Public Health Policy Forum

Public Policy and Environmental Noise: Modeling Exposure or Understanding Effects

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ABSTRACT

This paper argues that if the federal government is to successfully protect the public from the adverse effects of environmental noise, its policies will need to be informed by a scientific understanding of the psychological and social factors that determine when noise results in annoyance and when noise may affect health as an environmental stressor. The overreliance of federal agencies on mathematical modeling of average group responses to physical noise levels is discussed as oversimplifying and limiting the understanding of noise effects in crucial ways. The development of a more sophisticated information base is related to policy needs, such as the need to make accurate predictions about the annoyance of particular communities, the need to understand relationships between public participation in noise abatement efforts and annoyance, and the need to identify populations that may be susceptible to stress-related health effects. (*Am J Public Health.* 1997;87: 2063–2067)

Introduction

It is estimated that community noise levels in the United States have increased more than 11% over the last decade and will continue to increase at least at that rate, with aviation noise projected to increase at an even more rapid rate.[1] With rising noise levels, there has been growing public concern about the effects of noise on health and well-being as well as opposition to the noise-producing airport expansions needed to accommodate the projected doubling of air traffic in the next 2 decades.[2–4] Although the Noise Control Act of 1972[5] charges the federal government with protecting public health and welfare from the adverse effects of noise, research on the effects of environmental noise virtually stopped in the United States in the early 1980s when budgetary support for the Environmental Protection Agency's Office of Noise Abatement was discontinued. Instead, federal policy determinations about transportation noise have relied on dose–response data that relate level of physical exposure to reported annoyance, averaged across communities (Figure 1), using a single-number descriptor of stimulus properties (i.e., an average day–night sound level of 65 dB or above) to designate areas that need protection.[6]

However, the mathematical modeling of community annoyance, as determined by physical noise levels, oversimplifies and limits the understanding of noise effects in crucial ways. It relies on "annoyance" as the index of public response to noise without an understanding of the social and psychological variables that determine when a given noise level generates annoyance in a particular individual or particular community.

Moreover, the convenience and simplicity of the annoyance averaging methodology have had the effect of curtailing a consideration of other key outcomes such as health-related physiological effects (i.e., blood pressure increases, increased catecholamine secretion, and inhibited immune system functioning) that also appear to be moderated by psychosocial variables. For these reasons, this paper argues that continued overreliance on one-dimensional dose–response relationships to the neglect of a more basic understanding of the factors moderating and mediating reported annoyance and other noise effects will bring diminishing returns and will limit decision makers in their ability to predict accurately the annoyance of particular communities and to determine whether particular groups are subject to health-related effects.

Problems Related to the Failure to Understand Factors Moderating Community Annoyance

Psychosocial factors account for more variation in individual annoyance than does noise level alone,[8] and these individual differences do not appear to be equally distributed among various communities.[9,10] In an earlier article, I noted a variety of problems faced by decision makers (discussed subsequently) that can be related to the failure to consider and understand the psychosocial factors that moderate the annoyance produced by a given noise level.[11]

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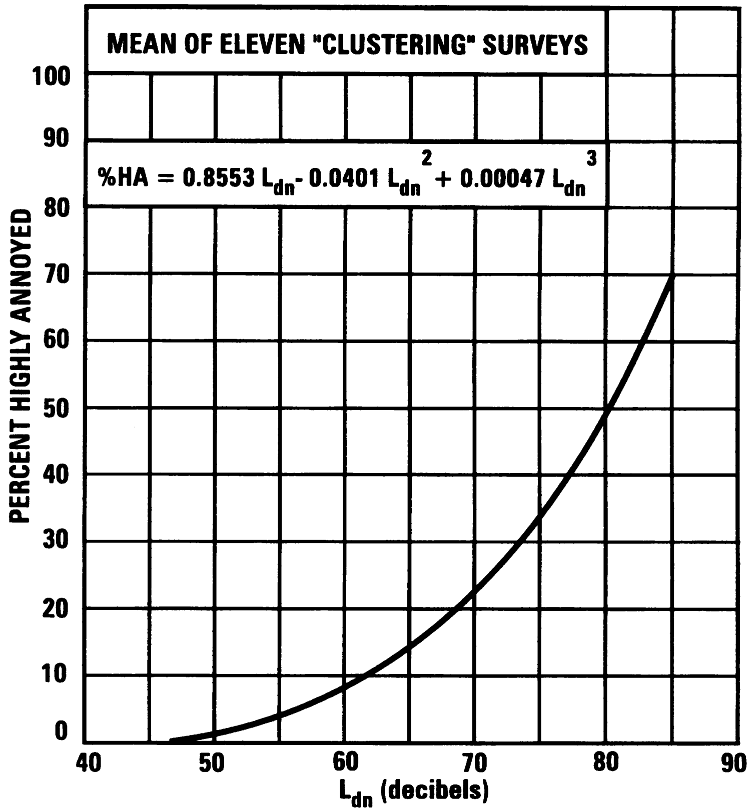
Federal interagency groups have been faced with the need to consider the extent to which day–night sound levels below 65 dB should be taken into account in assessing airport effects[12] as a result of the fact that people around certain mid-sized airports often report higher levels of annoyance than predicted by the dose–response relationship described by Schultz (Figure 1).[13] This discrepancy has been explained by the fact that communities, as well as individuals, differ in the criteria they set for acceptable noise levels as a result of factors such as expectations about the amount of quiet that should be available in a particular location, attitudes about the relative importance of economic vs environmental considerations, and related public discourse.[10,14] A methodology that does not incorporate this variability in the criterion for reporting annoyance will be compromised in its ability to predict, no matter how accurately exposure levels are measured.

As noise levels continue to increase and noise intrudes into less-developed areas not previously exposed, policymakers are increasingly handicapped in decision making by their limited understanding of the psychosocial factors that could explain the response of different populations and conditions. The survey data that Schultz used to synthesize a response curve were obtained, for the most part, from developed urban areas where respondents had been exposed to long-standing, high-level noise sources.[7] The annoyance of people who have continued to live in areas of high exposure is not appropriate for predicting community responses to new noise in areas where people may have chosen to reside because they value quiet and where background noise levels are much lower.[15] If policymakers use their current, context-dependent definition of annoyance to make decisions about new noise sources, they will be attempting to solve the wrong problem, and policy failures can be expected.

The unanticipated community protest following the implementation of the Expanded East Coast Plan, a major East Coast rerouting of metropolitan traffic into areas not previously exposed, is an example of a costly policy failure that resulted from an oversimplified technical approach that ignored the psychological dimensions of a problem. The failure to predict this public outcry resulted in a congressionally mandated retroactive environmental review that cost the government $4.5 million.[16] A government-commissioned study attributed the adverse reaction to the Federal Aviation Administration's unilateral action, absent public awareness or input, and to the fact that, although noise levels were below the lowest energy level identified by the government as acceptable for "quiet" locations, they were perceived as four to eight times as loud as what was familiar and expectable.[17]



Note. In surveys evaluated, measurement scales were transformed into comparable units. Noise ratings from various sources were transformed to average day–night sound levels (L_{dn}) in decibels. The percentage highly annoyed (HA) was determined by counting the number of respondents self-rating their annoyance in the upper 27% to 29% of various scales. The equation describes the relationship between level of exposure and percentage highly annoyed (from Schultz[7]). *Source.* Reprinted with permission from Schultz.[7, p382]

Figure 1—Means of 11 clustering surveys proposed as the best currently available estimates for public annoyance due to transportation noise.

Psychosocial Factors Implicated in Stress-Related Health Effects

An understanding of the factors that moderate and mediate response to noise may be necessary not only to accurately predict annoyance as a measure of public response but also to determine which groups need protection from health-related physiological effects.

Exposure to high-level noise is a physical stressor that can directly alter physiological processes, particularly the functioning of the cardiovascular and endocrine systems. Under some laboratory conditions, physiological responses to high-level noise do not habituate,[18–21] and some groups consistently show greater physiological responsiveness[22–24] and reduced habituation.[24,25]

At the moderate levels characteristic of community exposure, the effects of noise as a stressor are determined by how it is cognitively processed by individuals. Noise can affect the same physiological processes as do psychological stressors such as bereavement, surgery, or sleep deprivation (for a review, see Cohen et al.[26]). Increasing evidence in the medical literature points to the relationship between stress, the physiological changes it produces, and illness.[27,28] Appraisal factors appear to determine for whom and under what conditions noise may result in health-related outcomes such as blood pressure increases, increased catecholamine secretion, and inhibited immune system functioning.[29] For this reason, it has been difficult to quantify risk or to establish causal relationships with identified disease entities. In order to identify subgroups that are at risk for health effects, it will be necessary to identify intermediate variables and to formalize the relationship between these variables, noise exposure, and adverse effects. The research evidence points to appraised threat, self-reported sensitivity to a variety of noises, degree of annoyance, coping strategies, and developmental status as some of the factors that place certain groups at risk for stress-related physiological effects. These factors can be discussed in terms of the mechanisms implicated.

The degree of threat presented by a stressor, rather than its objective physical intensity, best predicts human response.[26,30] Physiological changes such as increased galvanic skin response decay time, diminished adrenocortical response,[31] and blood pressure increases[32] follow experimental exposure to noise that has been determined to be important or salient for subjects; however, such changes do not follow exposure to white noise of the same intensity. In the field, beliefs and valuations have been shown to determine whether a noise event is perceived as threatening. Belief that one is unfairly, unreasonably, or dangerously affected by noise[33] and valuations concerning the relative importance of environmental vs economic considerations (see Vaughan[34] regarding sociocultural differences in adaptation to environmental risk) may dispose individuals to react to noise with repeated attention and continued distress over prolonged periods. This may be a factor in explaining the robust finding that annoyance with community noise does not decrease over time[35,36] and may be a factor in determining in what circumstances physiological responses to noise do not habituate.

Some findings suggest that subjective reactions to noise better predict health problems than does actual noise level. Otten, Schulte, and von Eiff[37] found that blood pressure increases were correlated with self-reported sensitivity to noise and self-reported annoyance in both noisy traffic areas and control areas. Pulles, Biesiot, and Stewart[38] found that although an avoidant coping style interacted with aircraft noise to result in higher levels of health complaints, the effect of another psychological variable, perceived control, was independent of noise level. Neus, Ruddle, and Schulte[39] found that self-reports of annoyance and noise sensitivity were correlated with treatment for hypertension in areas of moderate noise intensity but not within areas heavily affected by traffic noise. Some investigators[7,26] have concluded that the moderating influence of subjective reactions such as self-reported noise sensitivity and annoyance may be greater at moderate than at extreme noise levels, and others[40] have concluded that annoyance with low-level noise reflects a general vulnerability to stress.

Once noise is appraised as a stressor, an individual's perceived control over exposure is one of the most important predictors of adverse effects.[41] The feeling of control over community noise is associated with reduced annoyance and health complaints.[38,42] Similarly, findings from developmental studies suggest that the adverse effects of noise on children's cognitive development are ameliorated if the children have access to a secluded quiet room within the home.[43] However, individuals frequently perceive environmental noise as intractable to control efforts. As a result, effective coping is difficult. The likelihood of adverse effects is increased by frustrated and ineffective coping as well as by feelings of helplessness; both have been linked to psychological distress and physiological changes. Learned helplessness in attempts to control laboratory stressors has been related to depressed mood, illness, overstimulation of the parasympathetic nervous system, and decreased immune responsiveness.[26] Frustrated or ineffectual coping with laboratory stressors that are difficult to control results in anxiety and physiological response patterns similar to those of subjects who are unable to control an adverse event.[44] Consequently, individuals who feel helpless to control outcomes in their lives or are subject to multiple stressors and those who feel threatened by a perceived loss of control over aspects of their environment (e.g., those with type A behavior patterns or those with an internal locus of control) may be at special risk for adverse health effects. Indeed, the fact that cognitive, physiological, and motivational deficits have consistently been identified in children chronically exposed to noise[45–48] supports the possibility that noise has more deleterious effects on populations limited in terms of ability to control outcomes.

Empirical studies of psychophysiological stress reactions illustrate the ways in which psychological processes are central to the mechanisms by which noise induces adverse effects. First, noise is a stressor that affects multiple domains of functioning, and an interplay between psychophysiological and cognitive processes is involved in coping with a noise stressor. Consequently, effects on one system cannot be artificially separated from effects on another. For example, efforts to maintain performance in the face of the distracting effects of noise can come at the expense of heightened sympathetic arousal. Tafalla, Evans, and Chen[49] found that although performance on a moderately complex arithmetic task was unaffected by noise when subjects were directed to work at maximum effort, there were significant increases in blood pressure. When subjects were not directed to work at maximum effort, performance was adversely affected by noise, but blood pressure remained constant. Likewise, findings suggest that for children chronically exposed to noise, learning to tune out noise may come at the expense of deficits in auditory discrimination.[48,50]

Because of the interplay of processes involved in efforts to cope with chronic noise stress and the multiplicity of systems affected, overreliance on a measure of a specific disease outcome such as cardiovascular disease may artificially limit findings. Instead, Cohen and his colleagues have suggested that noise may not be etiologically related to any given disease but may enhance susceptibility to disease in general and, thus, may cause a wide variety of physiological, behavioral, and somatic symptoms.[26]

Implications for Policy

What does a better understanding of the psychological and social factors that account for individual variability in response to environmental noise mean for public policy? First, because noise annoyance is moderated by psychological and social factors, no single response curve will accurately predict community annoyance in all circumstances. Goldstein, addressing the need to restore the public health basis for environmental control, has argued for the need to move assessment away from "one size fits all" mathematical models.[51] In a similar vein, Weinstein, a researcher of community noise in the 1970s, has suggested that, rather than a single response curve being endorsed, efforts should be made to understand the factors that change dissatisfaction from site to site.[15] For policymakers, this would mean that different curves would be used to predict in different situations or that correction factors would be used to account for differences in exposure history or for differences in ambient noise levels, as recommended by the US Environmental Protection Agency in its 1974 levels document.[52]

Using signal detection theory,[53] Fidell and colleagues have attempted a more systematic accounting of the variability in community annoyance from a given noise dose.[54,55] They propose a probabilistic model for determining how individuals in a community decide whether a noise level is acceptable. The criterion adopted by individuals in a given community is conceptualized as a decision about whether a specific exposure is appropriate and expectable given interrelationships among particular physical, nonacoustic, and psychosocial variables. Conceptualizing noise annoyance in the context of its links to psychological and social factors (such as exposure history, the value of needs or activities that are disrupted, and the valuation of the noise source) and its links to behaviors such as decisions about moving or about complaining to authorities has the advantage of portraying not only how individuals are affected by noise but also how they make decisions about the type of environments in which they will live. Decision makers need this more sophisticated type of model that portrays how people make the complex decisions that inform their response to environmental noise levels.

Second, although federal agencies have recently recognized the value of involving the public in the evaluation and mitigation of noise effects, airport and regional efforts are proceeding with little understanding of the relationship between public participation and annoyance. If this new approach is to be successful, it will be important to determine when public participation is likely to decrease annoyance (because it affords a perception of control and indeed some measure of control) and when it is likely to increase annoyance (because it increases expectations for control beyond actual possibilities for control). It will also be important to determine which populations may be ill served by participant noise control strategies. For example, although disadvantaged groups that feel helpless to affect outcomes may be more vulnerable to stress effects, they are also less likely to participate in public forums to manage risks.[34]

Third, it is often argued that federal research dollars cannot be devoted to elaborating health effects until overall effects or dose–response relationships can be demonstrated. Yet, given that health-related stressor effects are, in large part, psychologically mediated, this argument puts the cart before the horse and has the effect of precluding risk quantification. In a 1993 review of the adequacy of current research data for quantifying noise-induced health risk, Thompson concluded that there is a need to better understand underlying biological mechanisms and effect modifiers in order to adequately design epidemiological studies that can quantify health risk from noise.[56]

Finally, although it is not presently possible to use formal relationships between physical and psychological variables to quantify risk from noise, there is enough evidence to know that noise has the potential to impair children's development and learning. More than 10 million American schoolchildren are exposed to noise levels equivalent to or greater than those (i.e., 24-hour Equivalent Sound Level of 68.1 dBA) that have been related to adverse cognitive, psychophysiological, and motivational effects.[47] Despite this cause for concern, public health is not represented on the Federal Interagency Committee on Aviation Noise, the government forum created for determining future research needs regarding the effects and control of aviation noise. Needed and reasonable government responses to this potential public health risk would be (1) to include representation from the health and behavioral sciences on the committee and (2) to use the Environmental Protection Agency to coordinate and support interdisciplinary research out of several univer-sity-based national centers, as recommended by the American Speech-Language and Hearing Association in its final report to the 102nd Congress.[29] □

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