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Negative Responses to Urban Residential Noise as a Social Rebound Effect of Increasing Population Density: Legislative Challenges and Auditory Territoriality

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Abstract

Populations in cities are projected to increase globally, densifying urban residential environments with both positive and negative effects. Positive social effects are offset by negative health effects however; urban residential noise has been identified in a large number of studies as a significant contributor to social unrest as well as a risk to physiological and psychological health caused by stress, making this topic highly relevant to the discussion on sustainability urban growth. Focusing on the psychological rebound effect of urban residential noise, this paper attempts to explain how and why auditory aspects of the spatial environment negatively influences urban residents. To provide context and to indicate areas in need of improvement, the legislative challenges to be faced are considered, with Sweden as a prime example of a first world country grappling with the effects of increased urban density. Existing building legislation regarding residential noise is considered in relation to studies investigating the effects of residential noise on psychological and physiological

health, outlining areas in need of future development. Then, health responses to residential noise are placed in a broader evolutionary context by considering how these effects might be the result of triggered evolutionary mechanisms for keeping population size optimal. Further, the spatial dimension of hearing is discussed with reference to theories of territoriality in environmental psychology and the concept of auditory territoriality is described.

Keywords: Urban density, residential noise, auditory territoriality, social rebound effects

INTRODUCTION

How does intrusive noise inside the home contribute to problems associated with urban population density? Noise is primarily defined by the fact that it is *unwanted* [1] and has therefore been identified as the main cause of neighbour disputes in many countries.[2,3,4,5] The topic of residential noise is of increasing importance to the development of sustainable cities as urban spaces grow more populated and people live in increasing proximity to one another, a trend that is expected to increase.[6] Although the negative health and psychological effects of population density for humans[7,8] and animals[9,10] have been extensively researched, urban density has been seen as a positive step towards meeting sustainability targets from a theoretical standpoint. For example, living in closer proximity could mean lower carbon emissions from transport sectors, and indeed results from a large-scale study carried out on 10,093 cities in the USA indicate that carbon emissions decrease logarithmically after a threshold of 3000 people per square mile has been reached[11]. However, the relationship between society and sustainability is more complex, as benefits are often offset by unforeseen circumstances, referred to by Greening, Greene and Difiglio (2000)[12] as “rebound effects” within the field of energy efficiency and consumption, but conceptually applicable to other areas. This is exemplified in the case of carbon emissions and urban density, for as the city grows, a wealthy suburbia also springs up around it in which carbon footprints are generally higher.[11,13] Similarly, although the psychosocial benefits of urban density are also considerable, such as increased access to resources such as jobs, goods, and psychologically beneficial support networks, these benefits are also offset by the possible negative effects for mental and physical well-being, leading to what could be considered a psychosocial “rebound effect”.

Peen, Schoevers, Beekman, and Dekker (2010)[7] conducted a meta-analysis of studies comparing high- and low-density groups, which shows that city dwellers are more prone to psychiatric, mood, and anxiety disorders. Increased activity in areas of the brain responsible for regulating negative affect and stress in city dwellers indicates a biological underpinning, but the variety of socio-environmental factors that contribute to this, including pollution, toxins, crowding, noise, and demographic factors, need to be considered in some detail.[14] As neighbour noise has been identified as a central obstacle to public well-being in a number of studies,[2,3,4,5] the purpose of this article is to consider the role that low-level residential noise might play in contributing to the psychological and psychological health effects of increased urban density. More specifically, how and why sounds which are not necessarily damaging to the ear, and yet constitute an unwanted intrusion into one’s home environment, might negatively affect those living under such conditions.

An overview of the existing residential noise legislation in Sweden will also be given in order to highlight the challenges that face regulatory bodies as neighbour noise becomes an increasing problem and the literature on its negative health effects grows. Sweden is used here as a lens for examining this issue in a prominent first-world European country under the

strain of increased urbanization, however, it is emphasized that this issue has international relevance due to the similarity and rate of social change worldwide. A discussion section also considers which psychological and evolutionary mechanisms might explain the responses to low-level yet unwanted noise occurring in dense urban settings, with specific regard to Christian's[15] social stress theory, Wilson's[16] evolutionary arguments, and the contribution of the auditory system to human territoriality.[17] Ultimately, this article argues the case for reformed noise legislation and stricter regulation of the built environment to reduce the psychological effects of residential noise worldwide.

Noise legislation in Sweden

The health and cognitive effects of intrusive sounds have been exhaustively examined in classroom and office environments.[18,19,20] Already this research has begun to influence legislation, but this process is still in need of development, as exemplified by the current building acoustic standards classification of schools in Sweden (SS25268: 2007). Swedish acoustic standards for indoor environments are ranked according to sound classes A to D, which specify the required quality of the sound environment. Class A is suitable for spaces and activities where a very high-quality audio environment is prioritized. Sound class B is suitable for spaces and activities where a "better" sound environment is prioritized. Sound Class C provides sound conditions that meet the *minimum* requirements of the Board of Directors' regulations, BBR (Boverkets Byggregler), and sound Class D is intended to be applied only when audio class C is unable to be reached due to technical or economic constraints. Currently, classrooms in Sweden are ranked as Class C sound environments.[21] This gross oversight shows an obvious underestimation of the role of speech in education and a lack of understanding of how unwanted sounds affect cognitive functioning and performance despite the abundance of research available on the topic.[19,22]

Similarly, there is a high volume of ongoing research on the effects of environmental noise resulting from street and airplane traffic on pre-clinical and clinical health outcomes,[23,24] but a gap in research concerning interior residential noise, which this article highlights. Residential noise consists of both noise that is present in the environment in which the building is placed ("environmental noise"; i.e. aeroplanes, traffic noise) and noise within the building ("interior noise"; i.e. noise from neighbours). In Chapter 2, section 6a of the Swedish Planning and Building Act (PBA; 20100:900), regulations state that the environment in which a building is placed should be free of noise at a level that harms human health; noise, in this case, is defined as "a disturbance that, according to medical or hygienic assessment, could detrimentally affect people's health and that is neither insignificant nor completely temporary". However, incidents of resident complaints such as those mediated by the Vaxjö Land and Environmental Court in Sweden have prompted more refining of definitions as to what constitutes a harm to human health. As such, the Government Bill 2013/14:128 reviewed the PBA's definition in light of how noise is defined in the Swedish Environmental Code (EC; 1998:808) in an attempt to streamline definitions of noise and its harmfulness between the two regulatory frameworks. As of the beginning of 2015, the revisions proposed by this bill include a coordination of definitions of noise disturbances, new requirements for noise pollution prevention in the planning stage of new residential buildings, individual assessments of environmental effects prior to the granting of planning permission, and continued assessment of noise disturbance so as to account for incorrect noise projections prior to building. This legislation directly affects the building sector by requiring a more comprehensive environmental noise survey, and therefore a higher financial burden.

Although legislation states that residential buildings must be built in a way and place that does not threaten the health of the occupant due to environmental noise, the laws with regard to residential neighbour noise are conspicuously lacking in Sweden. However, there is an accumulating body of evidence that should begin to inform policy decisions going forward. For example, in 20022003, the World Health Organization (WHO) carried out its "LARES" Survey (Large Analysis and Review of Housing and Health) in Europe, covering roughly 400 households and 1000 inhabitants in each city. A study based on data drawn from LARES showed that there was an association between long-lasting severe annoyance and emotional stress caused by neighbour noise and cardio-respiratory illnesses (bronchitis), arthritis, depression, and migraine in adults and children.[25,26] The overall results of Lares concluded that neighbour noise can be defined as a health risk comparable with traffic noise and recommended improvement in sound insulation in residential buildings.[27] However, a more recent and exhaustive review carried out by the International Commission on Biological Effects of Noise was silent on the topic of neighbour noise,[18] further indicative of this "blind spot", but confirmatory evidence of Lares findings can be found elsewhere too. For example, a longitudinal study conducted in the Netherlands widened this view of the health effects of neighbour noise, surveying 5000 adults over a period of 5 years (2008–2013) and concluding that interior neighbour noise was even worse for health than environmental noise from the street.[28] Although still developing, this gap with regard to regulations for interior residential noise has not gone altogether unnoticed. A European Union funded project known as COST Action TU0901 "Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions" was ongoing from 2010 to 2013 and aimed to assess the degree of the neighbour noise problem.[29] Furthermore, environmental health initiatives such as I-ACT have set out a framework for policy change to respond to this growing problem.[30] Despite this body of evidence, the WHO's most recent attempt to provide noise guidelines for the European region based on comprehensive systematic reviews of the noise literature[31] stated that it was unable to take account of neighbour noise due to the noise-exposure mapping process used (END 2002/49/EC), and therefore "such a noise has not been considered in the development of the WHO Environmental Noise Guidelines".[32]

Together, these provide questionable indications that authorities hope to take appropriate measures in the coming years and highlight a dearth of guiding literature for policymakers to determine fixed criteria for what constitutes a noise disturbance as well as levels of acceptability. For example, neighbours having loud parties every weekend would break obvious boundaries, whereas a neighbour in an adjoining flat with three small dogs that bark intermittently from 4 AM every morning would not, even though the latter might be even more detrimental to one's health due to sleep loss. One thing is certain: the standards that currently exist are not sufficient for coping with the additional noise burden predicted by an increasingly dense urban future.[33,34] The research that will now be discussed indicates that this is a legislative gap that needs to be strongly addressed worldwide as cities are projected to hit increasingly dense population targets.[6]

Effects of low-level residential noise of psychological and physiological health

Neighbour noise can be anything from the most extreme to lesser complaints, but current criteria for assessing what constitutes acceptable versus unacceptable neighbour noise is based on sound pressure level (SPL), namely, an objective measure of a sound's perceptual loudness. However, research has shown that that SPL is insufficient to explain psychological responses to residential noise. Researchers have argued that rather than considering

residential noise to be a physical quantity with corresponding acoustic measurements, it should also be considered as a socially constructed phenomenon.[35] Indeed, removing the social context from a consideration of the effects of noise does not make much sense as the word itself is negatively valenced, most often referring to something "heard in the wrong time or place"[36] by people that are otherwise tolerant of reasonable degrees of sound disturbance.[35] In considering this social dimension, researchers conducted a study evaluating transcriptions of 30 hours of noise-related neighbour dispute discourse from telephone calls to mediation centres in the UK as well as follow-up interviews and mediation sessions in order to determine how conceptions of noise are formulated and described. Their findings indicated that the most frequent lexical descriptors included "screaming", "crying", "banging", and "shouting", all of which describe sounds with a social dimension. They also found that noise formulations were temporal in nature, that is, defined by the fact that they occurred frequently and for long periods. Other descriptors used in noise complaints include: music, television, radio, voices, playing children, footsteps, losing and banging doors, sockets, switches, impacts on kitchen work surfaces, plumbing noises, and appliance noises (e.g. washing machine, vacuum cleaner, telephone).[37] Owing to the multiplicity of neighbour noise sources as well as their social complexity, the effects of neighbour noise have proven to be extremely difficult to quantify and empirically test.

Responses to neighbour noise also range from extreme disturbances to comparatively mild ones. For example, in response to a housing company's resident report of extreme irritation due to the flushing of a toilet in a downstairs apartment, a study by Kitamura, Sato, Shimokura, and Ando (2002)[38] considered, from an acoustic and neurological standpoint, why a sound of 35 dB (decibels) measured in the apartment in question should be considered so irritating to this resident; 35 dB corresponds approximately to the volume of a quiet voice talking. Researchers suggested the sound has spatial and temporal features that the brain is sensitive to and would be stimulated by, producing unwanted awareness of the sound in question regardless of the relatively low level. They concluded that studies that only take overall SPL and frequency into consideration would not have accounted for the negative acoustic effects that came about as a result of other acoustic features, namely, spatial and temporal ones. This resident's complaint highlights the fact that annoyance is subjectively and not acoustically (i.e. objectively) determined, and therefore non-acoustic factors (e.g. psychological) relating to the resident must be taken into consideration when defining their influence.

The role of self-reported subjective as well as reported acoustic factors in quantifying neighbour noise disturbances is prevalent in the literature. In a study looking at reactions to floor impact noise in apartment buildings, non-acoustic factors that might mediate coping with residential annoyance caused by floor impact noise were considered.[39] The researchers found that noise sensitivity and annoyance, attitudes to authorities (which could be contacted in the case of noise issues), relationships with neighbours, and marital status contributed to subjective reactions. Furthermore, higher noise annoyance indicated an increase in "avoidant coping behaviours" (e.g. putting on music to mask the noise) and health complaints (headache, stomach ache, and tiredness). In a related study, Ryu and Jeon[40] found that awareness of, and annoyance caused by, indoor residential noise consisting of floor impact, airborne noise, and drainage noise was highly influenced by annoyance and noise sensitivity. Meanwhile, Yang, Kim and Moon[40] looked at conditions that might exacerbate reactions (noisiness, loudness, annoyance, and complaints) to floor impact noises, namely, room air temperature (range: 20–50°C) and background noise levels. Results indicated that noisiness, loudness, annoyance, and complaints regarding floor impact noise

increased in relation to SPL of the background noise, but the relationship with room air temperature was less clear and showed peak annoyance at 25°C.

The relationship between sub-clinical measures of health and residential noise as well as noise-driven stress and annoyance has also been investigated. Wallenius[41] reported how residential noise, including neighbour and traffic noise, impacted on everyday restorative activities (sleeping, relaxing, reading, studying, and watching television) and subjective health in noisy versus quiet residential environments. Results suggested that noise annoyance and associated disturbances in restorative activities were significantly related to poorer subjective health as well as more self-reported somatic symptoms, such as stomach aches and runny nose, after negative affectivity in participants was controlled for. Findings indicated that neighbour noise from inside the house was more associated with health than traffic noise, ostensibly due to the disruption in restorative activities.

Epidemiological surveys have tried to establish a strong link between neighbour noise and health outcomes, primarily through linking noise with the evocation of slight to extreme annoyance as well as sleep disturbances, both of which are linked to health outcomes.[25,26] The LARES study indicated that one or more sources of neighbour noise (described as "neighbour flat noise, stairwell noise, noise from children playing in buildings, as well as the annoyance from noises within the dwelling") were associated with disturbed sleep or frequently occurring annoyance in 9.5% and 47.6% of respondents, respectively.[25,26] Neighbour-noise invoked moderate annoyance was reported by 35.2% of LARES respondents, while strong and extreme annoyance was reported by 12.4% of respondents (the remaining 52.4% of respondents were undisturbed).[26] Results from their adult respondents indicated 1.3 times higher odds of allergies, arthritic symptoms, cardiovascular symptoms, and hypertension in the moderately annoyed group, after controlling for a number of relevant confounding factors (including smoking, body mass index, exercise and alcohol consumption, satisfaction with residential and green areas, and perception of their dwelling, including temperature and daylight). Severe annoyance in adults was linked to significantly higher odds for allergies (1.4), asthma (2.3), bronchitis (1.9), cardiovascular symptoms (1.9), depression diagnosis (1.8), hypertension (1.7), migraine (1.8), respiratory symptoms, and trend towards depression (1.9; according to the sleep disturbance, anhedonia, low self-esteem, and appetite change screening tool). Meanwhile, children also registered higher odds of having respiratory symptoms and bronchitis (2.6), while the elderly seemed particularly vulnerable to musculoskeletal disturbances such as arthritis (1.3).[26] Although a causal relationship due to the correlational nature of the LARES survey, it was concluded that the soundness of the methodological approach used, as well as the potential for noise to produce stress and thereby changes in the psychological, musculoskeletal, respiratory, and cardiovascular systems, provides strong substantiation for these findings to warrant serious consideration.[25]

Another study assessed nationwide mental and physical health symptoms associated with neighbour noise exposure in those living in multi-storey housing in Denmark, while controlling for a number of factors (sex, age, marital status, education, degree of urbanization, owner/tenant status, and ethnic background).[42] Noise annoyance was assessed in terms of "very" and "slightly" annoyed and the type of noise was only vaguely defined. Odds ratios for slightly - very annoyed compared with those who were unaffected indicated that noise was associated with pain or discomfort in the shoulder or neck (1.3; 1.7), pain or discomfort in the arms, hands, legs, knees, hips or joints (1.3; 2.2), pain or discomfort in the back or lower back (1.6; 3.3), fatigue (1.5; 2.9), headache (1.2; 1.8), sleeping problems

or insomnia (1.5; 2.6), melancholy, depression or unhappiness (1.5; 2.1), and anxiety, nervousness, restlessness or apprehension (1.6; 2.6). Reported physiological problems in people who were very annoyed by neighbour noise were much higher in women than men.

However, the specific acoustic qualities of the neighbour noise associated with complaints are almost always vaguely defined in studies and also almost never subject to objective measures. It should also be emphasized that correlational studies are unable to determine a causal direction and therefore cannot clarify whether neighbour noise is a risk factor for illness or whether those who are more susceptible to illness are also simply more likely to be noise sensitive. Given the incidences of health problems in highly noise-sensitive people,[43] this could offer an alternative explanation. In a wide variety of results from a large survey examining the health effects suffered by those with higher sensitivity to noise, Park et al.[43] found that noise-sensitive people were 1.43 times more likely to experience tinnitus, 1.54 times more likely to be diagnosed with diabetes, 1.78 times more likely to be taking or have taken psychiatric medication, 2.24 times more likely to have a depression diagnosis, 1.89 times more likely to be in the stress group, 2.05 more likely to be insomniac, and 1.93 times more likely to have reported anxiety. They concluded that noise sensitivity and not the level of the offending noise was a risk factor for psychological and physiological illnesses.

One thing these studies cumulatively confirm is that noise is a big problem for a lot of people, causing annoyance and loss of sleep. Although identifying whether neighbour noise complainants fit a particular psychological profile is certainly a step in the right direction, it does not change the fact that mitigation of neighbour noise is the only solution to this widespread urban problem. Research is now desperately needed that strongly tracks links between specific acoustic characteristics of noise and psychological and physiological health variables over time (whilst simultaneously controlling for the abundance of relevant confounds) so that a causal direction can finally be ascertained.

Discussion: Evolutionary and environmental psychological explanations for responses to low-level neighbour noise

What makes unwanted yet relatively low-level sounds lead to the activity and sleep disturbances, negative emotional responses, and perceived ill health, which constitute the primary causes of neighbour disputes and residential complaints?[44] Starting with the broader context, the evolutionary bases of these responses will first be discussed as a possible explanation for understanding negative responses to urban population density, in which negative responses to noise could act as a “density-dependent control” developed to keep population size optimal.[16] Then, developing on theories of territoriality in the environmental psychology literature, the concept of auditory territoriality is proposed as an underlying mechanism that mediates between the cause (e.g. residential noise) and its effects (annoyance, illness, etc.).

Non-animal studies have found that under conditions of increasing social density, negative biological and social abnormalities begin to occur. Under extreme conditions, effects include lower fertility in males and females, increased mortality in infants and adults, the development of abnormal social hierarchies, decreased immune response leading to greater incidence of disease, and abnormal hormonal activity.[23] Extreme cases have been notably violent in the animal world, as in the increased aggression and mass suicides of lemmings as population sizes reach unsustainable tipping points.[10] Calhoun[9] studied the change in

behaviour of rats in a famous experiment and surmised that these oddities are part of an evolved response to overpopulation, which aims to maintain an "optimal group size" in which there is a balance in "gratifying" versus "frustrating" experiences. On the human level, high social density has been found to impact humans by increasing stress[14] whilst decreasing opportunities for restoration from stress and fatigue.[45] Environmental factors that occur as a knock-on effect of urban population density such as noise pollution (planes, traffic, neighbours) are the cause of physiological responses such as increased adrenal activity and other markers of stress.[45,46,47] These effects are not merely negative but perhaps serve an evolutionary function. Human and animal existence is density dependent and when population density exceeds the levels that environmental resources can support, extinction becomes a very real threat.[48,49] Christian[15] theorized that physiological (e.g. endocrine) responses in mice reacting to environmental stressors of population density could be a "density dependent physiological mechanism", providing a feedback system that triggers susceptibility to disease and other hardships, thereby indirectly keeping social density at the optimal level. Therefore, these density-dependent controls could be natural selection's way of adjusting populations according to negative responses to social density such as disease, aggression, and stress.[16]

As has already been discussed, noise is an urban environmental stressor that is a predictor for a large variety of worrying physiological and mental health effects.[18,50] As individuals monitor and evaluate their environment on the basis of sensory input, it is plausible that increases in certain types of auditory input could be used as markers of overpopulation, indirectly triggering evolutionary responses that curb population size. Population density increases at the expense of human residential space as city planners struggle to keep up with the rate of urbanization in cities. Crowding due to urban population density is intrinsically connected to human territoriality and connected notions of survival. For humans, a primary territory is a geographical area which is perceived to be owned, with attending notions of control over that space and being able to mark or personalize it.[17] Defence is inherent in the notion of territory, as territorial boundaries need to be maintained for survival, and therefore responses to perceived invasion of territory are often extreme and marked by certain behavioural responses such as hostility, aggression, and violence, as exemplified in an extreme case by the phenomenon of war. On a smaller scale, it is natural for people to perceive a violation of their territory, such as trespassing, with an emotional response at the very least; as a result, the legal limits of individuals' rights regarding their owned territory and right to limit access to it and defend it are continually being tested and redefined.[51] As perceived territorial boundaries are spatial and the auditory system is fine-tuned to perceive and interpret spatial cues (i.e. localization),[1] audition plausibly plays a significant role in establishing and maintaining territorial boundaries. Ears provide 360° coverage of the environment, and therefore humans and other animals rely heavily on auditory signals to warn them of approaching danger. Humans are thus biologically designed to urgently respond to signals that are considered to be invasive of their territory. Under dense urban or overpopulated conditions in which territorial boundaries are continually tested, "auditory territoriality" is continually triggered. This could account for reported sensitivity to low-level sounds which would otherwise be perfectly acceptable in a secondary or public territory (e.g. people talking at the next table in a restaurant), but which are received with annoyance, irritability, and even hostility when perceived in the listener's primary territory. It is also probable that levels of annoyance grow in proportion with the frequency of occurrence, duration of occurrence, and intensity level of the perceived invasion. This would explain why these factors are already primary considerations when shaping current requirements for noise

laws and are the primary independent variables considered when looking at the impact of noise on health across the broad body of noise research.[34]

CONCLUSION AND OUTLOOK

Urban noise constitutes one of many potential hindrances to sustainable urban growth. Neighbour noise has been identified as a primary cause of neighbour complaints in many countries and potential relationships with health have been identified. The concurrent analysis of noise research and legislation indicates insufficiencies and highlights that legislative bodies are in need of groundbreaking research regarding the scourge of neighbour noise to support reforms. This article has also considered how neighbour noises constitute potential psychological and physiological stressors capable of evoking territorial responses, namely, "auditory territoriality", which might serve as a trigger for density-dependent controls (e.g. sub-clinical and clinical psychological ill health) serving the function of keeping population size optimal throughout our evolutionary history. Therefore, this article is a rallying call for academic institutions and legislative bodies to turn their gaze towards co-creating a sustainable future for those living in increasingly dense urban environments.

A major stumbling block for policy change is that, in most countries, neighbour noise is legislated under nuisance rather than noise regulations.[28] However, legally enforced behavioural constraints for urban should not be the only area of reform. Building regulations for interior noise are currently insufficient for mitigating disturbance; it is arguable that buildings should be designed for the "worst-case scenario" so as to pre-empt the most disagreeable conditions rather than designed with considerate and amicable neighbours in mind. Furthermore, owners of old buildings need to be legally accountable for bringing their buildings up to acceptable regulation standards.

Most important, it must be recognized that the effects of neighbour noise impacts most strongly on mental health and, as such, their effects might be invisible but not insignificant. Future research programmes are needed to quantify the extent of residential noise and within the context of increasing urban densification in more detail. Owing to the literature on noise sensitivity, it is essential to consider relative risks according to individual differences in personality, anxiety profile, sensory processing sensitivity, perceived quality of life, and other relevant predictors. Furthermore, it is probable that those experiencing higher levels of discomfort engage in certain behaviours that could further mitigate the positive environmental effects of increased urban density. Therefore, potential environmental rebound effects should be evaluated, such as the increase in air travel as a means of escaping an urban environment that has developed unsustainably. Finally, the environmental, physical, and psychosocial effects of urban densification need to be considered holistically so as to ensure a sustainable future for urban dwellers.

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