Evaluating the health benefits of natural sounds: an approach for assessing the environmental impacts of transportation noise

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Excessive anthropogenic noise has been associated with annoyance, disruption of sleep and cognitive processes, hearing impairment, and adverse impacts on cardiovascular and endocrine systems. Although transportation is a major source of noise, national policy in the U.S. has de-emphasized noise control efforts at the federal level and as a result, research and regulation of noise sources has lagged compared to that of other important environmental pollutants. But as global population and urbanization continue to grow at unprecedented rates, noise control and research will warrant increased attention if development is to proceed in concert with sustainable development principles. Adding to the development challenge are the limitations of current noise impact assessment practice, wherein the incremental effects of anthropogenic noise insults are often studied in isolation and are based on subjective measures, which introduces difficulty in teasing out individual or cumulative impacts. To address these problems, a new research approach is proposed, which seeks instead to characterize the underlying value of the acoustical environment being intruded upon by exploring the health benefits of natural sounds through a comprehensive program based on objective, physiological outcomes. Rooted in well-established methodology common to environmental health and clinical research, a proposed study methodology is outlined within the context of addressing noise impacts from commercial air tours over national parks, but may have broader applicability to clinical, occupational, and other environmental health analysis research areas.

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1 INTRODUCTION

1.1 Control of Transportation Noise

Transportation has long been recognized as a major source of noise pollution. Excessive anthropogenic noise has been associated with annoyance, disruption of sleep and cognitive processes, hearing impairment, and adverse impacts on cardiovascular and endocrine systems[1]. In the U. S., serious federal efforts to control noise, air, and water pollution emerged in the 1970s and were enabled by a series of sweeping environmental statutes issued in response to a growing recognition that pollution posed a serious danger to health and welfare. The Noise Control Act of 1972[2] and the Quiet Communities Act of 1978[3] ranked among the giants, residing in a legislative pantheon administered by the Environmental Protection Agency (EPA) that included the Clean Air Act of 1970[4] and the 1972[5] and 1977 amendments[6] to the Federal Water Pollution Control Act (the Clean Water Act). The Noise Control Act established a means for coordinating federal noise control research and activities, authorized the establishment of federal noise emission standards for products, and facilitated the dissemination of product information to the public. The Quiet Communities Act limited noise from civil aircraft and other civil transportation and initially set aside funding for noise control research. But unlike their peers, who through regulation, amendment, and operational funding have reinforced or expanded the federal government's role, the Noise Control and Quiet Communities Acts, though still in effect, are today essentially unfunded – the result of a 1981 policy decision that noise issues were best handled at the State or local government level[7].

Noise control research activity has since lagged behind that of other environmental pollutants and with EPA's role diminished, subsequent activity has been led by other agencies and has focused largely on addressing the adverse impacts of anthropogenic noise in occupational settings and around airports with concern directed mostly towards hearing loss, annoyance, and sleep disruption. Aviation noise has received increased attention in recent years in the European Union (EU) and North America and some progress has been made towards reducing uncertainties that have been reported concerning health effects[8]. Although much of the EU's effort has focused on noise measurements and mapping, recent work such as the Hypertension and Exposure to Noise near Airports (HYENA) study has explored the association of noise with physiological indicators of cardiovascular health, sleep, and stress[9]. Aviation noise research has also been advanced through the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) – a Federal Aviation Administration (FAA) Center of Excellence, sponsored by the FAA, National Aeronautics and Space Administration, Transport Canada, the Department of Defense, and the EPA, which supports research on alternative fuels, emissions, noise, operations, aircraft technologies, and policy assessment[10].

1.2 Increasing Urbanization and Pressures on Natural "Soundscapes"

As the global population expands, more individuals are living in cities now than ever before and the effects of pollution, including noise, will warrant increased attention if projected development is to proceed in concert with sustainable development principles. In developed nations, 74% of the population lives in cities[11]. In addition, the size and density of cities are growing at an unprecedented rate. According to population projections for 2025, twenty-seven cities in the world will be considered "megacities," with over 10 million inhabitants, up from just three megacities in 1975[11]. Urban residents face significant challenges to their health, such as exposures to air and noise pollution, and limited open spaces for physical activity, socialization

or restoration. Previous research studies have found that residents chronically exposed to these environmental conditions are at increased risk of disease and premature death[12-14]. For example, poor air quality has been associated with cardiopulmonary disease[15] and repeated exposures to noisy environments have been associated with fatigue[16], insomnia[17], hypertension[18], heart disease[19], mental health[20], learning deficits[21], and hearing loss[22]. In sum, the accumulated evidence suggests that these built environments impact our health and specific strategies to manage these problems are needed.

In contrast to the built environment, parks and other natural settings offer a measurable difference in air quality, sounds, and open spaces. More importantly, previous research has shown that time spent in natural settings improves mood and sense of well-being[23-25]. Further, several laboratory studies and field studies of individuals in nature or nature-like surroundings have shown improvement in their cognitive performance[26], sleep quality, and an attenuation of their stress or pain response during or immediately after their exposure to some or all of the following experiences: natural sounds[27], sights and smells of nature[28,29], or exercise in "green" environments[30]. These studies would suggest that urban dwellers, particularly those with cognitive deficits, chronic stress burdens, or stress-related conditions, could benefit therapeutically from "getting away" to natural places, but this intervention has never been clinically tested, with a few exceptions. Prior studies, typically dependent on subjective measures, have yet to explain the mechanism for any observed positive responses or to show a lasting therapeutic benefit from the effects of nature.

Natural places, however, have long suffered from encroachment by urban development. Historically, parkland has been especially vulnerable to transportation projects. In the development boom of the early to mid-twentieth Century, publically-owned parkland in the U.S. quite literally represented the path of least (political) resistance and was sacrificed in great numbers to make way for transportation projects, especially highways. As the nation became more aware of both the adverse effects of transportation infrastructure and the underlying values of natural environments, the U.S. Congress passed the Department of Transportation Act of 1966[31], which included a special provision, Section 4(f), which stipulated that U.S. Department of Transportation (DOT) agencies cannot approve the use of land from publicly owned parks, recreational areas, wildlife and waterfowl refuges, or public and private historical sites if there are feasible and prudent alternatives. Although the physical "taking" of parkland is more difficult today, parkland – even many national parks – now have considerable road networks and park visitors and wildlife suffer from the adverse effects of noise from cars, buses, motorcycles, snowmobiles, and other sources within the parks as well as commercial aircraft, including commercial air tours over parks.

Consistent with their preservation missions, many resource management agencies have become increasing more engaged in the control of anthropogenic noise, including transportation noise in natural areas. For example, the National Park Service in the U.S. recognizes acoustical environments or "soundscapes" (analogous to landscapes) - defined as the combination of both natural (wind, water, wildlife, vegetation) and cultural sounds (battle reenactments, tribal ceremonies, quiet reverence) appropriate for individual parks. The Park Service has begun developing soundscape management plans for individual parks[32] and has coordinated research to characterize acoustical environments and assess the impacts of transportation sources on visitor experiences and wildlife ecology. The National Parks Air Tour Management Act of 2000[33] specifically authorizes the FAA to regulate commercial air tour operations over national parks in cooperation with the Park Service through Air Tour Management Plans (ATMPs). The objective of the ATMPs is to develop acceptable and effective measures to mitigate or prevent significant

adverse impacts on natural and cultural resources and visitor experiences in national parks units and on tribal lands in or abutting parks.

1.3 Limitations of Current Noise Impact Assessment Practice

Persistent challenges in assessing the impacts of transportation noise sources in national parks include the potential for exposure mischaracterization and the reliance on a limited set of subjective outcome measures. For example, in characterizing the impacts of commercial air tours under the Air Tour Management Program, acoustical information is obtained from fixed monitoring sites and surveys are administered to park visitors in an effort to parse out an incremental level of annoyance attributable to intermittent aircraft noise exposures experienced over a park visit. However, during the visit, the visitor moves between the fixed monitoring sites and receives an integrated exposure based on air quality, visual, olfactory, and a variety of acoustical inputs. Such studies are understandably popular because they are relatively simple and inexpensive to conduct. And, although they are rooted in the well-established social sciences and have been useful in advancing the level of understanding of noise impacts on the perception of annoyance, the results can be difficult to interpret and may be of limited use from a regulatory perspective.

2 DISCUSSION

2.1 A New Research Approach

But what if we turn the problem around and instead of separately looking for the incremental effects of multiple anthropogenic noise sources, we ask what is the underlying value of the natural resource - in this case the natural soundscape being intruded upon? The acoustical properties of natural settings may provide an important index to the positive health benefits of these environments. Importantly, sounds pervade our environments (even in sleep), stamp our memory, communicate danger, and even, rock us to sleep, if we believe the claims of the many "soothing nature sound" products on the market today. Many people incorporate relaxation regimens into their daily lives, including contemplative meditation, yoga, or other activities in quiet or to the sounds of nature. To improve productivity, employers dedicate space and devices to encourage workers to use sound and other techniques during break periods. Research has shown that the imprinting of nature sounds in the brain is sufficiently remarkable to survive recognition even when memories fade, such that individuals with dementia are unlikely to forget the sounds of a bird[34]. Despite the seemingly intuitive appeal and resonance of natural sounds, surprisingly few studies have tracked the overall health benefit of natural sounds, particularly as relief to the stressors of urban life[35,36].

2.2 Natural Sounds as Therapy

To understand the therapeutic value of natural sounds, further research is needed beyond subjective information. In particular, studies are needed that measure physiological responses to natural sounds not only in the short-term, but over time, including the effects of repeated exposures and the duration of effects after return to the built environment. Because acoustical memory is strongly imprinted in the brain[37], the extension of potential benefit from natural settings to built environments is an important consideration. For example, is it possible to recreate a benefit derived from an experience in a natural setting upon hearing a reproduction of

those natural sounds at home, at daycare, or at the office? Can acoustical cues from nature enhance learning, school performance or productivity? Further, can the benefit of natural sounds be enhanced with guidance in attentive listening, such as, cuing the listener into specific natural sounds? Are health benefits related to natural sounds intensified by immersion in natural settings, for example, when the experience is coupled with other sensory cues such as visual cues? Finally, what is the overall health impact of these sounds, for example, is it possible that listening to nature sounds will achieve the same health benefit as meditation or medication? Does exposure to nature sounds and the natural environment have a measurable therapeutic benefit to overcome the noise and stressors of the built environment, including spillover effects to motivate active healthy lifestyles? These are important questions at a time when obesity rates are soaring, hearing loss in youths is increasing, health care costs are spiraling, and a plethora of anthropogenic sounds are encroaching on many accessible public spaces.

Prior studies that have shown benefits from exposure to nature suggest that the benefits may be particularly therapeutic in vulnerable populations[38,39]. Children in inner cities, for example, may be susceptible to the loss of nature sounds[40]. Confronting rampant noise pollution in the cities, and without a reasonable choice of replacement experiences or access to nature sounds, individuals may opt to shut out sounds in extremely unhealthy ways, such as with loud music on portable earphones or earbuds. One recent study found that a third of teenagers today have some kind of hearing loss—arguably related to these practices. With a spotlight on natural sounds as part of the therapeutic benefit of nature, and as an important antidote against harmful exposures, or even, as treatment for certain ailments, the nation may begin to appreciate nature settings and parks as more than just leisure spaces. Instead, the natural setting may be viewed as an important therapeutic resource to improve the health and quality of life of the nation. The first step to this valuation will come from an evidence-based understanding about the relationship between natural sounds and health and well-being.

2.3 Study Aims

In response to a request from the National Park Service Natural Sounds and Night Skies Program, a research team led by the Volpe National Transportation Systems Center and the Harvard School of Public Health outlined a comprehensive program dedicated to research, educational outreach, and partnership to advance the gathering, testing, and evaluation of the health benefits of natural sounds. The specific aims of the proposed program and research are to:

1) Identify the physiological and behavioral responses associated with exposure to the natural sounds in different park settings (e.g. the sounds of the ocean, the forest, and the desert) through laboratory measurements and field testing;

2) Evaluate the therapeutic potential of exposure to natural sounds and natural settings in vulnerable populations (e.g. post-traumatic stress veterans, Attention Deficit Hyperactivity Disorder (ADHD) children, disadvantaged urban youth, elderly); and

3) Build a comprehensive evidence base to support public policy decisions directly related to the management of soundscapes in national parks, and indirectly related to health care services, child services, recreational and physical education, sustainable aging, urban planning, transportation, air traffic management, and environmental health.

2.4 Study Design Considerations

The customer-centric model (Figure 1) depicts a study design paradigm and study design considerations from the perspective of a park visitor. Exposures may include visual, olfactory, noise, and other pollutants in addition to natural sounds. These inputs may be modulated based on a number of interventions or underlying impairment. For example, a park visitor may listen to music while hiking using a portable listening device that may block out or otherwise interfere with other noise or natural sound exposures or the visitor may have an underlying visual or hearing deficit. Physiological outcomes can be grouped into various physiological response categories, including neurological (e.g., brain response, attention, cognitive performance), mental health (e.g., anxiety, depression, fatigue, substance abuse), stress (heart rate (HR), heart rate variability (HRV), blood pressure (BP), cortisol, skin conductance), and resilience and recovery (e.g., increased productivity, engagement, coping, immune function, startle response, respiratory, restful sleep, reduced need for pain medication). A number of important subject-specific factors, many of which that are commonly encountered in environmental health and clinical research, can modify the exposure effects either positively or negatively. These factors include age, sex, health status, ethnicity/genetics, socio-economic status, activity/behavior, personality, and expectations.

In a basic longitudinal study design, subjects would be recruited from different populations that would receive varying exposures with physiological outcomes measured over time (Figure 2). To isolate the effect of natural sounds from other exposures, field studies would be augmented by laboratory studies where exposures could be more carefully controlled. Where real-time physiological outcomes are of interest (e.g., stress indicators), mobile physiological and acoustical monitoring devices would be necessary. This may require the improvement or development of acoustical monitoring techniques and devices (dosimeters) that can travel with the study subjects, have adequate sensitivity, and overcome various technical problems such as self-noise generated by the activity of the study subjects themselves.

2.5 Potential Study Populations and Research Collaborations

Several potential target research populations are proposed in Table 1 to illustrate the range of study populations that might be of interest to various potential research partners. In each study, subgroups of children, clinical patients, backpackers, veterans, and workers would be exposed to natural sounds. A children's study might examine improved cognition, lowered stress, and behavioral changes in subgroups of urban, rural, and ADHD children. Such a study might be of interest to children's health advocacy groups or public health agencies such as a state department of health. A wide range of clinical studies can be imagined that could investigate healing and recovery, decreased pain, mood, lower BP, increased heart rate variability, and improved cognition in subgroups of oncology, anxiety/depression, cardiac, and geriatric patients. These clinical studies might be of interest to manufacturers of acoustical equipment (e.g., speakers, headphones) or various public health advocacy groups, including those focused on the prevention and treatment of specific diseases. Large sporting/outdoors goods retailers might be interested in participating in studies examining cognitive performance and sleep in backpackers venturing into the backcountry. The Veterans Administration (VA), veterans advocacy groups, and the Department of Defense (DoD) might be interested in testing the effectiveness of natural sounds as a therapy for improving stress and coping in veterans returning from conflicts in Afghanistan and Iraq with Post Traumatic Stress Disorder (PTSD). Finally, a variety of employers may be interested in natural sounds exposure as an intervention to improve

productivity, engagement, and reduce fatigue, especially in high stress occupations such as air traffic controllers.

3 CONCLUSIONS

To address a growing problem of anthropogenic noise pollution and overcome the limitations of current impact assessment practice, a new research approach is required, which seeks instead to characterize the underlying value of the acoustical environment being intruded upon by exploring the health benefits of natural sounds through a comprehensive program based on objective, physiological outcomes. If such benefits exist and the scientific evidence base can be documented, this line of research has the potential to "change the conversation" and potentially could support policy decisions that might discourage anthropogenic noise intrusions in parks and other settings despite current uncertainties or ongoing disagreements concerning adverse effects. Rooted in well-established methodology common to environmental health and clinical research, the study methodology outlined herein may have broader applicability to clinical, occupational, and other environmental health analysis research areas.

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Table 1 - Potential Research Populations and Sponsors

Target	Subgroups	Questions	Sponsors
Children	Urban Rural ADHD	Improve cognition, lowered stress, Behavior change	Children’s health advocacy groups Public health agencies
Patients	Oncology Anxiety/ depression Cardiac Geriatrics	healing and recovery, decrease pain Mood, lower BP, increase HRV, improved cognition	Acoustical equipment manufacturers Public health advocacy groups
Backpackers	Urban dwellers	Cognitive performance, sleep	Sporting/outdoors goods retailers
Veterans	PTSD	Stress and Coping	VA Veterans advocacy groups DoD
Workers	FAA controllers	Productivity, engagement, fatigue	FAA Private employers

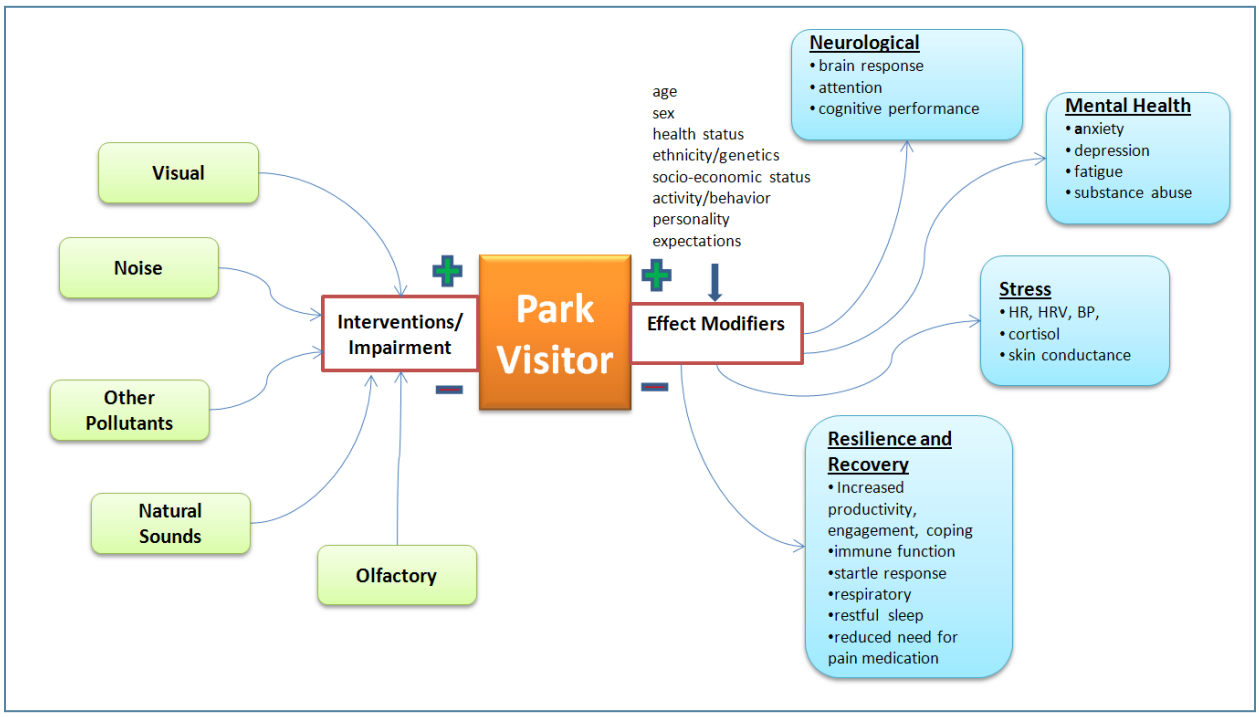

Figure 1 - Customer-centric Model

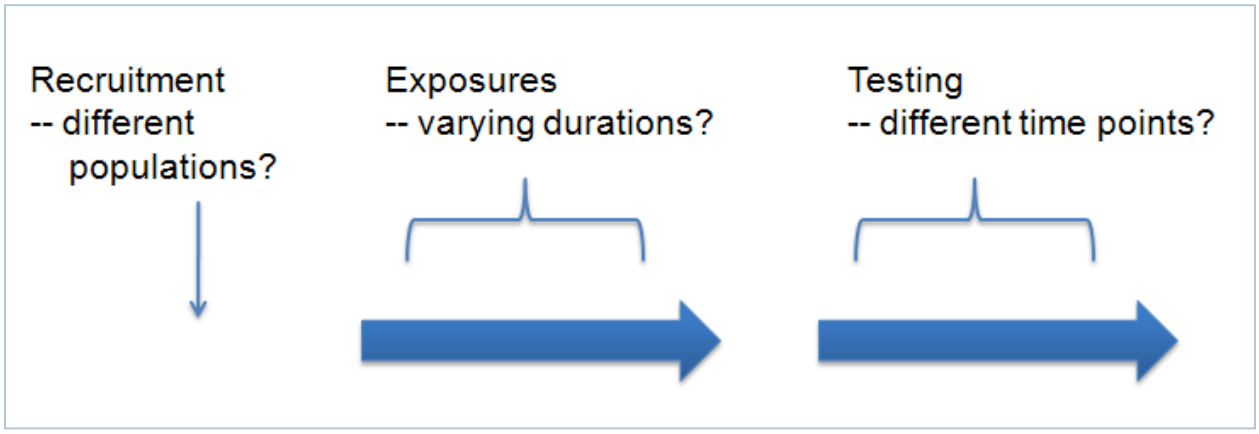

Figure 2 - Simplified Study Design