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Contrasting urban and natural soundscapes: implications for child development, cognitive functioning, and physical and mental health

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Abstract
Soundscapes, defined as the collection of biological, geophysical, and human-generated sounds, can exert meaningful effects on various aspects of human wellbeing. Not all soundscapes are created equal: natural and anthropogenic sounds often elicit fundamentally different physiological and psychological responses. As global urbanization accelerates and more people spend their lives immersed in acoustic environments dominated by anthropogenic sounds, understanding these differences has become increasingly important. Although the scientific study of soundscapes is relatively new and still developing, current evidence reveals three consistent patterns for urban soundscapes: they tend to elevate physiological stress and sympathetic arousal, impair attention and working memory, and contribute to negative physical outcomes such as sleep disruption or cardiovascular strain. In contrast, research on natural soundscapes identifies three recurrent benefits: they promote rapid stress recovery, support attentional restoration through low effort "soft fascination," and reliably enhance mood and emotional stability. Yet urban and natural soundscapes are not uniformly harmful or beneficial; both may contain elements that can produce positive or negative effects depending on context, intensity, and listener characteristics. This paper further proposes a feature-based framework for understanding soundscapes, suggesting that human responses may depend less on broad categories such as "natural" or "urban" and more on acoustic properties including predictability, informational load, intensity, and spectral entropy. It also synthesizes mechanistic hypotheses, including evolutionary signaling, acoustic similarity, and habituation, to explain why certain sounds promote restoration while others provoke stress or cognitive disruption. In addition, the paper highlights underexplored roles of culture, developmental timing, circadian alignment, and multisensory integration in shaping responses to sound environments, and outlines future research directions for designing healthier acoustic spaces.

Keywords
Soundscape ecology, Environmental noise, Cognitive restoration, Attention restoration theory, Urbanization, Mental health, Child development, Physiological stress, Acoustic environment, Noise pollution

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1. Introduction

Humans are surrounded by sound every day, from the hum of traffic to the rustle of leaves, creating a constant auditory environment that shapes experiences and interactions. This world of sound can be described as a "soundscape". Soundscapes have been defined as ''the collection of biological (e.g. animal activity), geophysical (e.g. nonbiological natural sources) and anthropogenic (e.g. human activity) sounds that emanate from a landscape and which vary over space and time, reflecting important ecosystem processes and human activities (1)." People often further group types of sounds into "natural" or "urbanized" (see Table 1 for examples).

Table 1. Examples of urban and natural soundscapes

Category	Examples
Urban Soundscape Features	Traffic (cars, buses, motorcycles), construction, sirens, industrial machinery, car alarms, crowded subway/train screeches, aircraft noise (low-flying planes, helicopters), music, human voices (social, ambient), water features, quiet footsteps on pavement
Natural Soundscape Features	Birdsong, soft rain, streams, rivers, waterfalls, gentle ocean waves, rustling leaves, insects, frogs, gentle animal sounds, thunderstorms, loud winds, rockfalls, landslides, animal distress calls, hailstorms, breaking branches during storms

Before continuing, it may be of use to clarify the meaning of the word "natural" as it is to be used in the rest of this paper. When referring to sounds, "natural" does not mean "not human," as it is impossible for humans to evolve in a non-human environment. Laughter, cooking, dialogue and other human voices also can be considered "natural."

Urbanization is a fairly recent but rapidly accelerating phenomenon in human society. More than half of the global population now lives and works in urban areas, exposing millions of people daily to a complex sound environment dominated by traffic noise, construction sounds, and other sounds generated by human activities. This type of urban soundscape creates sound conditions very different from the natural environments in which humans have existed for centuries and have biologically adapted to. Understanding how these urban sounds; combined with the natural sounds they replace or dominate over; affect early childhood development, mental health, physical health and cognitive function is becoming increasingly crucial to the wellbeing of humans as a species.

The study of soundscapes is a new and emerging field, having only been studied by the scientific literature for the past 20 years (2-5)**.** Currently, existing research suggests that natural soundscapes possess many restorative and beneficial effects for humans (6), while urban soundscapes are often associated with stress (7), distraction (8), and negative impacts on cognitive (9), emotional and physical health (7). Although the negative effects of urban noise and beneficial effects of natural noise are well documented, less is known about the potential

benefits of urban soundscapes (10, 11), or the circumstances under which natural sounds might have unintended negative consequences. As more and more people are beginning to live and work in urban areas (12, 13), it will become increasingly important to study the full range of effects urban soundscapes can have on human physiology and mental health. In addition, given the considerable societal costs of mental disorders in children and adolescents (14, 15), gaining deeper understanding of the putative role of environmental noises as a risk factor may serve to expand our perspective on the prevention of neurodevelopmental problems in childhood and into adulthood.

The effects of urban and natural soundscapes on human physiology and well-being may arise from two interacting influences: innate biological mechanisms and the cultural environments in which individuals develop. Humans differ widely in their experiences, and the ways individuals are socialized—as well as the values and beliefs emphasized within their cultural environments—may strongly influence how urban and natural sounds are perceived and interpreted. For example, if the sound of an engine is taught as progress, overcoming the limitations of distance and time that otherwise nature would impose, then anthropogenic sound may not be as detrimental to health as it is perceived to be. However, relatively consistent evidence has been found across cultures and age groups in the fact that urban and natural noise have the effects they do due to innate biological and evolutionary mechanisms. Currently, humans are living in a landscape vastly different from the one they originally inhabited (16).

For most of history, humans did not live in isolated silence or untouched wilderness, but in tightly bonded groups embedded within dynamic natural soundscapes. Early humans moved through forests, grasslands, and coastlines together, hunting in coordinated teams, gathering plants, cooking meals, laughing, arguing, and telling stories. Their acoustic world consisted of rustling leaves, bird calls, flowing water, crackling flames, animal footsteps, and the layered rhythms of communal life. Today, however, that acoustic environment has been replaced by a radically different one: the constant roar of cars and trucks, the overhead thunder of airplanes, construction machinery, electronic alerts, and the persistent low-frequency hum of urban infrastructure. This dramatic shift represents an environmental mismatch - human sensory systems evolved to process natural and socially meaningful sounds, yet are now chronically exposed to artificial, high-intensity, and often unpredictable mechanical noise.

Although culture likely influences how people interpret and respond to sounds, research across diverse populations suggests that many auditory responses are innately and biologically rooted. This idea will be further discussed in section 3.3. Humans tend to show similar stress reactions to loud, sudden, low-frequency, or unpredictable noises - acoustic features that historically signaled potential danger in natural environments, such as thunderstorms or the sounds of animals in distress. Modern urban soundscapes, dominated by traffic, aircraft, and industrial machinery, often contain these same qualities, potentially triggering stress responses

that were once adaptive but may now be chronically activated (Table 2).

This paper will first summarize what is known about the dual nature of soundscapes, exploring the positive and negative effects of natural and urban acoustic environments on development, mental health, cognitive performance, and physical health (summarized in Table 3). It will then propose underexplored avenues for future research, such as identifying key gaps in the literature, including clarifying causal mechanisms, expanding the range of studied sound types, and developing informed strategies for designing healthier sound environments in an increasingly urbanized world.Throughout this paper, the term "anthropogenic" will be used to refer to human-produced noise, while the term "urban soundscapes" will be used to refer specifically to human urban environments.

Table 2. Examples of urban and natural soundscapes divided by effects

Soundscape category	Effect	Examples
Urban	Negative	Traffic (cars, buses, motorcycles), construction, sirens, loud industrial machinery, car alarms, crowded subway/train screeches, aircraft noise (low-flying planes, helicopters)
	Positive	Music, human voices (social, ambient), water features, quiet rhythmic footsteps on pavement
Natural	Negative	Thunderstorms, loud winds, rockfalls or landslides, animal distress calls, sudden hailstorms, breaking branches during storms
	Positive	Birdsong, soft rain, streams, rivers, waterfalls, gentle ocean waves, rustling leaves, insects, frogs, gentle animal sounds

2. Positive and negative effects of natural and urban soundscapes

2.1 Early life

Since children are still undergoing physical and physiological development, they constitute a population especially sensitive to the effects of the ambient soundscape. Certain types of natural noise have been shown to facilitate attention restoration in children. For instance, in a study examining the effects of natural sounds on mental fatigue recovery in children aged 8–12, exposure to music, birdsong, fountain sounds, and stream sounds produced greater improvements in reaction time than other auditory stimuli, indicating enhanced recovery from mental fatigue (17). Participants also showed better performance in short-term memory after exposure to these naturalistic sounds. Among the stimuli tested, fountain and stream sounds generally produced the strongest restorative effects, followed by music and birdsong, whereas bell ring sounds showed potentially adverse effects (17). These differences may be explained by psychoacoustic characteristics of the stimuli; sounds with less fluctuation and more steady background rhythms, like ambient water sounds, appear to provide greater cognitive restoration than intermittent noises with higher sharpness, roughness, or fluctuation in frequency and volume (18). Thus, the contrast between urban

and natural soundscapes can be understood in part through their psychoacoustic profiles, with urban environments dominated by intermittent and harsh sounds and natural environments characterized by steadier, softer, and more predictable auditory patterns.

A meta-analysis of 36 studies further supports the conclusion that natural sounds, particularly water and birdsong, were linked to reduced stress, improved mood, and enhanced cognitive function across age groups (6). Moreover, exposing children to natural physical surroundings has also been linked to positive neurodevelopmental effects. Nature-based school interventions, such as outdoor classrooms and green soundscapes, have been associated with improved executive function and reduced behavioral problems in children (19, 20).

While natural sounds are often associated with restorative and attentional benefits, they may also become sources of distraction or anxiety if they are unfamiliar, overly intense, or linked to threatening associations, such as howling wind, thunderstorms, or animal cries (21). In toddlers (23) and children aged 3–6 (22) with sensory processing disorders or autism spectrum conditions, even relatively mild natural sounds —such as rustling leaves or insect noises—may trigger sensory overload, leading to agitation and reduced cognitive performance. These findings suggest that the restorative effects of natural soundscapes depend not only on the sounds themselves, but also on their intensity, acoustic qualities, and the listener's individual sensory profile.

A growing body of research indicates that children (aged 4-17 years) residing in noisy urban environments may be at heightened risk for neurobehavioral difficulties (24). For example, Dreger et al. (25) found that exposure to road traffic noise was a significant risk factor for incident behavioral problems in school-aged children (ages 6-10), consistent with earlier findings by Evans ett al. (26) in children aged 9-10. Similarly, several studies have reported that higher levels of aircraft noise around schools is associated with increased hyperactivity symptoms among children aged 9-10 (25, 27, 28). Three studies in particular (30-32) reported significant links between traffic noise exposure and hyperactivity/inattention problems in children aged 7-11. Beyond hyperactivity, multiple studies have also linked exposure to road (25, 30–32), railway (32), and aircraft noise (25, 28) with difficulties in peer relationships and social functioning. More specifically, Weyde et al. (33) found that road traffic noise exposure was significantly associated with inattention at age 8, as well as with cumulative exposure to inattention from ages three to eight. Aircraft noise is often perceived as particularly disruptive due to its higher intensity and variability (29). Hygge et al. (34), studied children aged 8–12 years from schools near the old and new Frankfurt Airport in Germany who participated in a natural experiment examining the effects of chronic aircraft noise on cognitive performance, with assessments conducted before and after the airport relocation. The study found that children exposed to higher aircraft noise showed significant impairments in reading comprehension, long-term memory, and attention, while children experiencing reduced noise exposure after the airport closure

demonstrated improvements, indicating that chronic environmental noise negatively affects cognitive functioning in school-aged children. Sleeplessness is also a common consequence of environmental noise exposure (35), and studies indicate that children living in noisy environments may be at higher risk for elevated blood pressure and increased adiposity (36). Preschool-aged children exposed to urban traffic noise exceeding 60 dB(A) exhibited elevated systolic and diastolic blood pressure, suggesting that chronic noise exposure may trigger physiological stress responses during critical developmental periods (37). Collectively, these findings suggest that chronic exposure to traffic and aircraft noise is consistently linked to behavioral, attentional, and social difficulties in children, underscoring noise as a critical environmental risk factor for neurodevelopment.

Although natural sounds provide clear benefits, studies also suggest that certain urban environments—particularly those that incorporate natural elements—can support positive neurodevelopmental outcomes in children. Studies on urban acoustic enrichment suggest that thoughtfully designed urban spaces, which integrate desirable acoustic features such as water elements, vegetation, and controlled human activity, can create restorative soundscapes that enhance children's cognitive and emotional well-being. (38). However, it is important to note that these benefits are primarily derived from the integration of natural elements within urban environments, rather than from the urban elements themselves.

2.2 Physical health

In addition to shaping neurodevelopment and behavioral outcomes in children, natural and urban soundscapes can also exert measurable effects on physical health.

Exposure to natural landscapes—such as those featuring vegetation, water, or other natural sound elements that might indicate a benign environment in which to live—has been shown to alleviate physiological symptoms of stress (39). More recent work has expanded on these findings specifically in the auditory domain, demonstrating that natural soundscapes in forest and national park settings are linked with physiological signs of relaxation, such as decreased skin conductance and greater activation of the parasympathetic nervous system, both of which indicate relaxation and physical recovery (40). Similarly, natural sounds, particularly those involving water, have been associated with lower cortisol secretion, an essential stress hormone, when compared to music or silence, further underscoring their role in reducing stress hormones and promoting restoration (41). Beyond mood improvements, physiological changes have also been observed, with decreases in heart rate consistently correlated with exposure to natural sounds (41-43) Clinical evidence supports these patterns as well: patients in cardiac care units exposed to 30 minutes of nature sounds showed statistically significant reductions in heart rate and diastolic blood pressure, especially during the initial sessions (44). These individual findings are echoed in broader reviews; for instance, a meta-analysis of 15 studies including 1,285 participants spanning 3 continents confirmed consistent reductions in heart rate, systolic and

diastolic blood pressure, and respiratory rate following exposure to natural sounds (45). Taken together, this growing body of research highlights the restorative effects of natural soundscapes on physical health, suggesting they may serve as a valuable complement to stress reduction and recovery practices.

However, under certain conditions, exposure to certain types of natural sounds or environmental events can trigger acute stress responses and adverse health effects. Noises such as thunderstorms, loud animal calls (e.g., howling wolves, screeching birds), or sudden strong winds can activate the fight-or-flight response, increasing the heart rate, blood pressure, and stress hormone release (46). Frequent or intense exposure to these sounds may contribute to health issues such as hypertension or sleep disturbances (47). Studies have shown that intermittent natural sounds at night—like rain, wind gusts, or animal calls—can cause micro-arousals during sleep, reducing sleep quality and resulting in daytime fatigue or cardiovascular strain, particularly in noise-sensitive or vulnerable populations, such as individuals with sensory disorders or sensitive hearing (48).

Excessive urban noise presents many risks, with substantial evidence linking it to cardiovascular problems, sleep disruption, and other adverse health outcomes. Most research studies have focused on traffic noise, which is the dominant aspect of urban soundscapes. These types of sounds grab attention instantly, invoking an involuntary stress response in the body (elevated heart rate, cortisol release, heightened alertness). Research has shown that loud and persistent noise is associated with hypertension, heart attacks, and other cardiovascular morbidities (49, 50). Sleeplessness is also a common consequence of environmental noise exposure (51). Experimental research with animals further supports this link, showing that exposure to unpredictable environmental noise —particularly high-frequency or ultrasonic sounds—can disrupt sleep, fragment rest, and trigger stress-related physiological changes (52). These findings suggest possible parallels for humans, especially in relation to unpredictable natural sounds such as thunderstorms or sudden wind gusts, which may provoke similar sleep and stress disturbances in sensitive populations. Loud noises have been associated with major physiological pathways leading to increased blood pressure, heightened stress responses, disrupted sleep (6, 53), and a greater likelihood of adverse cardiovascular events (50, 54). A U.S. cohort study found that each 10 dB increase in residential noise exposure was associated with a 1.1–1.2 mm Hg increase in blood pressure and a 20% greater likelihood of treatment-resistant hypertension (55). Overall, millions of Americans face increased risks of hearing loss, heart disease, and other health conditions from pervasive noise exposure exceeding 70 dB(A), with urban residents particularly vulnerable to these hazards (56). Examples of pervasive urban noises that exceed 70 dB(A) include busy traffic noises, sounds from construction sites, and busy sporting events or street festivals. Research has also shown that the reason urban noise is so often associated with stress and mental health issues is because it contains prominent, startling stimuli, such as emergency sirens, screeching brakes, or car horns, that likely trigger an alert physiological and psychological state (57). The

effects of these persistent startling stimuli may resemble a state of near-constant exposure to a thunderstorm, maintaining the body in a prolonged state of physiological alertness (58). Over time, these harmful effects may build up in the body, leading to physical and cognitive strain as well (7).

While natural sounds offer clear benefits to physical health, studies also indicate that thoughtfully designed urban spaces and preferred urban sounds can contribute positively to residents' physical well-being. In a separate study, 120 senior adults were exposed to different sound recordings, including traffic noise, sports sounds, and music. Music was rated as the most comfortable and was associated with smaller increases in heart rate and blood pressure, suggesting that preferred urban-style sounds, such as background music, can mitigate physiological stress in built environments (59). This idea is supported by evolutionary perspectives on music, which suggest that music taps into long-standing auditory and emotional systems that help regulate stress, create a sense of predictability, and promote feelings of safety and comfort (60).

2.3 Mental health

There is increasing evidence that natural environments and their associated soundscapes can play an important role in supporting psychological well-being. The restorative benefits of soundscapes can be framed in terms of two prevailing theories of restorative environments, one of which is the Stress Reduction Theory (SRT) (61). The SRT posits that natural environments promote rapid, automatic recovery from stress because humans evolved in nature and are biologically predisposed to respond positively to it (58, 61). SRT emphasizes the physiological and emotional relief that occurs when individuals encounter calming natural environments, suggesting that sounds like flowing water, gentle wind, or birdsong can trigger automatic stress recovery.

Recent studies highlight the beneficial effects of the auditory aspects of nature, particularly birdsong, water, and wind sounds, which have been linked to improved mood and recovery following stressors (62, 63). Birdsong in particular has been associated with reductions in anxiety, depression, and paranoia, highlighting its potential as a restorative auditory stimulus that supports psychological well-being (64). Together, this body of evidence underscores the role of natural landscapes and soundscapes in fostering both emotional recovery and physiological relaxation.

It is important to note that not all individuals experience soundscapes in the same way, and sensitivity to noise can significantly influence the degree to which natural sounds promote psychological restoration. A population study of 1856 individuals aged 19-91 years residing in Ulsan and Seoul, South Korea, found that individuals with high noise sensitivity are at greater risk of depression, anxiety, and stress, regardless of whether the sound source originates from natural or urban environments (65).

Urban environments introduce additional stressors that may elevate risks for psychiatric and mood-related disorders. Traffic noise, for

example, has been linked to increased depressive symptoms (64) and higher overall rates of depression (66). More severe outcomes have also been observed, as studies estimate that ~ 30% of schizophrenia incidence may be attributable to urban factors interacting with genetic and social adversity (67). The risk of schizophrenia is ~ 2.4 times higher in the most urbanized environments than in the most rural ones (68), underscoring the significant influence of environmental context on mental health. Specific urban conditions—such as crowded proximity to strangers, heightened crime or visible police presence, unpredictable street interactions, and the chronic overstimulation of noise and sensory overload—can also create ongoing feelings of ambiguity and threat, which are known to trigger paranoia (69). In fact, state paranoia (temporary feelings of suspicion and mistrust, often triggered by specific threatening environments) has been shown to increase in response to traffic noise (70). Similarly, mood and anxiety symptoms occur at elevated rates in urban populations compared to rural populations (71), further reinforcing the psychological vulnerabilities linked to city living.

While natural soundscapes provide clear benefits, evidence also indicates that certain urban sounds and thoughtfully designed city environments can foster positive emotional and psychological outcomes. Although urban environments are often associated with noise and stress, certain sounds within cities can instead foster positive emotional and psychological outcomes. For example, human voices, laughter, and casual chatter have been shown to evoke joyful and uplifting emotional responses (72). More broadly, positive and pleasant sounds in urban contexts, including music, social voices, or natural sounds incorporated into the cityscape, have been associated with reduced stress, improved well-being, and restorative effects. This perspective highlights the value of considering some aspects of urban soundscapes as psychological resources, rather than solely as nuisances (4).

2.4 Cognition

Cognitive performance encompasses processes such as memory, reaction time, attention and focus, problem-solving, task performance, comprehension, and reasoning. Research has primarily focused on how exposure to natural soundscapes can support attention restoration and overall cognitive performance. One key framework describing this effect is the Attention Restoration Theory (ART), which proposes that natural environments help restore directed attention (the effortful attention used for tasks such as studying and problem-solving) by engaging the mind through soft fascination, a gentle and effortless form of attention (73). Exposure to stimuli with inherently fascinating qualities can draw involuntary attention, allowing fatigued directed attention mechanisms to recover (17). While SRT highlights emotional and physiological relief, ART focuses on cognitive restoration; together, these theories explain how natural or carefully designed soundscapes can promote well-being.

Empirical studies support these frameworks, showing that sounds like singing birds and flowing water reduce attentional demands and improve cognitive function in both clinical and everyday settings (21, 74). Laboratory research

further indicates that patients exposed to hospital soundscapes incorporating natural sounds demonstrate improved cognitive responses, including increased interest and understanding (75).

Despite positive findings, it is important to note that not all studies have observed consistent cognitive benefits from natural sound exposure, particularly when using objective measures of performance. The studies described above in positive effects of natural sounds on cognitive restoration were primarily based on self-reported experiences, while several empirical studies have measured cognitive performance using objective tasks. For example, one study employed a digit span backwards test—a neuropsychological assessment of working memory and executive function—to compare the restorative effects of different sounds (76). Interestingly, participants exposed to natural sounds did not perform better than those exposed to anthropogenic sounds. Similarly, a laboratory study assessing task performance before and after sound exposure found that although all sounds improved performance, there was no significant difference between natural and urban noise conditions (17). However, these inconsistent findings may be partly explained by differences in experimental stimuli, methodologies, and measurements across studies, highlighting the need for standardized approaches in evaluating cognitive restoration from soundscapes.

Urban soundscapes present additional cognitive challenges, with evidence suggesting that exposure to traffic noise and other city sounds can impair learning, attention, and cognitive efficiency across the lifespan. Exposure to urban soundscapes has been linked to a range of cognitive challenges, particularly in children and older adults. Studies have found that traffic noise and other urban sounds are associated with cognitive decline in adults (66). Neuroimaging research further suggests that urban soundscapes may reduce cognitive efficiency: increased brain entropy—a marker often linked to less efficient processing—has been observed in participants exposed to urban noise (77). Additionally, an fMRI study in which participants were randomly assigned to different soundscape conditions found that exposure to urban soundscapes was associated with increased activity in the superior temporal gyrus —an area involved in auditory processing— during cognitive tasks, suggesting greater processing demands and reduced cognitive efficiency (9). Collectively, these findings underscore the potential for urban noise to negatively affect cognitive function across the lifespan.

While much of the literature emphasizes the benefits of natural sounds, emerging evidence also highlights that thoughtfully designed urban soundscapes can have positive effects on cognitive and emotional functioning as well. For instance, soundscapes rated as pleasant by participants have been shown to activate additional brain regions compared to neutral soundscapes (78). However, Irwin et al. did not mention specifically which kinds of sounds were dominant in the “pleasant” vs. “neutral” sets. Similarly, ambient music, conversational murmurs, or well-designed environmental sounds can engage emotion-related areas of the

brain, potentially fostering well-being and contributing to cognitive resilience.

Table 3. Benefits and harms of natural and urban soundscapes

	Natural Soundscapes	Urban Soundscapes
Benefits	Improves anxiety (77) Reduces the psychological and physiological symptoms of stress (39) Restore cognitive function by reducing attention demands of the endogenous attention system (74) Beneficial effects on mood, arousal levels, and cognitive performance (21) Significantly alleviates anxiety, depression and paranoia (77) Mood recovery (after a stressor) or beneficial mood effects (63)	Children adapt to auditory distractions/build selective attention (34) Preferred urban-style sounds(like music) mitigate physiological stress (72) Human voices or music fostered a joyful and uplifting emotional response (72)
Harms	Unfamiliar, intense sounds, such as animal cries or extreme weather, become distracting or anxiety/stress-inducing. (21) May trigger sensory overload in children with autism spectrum conditions or sensory processing disorders. (22, 23) Thunderstorm noise linked to sleep fragmentation and increased heart rate variability (47)	Higher depressiveness (77) 30% of the incidence in schizophrenia may be attributed to urban factors (67) Risk for schizophrenia in the most urban environment is ~2.37 times higher than in the most rural environment (68) Key environmental factors known to trigger paranoia (threat/ambiguity) may be more often found in urban compared to natural environments (69) Elevated risks for mood/anxiety symptoms (71) Association between traffic noise and depression/cognitive decline (57) State paranoia - a symptom in psychosis - has been shown to increase in response to traffic noise (70)

3. Using soundscapes to better human health

Soundscapes play a critical role in shaping human physical health, mental health, cognitive health, and development. While natural sounds consistently demonstrate restorative effects, and certain urban sounds can provide benefits when intentionally designed, harmful noise exposure remains a significant risk factor across the board. These findings point toward practical opportunities for integrating soundscape

considerations into public health, education, and urban planning, ensuring that acoustic environments actively support; rather than undermine; well-being.

3.1 Policy and urban planning

Urban environments could more intentionally integrate high-quality, nature-based soundscapes into public spaces to promote psychological restoration and reduce stress in daily urban life. Prior studies have shown that urban acoustic environments incorporating naturalized sound elements—such as fountains, vegetation, and water features—can produce positive emotional and attentional responses among listeners (38, 79). Building on this evidence, the intentional integration of natural audible elements into built environments may help reduce stress and tension in high-pressure settings. Public locations such as schools, bus stops, and train or subway stations may particularly benefit from such soundscape enhancement. However, research also cautions that nature recordings which are artificially distorted, of low audio quality, or played at excessive volumes may cause annoyance rather than restoration, particularly when they disrupt concentration or ongoing cognitive tasks (46). Therefore, when designing these soundscapes, careful attention must be paid to sound quality and the absence of background noise, as poor audio fidelity can diminish or even reverse the intended restorative effects. Furthermore, restorative soundscapes are unlikely to be universally beneficial in all contexts. Their effectiveness may depend on how harmoniously they align with the surrounding environment and ongoing activities, as continuously imposing contextually mismatched or overly intrusive sounds—even natural ones—may increase distraction, cognitive strain, or discomfort rather than support well-being.

In city dwellings exposed to roadway noise, access to nearby green areas has been shown to significantly improve residents' well-being. These green spaces reduce long-term noise annoyance, lower stress-related symptoms, and encourage greater use of outdoor environments, even in otherwise noisy urban settings. This may be because, even in the absence of direct natural sounds, visual interaction with such natural environments can evoke internally associated natural soundscapes, potentially contributing to their restorative effects. In addition, exposure to natural surroundings has been associated with restorative health benefits, including improved sleep quality and reduced blood pressure (80). Together, these findings suggest that the strategic implementation of green spaces within urban environments may serve as an effective, multifaceted intervention for mitigating the adverse health effects of chronic urban noise while supporting psychological and physiological restoration.

Educational and clinical environments could purposefully integrate restorative natural sounds; or visual elements that evoke such sounds; to promote cognitive recovery, reduce stress, and improve attention and memory performance in children and other individuals. Empirical findings indicate that while moderate classroom noise levels, such as the 45 dBA background noise typically observed, do not enhance children's cognitive performance, the complete absence of auditory stimulation likewise fails to facilitate cognitive recovery

(18). Instead, exposure to restorative sounds—particularly those associated with natural water sources such as fountains or streams—has been shown to support cognitive restoration in children (17, 81). These results suggest that water sounds may be purposefully integrated into school environments, for example during intervals between classes, to promote recovery of key cognitive functions including sustained attention (the capacity to maintain focus over time) and short-term memory. Moreover, music and birdsong appear especially beneficial for children requiring restoration or improvement of response speed (18). In further applied contexts, such restorative soundscapes could be implemented in environments such as clinics, schools, and hospitals—for instance through the installation of fish tanks or indoor fountains in waiting areas or classrooms—to alleviate stress and enhance attentional and memory performance.

Environments intended to reduce stress and support well-being could adopt multisensory design strategies that combine natural sounds and visuals to create more immersive, restorative, and cost-effective spaces. Research has shown that audiovisual stimuli generally produce more restorative and calming effects than solely auditory or visual stimuli. The combination of natural sights and sounds enhances relaxation responses, reduces physiological stress indicators, and fosters a stronger sense of presence within a simulated natural environment (82, 83). These findings suggest that environments designed to alleviate stress—such as hospitals, clinics, schools, and workplaces—could significantly benefit from integrating both auditory and visual components that mimic natural settings. For example, pairing natural soundscapes such as birdsong or flowing water with posters or projections of nature scenes or physical plants and greenery may create a more immersive and restorative experience. Implementing such multisensory designs could serve as a cost-effective and evidence-based approach to improving occupants' psychological well-being and overall life quality.

Educational institutions could incorporate restorative design and scheduling practices to optimize students' attention, learning outcomes, and mental well-being. Studies show that people perform better on cognitive tasks requiring directed attention abilities after interacting with restorative stimuli (74, 84). This highlights the measurable cognitive benefits of exposure to restorative environments. In educational settings, these insights can be applied to improve student performance and well-being. For instance, schools—particularly at the middle and higher levels, where studies and focus are more significant—could strategically organize their timetables so that cognitively demanding subjects, such as mathematics or reading comprehension, occur after recess, lunch or other periods of exposure to restorative stimuli. These restorative experiences might include time outdoors, interactions with natural sights and sounds, or engagement in well-designed indoor environments that promote calm and attentional recovery. Incorporating such evidence-based scheduling practices could enhance students' sustained attention, academic performance, and overall mental health.

3.2 Hypothesis for differential responses to sound environments

Although many studies report differences in how natural and anthropogenic soundscapes affect stress, cognition, and emotional state(4, 6, 7), the mechanisms underlying these effects remain unclear. Several hypotheses may help explain why certain sounds tend to produce restorative responses while others are associated with stress or cognitive disruption.

One possibility is the predictability hypothesis, which suggests that sounds with stable, repetitive patterns, such as flowing water or steady rainfall, may be easier for the brain to process and anticipate. In contrast, irregular or intermittent sounds, such as traffic bursts or sudden mechanical noises, may require greater attentional monitoring and increase cognitive load (85).

A second explanation could be the informational load hypothesis. Some sounds carry signals that demand attention or interpretation, such as speech, alarms, or traffic cues. These sounds may require continuous monitoring, whereas many background environmental sounds convey little actionable information and may therefore place fewer demands on cognitive systems (86, 87).

A third possibility is the evolutionary signaling hypothesis, which proposes that humans may respond differently to sounds depending on the environmental cues they historically conveyed. For example, certain sounds, such as rustling leaves or gentle streams, may signal safety or resource availability, while others may historically have indicated potential threats, such as thunderstorms or predators.

Finally, the acoustic similarity hypothesis suggests that some anthropogenic sounds may trigger stress responses because their acoustic properties resemble those of naturally threatening sounds. Features such as low-frequency rumbling, sudden bursts, or high intensity - present in sounds like thunder or animal distress calls - may overlap with modern sounds such as aircraft or heavy traffic, potentially activating neural systems related to threat detection (88).

These hypotheses are not mutually exclusive, and responses to sound environments may emerge from interactions between acoustic structure, informational demands, ecological signaling, and learned interpretation.

3.3 Future research directions

While this paper highlights key findings on the cognitive and emotional benefits of restorative soundscapes, many aspects of this field remain open for exploration. Robust scientific evidence is critical for informing public policy, as meaningful and equitable environmental regulations cannot be developed without a strong empirical foundation. Therefore, continued investigation is essential to refine our understanding and guide the development of more effective, evidence-based applications of restorative sound design in urban and educational settings as well as understand how restorative sound interventions function across varying cultural, economic, and environmental conditions, particularly in regions where noise

pollution and limited access to nature may exacerbate psychological stress.

3.3.1 *The role of culture in shaping physiological responses to soundscapes*

While some recent research has begun exploring some of these suggested directions, such as cross-cultural differences in sound perception (5, 82, 89), most of these studies are still in early stages. Additionally, questions persist regarding how different populations and environments uniquely respond to various sound types and intensities. Moreover, much of the existing evidence is derived from WEIRD (Western, educated, industrialized, rich, and democratic) populations, limiting its applicability to more diverse or disadvantaged communities (90). Even within the same city, individuals with different socioeconomic access may have limited access to green spaces (91-94).

Humans are living in an era of rapid industrialization and urban expansion, as countries across the globe modernize and growing numbers of people migrate from rural communities to urban centers. This large-scale demographic shift is transforming the acoustic environments in which billions of individuals live. To better understand the health implications of these changes, it is essential to examine whether similar soundscape–health patterns emerge across different cultural contexts and across varying socioeconomic statuses, both at the individual level and at the level of the cities themselves.

In addition, research has not yet fully disentangled innate physiological responses to sound from the meanings and associations attributed to sounds through cultural and social influences. Urban and anthropogenic noise is typically framed as inherently detrimental, but this perception may arise from a combination of innate physiological reactions and learned association. An open question is whether contextual framing can, under certain circumstances, supersede baseline physiological responses to sound, and if so, which influence exerts the stronger effect and why. What we do not know is whether changing that association, without altering the acoustic stimulus itself, can meaningfully shift cognitive or physiological outcomes over time. For example, sounds such as traffic or machinery could be reframed as signals of connectivity, progress, or human ingenuity, while natural sounds like waterfalls could be associated with danger or loss of control. This question becomes even more compelling when considering infants, who exhibit differential responses to urban and natural soundscapes before acquiring abstract associations such as “technology enables progress” or “nature is restorative,” suggesting a foundational physiological component that later experience may modify.To further disentangle how life experiences may modify innate physiological responses to urban and natural soundscapes, future studies could experimentally manipulate contextual framing while holding sound exposure constant. For instance, raising groups of animal models in controlled sound environments (traffic noise, natural sounds) and later reversing exposures. Another option could be having human participants read contrasting educational narratives about technology and nature before presenting identical sound stimuli. Ultimately, comparing physiological responses and self-

reported preferences when only one soundscape is contextually reframed versus when both are reframed could help clarify whether long-term cognitive and health effects are driven primarily by perception, underlying physiology, or the interaction between the two.

The extent to which economic systems, religious traditions, and historical memory shape human responses to sound, in addition to the cultural narratives as discussed above, is another area that warrants further investigation. While individual experiences and preferences undoubtedly contribute to variation in how people perceive and respond to different soundscapes, existing research also suggests that there may be some universal reactions to certain types of sounds. Future studies should therefore aim to examine both individual variation and the social, cultural, and environmental factors that may help explain the extent to which these responses are universal, as well as why differences emerge across individuals and populations. Such work could include cross-cultural comparisons, longitudinal studies, and research examining how socioeconomic conditions, urban infrastructure, and cultural meanings attached to sound influence physiological and psychological responses. Expanding research in this direction would help clarify the balance between universal biological mechanisms and culturally mediated interpretations of sound.

3.3.2 *The role of bias and familiarity in soundscape research*

Another important direction for future research is examining potential normative biases in soundscape research. It would also be important to determine the origins and directionality of these biases—whether they reflect longstanding innate tendencies, culturally learned associations, evidence-based perceptions, or some interaction among these factors. Much of the environmental psychology literature emphasizes the restorative effects of natural soundscapes while highlighting the harms of industrial or mechanical noise. While existing evidence suggests that certain acoustic features commonly found in natural environments, such as moderate intensity and predictable temporal patterns, may support stress reduction and attentional restoration, it remains unclear whether these responses reflect purely biological processes, aesthetic preferences, or an interaction between the two. Future studies could address this question by experimentally manipulating contextual framing to examine how cognitive interpretation interacts with underlying acoustic properties in shaping responses to sound environments. This could be done by presenting participants with different narratives about sound sources (e.g., describing an industrial sound as progress or as stressful) before exposure, then evaluating their physiological response to the sound.

Throughout this paper, several points highlighted the positive role of human voices and social interaction, particularly in relation to mental health outcomes (4, 72). This pattern may reflect an intrinsic human tendency toward social connection and community, where exposure to familiar vocal sounds can elicit subconscious feelings of safety and relaxation (2, 6). Future research could further examine the underlying cognitive and physiological mechanisms driving these effects, as well as the

specific acoustic and contextual parameters that shape them. Key areas of inquiry might include the influence of vocal characteristics, such as tone, cadence, familiarity, and style of speech, on emotional regulation and perceived safety; potential demographic or cultural differences in how individuals respond to familiar versus unfamiliar voices; and the role of contextual factors such as volume, spatial perception, and emotional tone (e.g., laughter and casual conversation versus conflict or public announcements). Moreover, future work should explore how environmental noise sources, such as traffic, interact with or interfere with social soundscapes, and whether sounds typical of different social contexts, such as neighborhood gatherings, stadium crowds, or transportation hubs, are processed differently in terms of emotional and physiological response. Emerging research examining multisensory and culturally varied sound exposures (5, 82, 89) may provide valuable insights into these questions.

3.3.3 *The role of temporal exposure in shaping physiological responses to soundscapes*

Another important question is how much exposure to natural or urban soundscapes is needed to impact well-being. Current research offers promising insights but often focuses on short-term or controlled settings (e.g. 6, 77, 86), leaving gaps in our understanding of how these effects translate to real-world, long-term contexts. While natural sounds are known to be restorative, it remains unclear whether brief daily exposure provides similar benefits to longer, less frequent experiences. Likewise, the threshold at which urban noise exposure begins to produce harmful effects remains poorly defined, particularly given evidence that chronic exposure to traffic or construction noise may gradually increase stress and fatigue over time. Understanding these dose–response relationships - how much restorative sound is enough and how much anthropogenic sound is too much - will be key for guiding urban design and public health efforts aimed at improving auditory environments.

Building on these dose–response considerations, another open question is how long-term changes in soundscape exposure shape sensitivity to urban noise over time. Most studies implicitly assume continuous exposure, yet many individuals move between dramatically different acoustic environments across their lives. It remains unclear whether extended periods spent in quiet, natural settings recalibrate baseline stress or attentional systems, thereby amplifying the impact of urban noise upon re-exposure, or whether early-life exposure to urban soundscapes produces a lasting tolerance to such environments, even after prolonged periods away from them. This raises the possibility that duration and timing of exposure, not just intensity, may determine whether urban noise is experienced as disruptive or manageable. Clarifying how long an individual must be removed from, or immersed in, a given soundscape before these effects shift would add an important temporal dimension to existing dose–response models of auditory environments.

An additional direction for future research is the role of circadian alignment in soundscape perception. In everyday environments, certain sounds tend to occur at predictable times of day,

and alignment with these expectations may influence stress and attentional responses. For example, sounds designed to prompt action (e.g. bells or alarms) are typically salient and high in intensity, whereas routine background sounds (e.g. cooking, morning activity, or nighttime insect noise) may be processed differently depending on their timing and predictability. However, it is possible that highly salient sounds may elicit reduced stress responses when they occur in alignment with circadian expectations. This hypothesis could be tested by comparing physiological and cognitive responses to identical sounds presented at expected versus unexpected times of day. Such studies would help clarify whether predictability, acoustic structure, and temporal exposure interact to shape responses to sound environments.

Another important direction for future research concerns how the effects of sound exposure may vary across developmental stages. A substantial body of research has examined prenatal auditory exposure, demonstrating that fetuses can perceive and learn from sounds before birth (95-97). These studies suggest that early acoustic experiences may shape postnatal auditory recognition and preferences. However, despite this literature on fetal auditory learning, direct comparisons of how sound exposure influences health and cognition across developmental stages, such as infancy, middle childhood, and adolescence, remain relatively limited in soundscape research. In the present review, existing studies discussed in the early-life section primarily examine toddlers (approximately ages 1–3) and children between ages 4–17. Understanding how sound exposure during these early stages interacts with the maturation of the auditory system may be particularly important, as infancy and puberty both represent periods of substantial neural and physiological development. Future studies comparing responses to sound across prenatal, infancy, childhood, and adolescent stages could help determine whether the positive or negative effects of sound environments are more pronounced during sensitive developmental windows and whether these effects differ across phases of auditory system maturation.

3.3.4 *The role of individual differences in shaping physiological responses to soundscapes*

Another important area for future research is the role of habituation and neural plasticity in shaping human responses to sound environments. Individuals who grow up in chronically noisy settings, such as dense urban environments, may develop adaptive mechanisms that allow them to filter or selectively attend to relevant auditory signals while suppressing background noise. Some studies suggest that prolonged exposure to noise can influence auditory cortex development and attentional processing, potentially leading to enhanced selective attention or adaptive filtering strategies (34). At the same time, the long-term health effects of such adaptations remain unclear. While some individuals may demonstrate cognitive resilience to persistent noise exposure, others may experience cumulative physiological stress or reduced attentional capacity over time. Understanding these differences and their underlying causes may require integrating concepts such as neural plasticity, differential susceptibility, and

environmental adaptation. Future research examining how early-life acoustic environments shape auditory processing, stress regulation, and cognitive development could help clarify whether habituation represents a protective adaptation or whether it masks underlying cumulative health burdens associated with chronic noise exposure.

An additional unanswered question concerns how individual differences influence the perception and psychological effects of natural and urban soundscapes. For example, individuals with hearing disabilities may perceive and process soundscapes differently because auditory input may be distorted, reduced, or supplemented by assistive technologies. As a result, the positive or negative effects of certain sounds may be amplified, diminished, or qualitatively altered. Similarly, individuals who are more sound-sensitive, such as autistic individuals or those with high noise sensitivity, may experience urban and natural sound environments in ways that differ significantly from the general population. Personal history may also play an important role; prior experiences with certain sounds, such as trauma associated with loud noises, could shape emotional and physiological responses. In addition, environmental and cultural factors, including whether someone was raised in an urban or rural setting or within particular cultural sound traditions, may influence how sounds are interpreted and evaluated. Examining how these neurological, psychological, and cultural factors interact with soundscape perception would help clarify whether restorative or stressful effects arise primarily from acoustic properties of sound environments themselves or from individual interpretation and experience.

3.3.5 *Underlying acoustic features*

Building on this discussion, future research should further examine how different types of urban and natural sounds influence human perception, stress, and emotional response by recognizing that not all sounds within these categories are created equal. While many studies group environmental noise into broad "urban" or "natural" categories, the specific acoustic features of each sound type may have very different psychological effects. For instance, traffic noise, with its low-frequency rumbles and sudden intensity changes, may unintentionally resemble the auditory structure of natural sounds that historically signaled danger, such as thunderstorms, roaring water, or animal movement (98). These similarities could activate deeply rooted responses that heighten alertness or anxiety. By contrast, diverse natural sounds like birdsong, rustling leaves, and flowing water often vary rhythmically and tonally in ways that promote relaxation and cognitive restoration. These variations raise important questions about the specific acoustic structures that make some sounds beneficial while others are unsettling. Are rhythmic, moderate-frequency, and harmonically rich sounds inherently more calming, while irregular or abrupt sound patterns elicit stress responses?

Soundscape features may be more precisely characterized in terms of their acoustic properties rather than broad categorical labels such as "natural" or "urban." Key features include overall sound level (intensity), predictability (the extent to which a sound

follows stable, repeating temporal patterns), and spectral entropy (the degree of randomness in frequency content). While predictability describes how consistent and regular a sound is over time, spectral entropy captures the complexity of its frequency composition at any given moment. In other words, a sound may be temporally predictable yet still vary in how ordered or random its frequency content is. Together, these properties reflect how sounds are encoded and processed by the auditory system.

Within this framework, soundscapes occupy positions within a continuous perceptual space defined by these acoustic features, rather than belonging to discrete categories such as "natural" or "urban." For example, sounds such as flowing water or steady rainfall often exhibit moderate intensity, high temporal predictability, and relatively low spectral entropy due to their smooth, repetitive structure. In contrast, sounds such as traffic or construction noise may be characterized by higher intensity, lower predictability, and greater spectral entropy, reflecting their irregular timing and more complex frequency composition. Importantly, some anthropogenic sounds, such as music or human speech, may share key acoustic properties with natural sounds, placing them in similar regions of this space and helping to explain their frequently observed restorative effects.

This feature-based perspective offers a unifying explanation for inconsistencies in the literature. Studies that treat sound categories as homogeneous often overlook substantial variation within the categories themselves; as has been presented previously in this paper, not all natural sounds are calming (e.g. thunder), and not all urban sounds are harmful (e.g. music). By focusing on acoustic structure rather than labels, this framework accounts for such variability and enables more precise predictions of human responses.

It also provides a foundation for both computational and experimental approaches. Computationally, machine learning models could be used to learn mappings between acoustic features and human outcomes, such as stress, attention, and emotional state. By training models on large datasets of sound recordings paired with physiological and subjective measures, researchers could identify which combinations of features are most strongly associated with beneficial or adverse effects, shifting soundscape research from descriptive comparison toward quantitative prediction. Experimentally, researchers could test human responses to different sounds through controlled manipulation of acoustic features. Rather than comparing "urban" sounds to "natural" sounds, specific properties of sounds, such as predictability or temporal regularity, could be systematically altered while preserving the overall identity of the sound. For example, a sound clip of a stream could be modified to include intermittent, high-intensity bursts to introduce unpredictability, or traffic noise could be adjusted to exhibit smoother, more regular temporal patterns resembling rainfall. Measuring physiological and cognitive responses to these controlled manipulations would allow for direct testing of how individual acoustic features contribute to perceived stress or restoration.

3.3.6 *Interactions between soundscapes and other sensory modalities*

While this paper focuses specifically on sound, other sensory modalities may also influence human physiological health. Future research should also explore how smell and multisensory stimulation influence restoration and well-being. Natural scents, such as those from forests, flowers, or rain, have been shown to evoke calming physiological responses and reduce stress, suggesting that olfactory cues may play an important role alongside auditory and visual ones (99, 100). Aromatherapy studies, for instance, indicate that pleasant natural odors can lower heart rate and improve mood, but it is unclear how these effects interact with other sensory inputs (101). Would combining multiple natural stimuli, like sound, scent, and visual scenery, enhance restorative outcomes more than any single sense alone? What is the evocative contributory effect of the unpleasant odor of emissions on the psychological, mental and cognitive decline associated with the traffic soundscape? Understanding whether more sensory engagement leads to stronger or more sustained benefits could help guide the design of holistic environments, from urban parks to therapeutic spaces, that support mental and physical health through multisensory connection with nature.

Recent research has begun exploring some of the suggested directions above, such as multisensory restoration and cross-cultural differences in sound perception, but most of these studies are still in early stages(5, 82, 89). More work is needed to expand on these ideas through larger, long-term, and real-world investigations.

Table 4. Key unanswered questions in soundscape–health research

1. How do culture and socioeconomic status shape responses to soundscapes across individuals and cities?
2. How do physiological responses interact with meaning, context, and learned associations, and can these override baseline reactions to sound?
3. What acoustic features make sounds stressful or beneficial, and do anthropogenic sounds mimic naturally threatening sounds?
4. How do responses to sound differ across developmental stages, and how do early-life exposures shape long-term outcomes?
5. Are there sensitive periods when sound exposure has stronger effects?
6. Do individuals in noisy environments develop adaptation or accumulate long-term harm?
7. What role do neural plasticity and habituation play in soundscape perception?
8. How do duration and intensity of exposure influence soundscape effects?
9. How does timing of sound (circadian alignment) affect stress and attention?
10. Do predictable daily sound patterns reduce stress compared to irregular sounds?
11. How do other sensory inputs interact with sound to shape perception?
12. How do neurodivergence, hearing ability, and noise sensitivity affect responses?
13. How do economic systems, religion, and historical memory influence sound perception?
14. Are soundscape preferences driven by biology, aesthetics, or both?
15. To what extent do innate responses differ from learned responses across cultures?
16. How do soundscape effects vary between individuals and populations?

4. Conclusion

Soundscapes play a vital role in shaping human health and development, yet their influence remains underrecognized in modern society. As urbanization accelerates and human environments increasingly diverge from the acoustic conditions under which humans evolved, the sounds surrounding daily life may exert profound effects on neurodevelopment, cognition, stress physiology, and both mental and physical well-being. This paper has argued that responses to soundscapes cannot be fully understood through broad categorical distinctions such as "natural" versus "urban" alone. Instead, it proposes a more integrative framework in which human responses emerge from interactions among acoustic structure, temporal predictability, informational load, evolutionary signaling, contextual congruence, habituation, cultural interpretation, and multisensory integration.

In addition to synthesizing existing evidence on the restorative and harmful effects of different sound environments, this review highlights several underexplored dimensions of soundscape research, including the roles of developmental timing, circadian alignment, contextual framing, sensory sensitivity, social meaning, and long-term adaptation to changing auditory environments. It further emphasizes that restorative effects may depend not only on the presence of natural sounds themselves, but also on their harmony with surrounding activities, environments, and associated sensory cues. Collectively, these perspectives suggest that soundscape perception is shaped not by isolated acoustic stimuli alone, but by dynamic interactions between physiology, experience, environment, and cognition.

Advancing soundscape research beyond short-term, WEIRD-centered studies toward longitudinal, cross-cultural, mechanistic, and multisensory approaches may therefore provide a more comprehensive understanding of how humans perceive and adapt to their auditory environments. Such insights could help guide public health policy, urban planning, education, and architectural design toward the creation of healthier, more cognitively restorative, and psychologically supportive environments in an increasingly urbanized world.

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