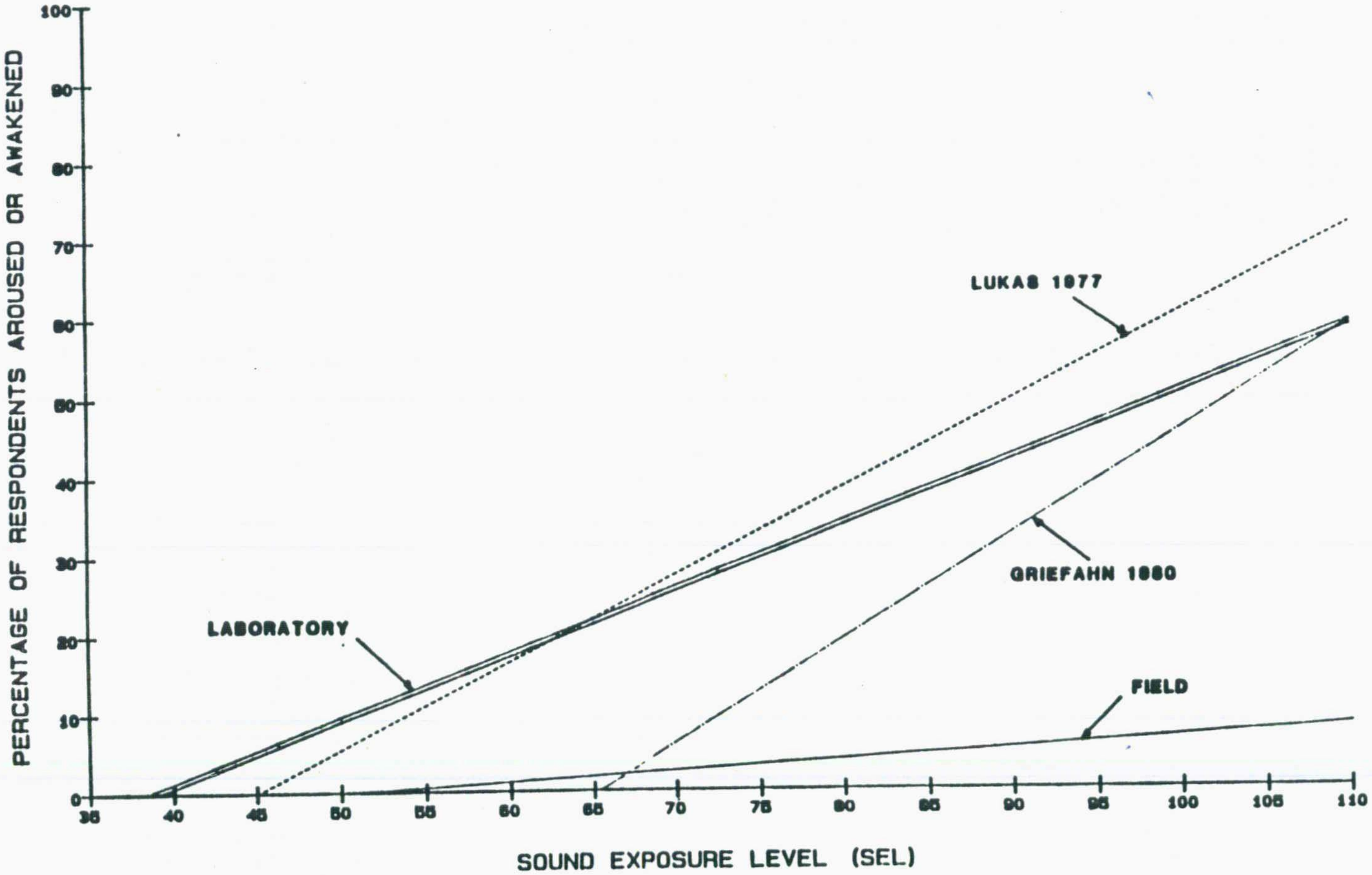

Figure 4-9. Comparison of Reviews Showing Awakening or Arousal for Various Sound Exposure Levels.

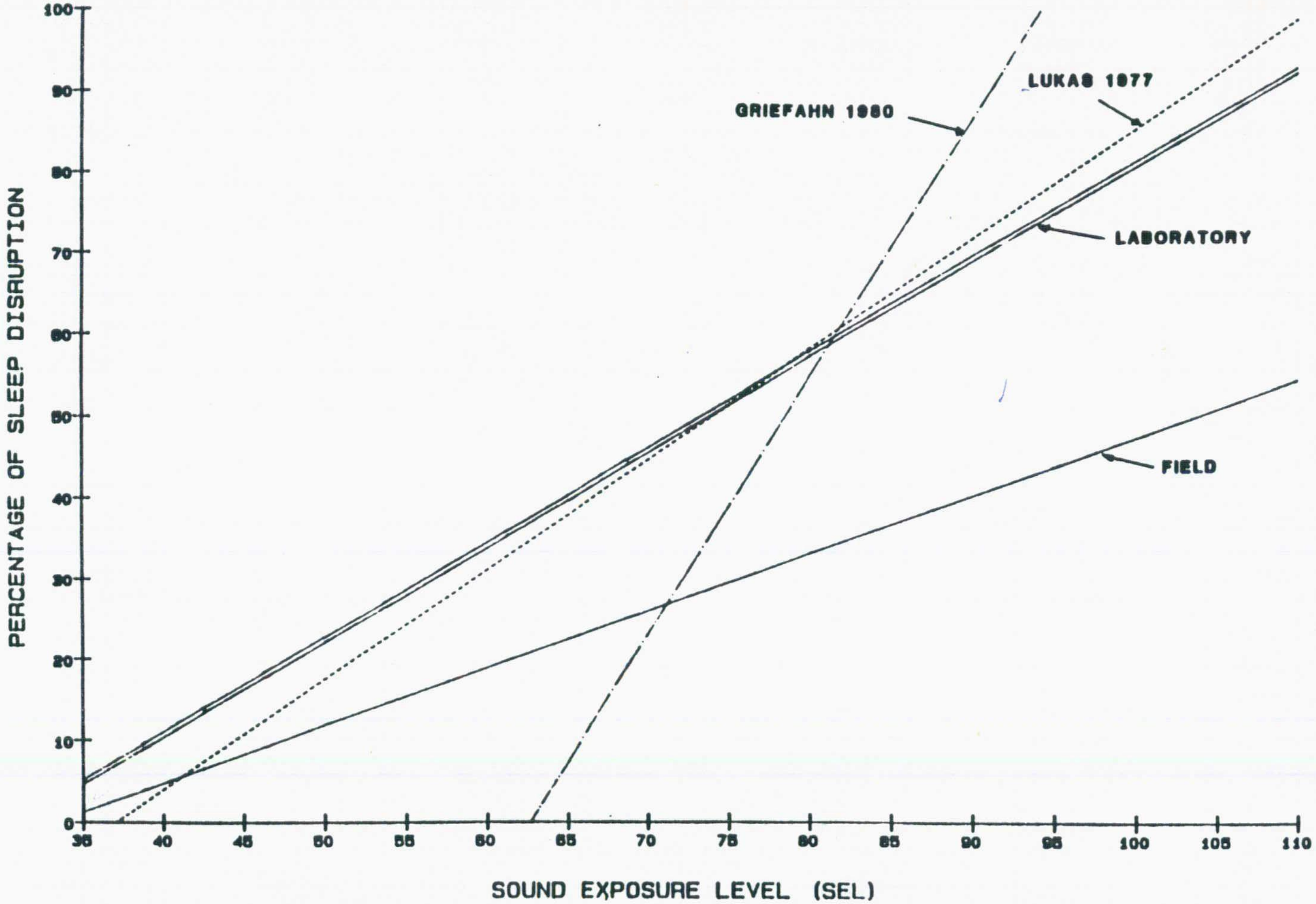

Figure 4-10. Comparison of Reviews Showing Some Sleep Disruption (Sleep Stage Change or Awakening) for Various Sound Exposure Levels.

difference may be due to the estimation of SEL values from the maximum AL_{max}s provided by Griefahn. However, this should not greatly affect the slope of the relationship. At this time, it can only be suggested that the discrepancy relates to the particular subset of studies included in the reviews; this reinforces the need for additional study.

4.2.4 AL_{max} vs. SEL

Higher prediction of arousal/awakening was evident with SEL rather than AL_{max} as a noise metric using a test for the difference between paired correlations with laboratory and field data combined, $z = 3.22$, $p < .01$. However, when predicting sleep disruption a stronger relationship using AL_{max} was found as a metric, $z = 2.24$, $p < .05$.

4.2.5 Other Factors Predicting Sleep Disturbance

Table 4-1 summarizes the hierarchical regression of various study variables on the probability of awakening as a result of a noise intrusion measured in AL_{max}. After considering all predictors together, a statistically significant relationship emerges, $F_{10, 122} = 14.67$, $p < .01$. In combination, all predictors considered account for 55% (51% adjusted) of the variability in awakening. All types of variables contribute significantly to prediction of arousal/awakening. Both dummy coded gender variables significantly predict awakening ($p < .01$). The noise type offering the major contribution to prediction is whether sonic booms were used ($p < .01$). All variables encompassing study characteristics except its length contribute reliably to prediction ($p < .01$). As in all multiple regression analyses amount of noise, here measured in AL_{max}, was the strongest predictor of probability of awakening, after adjusting for all other variables.

Table 4-2 summarizes the hierarchical regression using the same variables, except that noise intrusion is measured in SEL. Since SEL produces a better prediction than AL_{max}, the overall relationship is stronger, accounting for 61% (57% adjusted) of the variance in awakening, $F_{10, 122} = 19.03$, $p < .01$. Variables in all levels of the hierarchy contribute to prediction of disruption. Both dummy coded variables representing gender significantly contribute to prediction ($p < .01$), as does whether noise was induced by sonic booms. Statistically significant ($p < .01$) contribution to prediction is provided by whether the study was conducted in the field (with natural noise sources) and by background noise level, among study characteristics.

As seen in Table 4-3, greater prediction of sleep disturbance is possible when measuring more subtle types of disruption measured by EEG, in addition to awakening, $F_{10, 72} = 35.30$, $p < .01$. With all variables considered together, 83% of the variance (81% adjusted) was accounted for in predicting disruption. Among subject characteristics, whether subjects were female contributes significantly to prediction of disruption, $p < .01$. For type of noise, significant contribution to prediction is provided by whether noise was sonic-boom induced ($p < .01$). Length of the study is the characteristic that provided reliable prediction of disruption ($p < .05$).

Table 4-4 shows a similar pattern of results; all predictors together account for 83% of the variance (80% adjusted) when using SEL as the measure of noise intrusion along with the other predictors, $F_{10, 72} = 34.69$, $p < .01$. The statistically reliable predictor among subject characteristics is whether or not the study was conducted on women ($p < .05$). Among noise types, significant prediction was provided by whether the intrusion was induced by traffic ($p < .01$). Length of study was the study characteristic providing reliable prediction ($p < .05$).

4.3 Discussion

Prediction of sleep disturbance was strongly influenced by whether the study was conducted in the field with natural noise sources (designated field studies) or conducted using operator-produced noise sources (considered laboratory studies for analysis purposes whether conducted in a contrived or natural setting). These differences emerged whether disturbance was measured by awakening or by EEG indicators of change to a lighter level of sleep, and whether noise was measured as AL_{max} or SEL.

TABLE 4-1.

HIERARCHICAL REGRESSION OF SEVERAL STUDY VARIABLES INCLUDING AL_{max} ON PROBABILITY OF AROUSAL OR AWAKENING.

Variables	AWAKE(DV)	MALE	FEMALE	JET	BOOM	TRAFFIC	LAB	FIELD	BACKGRD	LENGTH	DBA	B	β	sr^2 (inc)
Subject characteristics														.06*
MALE	.15											14.40**	.35	
FEMALE	.15	-.16										18.86**	.20	
Type of Noise														.02*
JET	.15	.39	.13									-4.79	-.10	
BOOM	-.04	.11	.28	-.20								-21.68**	-.34	
TRAFFIC	-.03	-.32	-.11	-.28	-.17							-.80	-.02	
Study characteristics														.29**
LAB	.32	.46	.20	.33	.32	.004						-18.05**	-.46	
FIELD	-.47	-.01	-.09	.04	-.15	-.11	-.46					-18.32**	-.68	
BACKGRD	.12	.18	.18	.26	.28	.02	.67	.11				15.64**	.39	
LENGTH	.13	-.52	-.09	-.32	-.06	.28	-.28	-.50	-.44			.38	.16	
Amount of noise														.55**
DBA	.43	.24	.18	.30	.24	-.20	.37	.03	.41	-.35		.62**	.50	
										Intercept =		-1.78		
Means	23.97	0.34	0.04	0.25	0.10	0.19	0.53	0.31	1.59	12.52	64.33			
Standard deviation	19.59	0.48	0.21	0.43	0.31	0.40	0.50	0.73	0.49	8.16	16.01			
														R^2 = .55
														Adjusted R^2 = .51
														R = .74**

*$p < .05$.
**$p < .01$.

TABLE 4-2.

HIERARCHICAL REGRESSION OF SEVERAL STUDY VARIABLES INCLUDING SEL ON PROBABILITY OF AROUSAL OR AWAKENING.

Variables	AWAKE(DV)	MALE	FEMALE	JET	BOOM	TRAFFIC	LAB	FIELD	BACKGRD	LENGTH	SEL	B	β	sr^2 (inc)
Subject characteristics														.06*
MALE	.15											3.01**	.32	
FEMALE	.15	.16										19.79**	.21	
Type of Noise														.02
JET	.15	.39	.13									-5.80	-.13	
BOOM	-.04	.11	.28	-.20								-15.74**	-.25	
TRAFFIC	-.03	-.32	-.11	-.28	-.17							-.16	-.003	
Study characteristics														.29**
LAB	.32	.46	.20	.33	.32	.004						-7.12	-.18	
FIELD	-.47	-.01	-.09	.04	-.15	-.11	-.46					-13.16**	-.49	
BACKGRD	.12	.18	.18	.26	.28	.02	.67	.11				12.47**	.31	
LENGTH	.13	-.52	-.09	-.32	-.06	.28	-.28	-.50	-.44			.53	.22	
Amount of noise														.25**
SEL	.55	.15	.06	.28	-.01	-.20	.11	.02	.17	-.22		.73**	.54	
											Intercept =	-3.46		
Means	23.97	0.34	0.04	0.25	0.10	0.19	0.53	0.31	1.59	12.52	71.69			
Standard deviation	19.59	0.48	0.21	0.43	0.31	0.40	0.50	0.73	0.49	8.16	14.54			

R^2 = .61

Adjusted R^2 = .57

R = .78**

*$p < .05$.
**$p < .01$.

TABLE 4-3.

HIERARCHICAL REGRESSION OF SEVERAL STUDY VARIABLES INCLUDING AL_{max} ON PROBABILITY OF DISRUPTED SLEEP.

riables	DISRUPT(DV)	MALE	FEMALE	JET	BOOM	TRAFFIC	LAB	FIELD	BACKGRD	LENGTH	DBA	B	β	sr^2 (inc)
bject characteristics														.15**
LE	.30											6.57	.14	
MALE	.16	-.28										13.64**	.22	
ype of Noise														.14**
T	.45	.28	.30									-2.90	-.06	
OM	.07	-.14	.21	-.26								-18.42**	-.25	
AFFIC	-.29	-.43	-.25	-.50	-.20							5.35	.11	
tudy characteristics														.22**
B	.62	.51	-.13	.28	.24	-.34						2.16	.05	
IELD	-.57	-.44	.19	-.19	-.21	.14	-.87					-3.84	-.16	
CKGRD	.13	.01	-.32	.02	.16	-.04	.35	-.09				2.86	.05	
NGTH	.33	-.06	-.10	-.03	.27	.13	.64	-.54	.31			.53*	.19	
ount of noise														.33**
A	.82	.21	.19	.46	.25	-.45	.46	-.41	.13	.11		1.18**	.78	
											Intercept =	2.89		
ans	40.24	0.33	0.14	0.40	0.10	0.28	0.65	0.58	1.80	8.35	64.59			
tandard deviation	21.80	0.47	0.35	0.49	0.30	0.45	0.48	0.91	0.40	7.79	14.38			

$R^2 = .83$

Adjusted $R^2 = .81$

$R = .91$**

*p < [illegible]
**p < .01.

TABLE 4-4.

HIERARCHICAL REGRESSION OF SEVERAL STUDY VARIABLES INCLUDING SEL ON PROBABILITY OF DISRUPTED SLEEP.

Variables	DISRUPT(DV)	MALE	FEMALE	JET	BOOM	TRAFFIC	LAB	FIELD	BACKGRD	LENGTH	SEL	B	β	sr^2 (inc)
Subject characteristics														.15**
MALE	.30											6.12	.13	
FEMALE	.16	-.28										16.03**	.26	
Type Noise														.14**
JET	.45	.28	.30									-2.50	-.06	
BOOM	.07	-.14	.21	-.26								-5.40	-.07	
TRAFFIC	-.29	-.43	-.25	-.50	-.20							11.73**	.24	
Study characteristics														.22**
LAB	.62	.51	-.13	.28	.24	-.34						8.14	.18	
FIELD	-.57	-.44	.19	-.19	-.21	-.14	-.87					-2.98	-.13	
BACKGRD	-.13	.01	-.32	.02	.16	-.04	.35	-.09				1.06	.02	
LENGTH	.33	-.06	-.10	-.03	.27	.13	.64	-.54	.31			.55*	.20	
Amount of noise														.32**
SEL	.78	.28	.13	.55	.02	-.52	.36	-.30	.10	-.05		1.19**	.77	
											Intercept =	3.67		
Means	40.24	0.33	0.14	0.40	0.10	.28	0.65	0.58	1.81	8.35	69.22			
Standard deviation	21.80	0.47	0.35	0.49	0.30	0.45	0.48	0.91	0.40	7.79	14.09			

R^2 = .83

Adjusted R^2 = .80

R = .91**

*p < .05.
**p < .01.

In all cases, the influence of noise on sleep was greater in the laboratory. In the laboratory studies, a large change in probability of sleep disruption was associated with a given change in noise level, while in the field, the same change in noise level had far less influence on disruption. While this discrepancy was also noted in more subtle measures of sleep disturbance, the trend was stronger when predicting arousal or awakening. For example, Figs. 4-3 and 4-4 show that when measuring response as awakening and noise in SEL, a 10 dB increase in noise was associated with an increase in probability of awakening of about 8% in the laboratory, but only about 1% in the field. Indeed, Figs. 4-2 and 4-4 show that with noise levels as high as 85 dBA or SEL, there was a zero probability of disruption of sleep of any kind for at least 1 data point. Since these are the data produced by participants sleeping in their natural environments with familiar noises, this finding provides a suggestion of the magnitude of the effect of habituation.

Although laboratory studies show greater influence of noise on sleep, they also provide less reliable data. There is far greater variability in data produced by operator-induced than in natural noises. Particularly at high noise levels, the range of sleep interference is enormous. At 85 dB (SEL), the probability of awakening varies from under 5% to a high of 75%. Thus, although all 8 bivariate regressions were statistically reliable, a glance at the confidence bars in Figs. 4-1 through 4-8 reveals considerable uncertainty in regression lines, greatly limiting the generalizability of these findings, particularly those deriving from nonnatural noise sources.

Bivariate results favor SEL when predicting arousal/awakening and dBA when predicting the broader response of sleep disruption as measured by EEGs. In general, measures of sleep disruption derived from EEGs can be predicted more reliably in this data set than full arousal or awakening, as noted in both the bivariate and multiple regression analyses. Although EEG offers more predictive power, it is not clear that it is a more useful measure in terms of community response to noise. In the absence of evidence of any harmful effects of change to a lighter level of sleep, it may well be that this definition of sleep disruption is an inappropriate measure for generalization to the community.

The results clearly show that prediction of sleep disturbance can be enhanced by taking into account factors other than noise level, although interpretation must be tempered by the crude nature of most of the measures. As expected, the strongest determinant of sleep disturbance among the predictors investigated is noise level, whether measured in AL_{max} or SEL.

The contribution of predictors other than noise level can only be seen as suggestive in this study because of the coarseness of their measurement. None of these additional predictors were measured with sufficient accuracy or reliability to reveal the magnitude of their influence on interference with sleep. Habituation, almost certainly a major confounder of the influence of noise on sleep in reality, was measured only in the crudest fashion as the length of the study. Background noise level, too, was measured only roughly, coded into 3 wide-band categories. Type of noise, similarly, was divided into broad categories. For jet aircraft noises, no distinction could be made in these analyses between types of jet aircraft or distance from the source. Similarly, for sonic booms the analysis could not take into account distance from the source. Even gender was measured coarsely in that studies were classified as all male, all female, or mixed. Other variables, such as age, may have been confounded with gender.

Correlations among predictors in this data set tended to be much higher than would be expected in the population to which generalization is desired, because some were spuriously produced by the way the studies were conducted. For example, strong correlations emerged between sex and study duration for the data on awakening. This result is because studies of longer duration tended to use men as subjects. In real life, there is no reason to expect that women have less opportunity than men to become habituated to noise because of shorter exposure durations. The effect of these spurious correlations is to limit the magnitude of the apparent contribution of any 1 predictor, particularly if it enters the regression equation late. In the just mentioned example, duration of the study (a surrogate for habituation) would show little prediction of sleep disruption after accounting for sex, even though, by itself, habituation might be a strong determinant of the effect of noise on sleep. Since each one of the independent variables significantly affected sleep in at least 1 of the multiple regressions, it is recommended that in future empirical studies they all be taken into account.

The foregoing discussion addresses the contribution of individual predictors to sleep disturbance but not the issue of overall prediction. Although some of the multiple regressions reported high predictability, these estimates may be low relative to those that could be obtained if better measurement of predictors were available. Another factor attenuating the obtained correlations is the finding that there is greater individual variability in arousal/awakening at higher noise levels. This can be seen in Figs. 4-1 through 4-4 where all data points fall well within the confidence intervals at lower noise levels, but some points fall outside the intervals at higher noise levels.

Other variables which might be considered in future studies are such additional subject characteristics as physical condition, personal history of insomnia, physiological state including arousal level, current stress level, and environmental conditions such as temperature and humidity. It is also likely that the intermittency of noise contributes to the effect of noise intrusions on habituation and, thus, on sleep. Interactions among variables studied here, such as between sex and habituation, might also be profitably investigated in future empirical studies. Taken together, it is clear that much better predictability of sleep disturbance is possible with a study designed to take into account all the predictors discussed and to measure them more reliably and accurately.

5 CONCLUSIONS

Available data do not support construction of a reliable and useful dose-response relationship between noise exposure and sleep disturbance. The influence of noise on sleep depends on a variety of factors: the noise metric chosen, the response metric chosen, consideration of numerous nonnoise factors affecting the relationship, and how the study is conducted.

The major differences observed between findings of laboratory and field studies makes it unwise to rely on dose-response relationships thus far established. In particular, it is not at all clear whether the laboratory results from which such relationships have been derived are directly applicable to prediction of sleep disturbance effects created by aircraft operations near MTRs and MOAs, the main interest of our study.

While many of the laboratory studies and contrived field studies used noise sources similar to those of concern to USAF planners, noises were typically produced at a far higher rate than they would be *in situ*. None of the laboratory studies reviewed was of long enough duration to track the effects of habituation that might occur under community conditions of concern to USAF environmental planners. Further, the field studies were not necessarily conducted in locales sufficiently similar to those of concern to the USAF, nor with noise sources generalizable to those produced by military aircraft overflights.

Because of these problems, it is concluded that insufficient relevant data currently exist to develop an improved model of the effect of noise on sleep.

6 RECOMMENDATIONS FOR FUTURE RESEARCH

The lack of adequate published data on sleep disturbance can only be resolved by research specifically designed to meet the needs of USAF planners. In designing such research, a first step is a review of the problems associated with the current data.

6.1 Deficiencies in Current Data

Several questions remain after detailed analysis of all of the studies reviewed to date on the effects of noise intrusions on sleep:

1. What effects do the short onset times associated with the low-level military flights have on sleep disturbance? None of the studies reviewed during this effort investigated any time patterns resembling these generated by low-level flights. Since the low-level flights represent a major portion of the operations related to MOAs and MTRs, it is critical that stimuli with a wide range of onset times be included in any future research.

2. Is SEL a better predictor of sleep disturbance than AL_{max}? Since SEL was not available in all of the reviewed studies, the metric had to be estimated in many cases. These estimates were made on data of varying accuracy, so that the conversions from published metrics are of varying adequacy. A new study with SEL measurements taken along with AL_{max} is needed to resolve this issue.

3. What are the effects of habituation in the community? How is habituation affected by frequency of occurrence of noise intrusions? Research to date fails to address the crucial issues of habituation and intermittency in a satisfactory manner.

4. Which other factors (e.g., personal characteristics, background noise level, type of noise source, time of noise intrusion) can be usefully applied by USAF planners to prediction

of environmental consequences of USAF operations? For USAF purposes, it may be worthwhile to limit inquiry to those variables which can be used, even though other variables may reliably enhance prediction of sleep disturbance.

5. What are the effects of military overflights on sleep in the communities exposed to those overflights? It is unclear to what extent data from laboratory studies are relevant to this issue. In any event, the issue can best be resolved only by designing a field study that closely mimics the conditions to which generalization must be made.

Failure of published studies to address many of these issues underscores the need for a new, large-scale research program conducted in the field under natural conditions in communities exposed to changing patterns of military overflights. Some alternative field study designs are described next.

6.2 Future Studies

The types of studies necessary to answer the questions raised by this review, and supply the critical information lacking in the sleep disturbance information currently available, must be of sufficient duration to resolve the habituation issue. Long-term studies are especially important in the environment of principal concern (residences in proximity to MTRs and MOAs) because aircraft noise intrusions in this environment are sporadic and infrequent. Therefore, regardless of the type of study design selected, data would need to be continuously gathered for at least 6 to 12 months. Because of the low data collection rate, we would recommend that the research program include a pilot study to confirm the utility of the data collection procedure, except for those study designs using the most rudimentary data collection techniques. The subjects for any investigation should include both men and women within an age range of 25 to 65 years or older, if available. Meaningful data analysis requires at least 30 subjects at each location; locations should differ in frequency and level of noise intrusions to establish a dose-response relationship. Several studies, varying in complexity and sophistication, are briefly outlined.

6.2.1 Sleep Study with Self Report Questionnaire - Pilot Study

The simplest approach to data collection is to obtain self-report information on sleep quality each morning upon arising, to be recorded on a postcard. This design is best seen as a pilot study. If the results from this study with postcards indicate no sleep interference as a result of overflights, no further sleep investigation is required. Conversely, if the results indicate sleep disturbance, then 1 of the following, more sophisticated, options outlined can be used. Even this pilot study, however, requires on-site noise-measuring equipment.

6.2.2 Sleep and Annoyance Study Combination

Since a future study is anticipated in which a portable response device will be used to assess annoyance in locations near MTRs and MOAs, it would be advantageous to evaluate sleep disturbance at the same time. The sleep component of the study would require that the portable response device be used to collect awakening responses during normal sleeping hours. The portable device would automatically store the noise level at the time of awakening. Other information that would be stored by the portable assessment device would include:

1. Answers to a brief questionnaire on subjective state prior to retiring and upon arising in the morning.

2. Indications of fatigue and mood during the day.

3. Assessment of the previous night's sleep quality, including estimates of number of awakenings and time to fall asleep.

4. Information on sleep stage from EEG inputs if available at the time.

5. Subject movement information using an accelerometer attached to the bed.

6. Data on behavioral awakening at the time of noise intrusions.

6.2.3 Sleep Study with Computer at Bedside

This study would be basically the same as the one to be conducted in conjunction with the annoyance study except that the portable response device would be replaced by a personal computer (PC). If the computer were to be located beside the bed it would not be available for obtaining information during the day. However, such an arrangement should be adequate for recording behavioral awakening and for collecting information prior to and following the night's sleep. Additional noise-measuring equipment would be required unless appropriate software were available or could be developed for use with the PC.

GLOSSARY OF TERMS

A-weighted Sound Level: A-weighted sound level is a modification of the sound pressure level which deemphasizes the low frequency portion of sounds in order to approximate the human ear's response to the sound.

Arousal: Arousal is an EEG pattern that exhibits some or all of the characteristics shown by an awake EEG.

Artificial Noise: Laboratory-generated noise produced by noise generator and filters.

Behavioral Awakening: Awakening from sleep that requires a specific motor action such as a verbal response or button pushing.

Bivariate Regression: The analysis of two variables where the goal is to predict one variable from another.

Correlation Coefficient: An indication of the strength of the linear relationship between 2 variables. The Pearson Product Moment coefficient (r) is a common metric used throughout this report.

Deep Sleep: Usually stage 4 sleep is considered deep sleep.

Delta Stage: Delta Sleep consists of an EEG pattern that indicates stage 3 or stage 4 sleep.

Dummy Coded Variables: Recategorization of a discrete (categorical) variable into a group of dichotomous ones (i.e., Field vs. Nonfield, etc.).

EEG (Electroencephalogram): A device used to graphically record brain wave patterns.

Effective Duration: Duration of a sound whose level is constant and energy is equal to that of the sound being evaluated.

Effective Perceived Noise Level (EPNL): EPNL is the perceived noise level of a single event that has been modified for the additional annoyance caused by duration and tones.

Equivalent Noise Level (L_{eq}): The A-weighted sound level averaged over a specific period of time.

Field Study: A study performed out of the laboratory that uses naturally occurring (i.e., not introduced by the experimenter) sounds or noise.

Habituation: To accustom or make familiar by frequent exposure. Usually habituation indicates a weaker response upon subsequent occurrences, however, the effect may be temporary.

Heteroscedasticity: The condition where the variability in scores for one variable is not (roughly) the same at all of the values for another variable.

Hierarchical Multiple Regression: An analysis where the independent variables are entered into the regression equation based on a prespecified order determined by the researcher.

Laboratory Study: A study that introduces sounds (usually recorded) in an environment (such as a sound chamber) designed to control extraneous variables.

Light Sleep: Light sleep is usually referred to as the nondelta or stage 1 sleep.

Mahalanobis Distance: A statistical method used to determine if certain data exert extreme (nonrepresentative) influence over the rest of the data in the analysis. These data points are commonly referred to as outliers.

MOA: Military Operating Area.

MTR: Military Training Route.

Multicollinearity: A statistical term used to describe the condition where 2 variables are so highly correlated that the matrix inversion necessary for analysis becomes unstable.

Multivariate Normality: The assumption that the joint distribution for a set of variables is normal.

No Sleep Disruption: The absence of at least 1 sleep stage shift to a lighter stage of sleep. No sleep disruption can, however, include such things as body movements and increases in muscular tension.

Noise and Number Index (NNI): Most commonly used in Great Britain, the Noise and Number index is based upon the average maximum perceived noise level for aircraft flyovers during a specific period.

Quasi-Lab Study: A study which was performed in the field (usually in the respondent's home) but which introduced experimenter controlled noise sources. These studies were combined with the laboratory studies for the purpose of the present analysis.

Rectangular Time Pattern: The time history of an event which increases immediately to some constant noise level, remains at that level for some time, and then returns to the original level. The noise produced by starting and stopping a jet engine represents a rectangular time pattern.

Regression Coefficient (Bivariate): The regression coefficient (B) is the weight applied to a particular "X" value (in this case a noise metric) that minimizes the sum of the squared deviations between the predicted and obtained values which facilitates optimal prediction of "Y" (in this case sleep disturbance).

REM (Rapid Eye Movement): A sleep stage that is associated with the eyes rapidly darting back and forth under the eyelids. This REM is the stage where dreaming is thought to occur.

R^2 : R squared is a measure of the predictive ability that a particular regression equation exhibits. It is the proportion of variance in "Y" (sleep disturbance) associated with "X" (noise). A larger value (up to 1.0) indicates more variability accounted for.

Sleep Latency: The amount of time it takes for one to get to sleep.

Sleep Disturbance: Any type of undesirable noise or intrusion that causes an awakening, sleep state change, or diminishes sleep quality in any way.

Sleep Quality: Usually referred to as how rested one feels upon awakening.

Sound Exposure Level (SEL): The energy-averaged A-weighted sound level over a specified period of time or event with a reference duration of 1 second. A sound with twice the duration of some other sound will be 3 dB higher than the other sound if both sounds have the same AL_{max}.

10dB Down Points: Levels which are 10 dB lower than the maximum and which occur closest in time (before and after) to the maximum noise level. Usually associated with triangular time patterns.

Triangular Time Pattern: The time history of an event which increases at a constant number of decibels per second, reaches some maximum level, and decreases at the same rate of decibels per second. The event exhibits a triangular shape on a graphic level recorder. A flyover noise usually produces a triangular time pattern.

Zero-Reaction: See No Sleep Disruption.

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APPENDIX A

TABLE A-1.

SUMMARY OF NOISE AND SLEEP DISTURBANCE INFORMATION USED IN THE STATISTICAL ANALYSES.

The following sets of paired tables are the summary of noise and sleep disturbance information used in the statistical analyses.

Study	Noise Type	SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/Night
nonymous. (Research Group n the Effect of Noise). (1971).	Jet Aircraft	71.30	65.00	43.00	52.00	10.3	54 in random order
		81.30	75.00	55.00	64.00	10.3	
		91.30	85.00	68.00	78.00	10.3	
ollins, W.E., Iampietro, P.F., (1973).	Simulated Sonic Boom	63.00	68.00	2.00	46.50	0.28	8
loronjeff, R., Bennet, R., and effeteller, S. (1979).	Transformer Line	65.00	60.50	9.30	ϕ	6.60	8
		76.00	70.50	17.50	ϕ	8.30	
		57.20	50.50	15.00	ϕ	3.30	
		87.20	80.50	34.00	ϕ	1.00	
		47.00	40.50	0.05	ϕ	10.50	
		35.00	30.50	6.00	ϕ	6.60	
		73.00	50.50	37.50	ϕ	177.80	
		93.00	70.50	40.00	ϕ	177.80	
		53.00	30.50	19.00	ϕ	177.80	
		83.00	60.50	32.50	ϕ	177.80	
		65.00	40.50	9.50	ϕ	281.80	
	Transmission	47.00	41.00	15.50	ϕ	9.30	
		75.00	71:00	30.50	ϕ	5.90	
		66.00	61.00	30.00	ϕ	7.40	
		55.00	51.00	21.50	ϕ	5.90	
		56.00	31.00	21.50	ϕ	316.20	
		75.00	51.00	38.00	ϕ	251.20	
		67.00	41.00	39.30	ϕ	398.10	
		83.00	61.00	46.50	ϕ	158.50	
		93.00	71.00	45.80	ϕ	158.50	

In Seconds							
In Lukas (1977)	Minimum	35.00	30.00	0	1.00	0.0066	1.40
Estimated	Maximum	109.60	105.00	93.10	82.10	562.30	57.00

Laboratory studies took place in a controlled environment, Quasi-lab studies introduced new noises into the home, and Field studies simply measured the effects of noises already present in the home.

Data not available

mber/Sex	Age Range	Response Measure	Lukas ⚙	Type of Study ♦	Background dB	Noise Nights	Comments
Males	20's	EEG, Physiological and Psychological measures.	Y	Laboratory	N/R		Anonymous, 1971 (Japanese Research Group on the Effect of Noise). Original report was not available, therefore, the data for this study were taken directly from Lukas (1977). The 10 dB downpoint duration was 10.3 seconds. Assuming a triangular shaped time pattern, the sound exposure level was calculated using the folowing formula: SEL = AL + 10log(duration) - 3.7
Males	21-72	EEG, mood assessment, performance measurement.	N	Laboratory	N/R	12	Collins, W., Iampietro, P.F., 1973. Simulated Sonic Boom: SEL = AL - 5
Males, Females	20-59	Behavioral awakening, EEG, sleep quality.	N	Quasi-lab	30 dB(A)	3 weeks	AL and percent awakened were averages of graphical results in the two referenced publications. Plotting errors in the SIL results from Figure 5 of the 1982 article necessitated approximations using the following relation: SEL=AL+6.3 for the short duration sounds and SEL=AL+10 LOG D for the long duration sounds. D depends on the level as follows: AL / D 30 dB / 338 seconds 40 / 436 50 / 242 60 / 194 70 / 168 If the estimation using the above formula was within 3 dB of the value

	7	25	1
618	72	42.00	30.00

Study	Noise Type	SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
loronjeff - (cont)	Air Conditioner	88.70	82.00	50.80	ϕ	0.10	
		59.00	52.00	9.30	ϕ	11.70	
		66.00	62.00	16.00	ϕ	5.90	
		38.00	32.00	2.50	ϕ	9.30	
		47.00	42.00	8.30	ϕ	7.40	
		78.70	72.00	21.30	ϕ	1.50	
		77.00	52.00	30.50	ϕ	316.20	
		84.00	62.00	50.50	ϕ	158.50	
		69.00	42.00	16.50	ϕ	501.20	
		94.30	72.00	37.80	ϕ	501.20	
		59.00	32.00	13.00	ϕ	501.20	
	Traffic	87.20	80.50	18.80	ϕ	2.10	
		67.00	60.50	11.00	ϕ	10.50	
		45.00	40.50	6.50	ϕ	6.60	
		58.00	50.50	9.30	ϕ	13.20	
		78.00	70.50	25.50	ϕ	13.20	
		92.80	70.50	40.00	ϕ	35.50	
		85.00	60.50	41.50	ϕ	281.80	
		74.00	50.50	39.30	ϕ	223.90	
		68.00	40.50	17.80	ϕ	562.30	
		56.00	30.50	17.00	ϕ	354.80	
hnson, L.C., et al.,(1973).	Artificial Ping	78.30	80.00	2.60	ϕ	0.0066	Every 22 seconds for 24 hours/day
		83.30	85.00	2.70	ϕ		
		88.30	90.00	3.30	ϕ		
amer, M., Roth, R., Trindar, J., hen, A. (1971).	White Noise	59.60	47.00	10.80	ϕ	The noise was increased by 1dB/6 sec. until the subject woke up.	8 (average)
		73.60	61.00	31.40	ϕ		
		99.90	87.30	63.70	ϕ		
		109.60	97.00	93.10	ϕ		

		SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
	Minimum	35.00	30.00	0	1.00	0.0066	1.40
	Maximum	109.60	105.00	93.10	82.10	562.30	57.00

In Seconds

In Lukas (1977)

:stimated

Laboratory studies took place in a :rolled environment, Quasi-lab lies introduced new noises into the :, and Field studies simply measured effects of noises already present in home.

ata not available

Number/Sex	Age Range	Response Measure	Lukas *	Type of Study ♦	Background dB	Noise Nights	Comments
							read from the graph, the graph value was used. Otherwise the estimated value was used.
:0 Males	17-32	Body movements, (EEG), median hours of nocturnal sleep, latency, awakenings.	N	Laboratory/ Quasi-lab	N/R	30	Johnson, L.C., et al., 1973. SEL = AL - 1.7
Males	25-70	EEG, psychological performance.	Y	Laboratory	42	7	Kramer (1970) reports the respondents individual data in Table "X" on page 56. The portion of the table reporting absolute SPL (in dB) "To Awaken" using continuous sound is presented in six levels (87, 87, 47, 88, 97, 61). Since three of the individual values reported by Kramer were within 1dB of each other (88, 87, 88), these were combined into a single point at 87.5. The awakening data was estimated by accumulating the proportion of the subject's responses with the assumption that the "Awakening Threshold"
	7				25	1	
618	72				42.00	30.00	

Study	Noise Type	SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
ramer - (cont)							
udlow, J.E., Morgan, J.E., (1972).	Sonic Boom	66.00	69.00	20.85	ϕ	approx .5	8-12
		76.00	79.00	29.83	ϕ		
		81.00	84.50	39.28	ϕ		
		68.00	71.20	15.80	ϕ		
		71.00	74.20	14.60	ϕ		
		74.00	77.60	12.30	ϕ		
ukas, J.S., Dobbs, M.E., and ryter, K.D. (1971).	Jet Flyover	65.30	63.00	6.00	20.50	4.00	16
		71.30	69.00	21.00	42.00	4.00	
		77.30	75.00	34.00	61.00	4.00	
		83.30	81.00	49.00	74.00	4.00	
	Simulated Sonic Boom	63.00	68.00	14.00	20.00	0.26	
		68.50	73.00	19.00	33.50	0.26	
		74.00	79.00	24.00	48.00	0.26	
		79.00	84.00	35.00	64.00	0.29	
ukas, J.S., and Dobbs, M.E. 1972).	Jet Flyover	70.30	68.00	30.00	49.10	0.40	10
		82.30	80.00	54.30	77.60	0.40	
		88.30	86.00	68.70	82.10	0.40	
	Simulated Sonic Boom	62.80	68.00	8.40	29.20	0.30	
		73.80	79.00	21.60	50.80	0.30	
		78.80	84.00	44.60	66.90	0.30	
ukas, J.S., Peeler, D.J., nd Dobbs, M.E. (1973).	DC8 Landing Treated Nacelles	66.90	60.40	20.90	29.20	10.50	9
		84.20	78.40	38.20	56.00	9.00	
	DC8 Landing Untreated Nacelles	66.20	61.10	26.10	34.80	7.50	
		84.00	78.90	65.40	70.90	7.50	
	Pink noise Burst	65.30	59.90	25.00	25.70	3.50	
		83.40	78.00	74.30	75.00	3.30	
ukas, J., Peeler, D., and avis, J. (1975).	Blown Flap STOL Sideline	75.20	64.80	19.80	32.10	25.50	21
		85.20	76.80	35.30	56.30	25.50	
		91.20	82.80	47.90	76.90	25.50	
	Minimum	35.00	30.00	0	1.00	0.0066	1.40
	Maximum	109.60	105.00	93.10	82.10	562.30	57.00

In Seconds

In Lukas (1977)

Estimated

Laboratory studies took place in a ontrolled environment, Quasi-lab udies introduced new noises into the me, and Field studies simply measured e effects of noises already present in e home.

Data not available

ber/Sex	Age Range	Response Measure	Lukas *	Type of Study ♦	Background dB	Noise Nights	Comments
							denotes the noise level needed to awaken a particular respondent at least half the time.
ales	17-30	Behavioral awakening, sleep quality	Y	Laboratory	37 dB(A)	4	Ludlow, J.E., Morgan, J.E., 1972. Proportion of awakenings were obtained by averaging the early and late presentation times for each respondent at a specific noise level. Duration was estimated to be .5 seconds. SEL = AL - 3.0
Males 'emales	7-71	EEG, subjective quality, behavioral awakening.	Y	Laboratory	32	20	Lukas, J.S., Dobbs, M.E., Kryter, K.D., 1971. Jet Flyover: SEL = AL + 2.3 Simulated Sonic Boom: SEL = AL - 5.85 (for .26 second duration data) SEL = AL - 5.38 (for .29 second duration data)
Males	29-49	Behavioral awakening, EEG, subjective quality.	Y	Laboratory		10	Lukas, J.S., Dobbs, M.E. 1972. Jet Flyover: SEL = AL + 2.3 Sonic Boom: SEL = AL - 5.2
1ales	46-58	EEG, behavioral awakening.	Y	Laboratory	32 dB(A)	9	Lukas, J.S., Peeler, D.J., Dobbs, M.E. 1973. DC8 Treated and Untreated Nacelles: SEL = AL + (10log(dur) - 3.7) Pink Noise Burst: SEL = AL + 10log(dur)
1ales	36-56	EEG, behavioral awakening.	Y	Laboratory	32 dB(A)	8	Lukas, J.S., Peeler, D.J., Davis, J.E. 1975. There appears to be some discrepancy on the duration periods
	7				25	1	
618	72				42.00	30.00	

Study	Noise Type	SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
Lukas - (cont)	Blown Flap STOL Take Off	69.00	63.00	25.40	40.40	9.30	
		81.00	75.00	41.90	61.60	9.30	
		87.00	81.00	50.00	62.50	9.30	
	Turbo Fan STOL Sideline	68.00	57.80	17.50	30.30	24.40	
		80.00	69.80	30.00	49.00	24.40	
		86.00	75.80	37.70	65.90	24.40	
	Pink Noise Burst	62.30	59.10	17.40	28.30	2.10	
		74.30	71.10	44.20	51.30	2.10	
		80.30	77.10	52.10	67.50	2.10	
Muzet, A., Scheiber, J.P, Oliver-Martin, N. (1973).	Aircraft	85.85	77.00	4.80	28.80	18.00	N/R
		85.05	80.00	8.80	57.60	7.50	
		92.61	82.00	16.00	67.10	27.00	
		99.29	96.00	27.00	74.80	5.00	
Ohrstrom, E. (1983).	Traffic	59.30	56.00	10.00	ϕ	N/R	N/R
		63.30	60.00	30.00	ϕ		
		66.30	60.00	13.00	ϕ		
		73.30	70.00	53.00	ϕ		
		83.30	80.00	38.00	ϕ		
Ohrstrom, E., Rylander, R., and Bjorkman, M. (1988).	Traffic	64.65	60.00	3.20	ϕ	7 ♦	57
Osada, Y., et al., (1975).	Rail	45.30	40.00	0.00	11.50	8.00	18
		55.30	50.00	0.00	39.50		
		65.30	60.00	0.00	38.50		
		75.30	70.00	0.00	38.00		
		85.30	80.00	2.00	58.50		

	SEL	dB(A)	Awake %	Disruption %	Duration	Stimuli/ Night
Minimum	35.00	30.00	0	1.00	0.0066	1.40
Maximum	109.60	105.00	93.10	82.10	562.30	57.00

* In Seconds

In Lukas (1977)

Estimated

Laboratory studies took place in a controlled environment, Quasi-lab studies introduced new noises into the home, and Field studies simply measured the effects of noises already present in the home.

Data not available

Number/Sex	Age Range	Response Measure	Lukas *	Type of Study ♦	Background dB	Noise Nights	Comments
							reported in Lukas (1975) and Lukas (1977). The durations from the latter paper are assumed to be correct and are used for the present analysis.
9 Males 9 Females	19-24	EEG, subjective sleep quality, latency.	Y	Laboratory	38 dB(A)	1	Muzet, A., Scheiber, J.P, Oliver-Martin, N., 1973. Muzet (1973) reported durations of 30 and 90 seconds as the total duration for the jet noise sources, however the durations appropriate for the 10 dB down points were recalculated upon examination of the time patterns (kindly provided by Dr. Muzet). SEL = AL + (10log(dur) - 3.7)
12	18-35	Sleep quality and mood, body movement, subjective awakenings	N	Laboratory	N/R	4	Ohrstrom, E., 1983. Intermittent noise data was used from experiment 1 and 2. SEL = AL + 3.3
106	N/R	Sleep quality, mood, performance.	N	Field	N/R		Ohrstrom, et al. 1988. 60 AL was interpreted as the applicable noise level since it was the highest level at which awakenings took place. The duration was estimated to be 7 seconds. SEL = AL + 4.7
5 Males	College Students	EEG, EKG, Biochemical	Y	Laboratory	30 dB(A)	5	Osada, Y., et al., 1975. SEL = AL = 5.3
	7				25	1	
618	72				42.00	30.00	

Study	Noise Type	SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
Pearsons, K., Bennett, R., and Fidell, S. (1973).	Aircraft	65.30	65.00	0.00	ϕ	4.00	1.4
		75.30	75.00	6.00	ϕ	4.00	
		85.30	85.00	0.00	ϕ	4.00	
		95.30	95.00	12.00	ϕ	4.00	
		105.30	105.00	6.00	ϕ	4.00	
Rylander, R., Sorensen, S., and Berglund, K. (1972).	Traffic	74.30	71.00	0.00	ϕ	5.00	N/R
Stevenson, D.C. and McKellar, N.R. (1989).	Traffic	51.30	46.50	ϕ	18.00	7.00	N/R
		56.30	51.50	ϕ	15.00		
		61.30	56.50	ϕ	33		
		66.30	61.50	ϕ	45		
		71.30	66.50	ϕ	29		
Thiessen, G. (1978).	Truck	37.50	35.00	0.00	12.00	4.20	7
		42.50	40.00	7.00	23.00	4.20	
		47.50	45.00	13.00	27.00	4.20	
		52.50	50.00	19.00	39.00	4.20	
		57.50	55.00	20.00	42.00	4.20	
		62.50	60.00	28.00	56.00	4.20	
		67.50	65.00	34.00	62.00	4.20	
		72.50	70.00	43.00	73.00	4.20	
		77.50	75.00	50.00	80.00	4.20	
Vallet, Michel, Gagneux, J.M., and Simmonnet, F. (1980).	Aircraft	46.30	40.00	1.00	27.00	10.00	5 to 35
		56.30	50.00	2.00	32.00	10.00	
		66.30	60.00	3.00	36.00	10.00	
		76.30	70.00	4.00	40.00	10.00	
		86.30	80.00	5.00	43.50	10.00	
		96.30	90.00	6.50	47.50	10.00	
Vernet, M. (1979).	Rail	ϕ	36.00	0.00	ϕ	15 ♦	N/R
		ϕ	44.00	0.00	ϕ		
		ϕ	48.00	0.00	ϕ		
		ϕ	52.00	1.50	ϕ		
		ϕ	56.00	1.50	ϕ		
		ϕ	60.00	2.50	ϕ		
		ϕ	65.00	1.50	ϕ		
		ϕ	69.00	4.50	ϕ		

* In Seconds

■ In Lukas (1977)

♦ Estimated

♠ Laboratory studies took place in a controlled environment, Quasi-lab studies introduced new noises into the home, and Field studies simply measured the effects of noises already present in the home.

ϕ Data not available

	SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
Minimum	35.00	30.00	0	1.00	0.0066	1.40
Maximum	109.60	105.00	93.10	82.10	562.30	57.00

Number/Sex	Age Range	Response Measure	Lukas ☼	Type of Study ♦	Background dB	Noise Nights	Comments
5 couples	24-55	Behavioral awakening.	N	Field	N/R	5	Pearson, K., 1973. Present analysis based on "before aircraft cessation" data. Duration was estimated to be 4 seconds. SEL = AL + 2.3.
251	18-20			Field	N/R	7	Rylander, R., et al., 1972. Outdoor dB(A) levels were converted to indoor by subtracting 15 dB. Duration was estimated to be 5 seconds. SEL = AL + 3.3
6	19-24	EEG, sleep stage changes.	N	Quasi-lab	25 dB(A)	N/R	Stevensen, D.C., and McKellar, N.R. 1989. SEL = AL + 4.8
26 Males 9 Females	16-75	Behavioral awakening, sleep stage change, sleep disruption.	N	Laboratory	32-35 dB(A)	24	Thiessen, G., 1978. Duration was calculated using Figure 2 (page 217) of Thiessen (1978). SEL = AL + 2.5
10 Males	20-55	EEG, awakening, stage change.	N	Field	N/R	4	Vallet, M., Gagneux, J.M. and Simmonet, F., 1980. Data was obtained via direct correspondence with Vallet. Jet Flyover Noise: SEL = AL + 6.3
10 Males 10 Females	23-60	Sleep disruption, sleep disturbance, awakening, sleep state change.	N	Field	30 dB(A)	1	Vernet, M., 1979. Train Noise: Duration was estimated to be 15 seconds. SEL = AL + 11.8 Traffic Noise: Duration was estimated to be 5 seconds. SEL = AL + 3.3

	7				25	1	
618	72				42.00	30.00	

Study	Noise Type	SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
/ernet - (cont)	Rail	ϕ	37.00	ϕ	1.00		
		ϕ	40.00	ϕ	1.00		
		ϕ	44.00	ϕ	12.00		
		ϕ	48.00	ϕ	12.50		
		ϕ	52.00	ϕ	19.00		
		ϕ	56.00	ϕ	18.00		
		ϕ	60.00	ϕ	19.50		
		ϕ	64.00	ϕ	24.00		
		ϕ	68.00	ϕ	27.50		
	Road	ϕ	37.00	ϕ	2.50	5 ♦	N/R
		ϕ	40.00	ϕ	2.50		
		ϕ	44.00	ϕ	16.00		
		ϕ	48.00	ϕ	17.00		
		ϕ	51.00	ϕ	13.00		
		ϕ	56.00	ϕ	22.00		
		ϕ	60.00	ϕ	23.00		
		ϕ	64.00	ϕ	18.00		
		ϕ	68.00	ϕ	24.00		
Zimmerman, William, B. (1970).	800 Hz Tone	59.20	59.20	25.00	ϕ	1.00	3 to 4
		73.60	73.60	75.00	ϕ	1.00	

		SEL	dB(A)	Awake %	Disruption %	Duration *	Stimuli/ Night
	Minimum	35.00	30.00	0	1.00	0.0066	1.40
	Maximum	109.60	105.00	93.10	82.10	562.30	57.00

* In Seconds

• In Lukas (1977)

› Estimated

♦ Laboratory studies took place in a :ontrolled environment, Quasi-lab ;tudies introduced new noises into the home, and Field studies simply measured :he effects of noises already present in :he home.

ϕ Data not available

Number/Sex	Age Range	Response Measure	Lukas ¤	Type of Study ♦	Background dB	Noise Nights	Comments
2 groups of 16	mean = 21	Auditory/Verbal Awakening Threshold.	Y	Laboratory	N/R	1	Zimmerman, W. B., 1970. Zimmerman (1970) used two groups which he labeled "Light Sleep" and "Deep Sleep". The present analysis calculated the mean "Auditory Awakening Threshold" for both groups as the minimum noise level required to awake half the respondents in that group. Zimmerman (1970) ran the test by presenting a tone for 1 second and increasing the intensity of that tone every 8 seconds by 5 dB until the respondent awakened.
	7				25	1	
618	72				42.00	30.00	

APPENDIX B

HIERARCHICAL REGRESSION

Appendix B
Hierarchical Regression

The following material is adapted from Tabachnick and Fidell (1989), Chapter 5, *Multiple Regression*.

B.1 Overview

Multiple regression analysis is a set of statistical techniques that allows one to assess the relationship between a single dependent variable (DV or criterion) and several independent variables (IVs or predictors). Regression analyses can be applied to a data set in which the predictors are correlated with one another and with the criterion to varying degrees.

Multiple regression is an extension of bivariate regression in which several IVs instead of just one are combined to predict a value on the DV for each case. The result of regression is an equation that represents the best prediction of a DV from several continuous or dichotomous IVs. The regression equation takes the following form:

$$Y' = A + B_1X_1 + B_2X_2 + \dots + B_kX_k \qquad \text{(Eq. B-1)}$$

where Y' is the predicted value on the DV, A is the Y intercept (the value of Y when all the X values are zero), the X's represent the various IVs (of which there are k), and the B's are the coefficients assigned to each of the IVs during regression. Although the intercept and the coefficients are the same for a whole sample, a different Y' value is predicted for each subject as a result of inserting the subject's own X values into the equation.

The goal of regression is to arrive at the set of B values, called regression coefficients (or β values, called standardized regression coefficients) for the IVs that bring the Y values predicted from the equation as close as possible to the *Y* values obtained by measurement. The regression coefficients that are computed accomplish 2 intuitively appealing and highly desirable goals: they minimize (the sum of the squared) deviations between predicted and obtained *Y* values and they optimize the correlation between the predicted and obtained *Y* values for the data set. In fact, one of the important statistics derived from a regression analysis is the multiple correlation coefficient R^2, the Pearson product moment correlation coefficient between the obtained and predicted *Y* values.

Hierarchical regression is a form of multiple regression in which independent variables enter the regression equation in an order specified by the researcher. Each IV is assessed in terms of what it adds to the equation at its own point of entry. Consider the example in Fig. B-1. Assume that the researcher assigns IV_1 first entry, IV_2 second entry, and IV_3 third entry. In assessing importance of variables in terms of their contribution to prediction, IV_1 "gets credit" for areas *a* and *b*, IV_2 for areas *c* and *d*, and IV_3 for area *e*. Each IV is assigned the variability, unique and overlapping, left to it at its own point of entry. Notice that the apparent importance of IV_2 increases dramatically if it is assigned first entry and, therefore, "gets credit" for *b*, *c*, and *d*. These areas are reflected in squared semipartial correlations (sr_i^2) which, in hierarchical regression, sum to R^2. Thus, the squared multiple correlation is partitioned into squared semipartial correlations in accordance with the contribution of predictor variables.

The researcher normally assigns order of entry of variables according to logical or theoretical considerations. For example, IVs that are presumed (or manipulated) to be causally prior can be given higher priority of entry. As an example, demographic variables (e.g., age and sex) can be considered prior to noise level in assessing sleep disturbances. Hierarchical regression can also be used to hold the effects of several IVs statistically "constant" while examining the relationship between an especially interesting IV and the DV.

VENN DIAGRAM ILLUSTRATIONS

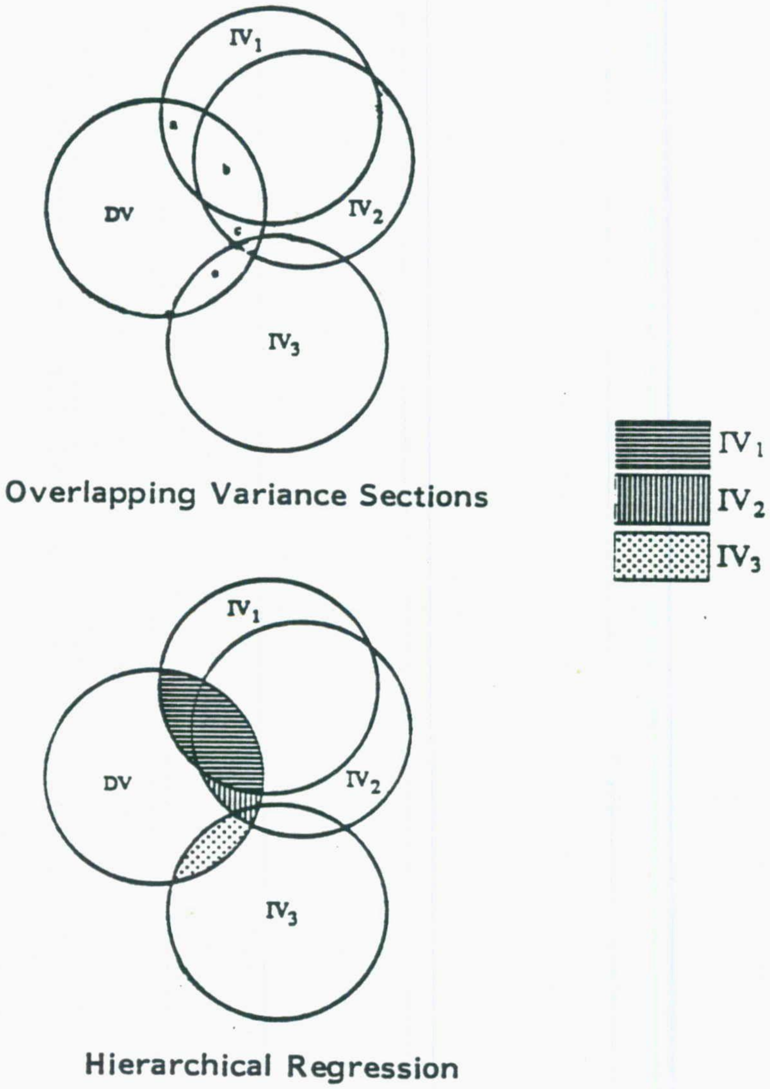

Figure B-1. Venn diagrams illustrating overlapping variance sections in multiple regression and allocation of overlapping variance in hierarchical regression.

The IVs can be entered one at a time or in blocks. The analysis proceeds in steps, with information about IVs both in and out of the equation computed at each step and summary statistics computed at the end of the final step. Squared semipartial correlations can be calculated for blocks of IVs as well as individual IVs, to assess the contribution of blocks of similar variables to prediction of the DV.

B.2 Assumptions and Limitations

The following sections list several issues to be considered in using multiple regression as a data analysis technique.

B.2.1 Ratio of Cases to IVs

The cases-to-IVs ratio has to be substantial or the solution will be perfect--and meaningless. With more IVs than cases, one can find a regression solution that completely predicts the DV for each case, but only as an artifact of the cases-to-IV ratio. If either standard multiple or hierarchical regression is used, one would like to have 20 times more cases than IVs. That is, if you plan to include 5 IVs, it would be optimal to measure 100 cases. In fact, because of the width of the errors of estimating correlation with small samples, power may be unacceptably low no matter what the cases-to-IVs ratio with less than 100 cases. However, a bare minimum requirement is to have at least 5 times more cases than IVs--at least 25 cases if 5 IVs are used.

A higher cases-to-IV ratio is needed when the DV is skewed, effect size is anticipated to be small, or substantial measurement error is expected from unreliable variables. If the DV is not normally distributed and transformations are not undertaken, more cases are required. The size of anticipated effect is also relevant because more cases are needed to demonstrate a small effect than a large one. Finally, if substantial measurement error is expected from somewhat unreliable variables, more cases are needed.

It is also possible to have too many cases, however. As the number of cases becomes quite large, almost any multiple correlation will depart significantly from zero, even one that predicts negligible variance in the DV. For both statistical and practical reasons, then, one wants to measure the smallest number of cases that has a decent chance of revealing a significant relationship if, indeed, one is there.

B.2.2 Outliers

Outliers are cases with such extreme values on 1 variable or a combination of variables that they unduly influence statistics. An outlier has more impact on a mean or regression coefficient, for example, than do any of the other cases.

Univariate outliers are cases with an extreme value on 1 variable; multivariate outliers are cases with an unusual combination of 2 or more scores. For example, a 15-year-old is perfectly within bounds regarding age, and someone who earns $45,000 a year is in bounds regarding income; but a 15-year-old who earns $45,000 a year is very unusual and is likely to show up as a multivariate outlier.

Univariate outliers are cases that have scores several standard deviations away from the mean of a particular variable. That is, they have very large standardized scores on 1 or more variables. Cases with standard scores in excess of ±3.00 are potential univariate outliers--larger cutoff values are used with larger samples.

The statistical procedure for detection of multivariate outliers (cases with an unusual pattern of scores) is computation of Mahalanobis distance for each case. Mahalanobis distance is the distance of a case from the centroid of cases where the centroid is the point created by the means of all the variables. Mahalanobis distance is also a discriminant function analysis where an equation is computed that best separates 1 case from the rest of the cases. If a case has an unusual combination of scores, then those scores are weighted heavily in the equation (the discriminant function) and the Mahalanobis distance of the case from the rest of the cases is statistically significant. A cutoff level of $p < .001$ is typically used for Mahalanobis distance.

Extreme cases have too much impact on the multiple (including hierarchical) regression solution and should be deleted or rescored to reduce their influence. In multiple regression, cases are evaluated for univariate extremeness with respect to the DV and each IV. Multivariate extremeness is evaluated with respect to the set of IVs considered jointly.

B.2.3 Multicollinearity and Singularity

Calculation of regression coefficients requires inversion of the matrix of correlations among the IVs, an inversion that is impossible if IVs are singular and unstable if they are multicollinear--that is, if they are very highly intercorrelated. Singularity and multicollinearity can be identified through perfect or very high squared multiple correlations (SMC) among IVs, where each IV in turn serves as DV in a multiple regression while the others are IVs, or very low tolerances (1 - SMC). In regression, these conditions are also signaled by a very large (relative to the scale of the variable) standard error for a regression coefficient.

B.2.4 Normality, Linearity, and Homoscedasticity of Residuals

Examination of residuals scatterplots provides a test of assumptions of normality, linearity, and homoscedasticity between predicted DV scores and errors of prediction. Assumptions of analysis are that the residuals (differences between obtained and predicted DV scores) are normally distributed about the predicted DV scores, that residuals have a straight line relationship with predicted DV scores, and that the variance of the residuals about predicted DV scores is the same for all predicted scores.

The assumption of normality is that errors of prediction are normally distributed around each and every predicted DV score. The residuals scatterplot should reveal a pileup of residuals in the center of the plot at each value of predicted score and a normal distribution of residuals trailing off symmetrically from the center.

Linearity of relationship between predicted DV scores and errors of prediction is also assumed. If nonlinearity is present, the overall shape of the scatterplot will be curved instead of rectangular. Failure of linearity of residuals in regression does not invalidate an analysis so much as weaken it. A curvilinear relationship between the DV and an IV is a perfectly good relationship that is not completely captured by a linear correlation coefficient. The power of the analysis is reduced to the extent that the analysis does not have available the full extent of the relationships among the IVs and the DV.

The assumption of homoscedasticity is the assumption that the standard deviations of errors of prediction are approximately equal for all predicted DV scores. Heteroscedasticity also does not invalidate the analysis so much as weaken it. Homoscedasticity means that the band enclosing the residuals is approximately equal in width at all values of the predicted DV. Typical heteroscedasticity is a case in which the band becomes wider at larger predicted values.