RESEARCH PERSPECTIVE:

TIME-OF-DAY EFFECTS ON NOISE ANNOYANCE

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As you may have noticed, the whole conference is divided between research and applications. The first obvious indication of this comes from comparing my presentation with Bill Galloway's. I have been asked to give a research perspective.

By way of introduction I should say that over the past year at NASA I've been looking at existing surveys of people's response to environmental noise. I've identified about 150 of these social surveys. About half of these concern aircraft. I will be drawing in one way or another on about 20 of these surveys in what I say. I should make it clear that I will not be providing a summary of these surveys' findings, but rather I will try to provide a perspective of the overall research approach to time-of-day studies.

Here is an overview of what I am going to say. (See fig. 1.) First, we want to take a look at the existing time-of-day research effort. Then we will examine some of the complications that these research findings have raised for the research approaches that have been used. Next, I will offer a conceptual framework for further time-of-day research. Finally, I will suggest some of the implications for the research methods that should be used.

When I looked at the time-of-day research that had been done, it seemed to divide into two general areas. (See fig. 2.) There is, of course, the time-of-day weighting issue, which Bill Galloway talked about. In the other area, which we might call the nighttime response model issue, a large amount of research is concerned with how people respond at night and how sleep disturbance and overall annoyance at night are related to noise level. A large number of issues could be brought up here, but let's just take the simple graphic one in this figure (fig. 2). We might think that during the daytime there is a roughly linear increase in annoyance with increasing noise level. At night though, the graph suggests that there might be a different type of response model with some kind of threshold phenomena.

In the area of research that has to do with the time-of-day weighting, one simple weighting model is presented in figure 2 where the overall response is a function of the level during the day and the level during the night. We aren't making any assumption about whether it's decibels or energy which is being added. The critical point here is that the whole focus of the research

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is to find the value of the weight which determines the relative effects of daytime and nighttime noise levels.

There has been a large amount of useful time-of-day research. I don't have time to go through it here, but I would like to take one piece of research that brings some particular issues into sharp focus. (See fig. 3.) This study was carried out at Los Angeles International Airport by Fidell and Jones. It's good that Sandy Fidell is here. He can keep me honest in case I bring up anything that is incorrect. Up to April 29, 1973, there had been about 50 flights a night over this area. From April 18 to 28 there were 328 interviews carried out. About 20 percent of the people interviewed in the high-noise-level area reported some sort of sleep interference in the past week. From April 29 on there was an almost complete elimination of flights from 2300 to 0600. A month later, an additional 228 interviews were conducted. In the same area sleep interference was now reported by about 22 percent. The change in sleep interference is insignificant. The most important finding is that in spite of a definite reduction in number of flights there was no change in annoyance. This finding raises four questions. (See fig. 3.)

The first question is whether people are insensitive to any change in operations. Fortunately there has been a recent study around the Burbank airport where a change in operations for several months meant a change in noise levels for many people. Interviews before and after the change show that people do report less annoyance after the reduction in noise level. The answer here then is "No". People are sensitive to some changes, at least when there are changes in daytime noise levels.

The second question is whether nighttime reactions are integrated over very long periods. In this study only about a month had elapsed since the change. People may still have been reacting to something that happened last summer when they were kept awake for one night. I think that a long period of integration is a possibility. We will come back to the problem later but I should say that since the particular question at LAX was about sleep disturbance in the past week, the period of integration can probably not explain this finding.

The third question is whether, even after the change, people were exposed to aircraft noise during a proportion of the hours when they were trying to sleep. There is a change here during a very substantial period of 7 hours. However, most people sleep 8 hours instead of 7. Some don't even try to sleep until after 2300. Others may be up before 0600. As a result, most people are exposed to some aircraft noise during the time they try to sleep. I examined this 2300 to 0600 period in the second Heathrow survey and found that 96 percent of the population would still have some flights going over during their sleep period. This may partly explain the continued sleep disturbance at LAX. Whatever the explanation, the central finding is that after an important reduction in the number of flights, there was no decrease in nighttime annoyance. This raises the fourth question, Does the number of flights have only a small effect at night? (See fig. 4.)

There is some evidence which suggests that the number effect and other components of the response model should be different for the day and night. I would like to just mention a few findings. Several studies in addition to the LAX study suggest that the number effect is weaker at night than during the day. In the second Heathrow survey the noise and number trading factor was weaker at night. The railway survey which I conducted in Great Britain showed that though the peak noise levels at night had an effect, the number of events at night had virtually no effect on annoyance. Some of the work John Ollerhead has done suggests that the number effect may be weaker at night. On the other hand, I will have to say that the evidence is not completely clear. One piece of Paul Schomer's work suggests that there may be a fairly strong number effect at night.

Day and night response models can also differ with respect to certain mediating variables; that is, there is some evidence that people's responses are affected by different variables at night more than during the day. Dr. Langdon in England and Aubrey in France found that older people and women are more likely to be disturbed by noise at night than are younger people or men. In general, we find that age and sex do not affect daytime annoyance.

The second general finding from the studies is that the simple time-of-day weighting model which we examined earlier (fig. 2) is inadequate. One reason for this conclusion is that there is not a consistent finding on the weights. Although generally nighttime noise is more annoying, different studies have provided different estimates for the value of the nighttime weighting factor. Depending on the study, you can find support for from a 0 to 17 dB weighting. The first Heathrow study suggested that 17 NNI (noise and number index) was a reasonable first adjustment. That has been transformed by other researchers into other energy measures with different assumptions to show there should be either an 11 or a 14 dB weighting. The railway study I conducted indicated no effect for numbers of nighttime events. Borsky suggests that his data support a 3 dB weighting. Schomer suggested something like 7 to 10 dB. The most striking feature of the reports presenting these findings is the tentativeness, even for researchers, with which they state their findings. I would like to quote from the much heralded first Heathrow study. "We must emphasize however, that this particular conclusion concerning critical nighttime exposure levels must be regarded as only a very tentative estimate, in view of the scanty evidence on which it is based." I think that if we took the time to go over the evidence we would find that, if anything, the statement overestimates the quality of the evidence.

The second point I would like to bring up is that the simple time-of-day weighting model is inconsistent with the research evidence. This should be leaping out at you by now. Half of the time-of-day research assumes that you can use the same metric for day and night (only the weight differs), while the other half shows that you cannot use the same metric for day and night. The simple time-of-day weighting model is inconsistent with the research findings. What do we conclude then? (See fig. 5.)

There are two conclusions. First, we need a more realistic conceptual framework to take into account the differences in the response models for the

night and the day. Second, we need some new types of study approaches. Ollerhead, the authors of the TRACOR surveys, and a number of other researchers have all pointed out that one of the major reasons we don't have definitive findings from existing studies is that the daytime and nighttime noise levels are too highly correlated in the samples. In fact, we should not be too surprised at the lack of progress when we realize there has never been a study which has been specifically designed to obtain good estimates of the nighttime weighting. All the findings come from studies which were designed for other purposes.

The two conclusions in figure 5 can be seen as the outline for the research part of this workshop. I want to try to cover the conceptual framework in this paper. The study approaches will be the subject of one of the remaining roundtables and workshops.

I have my own time-of-day response model (fig. 6). It has been labeled "tentative" to encourage discussion. The overall response to noise is some function of what happens during some number of different periods. What is important about each period is, first, the noise. The purposely vague term "noise" is used here because I'm not sure what sort of metric or description we ought to have. What's happening in the period has to do with the noise as well as any mediating variables. Beyond that there are the questions as to how the characteristics of these different periods are being combined. Is it energy addition or is it some sort of independent effects addition? Last is the question of weighting. How much weight should be given to the noise environment in each period?

This model suggests a research program where it is necessary to define the number of time periods, the dose response model for each time period, the mediating variable models, a model for combining all the period effects, and the weights for combining the periods. In the remaining time, I would like to just briefly go through each of these components to put forward what I think the major issues are.

The first problem is the definition of time periods. There is obviously a day/evening/night possibility. Perhaps there should be more periods. It may be that weekends are different. Galanter in some of his work has even suggested that there may be some sort of an interaction, that on the weekend there might need to be a different division of the periods. I have, however, looked at the TRACOR data. They suggest that the same time periods apply for the weekend as during the week, even though there might be a heightened reaction on the weekends.

Now, consider the second point, the dose response model for each period. (See fig. 7.) I see three research areas here. The first is the noise metric. We've said there is some evidence that the number of events has less effect at night than during the day. Perhaps the energy model doesn't represent all periods. A second issue is the shape of the dose response relationship. As I mentioned before, there may be some sort of threshold effect here. I don't know of any good survey research evidence on this issue. It may seem fairly obvious that if we want to look at the response at night, we have to look at

that response against the nighttime noise level. All the published results that I've seen, which compare daytime and nighttime activity interference by noise level, graph them both against the same 24-hour noise level. The only analysis which provides some evidence on thresholds is some work in Switzerland where the noise is represented by L_{eq} for each period. In that particular case, there is no evidence that the shapes are any different for different times of day. The third dose response issue is the more usual one. The question is simply whether the degree of response is different at different times of day even though the response model is otherwise the same during the different periods.

The third set of research issues for the time-of-day response model concerns the mediating variables (fig. 8). There are a number of issues we could talk about here which are outlined in figures 9 and 10. I'm just going to focus on the second issue in figure 8: the effect of the value of the mediating variable during the time period. In this case, there is the same relationship of mediating variable to response in the two time periods. For example, where there is a low ambient noise level, people are more annoyed than where there is a high ambient noise level. During the daytime, though, most people (90% in fig. 8) are in high-ambient-noise-level conditions; thus, the total response should be something like the dashed line in time period 1. At night most people (90% in fig. 8) are in the low-ambient-noise condition; thus, there may be a heightened overall response such as the dashed line in period 2. There are a number of mediating variables listed in the research. Those I have seen are listed in figure 9: the time a person spends at home, the room in the house that a person sleeps in (Is it in the back?), and ambient noise level. It has been suggested that age and sex have a different effect on daytime and nighttime annoyance.

Now let's consider the last time-of-day research issue: the model for combining periods (fig. 11). I suggest two alternative models here. One is the energy summation model such as L_{dn}. This can be compared to the independent effects model. In the independent effects model, the effect of any one time period is independent of the noise level in the other period. No matter what the noise level is during the day, if you reduce the nighttime level by a certain amount there will always be the same annoyance reduction. That is quite a different model from the energy summation model. Just take as an example, a 70 dB L_{eq} during the day and 50 dB L_{eq} during the night. We could ask whether there is any value in further reducing the noise level at night. Well, with the independent effects model there is; by further reducing nighttime noise, there can be a further substantial reduction in annoyance. According to the energy summation model, on the other hand, because the effect of the antilog of the nighttime level would be completely lost in the antilog of the daytime level, there would be no benefit at all in reducing the noise level further at night. I have discussed only two models but have left open the discussion of other possibilities with the "Others????" category. A model which might fit here would be one which would allow for time-of-day weights to vary with the amount of time people are at home. This is just one of a variety of other approaches which might be suggested.

Let's note one condition which is needed for a critical test to choose between the models. The requirement is that a study be designed where the day and night noise levels are not too highly correlated.

The last research issue is the traditional one of choosing weights for combining noise periods. This is essentially one of solving an equation for values of the weights. Of course, you have to decide which of the alternative models will be considered. I don't know of many attempts to choose between those two models. In fact, because day and night levels are so highly correlated, there aren't good data sets to help choose between the models. In general, the weak effects of nighttime levels on overall annoyance in the LAX study and second Heathrow study suggest that perhaps the energy summation model makes somewhat more sense. On the other hand, where the two models were examined in Bradley's work on traffic noise in Canada, a slightly higher correlation was found for the independent effects model. I think the intercorrelations are so strong that there isn't a lot to be drawn from these results.

I have suggested a time-of-day response model. I think this research approach contains two suggestions for study design discussions in the workshop and roundtable. (See fig. 12.) First, a wide range of time-of-day environments is needed for studies. Secondly, I would suggest that this large time-of-day model will have to be developed sequentially. The complexities and number of unknowns with respect to basic questions about the shape of the relationship and the noise metric are so great that it seems to be unlikely that we are going to specify the model in a single research project. Most likely we will have to develop any model sequentially.

OVERVIEW OF PAPER

REVIEW TIME-OF-DAY RESEARCH EFFORT

EXAMINE COMPLICATIONS RAISED BY RESEARCH FINDINGS

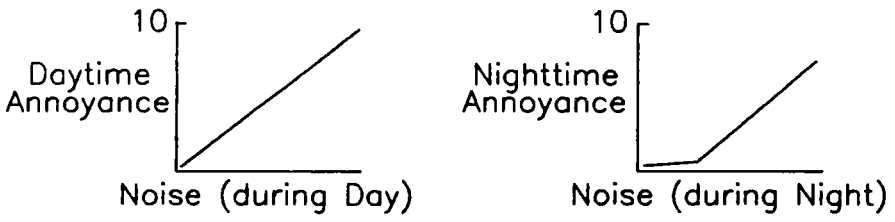
OFFER CONCEPTUAL FRAMEWORK FOR TIME-OF-DAY RESEARCH

SUGGEST IMPLICATIONS FOR RESEARCH METHODS

Figure 1

PREVIOUS TIME-OF-DAY RESEARCH ISSUES

- NIGHTTIME RESPONSE MODEL



- **TIME-OF-DAY WEIGHTING MODEL**

Simple Model

$$\text{OVERALL RESPONSE} \propto L_{DAY} + W \bullet L_{NIGHT} + C$$

Figure 2

LAX NIGHT FLIGHT REDUCTION STUDY

APRIL 18–28, (328 INTERVIEWS)

–20% REPORT SLEEP INTERFERENCE (50 FLIGHTS A NIGHT)

APRIL 29, ALMOST COMPLETE ELIMINATION OF FLIGHTS FROM 2300–0600

MAY 29–JUNE 11, (228 INTERVIEWS)

–22% REPORT SLEEP INTERFERENCE

QUESTIONS RAISED BY LAX STUDY

ARE PEOPLE INSENSITIVE TO ANY CHANGE?

ARE NIGHTTIME REACTIONS INTEGRATED OVER VERY LONG PERIODS?

WERE PEOPLE EXPOSED TO AIRCRAFT NOISE DURING SOME SLEEP HOURS?

DOES THE NUMBER OF EVENTS HAVE ONLY A SMALL EFFECT AT NIGHT?

Figure 3

FINDINGS FROM TIME–OF–DAY RESEARCH

- RESPONSE MODELS DIFFERENT FOR DAY AND NIGHT

  WEAK NUMBER EFFECT AT NIGHT

  MEDIATING VARIABLES

- SIMPLE TIME–OF–DAY WEIGHTING INADEQUATE

  NO CONSENSUS ON WEIGHTS

  INCONSISTENT

Figure 4

CONCLUSIONS ABOUT TIME-OF-DAY RESEARCH STRATEGY

- MORE REALISTIC CONCEPTUAL FRAMEWORK NEEDED
- NEW TYPES OF STUDY APPROACHES NEEDED

Figure 5

TENTATIVE TIME-OF-DAY RESPONSE MODEL

- **MODEL**

Period 1 Period 2 Period t

$$\text{OVERALL RESPONSE} = f\,[W_1(\text{NOISE}_1, M_1),\ W_2(\text{NOISE}_2, M_2),\ \ldots\ W_t(\text{NOISE}_t, M_t)]$$

- **RESEARCH PROGRAM TO DEFINE COMPONENTS IN MODEL**

  Definition of Time Periods

  Dose Response Model for Each Time Period

  Mediating Variable Model for Each Time Period

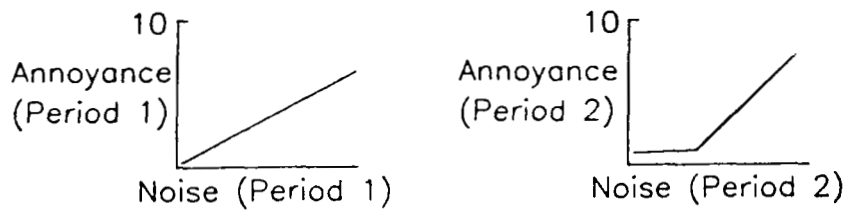
  Model for Combining Period Effects

  Weights for Combining Periods

Figure 6

DOSE RESPONSE MODEL FOR EACH PERIOD
RESEARCH ISSUES

- NOISE METRIC
- SHAPE OF CURVE



- DEGREE OF RESPONSE

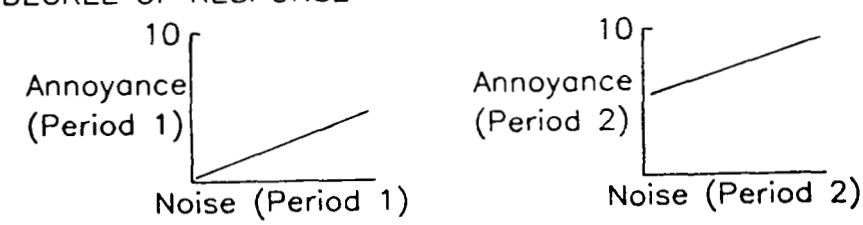
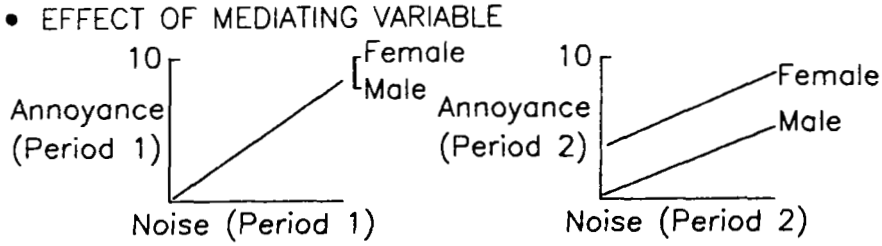


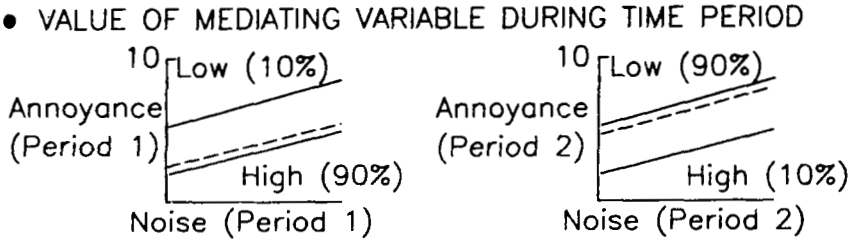
Figure 7

MEDIATING VARIABLE MODEL FOR EACH TIME PERIOD
RESEARCH ISSUES

- EFFECT OF MEDIATING VARIABLE



- VALUE OF MEDIATING VARIABLE DURING TIME PERIOD



(Ambient Noise Levels)

Figure 8

MEDIATING VARIABLES

CONTRASTING EFFECT VARIABLES

- Sex
- Age

DIFFERENT VALUES FOR MEDIATING VARIABLE DURING TIME PERIOD

- Ambient Noise Level
- Exposure Position at Home
- Time at Home

Figure 9

DEFINITION OF TIME PERIODS

SEPARATE TIME PERIODS NEEDED WHEN:

- Different Noise Metric
- Different Dose Response Relationship
- Different Mediating Variable Effect
- Different Mediating Variable Values

Figure 10

MODEL FOR COMBINING PERIODS

ALTERNATIVE MODELS

- INDEPENDENT EFFECTS

  OVERALL IMPACT = $\beta_1(\text{NOISE}_1) + \beta_2(\text{NOISE}_2)$

- ENERGY SUMMATION

  OVERALL IMPACT = $10 \log_{10}[\beta_1(\text{antilog}\frac{L_1}{10}) + \beta_2(\text{antilog}\frac{L_2}{10})]$

- OTHERS????

CRITICAL TEST

- ANNOYANCE FOR DIFFERENT PROPORTIONS OF DAY AND NIGHT NOISE

Figure 11

IMPLICATION OF RESEARCH APPROACH FOR STUDY DESIGN

- WIDE RANGE OF TIME-OF-DAY ENVIRONMENTS NEEDED

- MODEL MUST BE DEVELOPED SEQUENTIALLY

Figure 12