Sound, Safety & Society - Research on Sound & Sustainability

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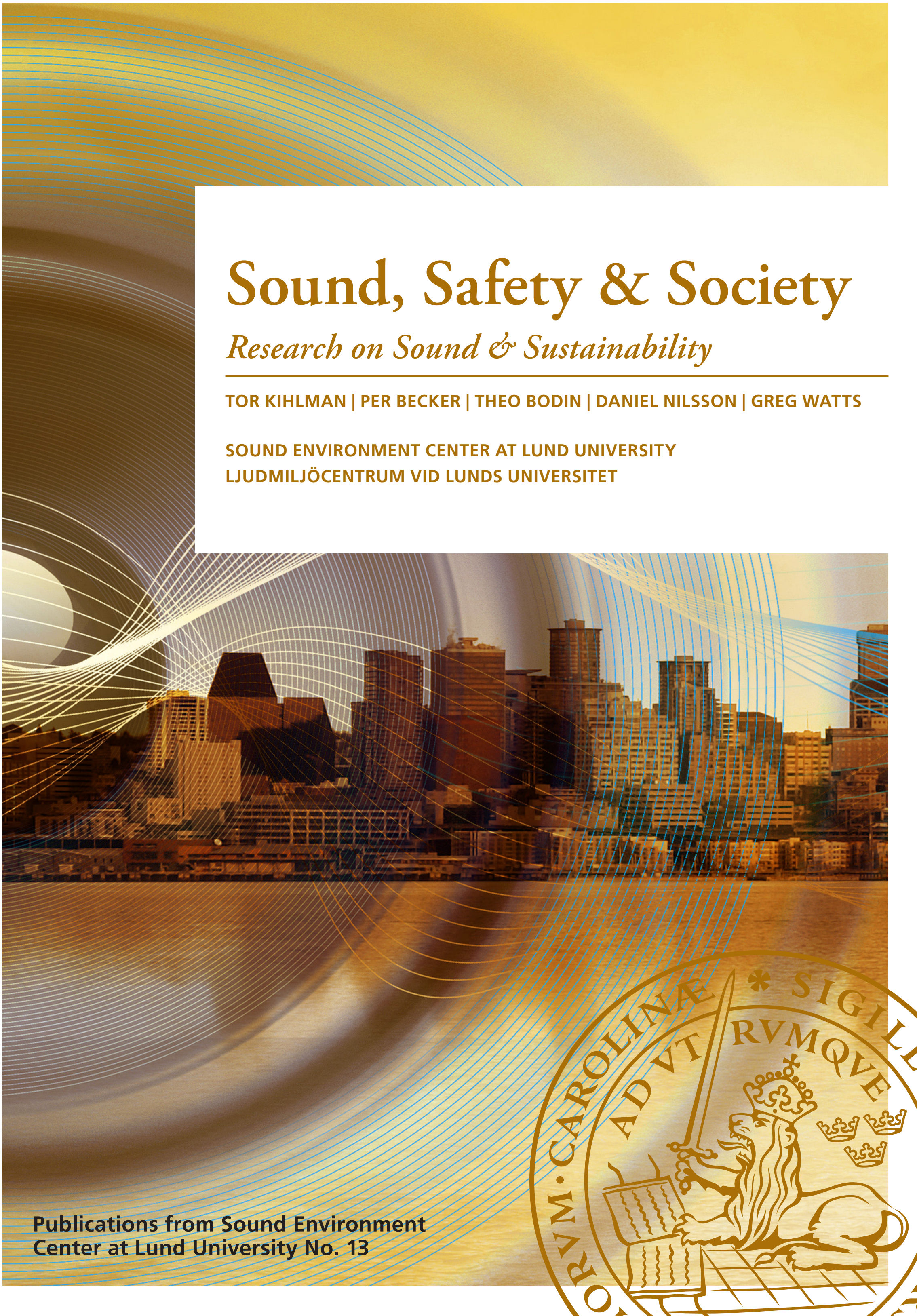

Sound, Safety & Society

Research on Sound & Sustainability

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SOUND ENVIRONMENT CENTER AT LUND UNIVERSITY
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Contents

Preface

Sustainability, resilience and safety are features of society that are more affected by sound environments than is generally acknowledged, even though other environmental threats may appear more prominent. However, when noise levels reach the limits of sustainability in society, its resilience to destructive processes of many kinds will be challenged.

In an interdisciplinary symposium in 2014 arranged by *The Sound Environment Center* in collaboration with the *Centre of Societal Resilience* at Lund University, a number of researchers came together to discuss aspects of safety, security and sustainability in society with regards to the sound environment. The presented research and subsequent discussions stressed the importance of beneficial sound environments not only for the health and well-being of citizens but also for security systems to work satisfactorily.

Rising exposure to noise from traffic and transport is evidently one of the major factors threatening health and well-being for millions of people in the world today. The World Health Organisation (WHO) has published a report on *Disability Adjusted Life Years* in Europe, "DALY´s". The WHO also produced a report from the department of emerging health risks on the development of hearing disorders connected to the use of portable music players in mobile electronic devices. Both reports made a major impact on the research community. We find these topics addressed in health and environmental medicine epidemiological research showing the effects of traffic noise on the cardiovascular health of large populations.

Professor Emeritus **Tor Kihlman** addresses the political realities met in noise abatement issues. In describing environmental noise policy as a complex problem with slow progress, he puts the uncomfortableness of noise on the agenda. Politicians find it irritatingly complex, difficult, too long term, not very fascinating or politically hot. Numerous speeches have been made by high level politicians on the need for action, yet little action has been taken, Kihlman states. In contrast to many environmental problems, he finds noise together with climate change amongst the most difficult ones for society to tackle. Societal noise has been noted as needing to be restricted since Roman times, but is still in need of "a master plan". He also connects possible solutions to both climate change and noise problems and argues for compact and concentrated cities as one way of minimising unnecessary emissions in both noise and airborne particles.

Per Becker, director of the Resilience Centre at Lund University, identifies two major trends in changing soundscapes associated with modernity; the tendency towards more complex and intrusive soundscapes on the one hand and tendencies towards more private soundscapes on the other, the latter relating to the self-chosen auditive environments in mobile players and ear-phones. Increasingly complex soundscapes, in combination with auditive isolation from the surrounding environment, pose problems as far as safety goes. Excessively high listening volumes in prolonged listening sessions are also threatening to both economic and social sustainability, he writes, as the medical costs of treating future hearing impairment are acknowledged. So are safety issues in terms of perceiving risk situations and warning signals, "when we intentionally step into our own private soundscape, we are unintentionally increasing the risk of accidents", Becker writes, and concludes that "we have to take sound seriously if we are to maintain and develop a safe and sustainable society in the future".

Daniel Nilson, Associate professor at the Department of Fire Safety Engineering at Lund University, investigates the use and design of public alarms and how they can facilitate evacuation in emergency situations. His report stresses the importance of avoiding uncertainty and panic by giving correct information to facilitate correct choices, which minimise evacuation times during incidents. The importance of choosing the best alarm signal is crucial. So is the design of the sound environment, as its sonic transparency and character play important parts in communication. The article mainly investigates fire alarms, but can easily be adapted to any type of emergency and security messages in any major airport for instance. The importance of conscious design of the sound environment for safety reasons cannot be overstressed in any large venue and public space.

Theo Bodin (MD, PhD), in collaboration with professor Maria Albin and colleagues at the Department of Occupational and Environmental Medicine, Lund University, has made further studies of the prevalence of a quiet side in dwellings and its effects on annoyance and health. Though exposure to traffic noise was associated with annoyance, sleep disturbance and concentration problems even at moderate levels of exposure (LAeq24 50-55 dBA), the group found that access to a quiet side or windows facing green spaces reduced these effects. However, the beneficial effect was attenuated at higher noise levels. Thus, they concluded that planning a quiet side and windows facing green space can reduce the impact of moderate exposure, but cannot be used as a rationale for the construction of housing in noisy areas. Bodin´s statement with this report challenges the recently proposed policy from the Swedish government to allow building of dwellings closer to noisier roads, a policy that will embed for unsustainability with annoyances and health problems.

Greg Watts, professor of Environmental Acoustics at the University of Bradford, is presenting what he calls a "Tranquillity Rating Prediction Tool", TRAPT, a prediction method which involves two main factors: man-made noise and natural and contextual features in visual scenes. How these factors interact with each other determines the perceived tranquillity (tranquillity rating TR). Congruent relations between the tranquillity ratings based on results of the TRAPT and reported feelings of relaxedness from the subjects, also showed support for laboratory findings of reported stress reduction from "natural environments".

Frans Mossberg, editor & director
Sound Environment Centre at Lund University

ENVIRONMENTAL NOISE POLICY

- a complex problem with slow progress

Tor Kihlman, Chalmers tekniska högskola, Göteborg

Political problems are mostly discussed and treated isolated from each other. This is the easiest way in decision-making. The main link which is discussed is the economical coupling. Expenses demand tax income.

Current approach to solve environmental problems

Many environmental problems have been treated and solved successfully in isolation from other problems. This is especially the case where it has been possible to find solutions without sacrificing essential utilities for the public. These are the easy ones. Some examples can be mentioned.

Today, many kinds of industrial and consumer products are recycled. It reduces the ”garbage mountain” and the need for new raw material. Recycling is a modest sacrifice for the consumer and is easy to include in every day life. It has been accepted by a majority of the public in many countries.

For polluted water and air, technological fixes have been found. Examples are the catalyst for car engines and various filters at the end of the exhaust pipes. We have built plants for processing of the sewage water.

The positive effects have been evident. Exhaust gases from car engines do no longer cause the same smog problems in western cities as they did a few decades ago. Cars can be used without severe restrictions for short-term air pollution reasons. During the last decades, we have got much cleaner rivers and lakes and cleaner air in the cities in the developed countries.

CFCs have been phased out and replaced by other substances, which provide the same service but with less effects upon the ozone layer.

Typical in these cases is that the solutions have not interfered very much with daily life. Further, the positive effects have occurred rather soon and have therefore been easy to understand and accept by the public.

Similar solutions do not exist for the two more complex problems I will discuss here today. Technological fixes are not available. Substitutes are not at hand. Unpopular restrictions which affect daily life may be necessary. Utilities and comfort may get in danger. Lifestyle changes may be needed. The positive effects may not be noticeable soon; they may not come until after several decades.

Solving complex problems

To solve complex environmental problems, which are often interrelated with other areas, a holistic approach is necessary. I think such problems can only be solved through a closer involvement of scientists and engineers.

I will discuss two complex environmental problems: The climate change which may cause losses for the globe. Noise causes losses for citizens' health. Both noise and climate are huge and difficult issues which concern billions of people.

There are principal similarities and differences between the climate and noise issues; climate change is a difficult problem but noise is at least as difficult and complex – both to understand and to solve.

Are there interrelations between noise and climate. If so could they be taken into account and made best use of in the development of solutions.

Both for climate and noise, the progress has been very slow.

Environmental noise policies have been ineffective for many years. An OECD report 25 years ago, "Fighting Noise in the 1990s" illustrates this. The statement is equally true today.

”More and more people in OECD countries are exposed to high and potentially harmful levels of noise, chiefly from growing road traffic. Although governments have adopted policy objectives at the national and international levels, little real progress to reduce exposure to noise has been made in recent years.”

Another example is the slow progress in setting stricter demands upon the noise emissions from road vehicles. There is a Working party, 29, within UNECE that among else formulates limit values on cars and trucks. The effects have been marginal. Trucks are today somewhat quieter at low speeds but cars are equally noisy, externally, today as 40 years ago.

Climate change has been questioned and will probably remain questioned by the deniers until it has become worse.

The existence of environmental noise is not questioned. It has been a reality for a long time (legislated already in Rome 2000 years ago, Restrictions in night-time traffic)

The noise problem is not questioned. But it is possible for many individuals to escape, move away, find a nice neighborhood (demanding transportation that may disturb other individuals in their homes).

Climate has mainly been discussed in terms of reduced emissions. Different actions which lead to less emissions. Energy saving through energy efficiency and change from fossil fuels to renewables. Measures on the immission side are protecting barriers to stop disasters from flooding. The emitting sources and the immission measures need not to be geographically close.

In the noise case measures both on the emission and immission sides are necessary. Emittent and immittent are close to each other. Traffic noise sources result in noise in the neighborhood which can be reduced by somewhat longer distance – a few hundred meters - to the traffic, barriers or better windows. This leads to the misunderstanding, loved by the politicians on the national level, that the problems are local. It is true that the emittent and immitent are close to each other. But, mitigation measures are in the hands of several different bodies. Each of the bodies tries to give the problem to the others. Only some of the bodies are local. A local authority cannot demand cars to be quieter. Local authorities have normally very limited competence in technical noise questions, an incompetence they share with many central authorities. Few authorities seem to understand that effective noise abatement must start at master plan level.

On the emission side, I have heard numerous speeches given by high level politicians talking about measures against this nuisance noise and tell that the effective way to tackle it is, of course, at the source, (also emphasized in the Swedish state budget), but I have never seen any consequences of this argumentation in sharp political decisions on the level where the power to do something lies.

The problem has been forwarded to the local politicians who again cannot do anything about the sources.

Needed reductions of the emissions to solve the problems

Climate

Compared to noise, the climate problem is new. It has not been realized by the public and the politicians until rather recently; only a decade or two ago. The problems are political and they are substantial.

The UN has instituted the International Panel for Climate Change, the IPCC, a large network of scientists around the world, established in1988. Proposed by Bert Bolin. It plays an important role in supplying the politicians and the concerned citizens with knowledge.

From their latest report we have learnt that to limit global warming to 2 degrees, it is estimated that the climate gas emissions need to be reduced by approx. 50 % within 30 – 40 years and nearly 100 % to next turn of century. The demands are easy to understand, 50 % is judged (by engineers and scientist) as not only needed but also possible. The technologies are understandable and within reach. There are substitutes/alternatives to fossil fuels.

The climate issue is not easy to handle. An illustration of what on the contrary is of interest in international negotiations is how the melting ice-cover in the arctic regions is met. The severe background to the melting ice is not the issue on the political agenda, but rather the new options to exploit the natural resources and get more oil to burn.

Noise

In the past 30-40 years, the adverse effects of noise have been measured and discussed in terms of annoyance. However, even high levels of annoyance have not led to any strong political actions. This is one reason why direct health effects are now being studied in more detail. We will hear more about that later.

Yet, few realize the severe effects upon public health. Some believe that today's noise levels are inevitable in the urban environment. It has not awakened political interest: Too long-term, not very fascinating, most people appear to accept the noise and,--- is it serious really?

In many city locations, the equivalent noise levels are 10-30 dB above the safe level of 50 -55 dB. 10-30 dB implies reductions with a factor 10 to 1000 i e 90 to 99,9 %. Technical solutions for emission reductions may be known for a factor 3 (-5 dB) in typical cases. There are few substitutes that have zero noise emissions. This implies that the problems can far from be solved through source/emission measures only.

The problems cannot be solved in short time but with firm actions the problems could be much reduced in a two or three decades.

The problems are both political and technological. They have been discussed for 50 years – or maybe 2000 - but the political interest on high level has been very minor. The problem has not been considered to be serious or politically interesting.

It is a very demanding task to decrease the environmental noise sufficiently much. Actions directed towards lower immissions are needed in several areas; emissions from major noise sources, city and regional planning, traffic planning and management, building orientation and design and choice of road covering, sound shielding and insulation. To handle these issues, demands good understanding of different technologies and industry's conditions, necessary lead times for implementation of new rules and also life times for the products. The options and limits to reduce the noise problems through good planning require understanding of sound propagation over open land and in built up areas. What is needed and what is possible with different measures.

An effective noise policy should be founded upon a balance between requirements on each factor. No actor can refer the problems and the solutions to "the others".

Involve science and technology

Few politicians can be expected to have a sufficient overview and understanding of the complexity of the environmental noise problem.

The complexity of the noise problem necessitates that engineers and scientists get involved and given a special responsibility to support and advice policy-makers. Cf the IPCC in the climate case. We must participate to explain the fields and what is demanded. This should lead to work with longer time perspectives. The scientific bodies are long-lived. If involved, we can also point at relations between different fields where such relations are not obvious.

Within the International Council of Academies of Engineering and Technological Sciences, CAETS, a Noise Control Technology Committee has worked for a few years as a step in this direction. The initiative is described in ref [9]. Activity reports and other information about the CAETS Noise Control Technology Committee are posted on CAETS' website, www.caets.org.

The road traffic noise problem

Road traffic noise is the biggest environmental noise problem in terms of number of affected persons. The majority of the persons exposed to high road traffic noise levels live in urban areas. Equivalent levels of 65 dB and more are common along major roads and busy streets, much too high to correspond to a healthy environment.

Transportation is the life-blood in our modern society. Transportation vehicles for people and goods represent the major source for environmental noise. The production of the vehicles plays an important role in many countries' economy. The automotive industry is influential.

Complicating here is that in one country the automotive industry produces family cars, in another the production of sport cars is important.

Transportation is also a very important part of the climate problem. The inertia in the development of the transportation systems is substantial and the necessary lead times for real changes in the emissions from the vehicles are substantial.

The car has also a very special position in the society, which does not make the problem easier; the car is much more than a solution to a transportation problem. Music hall, driving must be pleasant (körglädje), ownership making impression. The figure below illustrates this. Note "Beside the noise emission, all other performances remain unchanged."

PORSCHE 3

Assumption on the Overall Vehicle Performance

Thoughts can only be given based on the assumption that the acoustical measures will not have any conflicting impact on any other field, like

Fuel consumption, Emissions, Safety, Practical Use, Car Class

Examples:

1. A car is equipped with 195/65 R16 Tyres, but the rolling sound could be reduced, if equipped with 125 R13 tyres. But this would totally change, safety and usability performances
2. A car is equipped with a combustion engine, but could be equipped with an electrical drive. This has a huge impact on the customers use.
3. A car is packed with acoustical treatment, that it is no longer a sports car but an executive car.

Beside the noise emission, all other performances remain unchanged.

Hans-Martin Gerhard
Dr. Ing. h. c. F. Porsche AG

18. September 2013
Seite 3 von 14

The good liveable city

Most people live in cities. Many of those who do not, they wish to move there for different reasons. The city has to be the solution to the environmental problems. The cities have to offer sustainable solutions both for the globe and for the citizens. Is the good liveable city with a decent acoustic environment within reach?

Sprawled cities of LA-type cannot reasonably be a sustainable solution for the globe with present and projected population. The cities should rather be compact. We see today a general trend to compacting the cities. This is partly driven by concern for the environment but it is good for the global sustainability.

The compact cities must also be sustainable for its citizens. A city where a high fraction of the population develops serious illnesses due to the environmental noise cannot be regarded as sustainable. The city should instead be supportive for good health. In a good city the sounds from people talking and laughing should be more dominating than traffic noise.

Is this possible? We will certainly for long time still have a big gap to healthy environments everywhere in our cities. But much can be improved. Difficulties and possibilities were discussed in a CAETS forum in in September 2013. “Lessening the severe health effects of traffic noise in cities through emission reductions”. See ref [10]. The results are shortly as follows.

Progress regarding internationally agreed test methods and maximum noise limits for road vehicles has been very slow. They have recently been revised but the outcome of the latest decision within EU will not make any big change. Maybe 2 dB lower equivalent levels after 20-30 years.

The test methods are rather premature. They are not really directed towards traffic noise reduction from major roads. They do not distinguish between engine noise and rolling noise. They only regard speeds around 50 km/h. It is impossible within the present type approval system, to reduce the emissions from city traffic in general sufficiently much by lowering the limit values.

To lower the emissions demands technical development on vehicles, tyres and road surfaces. There are technological/scientific barriers:

For cars the rolling noise is the most difficult barrier. There are very limited possibilities to make the tyres quieter due to conflicts with other demands upon them. But the rolling noise also depends upon the road surfaces. Quieter pavements have been developed but further development is needed to make it possible to order low noise pavements with acoustic guarantees for some years.

For heavy trucks a severe difficulty is to make the diesel engine much quieter. The noise emissions can be lowered by encapsulation of the engine which is applicable to special vehicles for community services such as city busses, vehicles for garbage collection, etc but it is not applicable to all kinds of heavy vehicles.

Electric cars and busses may be part of the solution for personal transportation at speeds below 30 km/h. At higher speeds the rolling noise must be tackled.

Such technical solutions demand new test methods. Some of the existing test methods are not only insufficient, the data can be misleading.

With more relevant test methods, lowest possible noise limits, night time speed reductions (see fig on next page) and good city and building planning of today, there is still a serious gap of 10 dB or more to a reasonably healthy environment.

In order to bridge this gap, more is needed. To reduce the emissions, also traffic management and speed control are needed including mode shifts to bicycle and low noise public transportation.

However, the compact city can be developed to a win/win solution.

Different cities, compact as well as sprawled, are surprisingly equal in terms of traffic noise power expressed as emission per unit urban area. This is because the traffic work (the total traffic in the city) expressed as vehicle*km per unit time and urban area is surprisingly equal in most major cities. These characteristics of city traffic have been discussed in a couple of papers, [3], [4].

The data imply that the average traffic noise emission per unit urban area with today's vehicles, has a spread of approx. only 3 dB and is rather independent of population density. There seems to be an urban cultural law of traffic leading to this result. Cf also Zahavi's law [5].

Sprawling does not help for obtaining quieter neighborhoods in general. In some respects it rather worsens the situation. In the sprawled city, the longer distances demand higher typical speeds leading to higher noise emissions per km and longer distances are driven.

From a general point of view, sprawled cities are no quieter than compact ones but the noise problems are different and involve different challenges. The sprawled city may have enclaves with excellent quiet environment but the necessary high-speed main arteries which link these enclaves give rise to very noisy environments. Who suffers? This is also a democratic problem!

The compact city may have blocks which offer a high degree of quietness if the shielding is effective. However, the distances to the busy streets are short and the noise exposure of the buildings facing these streets may get high also if the traffic speed is low. A healthy environment demands stricter requirements regarding noise emissions esp. for heavy vehicles such as delivery vehicles and busses.

The compact city allows lower speeds. If top speeds are reduced, it should be easier and cheaper to meet the requirements. Lower speeds are beneficial for traffic safety. Lower average speeds lead to lower fuel consumption and lower noise emissions.

Conclusions

Noise is an integrated part or effect of almost every major activity in the society. Consequently, there are links between noise policy and other policy areas. Measures taken in one area may be counterproductive in the other. One important link to be observed is between the community noise problem and the global climate problem. Their solutions involve both conflicts and win/win situations. As both the climate problem and the noise problem are complex and demand long-term policies, the links between them may be difficult to identify by non-experts.

Short-term problems must not take over or delay progress and actions. Nevertheless, in the case climate change it has done so in the shadow of the economic crisis. But have in mind, that during long time periods there will always occur economic crises. How do we then maintain the pressure upon the work within climate and noise policies and prevent acute problems to take over, maybe resulting in serious mistakes in policy actions. Underlining the coupling between different fields may help to keep the interest. Continuous involvement of engineers and scientists close to the decision-makers could make a difference.

Global warming is attributed the emission of climate gases. Much of these come from burning fossil fuels in vehicle engines. Fuel consumption increases not only with travelled distance but also with traffic speed. Compact cities save land and have typical shorter travelling distances than sprawled ones. Lower speeds are possible. Conditions for public transportation are good. Lanes for quiet, special busses can be located close to dwellings. The compact city is advantageous for walking and bicycling. These are good reasons for compact cities from a climate point of view.

But the environmental noise must be more effectively handled. Compact cities may be very noisy and unhealthy. However, with very careful acoustic planning, they can also offer conditions for quiet and thereby healthy environments. But to make them a really good solution demands substantially lower noise emissions from road vehicles at low speeds in relation to what is common today. Public transportation vehicles have to be substantially quieter than today. Heavy vehicles for goods delivery and public services must be quieter.

With regard to climate and noise policies the compact city can be a real win/win solution but this demands concerted actions on noise sources and city planning. With proper political leadership we could in the future have compact, healthy cities where the dominant sound is not traffic noise but sounds from people in the streets talking and laughing.

Noise policy is challenging. It will take a long time to achieve a substantially quieter world with less health effects caused by noise. Adequate policies are needed. They must involve participation by many parties, the industry, the town planners, the builders and many others.

Few policy-makers comprehend the complexity of the noise issue with its intricate links to other policy areas. The involvement from independent organizations of engineers and scientists with a good overview of the different aspects of the environmental area could make a difference. The CAETS work in this respect has been a step in that direction.

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Safety and sustainability in changing soundscapes

Per Becker, Director, Centre for Societal Resilience, Lund University

Introduction

Society has taken giant developmental leaps in terms of life expectancy (Riley 2001), child mortality (Ahmad *et al.* 2000:1175), adult literacy (Parris & Kates 2003:8070-8071), etc. These unparalleled changes have been tightly connected to industrialization and modernity, which unfortunately also have been accompanied with side effects in terms of environmental degradation (Kates *et al.* 1990) and social upheaval (Bauman 2003). Even among the most affluent states new challenges have emerged and threaten to undermine the safety and sustainability of society. One of these challenges that is attracting relatively little attention is the changing soundscapes that the majority of people live in. We are immersed in complex combinations of sounds daily when moving through public space. Regardless if we are outside on a street corner or inside a department store or train station, we find ourselves saturated by sounds in increasingly invasive soundscapes. Studies are increasingly showing connections between noise and various direct health effects, but the changing soundscapes may also exacerbate risk more indirectly. This chapter presents two fundamental trends in our modern soundscapes and elaborates on what effects these changes may have on the safety and sustainability of society if not addressed.

Sound and soundscape

Sound has always been a fundamental aspect of our lifeworld. The vast majority of us enjoy or get disturbed by vibrations that travel through the air and into our ears on a daily basis. King's College Choir singing Angus Dei soothes my soul and the construction workers banging on the scaffolding outside the office window is making it very difficult to focus on writing this chapter. However, we are rarely exposed to a single sound in isolation, at least not when moving through public space. Instead we are subject to complex combinations of sound from various sources, with various frequency, amplitude, etc. Some of these sounds are purposeful and emitted with the intention to convey some information, emotion, etc, while others are simply by-products of what is going on around us. It is in this situation that the concept of soundscapes becomes useful.

Soundscape |ˈsaʊndskeɪp| may be defined as "the sounds heard in a particular location, considered as a whole" (Oxford Dictionary 2014). In other words, the soundscape I am currently in includes the beautiful song, the noise from the construction work, the voices of the people having a conversation out in the corridor, occasional notifications of incoming emails, traffic noise, the tapping sound of my fingers moving over the keyboard of my computer, and so on. While writing this paragraph I am literally bombarded by sounds, diverting more or less of my attention away from what I am trying to accomplish. However, it is important to note that what I perceive as disturbing noise in the situation I am in right now may convey crucial information in another situation. For instance, the siren of the ambulance passing in the distance is disturbing and insignificant when I am sitting in my office, but a crucial warning to everybody on and along the streets it is rushing through to reach the ill or injured person as quickly as possible. By definition we are always in a particular soundscape and for the vast majority of the people in modern industrialized society these soundscapes are changing.

Changing soundscapes

When contrasting where and how people lived in the past and how we live now it is rather clear that much that determine soundscapes have changed. Industrialization transformed the mainly rural livelihoods based on manual labour and working animals of our past to the overwhelmingly urban livelihoods based on powerful, ever-developing and often noisy technology of our present (Gellner 1989). Although people had been moving into cities and towns ever since the first cities appeared in Mesopotamia five thousand years ago, urbanization did not become a central process of change until the Industrial Revolution (Becker 2014:109) and it was not until 2008 that the majority of the global population are living in urban areas (United Nations 2009). However, the entire population growth for the coming 50 years is forecasted to occur there (*ibid.*) and the average level of urbanization in the most developed states (OECD) is currently around 80% (World Bank 2014). The tranquillity of resting after strenuous labour on swaying fields or in lush forests has for the majority been replaced by the commotion of cities and towns. Although the fundamental and relatively rapid changes in soundscapes associated with the onset of modernity are most pronounced in urban areas, most of the people still staying in the rural areas of industrialized states are also exposed to the sounds of machinery, traffic, stereos, etc. These transformations of industrialized society have spurred two main trends in changing soundscapes.

The first trend in changing soundscapes associated with modernity is a tendency towards more complex and intrusive soundscapes for the majority (Figure 1). It is not that the rural soundscapes of our past were always silent. Try talking next to the Niagara Falls or the rapids of Storforsen in Sweden, or imagine the noise at Rubislaw Quarry when hundreds of men chiselled out the granite blocks to build the city of Aberdeen. It is obviously so that larger areas are subject to loud noise now than in our past, but such quantitative change in scale is only part if the problem. What has changed more fundamentally is the increasing complexity of the soundscapes we emerge ourselves in, making it increasingly difficult for us to sort out the sounds we need to hear and ignore the rest. This is because the number and diversity of sources of sound has grown tremendously in modern urban contexts in comparison with our rural past. Moreover, and even more profoundly, the number of sources of sound that attempts to communicate an intentional message has literally exploded. In other words, we are not only being more or less constantly but intermittently bombarded with numerous sounds, each not necessarily causing problems in isolation but together forming an intrusive soundscape that disturbs us both consciously and subconsciously. We are also being bombarded by auditory messages that are designed to draw our attention. Think about your reaction when you walk down a street and hear the ringtone or sms-notification on your mobile phone. Then realizing that it was not yours making the sound, but somebody else's phone. Consider also sirens, car horns, PA-systems at train stations or on busses, etc. If you can block them out from your attention, they are not particularly effective in meeting their purpose. The problem here is that some of these messages might be vital for your life, wellbeing or plans, while others are directed to someone else.

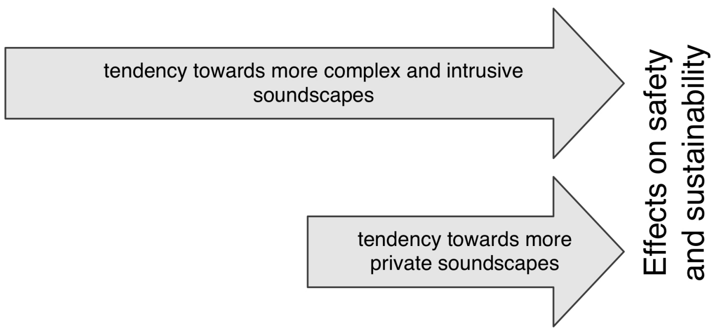

Figure 1. Two main trends in changing soundscapes.

The second trend in changing soundscapes is more recent and even more rapid. It entails the tendency towards more private soundscapes (Figure 1). Most often generated by the use of various forms of earphones and portable media players. Although similar effects are generated when using the sound systems in cars, this trend started to take off more significantly when Sony launched the first affordable portable media player in 1979-80 and has continued to accelerate since then. Today most mobile phones have built-in media players and the number of people moving around in public space but in their own private soundscape is staggering. Regardless how banal this change may appear to most people, it constitutes a fundamental change in how we experience our lifeworld. Suddenly, we do not share auditory input to how we perceive the situation we are in as a collective, which greatly reduces each persons ability to anticipate the behaviour of other people around them. Think about all the times that people on the street suddenly walk out in front a car or motorbike, or how people unexpectedly turn just ahead of you when you are out walking with a friend, even when you are talking to each other in such a way you expect them to know you are there. Consider also all the vital intentional messages that may be directed towards a person in her own private soundscape, which are effectively blocked with potentially severe consequences for her life, wellbeing or plans.

These two main trends in changing soundscapes are not only undermining the safety and sustainability of modern society by themselves, which I get back to in the coming section, but are also related to each other. Research shows that blocking out noise is one of the main purposes for using portable media players (e.g. Nettamo *et al.* 2006; Ayaß 2014), making the tendency towards more complex and intrusive soundscapes one of the causes behind the tendency towards more private soundscapes. This link aggravates the negative effect changing soundscapes have on the safety and sustainability of modern society.

Effects on safety and sustainability

The two main trends in changing soundscapes generate a whole range of effects on the safety and sustainability of society (Figure 2). First of all, research shows that noise can cause increasing risk of a number of physical health problems, such as hearing impairment (e.g. Davis 1989), high blood pressure (e.g. Paunović *et al.* 2011; Dratva *et al.* 2012), cardiovascular disease (e.g. Babisch 2008; Hansell *et al.* 2013), etc. Increasingly complex and intrusive soundscapes are thus likely to exacerbate illness, healthcare costs and even the number of premature deaths. This is not only an issue of safety in the sense of a relationship between soundscapes and detrimental conditions for human life, health and wellbeing, but also an issue of economic and social sustainability in relation to our expectations on society to address these effects and care for the ill. For instance, research indicates increased risk for hearing impairment among teenagers using earphones when listening to music (e.g. Chang *et al.* 2012). Considering the very large segment of young people listening to music with earphones more or less constantly today, it is worrying to think about the potential costs for society in the future.

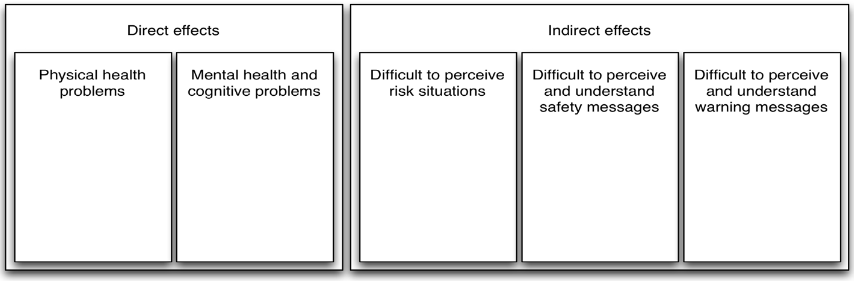

Figure 2. Effects of changing soundscapes on safety and sustainability.

In addition to effects on physical health, research also shows that different types of noise cause stress and annoyance (e.g. Stansfeld & Matheson 2003), sleep disturbance (e.g. Clark & Sörqvist 2012) and undermine peoples' cognitive abilities (e.g. Boman *et al.* 2005; Clark & Sörqvist 2012). The more cognitive effects are not only visible in relation to more traditional notions of noise, such as traffic noise, but even more so by noise in the sense of meaningful irrelevant speech (Boman *et al.* 2005), a type of noise we are emersed in more or less constantly when in public space. Although most research have focused on children, effects of noise on memory and reading comprehension have been shown to be equally significant regardless of age (*Ibid.*). Research have also shown that noise may lower the performance of school children (e.g. Pujol *et al.* 2014), which is particularly troublesome for the sustainability of societies that are based on the so called knowledge economy.

Although I am aware of the fact that I have not done the direct physical and mental effects of noise any justice, with only a few examples from the vast field of scientific work on these challenges, I need to move on and focus on the effects of the two main trends of changing soundscapes that are relatively less well researched. These are the more indirect effects undermining the safety and sustainability of society by eroding our most common way of perceiving and communicating important information guiding peoples' behaviour in risky situations.

First of all, the two trends in changing soundscapes both make it increasingly difficult to perceive risk situations (Figure 2). In a more complex and intrusive soundscape, where we are bombarded with sounds, some of which designed to catch our attention, it is more difficult to sort out what is important and what is not. You may miss the sound of the motorbike coming up behind you or of the ice sliding off the roof above you, since your ears are full of other sounds that happen to catch you attention at that time. The exact same problem arises when you consciously fill your ears with your favourite music and block out as much as possible of other sounds through the use of earphones. In other words, when we intentionally step into our own private soundscape, we are unintentionally increasing the risk of accidents. Research already indicates that pedestrians using earphones may aggravate the risk of being involved in traffic accidents (e.g. Lichenstein *et al.* 2012), and there are ongoing discussions in cities like London to ban the use of earphones when riding a bicycle.

The trends in changing soundscapes are also making it increasingly difficult to perceive and understand safety messages (Figure 2). Although these messages are designed to catch your attention, they simply have to compete with all other such intentional messages and other sounds literally creating a sound barrier that may block out important safety messages. Consider for instance an airport or train station and how difficult it is to hear the safety messages concerning theft, distance to the track when a train is passing, etc. So difficult that I sometimes wonder if the messages have any impact at all. Add then the use of earphones and you can be almost certain that the growing numbers of people in their own private soundscapes are missing the messages completely.

Finally, and tightly linked to the difficulties to perceive and understand safety messages, is the increasing difficulty to perceive and understand warning messages (Figure 2). The reason why I distinguish between these two effects is connected to fundamental differences in safety messages and warning messages as such. While a safety message cannot be too invasive to be accepted by the people moving in public space, warning messages are designed to be. Consider for instance sirens, car horns, fire alarms, bike bells, evacuation messages, public warnings (VMA), etc. They not only can be loud and stick out completely from the rest of the soundscape, they must do that for them to meet their purpose. Warning messages are thus not liable to the tendency towards more complex and intrusive soundscapes, though they do contribute to this tendency through their generally inexact targeting of addressees. Like the ambulance siren in the example above. However, warning messages are unfortunately liable to the impact of the tendency towards more private soundscapes. Think about the number of times you have been surprised by an ambulance or police car suddenly behind you when driving your car, as you have not heard the siren until it is really close. This is the reason for combing sound and flashing lights on emergency vehicles, which are unfortunately not particularly effective on a sunny day either. The use of earphones is also a major problem in this context, as loud music in modern earphones cancels out all but the loudest warning messages. Warning messages that are designed for our safety when moving in public space. I have not found any research quantifying the link between these changes in soundscapes and accidents, but if these trends continue unaddressed, it is likely that they will have far reaching consequences for the sustainability of our society.

Conclusion

It is clear that industrialization and modernity have had immense positive effects on the transformed societies, as well as negative effects in terms of environmental degradation and social upheaval. It is also clear that the changes spurred by this transformation include changes in the soundscape of the majority of the people on the planet and the vast majority of the people in the most developed parts of it. These changes are still ongoing and include two main trends: (1) the tendency towards more complex and intrusive soundscapes; and (2) the tendency towards more private soundscapes. These trends are linked to each other in such a way that the former is a cause of the latter, and both are undermining the safety and sustainability of society through a combination of direct effects on health and wellbeing and indirect effects by increasing the risk of various accidents. We have to take sound seriously if we are to maintain and develop a safe and sustainable society in the future.

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Design of fire alarms: Selecting appropriate sounds and messages to promote fast evacuation

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Abstract: Conditions can quickly become life threatening in case of fires in buildings and it is therefore essential that people quickly start to evacuate. Prompt evacuation requires that people are effectively notified about the fire incident, which can be achieved by using fire alarms. The most common fire alarms in buildings today are audible, i.e., (1) *fire alarm signals* and (2) *voice alarms.* In the present paper, the design of these two types of audible fire alarms is discussed in relation to research.

1. Introduction

Fires are potentially dangerous accidents that can lead to multiple injuries and fatalities when occurring in buildings [1,2,3]. Because fires, which generate both toxic/irritant products and heat [4], can develop rapidly in buildings [5] it is essential that people evacuate quickly in case of fire. Prompt evacuation requires that all phases of the fire evacuation process runs smoothly, but some phases are arguably more important than others for reducing the consequences of fires.

A simple model that is often used to describe the fire evacuation process is the egress time model [6]. According to this model, the evacuation process can be divided into two phases called (1) pre-movement and (2) movement (see figure 1). The pre-movement phase is assumed to start when people perceive the first indication of fire, i.e., the first cue, and ends when people start to deliberately move towards a safe location. The pre-movement is divided into (1a) recognition, which is the time taken for people to interpret the cue(s) as indicating fire/emergency, and (1b) response, which is the time taken to do preparatory actions before starting to move. The movement phase starts when deliberate movement is initiated and ends when people have reached a safe location.

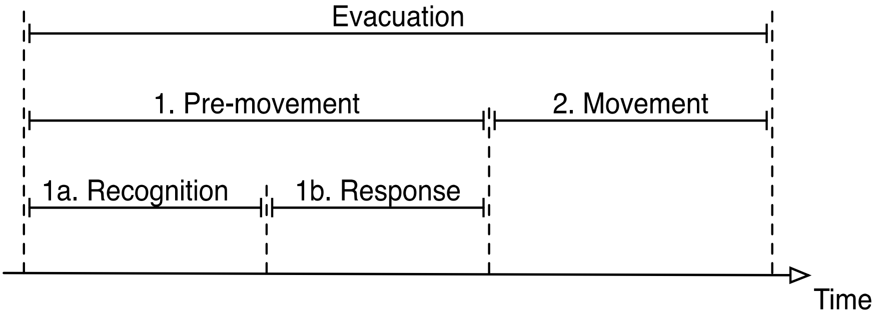


Figure 1. The phases of the evacuation process according to the egress time model (based on illustration in [6])

Shorter evacuation time can be achieved by reducing any of the phases of the evacuation process in figure 1. For example, people could potentially be influenced to move faster, which would result in a reduction of the movement phase. However, research has shown that the pre-movement phase often constitutes a significant part of the evacuation time [7,8], and that it in some cases can be reduced from an infinite time (no evacuation) to a very short time if the necessary notification measures are taken [7]. More specifically, effective notification can lead people to quicker recognize a fire situation as something requiring evacuation.

Although the egress time model does provide a basic explanation of the evacuation process, it has been criticized for being too simplistic. A more explanatory model is instead the behaviour sequence model, which was proposed by Canter, Breaux and Sime [9] (see figure 2). This model was developed based on data from interviews with survivors from fires in home and hospital environments. In the interviews, survivors were asked to provide an account of their actions. This information was then used to construct the generalised model of the sequence of actions in fire situations.

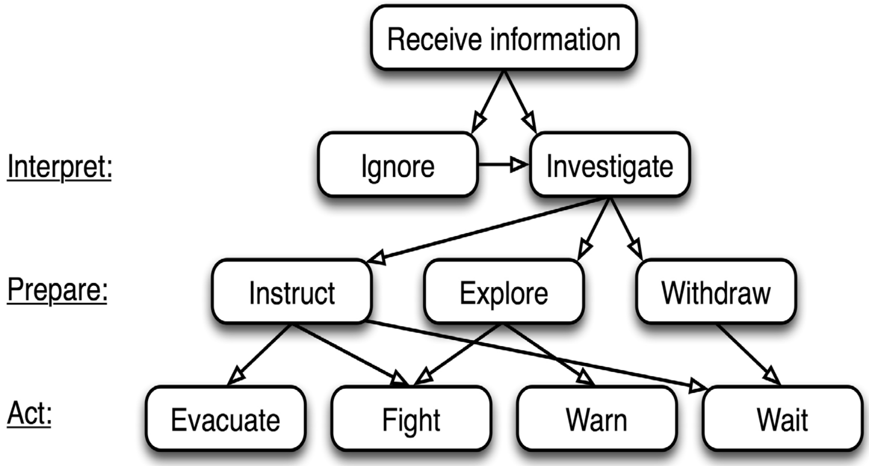


Figure 2. Behavioural sequence model
(based on illustration in [9])

Perhaps one of the most important conclusions drawn by Canter et. al. [9] during their development of the behaviour sequence model is that the initial phase it characterised by uncertainty. As can be seen in figure 2, people tend to either ignore the initial cue(s) or look for additional information before taking action, e.g., before initiating deliberate movement to a safe location. The model hence supports the idea that effective notification is key. By providing occupants with more relevant information, thereby reducing the initial uncertainty, the pre-movement phase can be reduced [7]. This will in turn lead to a reduction of the evacuation time, which will result in increased safety for building occupants.

There are different modes of notification linked to the human senses than can be used to notify people in case of fire, e.g., audible [10,11], visible [10,11], tactile [11], and even olfactory [12]. However, audible notification is undoubtedly the most common mode, and the two most frequent audible fire alarms in buildings are (1) *fire alarm signals* and (2) *voice alarms*. In the present paper, the design of these two types of audible fire alarms is discussed in relation to research. The discussion focuses on cognitive rather than acoustic aspects related to the design of fire alarms.

2. Design of fire alarms

In order for fire alarms to be effective, i.e., to promote fast evacuation, they need to be appropriately designed. Canter, Powell and Booker [13] have suggested design criteria for fire alarms based on empirical studies about alarm effectiveness. These criteria are [13]:

1) The meaning of the fire alarm must be obvious and distinct from other types of alarms
2) Fire alarms must be reliable and valid indicators of the presence of fire
3) People need to know the location of a fire so that they can authenticate the alarm and plan their response
4) There is a need to provide information to advise building occupants on the most appropriate response to an alarm, including information on available escape routes

The first criterion implies that fire alarms must be chosen so that they are not associated with other common sounds in society. For example, a fire alarm should not sound like a typical burglar alarm as this may cause unnecessary confusion and delay. The second criterion is mainly linked to the frequency of false (or unnecessary) alarms. A high frequency of false alarms can reduce the credibility and may lead to the alarm not being taken seriously. The third criterion suggest that the fire locations should be mentioned to aid authentication and planning, but it also implies that the cause of the alarm, i.e., the fire, should be mentioned. Finally, the fourth criterion relates to instructions of what to do, which is imperative because evacuations are usually unfamiliar situations for many building occupants.

The criteria proposed by Canter et. al. [13] should ideally always be adhered to, but certain restrictions might make this difficult or even impossible. For example, it is hard to achieve criteria three and four for fire alarm signals, e.g., a siren or a bell. For these types of fire alarms the uniqueness of the signal, i.e., criteria one, and people's associations instead become increasingly important.

2.1 Fire alarm signals

As mentioned previously, a fire alarm signal must be clearly distinguishable from other types of common alarms or sounds in society so that it can be recognized as a fire cue. According to the third criteria proposed by Canter et. al. [13] the signal should ideally also inform people about the fire. Although this is difficult to achieve with a simple signal, it is possible to choose a signal that is typically associated with fire emergencies or that is perceived as being urgent. It has also been pointed out by Laroche and Proulx [14] that perceived urgency of fire alarm signals is an important factor because urgent signals can better promote action in case of fire.

One fire alarm signal that has been examined in previous studies is the Temporal-Three (T-3) pattern [14]. The T-3 is used around the world, but the appropriateness of T-3 alarms has been debated. Empirical studies suggest that people might have heard the T-3 signal before, but do not necessarily associate it with a fire or evacuation alarm [14]. Instead, people often associate the T-3 signal with other types of less severe signals, e.g., alarm clocks. The research also suggests that the T-3 signal is not able to signal urgency.

The associations and perceived urgency of signals can often be connected to its physical characteristics [15]. Some commonly mentioned characteristics of acoustic signals are frequency pattern, pulse pattern and sound level. All these aspects should ideally work together to achieve a signal that is appropriate for fire alarms, i.e., a signal that is associated with fire emergencies and signals urgency.

In an extensive study about attraction capturing ability of fire alarm signals, Palmgren and Åberg [16] tested a total of 10 audible signals in laboratory style experiments with a total of 140 participants (see Table 1). Participants were asked to listen to the different signals and give them a score of how good they were at attracting attention.

Three of the signals in Palmgren and Åberg's [16] study, namely number 1, 6 and 7 in Table 1, received a significantly higher score than other tested signals. These three signals were therefore tested in unannounced evacuation experiments, i.e., experiments in which participants were not informed about the evacuation beforehand, where all three signals performed well and received high scores by participants [16]. In particular, it is worth pointing out that the alarm bell was given a high score in the study. The appropriateness of alarm bells as fire alarm signals is confirmed by other studies [14], which have shown that a bell is often able to signal urgency and is often identified as a fire alarm.

Based on the results of their study, Palmgren and Åberg [16] formulated recommendations for fire alarm signals. According to the recommendations signals should [15,16]:

1) be continuous (no silent periods)
2) vary between at least two frequencies
3) have a pulse rate not less than 1 Hz
4) be within the frequency range of 800-1000 Hz

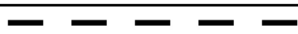
No	Source	Frequency range (Hz)	Frequency pattern
1	British standard	800/970	
2	Dutch standard	500-1200	
3	German standard	1200-500	
4	ISO (T-3 signal)	970	
5	Swedish standard	660	
6	British standard	800-970	
7	Swedish standard	n/a	Bell
8	ISO	800-970	
9	Unknown	300-1200	
10	ISO	970/800	

Table 1. Fire alarm signals tested by Palmgren and Åberg [16]

2.2 Voice alarms

Voice alarms are today common in many public buildings. These alarms are useful because they can inform people about the emergency and give them instructions, i.e., the previously mentioned criteria three and four according to Canter et. al. [13]. However, the use of voice alarms poses an interesting question: How should a voice alarm be presented and how should the message be worded?

Bayer and Rejnö [10] have performed one of the most extensive studies on the design of fire alarms. In their study, Bayer and Rejnö exposed cinema visitors to six different types of alarms, which included both fire alarm signals and voice alarms, and studied their responses. All experiments were unannounced, i.e., participants were not informed about the experiments beforehand, which resulted in realistic behaviour. The experiments by Bayer and Rejnö [10] provided valuable input in the development of the Swedish recommendations for fire alarms [17]. According to these recommendations, a voice alarm should consist of a signal and a message (see figure 3). The message should consist of a *call for attention*, *information about the cause* and *information of what to do*.

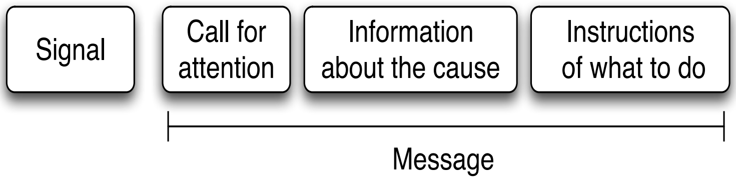


Figure 3. Design of voice alarms according to the Swedish recommendations [17]

In the following sections, the different parts of voice alarms are discussed in more detail and related to relevant research. The length of the message in voice alarms is also briefly discussed.

2.2.1 Signal

The main purpose of the signal is to attract the attention of people and make them stop what they are doing and listen to the message. In many environments, there might be background noise or other sounds, e.g., public announcements, which make it difficult to notice a message unless the attention is first attracted by a signal. A message might be even more difficult to notice if people are focused on specific tasks, but a powerful signal can potentially attract the attention.

The importance of having a signal for attracting people's attention has been shown by Cherry [18] in controlled laboratory experiments. In the experiments, participants were instructed to listen to and repeat a message played in the right ear while another message was played in the left ear. The left ear message was changed after a while from (1) a male to a female voice, (2) a male voice to an oscillating signal, (3) a male voice to a reversed male voice and (4) a male voice in English to the same male voice in German. It was shown in the study that the participants noticed the shift to the female voice and to the signal, but that the other changes were not noticed. This phenomenon, which is attributed to a process called filtering [19], is hence the reason for including a signal in voice alarms.

When selecting a suitable signal for voice alarms, it is relevantly to use the criteria by Palmgren and Åberg [16] presented above. Another important aspect to consider is the acoustic environment, since the echo of the signal needs to die out before the message is played [17]. For example, tunnels are known to be quite challenging acoustic environments where echoes can make voice alarms difficult to perceive [20].

2.2.2 Call for attention

The scientific basis for the call for attention in voice alarms is not thoroughly substantiated, but it is assumed to relate to the process of filtering [19] mentioned previously. Research has shown that some specific words can make people switch their attention for a message played in one ear to a message played in the other ear. For example, Moray [21] has shown that if people are actively listening to a message in one ear and ignoring the message in the other ear, their attention can be shifted to the rejected message if their name is called. Similarly, a call for attention, e.g., the phrase *"Important message, important message"*, can potentially shift people's attention to the voice alarm. However, it is currently not known if the signal in voice alarms is sufficient or if the call for attention is also necessary.

2.2.3 Information about the cause

According to the behaviours sequence model [9] the initial phase of the evacuation process is characterised by uncertainty. People will initially tend to either ignore the initial cue(s) or look for additional information before taking action. A voice alarm containing information about the cause of the alarm will therefore reduce initial uncertainty and lead to a quicker response. This trend has been demonstrated in unannounced evacuation experiments where different types of fire alarms, ranging from uninformative bells to instructive public announcements, were tested [7]. The experiments showed that more information leads to shorter evacuation time.

An argument that is sometimes put forward is that information about the cause of the alarm should be restricted due to the risk of *"panic"*. Old building regulations often rest on the assumption that panic will easily occur in the event of fire [22]. It is also sometimes suggested that panic can arise even when the danger caused by fire is minute and that panic may result in fatalities and serious injury [23]. These types of assumptions have in some cases lead to recommendations that information to the public should be restricted in the event of fire [22]. These restrictions are typically based on the belief that too much information about what has happened, e.g., that there is a fire in the building, will lead to an uncontrolled rush for exits [24].

The concept of panic as a serious risk in case of fire has been disputed [25,26] and it is pointed out that the word *"panic"* is often misused. Research has shown that clear information does not lead to panic, but instead promotes swift response and effective evacuation [7]. Proulx and Sime have suggested that telling people the truth about what has happened will actually decrease the risk of panic by making people respond quicker and hence not expose them to dangerous and highly stressful fire conditions [7].

Research suggests that the mention of *"fire"* as the cause in voice alarms has a positive effect on message perception [27,28]. In a series of unannounced evacuation experiments at Lund University, Sweden, two different types of voice alarms were tested. The two voice alarms were identical except for the fact that one did not contain any information about the cause and the other stated "*there is a fire in the building".* After each experiment participants were asked to repeat the message using their own words, which showed that the message that mentioned fire as the cause was interpreted more correctly and resulted in fewer misinterpretations [27]. It has been suggested that the word "fire" might act as a trigger, which sharpens people's attention and makes it easier for them to remember the message [27]. It is also argued that a more correctly interpreted message will have a positive influence on the evacuation process, although no significant effect on the pre-movement time has been observed in unannounced evacuation experiments [28].

2.2.4 Instructions of what to do

In line with the previously mentioned third criterion proposed by Canter et. al. [13], a voice alarm needs to contain instructions of what to do. These instructions might vary depending on the type of building and incident. For example, many new high-rise buildings include elevators as part of their evacuation strategy, but for many years people have been taught not to use elevators in case of fire [29]. It might hence be required in new high-rise buildings to use voice alarms that inform people that elevators can be used for evacuation. Similarly, the fact that many emergency exits are not used during evacuation [30] might require voice alarms with specific instructions that prompt people to use all exits.

Because people are typically unfamiliar with fire evacuation situations, it might be difficult for them to quickly decide how to act [31]. Instructions of what to do are therefore an essential part of voice alarms.

2.2.5 Length of the message

Although voice alarms offer the opportunity to provide people with much information, it has been argued that information in fire alarms need to be restricted to improve message comprehension [13]. This trend has been demonstrated in laboratory experiments where participants were asked to first listen to different voice alarms and then repeat the information using their own words [28]. Three different messages were used in the experiments, namely messages with 5, 7 and 9 chunks of information (one chunk is equal to a phrase). All messages contained the same basic information (consisting of 5 chunks), but 2 and 4 chunks of unnecessary information was included in the messages with 7 and 9 chunks respectively. The results showed that participants were able to remember less of the basic information for the message with 9 chunks of information. However, it should be pointed out the experiments were performed in a non-stressful situation, which is quite different from a stressful evacuation situation. It is therefore argued that voice alarms should ideally contain less than 7 chunks of information.

3. Conclusions

Effective notification is essential to guarantee quick evacuation in case of fires in buildings. In order for audible fire alarms, i.e., (1) *fire alarm signals* and (2) *voice alarms*, to be effective, they need to be designed appropriately. In the case of fire alarm signals, it is essential to choose signals that are associated with fire emergencies, signals urgency and are good at attracting attention. A signal that fulfils these requirements is the traditional alarm bell that is already used in some buildings.

Current research suggest that voice alarm should consist of a signal, which attracts people's attention, and a message that consist of a *call for attention*, *information about the cause* and *information of what to do*. The information about the cause of the alarm is particularly important because it can reduce the uncertainty that characterises the initial phase of the evacuation process, thereby making people take action quicker. Information about what to do is also important, because people are not used to fire evacuation situations and therefore require guidance. Care must always be taken not to put too much information in voice alarms since this can negatively influence comprehension of the information.

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Annoyance, Sleep and Concentration Problems due to Combined Traffic Noise and the Benefit of Quiet Side

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Based on Bodin, T., Björk, J., Ardö, J., & Albin, M. (2015). Annoyance, Sleep and Concentration Problems due to Combined Traffic Noise and the Benefit of Quiet Side. International Journal of Environmental Research and Public Health, 12(2), 1612-1628.

Introduction

Road traffic noise is a growing health hazard in the urbanized world. Conservative estimates assume that at least one million healthy life years are lost every year from traffic related noise in the western part of Europe [1]. Although Sweden is a fairly quiet country compared to continental Europe, noise derived from aircraft, railway and road traffic has increased over the years and is predicted to increase by 23%–27% until 2020 compared to the levels of 2001 [2].

The main health burden related to road traffic noise stems from noise annoyance and sleep disturbance [1]. Traffic noise has also been linked with several other adverse effects on life quality and health, including increased risk of hypertension, myocardial infarction, and in some studies stroke and diabetes, although these outcomes are less well studied [3-7].

The societal costs related to road traffic noise are most likely very high. A recent study from Switzerland concluded that one night's undisturbed sleep was worth CHF 7–24 (approx. 5–15 EUR) depending on severity of disturbance [8]. In the EU 22, the social cost of road traffic noise is estimated to be at least €38 (30–46) billion per year, which is approximately 0.4% of gross domestic product (GDP) and approximately one third of the social costs for traffic related accidents [9].

Disturbed sleep due to noise from aircraft, railway and road traffic has been shown in laboratory settings as well as in field studies [10, 11]. Traffic noise affects several aspects of sleep quality. The time it takes to fall asleep is prolonged in relation to noise exposure. Increased heart rate, blood pressure and changes in electroencephalogram (EEG) during sleep have been recorded in relation to traffic noise exposure. Traffic noise also affects subjective sleep quality and is associated with the notion of not being totally rested after a whole night's sleep. Awakenings during the night and premature awakening in the morning have been shown in short-term studies but it is concluded that substantial habituating effects exist [12]. However, habituation has not been observed with regard to arousal measured by increased heart rate or EEG-patterns [11, 13].

The benefit of quiet side

In policy discussions and research, there is an increasing interest in the benefit of access to a quiet side of the dwelling [14]. There is hope that access to a side, sheltered from noise, would allow people to sleep with bedroom windows open at night or to make use of balconies or other outdoor spaces close to the residency, thus compensating for high noise levels at the most exposed façade. This beneficial effect has earlier been found on noise annoyance and sleep quality [15, 16] but definitions have varied as well as the effect size and it is unclear whether the effect is sustained at higher noise levels.

In a recent study our group found clear evidence of several benefits of having access to a quiet side of one's dwelling. Having at least one window facing a yard, garden, water or green space was associated with reduced risk of noise annoyance and concentration problems. Lacking this access increased the reporting of road traffic noise annoyance (at a given exposure level at the most exposed façade) by 32%–50%. Having one's bedroom window facing a yard, garden, water or green space was associated with reduced risk of noise annoyance, concentration problems, as well as better sleep quality. Although noise sensitive persons were more annoyed to noise, they were not found to have a greater relative benefit from access to quiet side than non-sensitive individuals when it comes to self-reported noise annoyance.

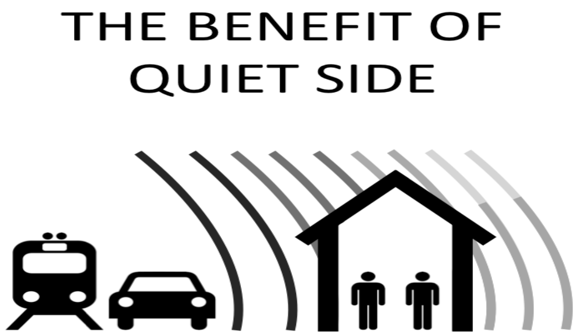

Figure 1. The concept of quiet side, a sheltered side of a dwelling where noise levels are lower than at the most exposed side.

These results suggest that to protect most people (80%) from experiencing noise annoyance, the sound levels from road traffic should not exceed L_{Aeq24h} 50 dB at the most exposed façade, even if the dwelling faces a quiet side. If there is access to a perceived quiet indoor space this level could be raised to 55 dB. Although noise sensitive persons are more annoyed to noise, they were not found to have a greater relative benefit from access to quiet side than non-sensitive individuals.

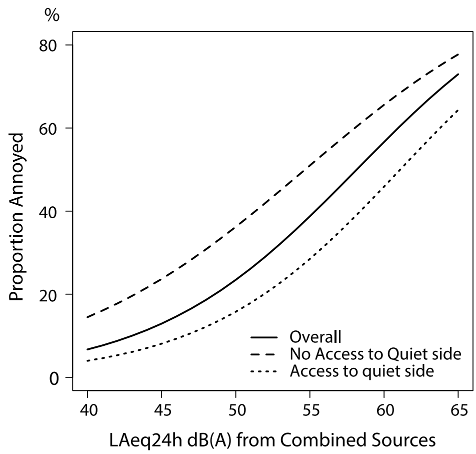

Figure 2. Predicted proportion of annoyed due to traffic noise and access to quiet side.

Relevance for policymakers

Levels of 55 dB(A) is the current WHO and Swedish guideline for acceptable outdoor noise levels at the most exposed façade [17]. Quiet side of dwellings have lately become a possible solution for regulators wishing to build in noisier environments. In Sweden a recent governmental report suggests that houses should be allowed to be constructed in areas exceeding L_{Aeq24h} 55 dB(A) at the most exposed façade, if at least half of the windows are faced towards a relatively quiet side [14]. A 5 dB benefit of a quiet side would in that case allow for construction in areas with up to 60 dB(A) at the most exposed façade. However, the proposed changes want to go further, claiming that modern buildings, due to improved insulation, allow for even higher noise levels. Current proposed policy changes in Sweden also rely heavily on the benefits of quiet side and that newer buildings isolate better for noise. In this context our results regarding access to quiet indoor space could be useful. We found that even with access to indoor spaces that were perceived as quiet, there was still a clear dose-response between annoyance and noise levels at the most exposed façade. Noise annoyance levels in the group with access to quiet indoor spaces were in our study shifted approximately 5 dB(A) compared to the average noise annoyance, but the noise annoyance prevalence with access to quiet indoor space was still 27% at levels 55–59 dB(A) and 41% at levels exceeding 60 dB(A). These prevalence's can hardly be considered as acceptable and clearly indicates that it is not only the noise levels indoors, and with closed windows, that matter for the noise annoyance.

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Towards designing tranquil and sustainable environments in the city

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Based on a presentation at the Interdisciplinary Research Symposium on 28th April 2014 in Lund, Sweden: "Safety, sustainability and resilience"

We examine the urban space where dense vehicle and pedestrian traffic create largely non-tranquil environments. However, our green spaces can be a refuge from the din of city life and the green environment provide shelter for wildlife and bird song can be heard. But are they sufficiently tranquil and sustainable and what guidance do we have for improving such spaces if they are not?

We know that tranquillity is to be found in natural outdoor environments where man-made noise is at a low level though natural sounds can be relatively high. Numerous studies have shown a link between such environments and stress reduction, longevity, pain relief and even how the brain processes auditory signals (Hunter et al., 2010). So it is important that these natural spaces are provided particularly in urban areas. In New York where the concrete jungle compares second to none there is a policy to provide a green space within a 10 minute walk of every citizen (BBC, 2008). The "High Line" in West Side Manhattan is an excellent example of how NYC authorities prompted by citizen action have risen to the challenge transforming a disused 1.6 km section of railway freight line in a derelict area to provide a linear park abundant with wild flowers, shrubs and trees and a "must see" for the city's many visitors (Figure 1).

Figure 1: Section of the popular "High Line" in NYC cutting through the old industrial district of West Side Manhattan showing laminar flow water feature and mixed wild grasses

Our work on elucidating the tranquillity of city parks has concentrated on the prediction and validation using the Tranquillity Rating Prediction Tool, TRAPT (Watts et al, 2011 and 2013). This prediction method includes two important factors: the level of man-made noise level (usually traffic noise) in the soundscape and the percentage of natural and contextual features in the visual scene (Pheasant et al., 2010). Figure 2 shows this in diagrammatic form together with the influence of other factors (moderating factors) which are generally not so influential e.g. the presence of litter and graffiti that are known to affect tranquility ratings adversely.

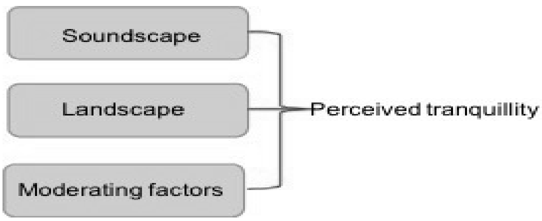

Figure 2: Influential factors affecting the tranquility of a place

The percentage of natural features in the landscape includes vegetation, water and geological features e.g. exposed rock outcrops. Contextual features include listed buildings, religious and historic buildings, landmarks, monuments and elements of the landscape, such as traditional farm buildings, that directly contribute to the visual context of the natural environment. Based on these factors TRAPT allows the prediction of the tanquillity of a place on a 0 to 10 scale.

The TRAPT equation (1) was based on laboratory studies where a number of subjects were ask to rate video clips of a range of environments from busy market place to natural coastal location far from any development.

$$TR = 9.68 + 0.041\ NCF - 0.146\ L_{day} + MF \qquad (1)$$

Where TR is the tranquillity rating on a 0 to 10 rating scales. NCF is the percentage of natural and contextual features and L_{day} is the equivalent constant A-weighted level during daytime. The moderating factor MF is added to the equation to take account of further factors such as the presence of litter and graffiti that will depress the rating and water sounds that are likely to improve it (Watts et al., 2009). This factor is unlikely to be large and in one experiment it was shown that the presence of litter depressed the rating by one tranquillity scale point (Watts et al., 2010).

Figure 3 shows the experimental setup that allowed TRAPT to be developed where experimental subjects rated video clips of natural and urban scenes. During data collection phase a video recorder was mounted on top of a dummy head ("Marina") as can be seen in the figure. Microphones in the ear channels allowed binaural recordings to be made which contributed to the realistic environment on playback as it created a 3-D stereo sound sensation for participants.

Figure 3: Experimental subject rating a video clip taken using "Marina"

Park surveys

To determine the tranquillity of a range of city parks seven parks were selected in urban areas within 2 miles of the centre of Bradford and a further park was Ogden Water the country park on the urban fringe that was featured in the previous article. Questionnaire surveys of park visitors were carried out in these open spaces where the dominant source of noise was from road traffic. Predictions of tranquility were made using TRAPT based on the predicted traffic noise and the percentage of natural features in view. This was later compared with results from interviews with park visitors to validate the prediction method.

Figure 4 shows the least tranquil open space (Thackley Green) with an average rating given by visitors of only 2.9. In contrast, visitors to Lister park gave an average rating of 7.8. The tranquility scale runs from 0 to 10 and scores of 5 or more are judged acceptable. A score of 7.8 is "good". The lack of trees and shrubs in Thackley Green and the high traffic noise level due to its small size and proximity of the A657 are the main contributory factors. On the other hand Lister Park has many mature trees and a lake and is large enough that traffic noise levels near the centre are not excessive despite the presence of a heavily trafficked road on one boundary (A650).

Figure 4 & 5:" Non-tranquil" green (Thackley Green) and "good" tranquil park (Lister Park)

The benefits of visiting the parks were obtained by asking: "Do you feel 'more relaxed', 'less relaxed' or 'no change' after visiting this park/ green/ garden?" The percentage of respondents reporting they were more relaxed was plotted against the average tranquillity rating reported by respondents. This relationship is very strong ($R^2 = 0.96$, $p<0.001$) as can be seen in Fig 5.

At a rating of approximately 2 it is predicted that no visitors would have reported being 'more relaxed'. Clearly this indicates a lower bound to the tranquillity rating for creating spaces with restorative value. For a 50% response the average tranquillity rating would need to be 5.4 and for a 75% response the rating would need to be 7.2. This lends some support to the judgements that a "just acceptable" level of tranquillity was considered to be ratings in the range 5.0-5.9 and a "good" level was considered to lie in the range 7.0-7.9. These results lead us to suggest that TRAPT can be used for designing new tranquil spaces and providing effective mitigation measures in existing parks where tranquility is low.

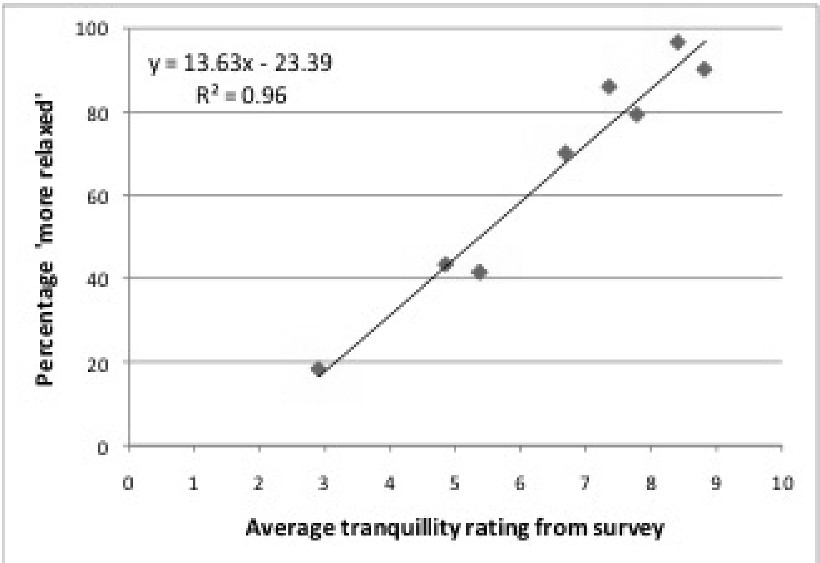

Figure 5: Percentage of respondents reporting they were 'more relaxed' after visiting the green space by average tranquillity rating from the survey

The data also support the results of a laboratory showing significant physiological stress reduction in a natural environment compared with urban environments (Ulrich et al, 1991). This indicates the importance of providing such tranquil spaces to citizens.

Designing for tranquillity

We can conclude that tranquil spaces exist in green open spaces in cities and that some of them are likely to be judged “excellent”. On the other hand some green spaces were found to have “unacceptable” levels of tranquility. In those case where tranquility is low we can use TRAPT to engineer some effective solutions. There are three approaches that can be used separately or in various combinations:

- Reduce man-made noise (usually traffic noise) e.g. re-routing traffic, lorry bans, low noise road surfacing, noise barriers
- Increase the percentage of natural features e.g. introduce trees, shrubs, trellising to “hide” building facades, roads, signage and advertising and to reduce the amount of concrete or bituminous surfacing used in the park.
- Encourage “natural” sounds by installing appropriate water features. Introduce ponds and lakes which will not only assist with increasing the percentage of natural features but will encourage water fowl and birds.
- Reduce litter and graffiti

The degree of improvement can be predicted with reasonable accuracy using TRAPT allowing consideration of a range of remedial treatments. The approach could also be used in planning new tranquil spaces which will contribute to health, well being and sustainability for as we have seen the degree of tranquillity is closely related to the degree of relaxation reported.

Currently we are extending our studies to interior spaces in health care settings where there is a need to reduce patient stress and improve mood and well being. Applying the principles outlined above it is expected that significant benefits will result.

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Sound, Safety & Society

Research on Sound & Sustainability

Texts from an Interdisciplinary Research Symposium 28/4 2014

Tor Kihlman | Per Becker | Theo Bodin | Daniel Nilsson | Greg Watts

Sustainability, resilience and safety are features of a society that are more affected by sound environments than is generally acknowledged, even if other environmental threats may appear more prominent. But when noise levels reach the limits of sustainability in society, it´s resilience to destructive processes of many kinds will be challenged.

In an interdisciplinary symposium in 2014 arranged by The Sound Environment Center in collaboration with the Centre of Societal Resilience at Lund university, a number of researchers came together to discuss aspects of safety, security and sustainability in society with regard to the sound environment.

The presented research and following discussions stressed the importance of beneficial sound environments not only for the health and well-being of citizens, but also for security systems to work efficiently.

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