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NECESSARY STEPS TO ADVANCE RESEARCH ON HEALTHY URBAN SOUND PLANNING

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ABSTRACT

The acoustic environment (AE) matters for human health and well-being. Decades of research revealed noise pollution to be a major disease burden. Well-established mitigation strategies like speed limits or noise barriers exist. Beyond noise, field and laboratory studies suggest salutogenic properties of the AE. However, for a more comprehensive understanding of the relationship between human health and the AE beyond noise, i.a., population-based epidemiological studies are necessary.
However comprehensive studies are missing, and robust strategies for health-promoting urban sound planning are scarce. Currently, several factors limit research in this area. A major factor is the difficulty in quantifying acoustic properties that may reflect the salutogenic properties of AEs on a population-level. This is particularly important, as such studies are needed to investigate health issues of defined populations in real-life settings. While various methods (e.g. the soundscape approach by DIN ISO 12913) aim to assess the "acoustic quality" of an AE and provide valuable insights, they do not provide the spatially high-resolution exposure data needed. Here, we outline requirements necessary to advance research at the population-level. We discuss and demonstrate approaches in AE research that show promise in meeting these requirements and could guide urban planning towards healthier AEs.

Keywords: *Public Health, Urban Planning, Soundscape, Epidemiology*

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1. INTRODUCTION

In recent decades, significant efforts were undertaken to investigate the link between the urban acoustic environment (AE) and human health. Among other definitions, the AE can be defined as “the sound from all sound sources as modified by the environment” [1]. While the link between environmental noise exposure and adverse health effects (e.g. cardiovascular disease or mental health) is well established [2], an increasing number of studies focusses on the potential beneficial effects that high quality AEs may provide [3]. For example, using laboratory settings, studies found that uneventful and more pleasant sounds were linked to a greater reduction in heart rate [4], that stress recovery was facilitated by sounds from nature [5] or that biophonic AEs have a favourable impact on the functional connectivity of the human brain [6]. In addition to laboratory studies, several field studies investigated the impact of natural sounds on different human health dimensions and found, e.g., associations with decreased pain, lower stress or enhanced cognitive performance [7]. However, so far, studies are missing that take into account a broad spectrum of urban neighbourhoods as well as population based studies. The lack of population based studies highlights a substantial research gap. These studies are essential to investigate patterns, causes and effects of health issues of defined population (groups) in real-life settings [8]. By addressing this gap, we can better identify which acoustic properties benefit human health and well-being in order to develop robust measures for health-promoting urban sound planning. Currently, a significant challenge in this area of research is obtaining the high-resolution spatial exposure data required for population based studies. Below, we will discuss reasons behind this challenge. We will focus on issues regarding definitions, operationalisations and measurements of exposure, as well as the difficulty of linking findings to urban planning.

2. THE CONCEPT OF EXPOSURE

In general, prerequisites to plan healthy urban AEs are insights into how the AE and human health are related. Here, the embedding into the framework of epidemiology is appealing, as it is concerned with the distribution, patterns and determinants of health and disease [8]. Following epidemiological basics, the determination of exposure and outcome is fundamental to gain such insights. Since the measurement of health outcomes on a population-level is a well-established research field, we will not address the challenges associated with defining and measuring outcomes here. Rather we want to focus on the challenges in defining and measuring the exposure (e.g. natural sounds) on a high spatial resolution, and how this complicates population based studies at the time.

2.1 Defining the exposure

One criterion to define the exposure is that it is derived from a research question, which reasonably connects it to a health outcome [8]. While the question of a reasonable connection is rather philosophical [8], there are multiple theories and studies on the relations between the AE and human health that can legitimize an investigation (e.g. stress reduction through biophonic sounds). Furthermore, the construct of the exposure needs to be clearly defined. Regarding the example above, questions such as whether biophonic sounds include human sounds, dog barks, or leaves rustling in the wind need to be answered. However, other constructs such as "(high) acoustic/sound-(scape) quality" or "fidelity" are frequently used but often only vaguely defined or have varying definitions. Acoustic and sound-(scape) quality are often used interchangeably, but lack a uniform definition. Kang and Schulte-Fortkamp [9] define "environments of high acoustic quality [as those] where one can postulate that type 1 restorative effects could occur", while soundscape quality may be defined as "warm-hearted, lively and peaceful, therefore noisy but enjoyable" [10] or solely by survey responses [11]. In addition to the latter being problematic from a measurement theory point of view, because the construct is not defined a priori [12], vague definitions of constructs complicate their operationalisation, and thus a valid measurement [12]. For example, biophonic sounds are often operationalized by the amplitude of a recording between 2 and 8 kHz, also allowing other sound sources in this frequency range to be considered biophonic. Besides physical-acoustic measures, constructs derived from the AE are also often operationalised by sound source classes or questionnaires.

Regarding the literature, there are also differences on which level the AE is operationalized as exposure. Hypotheses concern settings (e.g. urban vs. rural AEs), complex mixtures (e.g. pleasant sounds) as well as single agents (e.g. birdsongs) of exposures [8]. Neither of which are generally weaker approaches to assess exposures, but it underlines that there are most likely multiple relevant exposures that need to be considered, if we want to assess the relation between the AE and human health.

In summary, many theories in the field of AE have gathered sufficient evidence to warrant further investigation on population-level. However, the definitions and operationalisations of some constructs from the AE are often too vague, which can hinder interpretation, comparability and generisability of results.

2.2 Measuring the exposure

When it comes to measuring the operationalized constructs of the AE (e.g. urban soundscapes, pleasant sounds, biophonic sounds), the most widely used approaches include the use of acoustic indices and surveys using questionnaires. In the following, we will shortly describe each approach, followed by an evaluation of their respective challenges to assess the exposure on a high-resolution spatial level.

2.2.1 Acoustic indices

We refer to acoustic indices as those, which represent physical-acoustic properties of an AE. An elaborate example to illustrate the construct, operationalization and measurement of an exposure through an acoustic index is environmental noise. Among other definitions, the one from the European Directive 2002/49/EC is probably the most widely used. Here, environmental noise is defined as "unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity". The operationalisation is the A-weighted long-term average sound level and the exposure measures are derived from strategic noise maps, which model the a-weighted sound pressure level (SPL).

Beyond SPL, there is a plethora of acoustic indices that are designed to measure constructs in relation to, e.g., human perception of acoustic phenomena (e.g. from psychoacoustics) or specific sound sources (e.g. from ecoacoustics). Some examples are measures for psychoacoustic annoyance (as a combination of loudness, sharpness, roughness and fluctuation strength) [13] or biophonic activity (measured e.g. by the normalized difference soundscape index) [14].

However, unlike to SPLs, methods to derive exposure levels for these indices on a population-level are not established to this date. Acoustic measurements could provide the necessary exposure data, but are complex and costly, especially on a larger scale. In contrast to strategic noise maps, no models are yet established from which high-resolution exposure data could be derived. In addition, research into the performance of certain acoustic indices and their relations with exposure constructs (e.g. natural sounds) in the urban environment is a relatively new field of study. Still, there are significant developments in recent years that explore the relation between acoustic indices and, e.g., human perception in the urban environment [15, 16].
Drawing from the example of strategic noise maps, which utilise traffic estimates and the built environment to predict SPL, similar information could be used to create sound maps for additional acoustic indices (see Fig. 1), as their relations to the built environment are getting increasingly more evident. Additionally, these relationships provide insights necessary for urban sound planning.

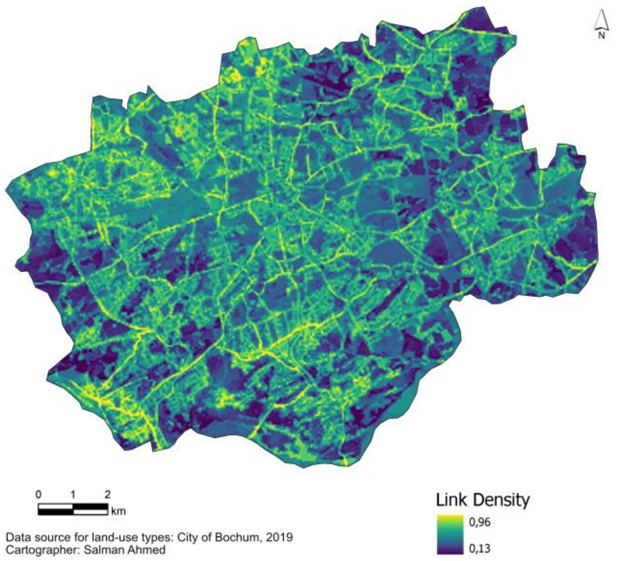

Figure 1. Exemplary presentation of preliminary results for exposure assessment of an acoustic index. Here, acoustic dominance, operationalised by the acoustic index link density, is shown using a prediction model based on land use types. The area depicted is Bochum, Germany.

2.2.2 Questionnaires

In recent years, the use of questionnaires has emerged as a popular method to investigate the urban AE. Among the various questionnaires deployed, one of the most frequently applied is from the DIN ISO 12913 [1]. Here, e.g., the construct of perceived acoustic pleasantness, operationalised as a combination of multiple human answers on a 5-point Likert scale, is investigated. In addition, the context (e.g. the built environment, socioeconomic factors) plays a crucial role here, as it influences the rating of the respondents and should always be considered[1].
Regarding the exposure measurement on population-level, the application of questionnaires on the AE represents a highly feasible approach, as questionnaires are an established method for population surveys. Such surveys could also gather additional person-related variables, offering insights into the contextual factors influencing AE perception or even individuals' health. However, this approach is not without challenges. Existing questionnaires are primarily designed for in-situ applications, which poses difficulties when adapting them for population surveys[2]. Here, the reliance on context also raises the question of whether people can be effectively queried about their responses to hypothetical or memorized acoustic scenarios (e.g. the perception of the AE at home for the last month). Currently, the research field lacks widely established questionnaires for population surveys [18].
In addition, the insights required for healthy urban sound planning regarding the interplay between the built environment and the perceived AE would need to be gathered through additional surveys or similar methods.

2.2.3 Additional considerations

In addition to the method specific challenges, there are general factors that need to be considered in exposure assessment, namely the intensity duration, and timing [9]. For example, the mitigating effects of being indoors might be important for the intensity of the exposure to the outside AE. This might also be important for the duration of exposure if we expect an isolation from the outdoor AE. Furthermore, the place of stay needs to be considered, as the exposure may vary from being at home, being outside or at work. Even the place at home might matter, if the exposure

[1] An issue that arises here concerns whether the operationalization measures the acoustic pleasantness of the AE specifically, or rather the overall pleasantness of the investigated place, as recent research suggests [17], but this question remains open to future debate.
[2] Due to its high expenditure on time and personnel we do not consider in-situ measurements (e.g. soundwalks) a feasible option for assessing exposure on a population-level.

differs across rooms. Also the timing might be important. For instance, the recommendations for SPLs are lower at night than at daytime.

3. CONCLUSION

There remain multiple challenges that need to be addressed to assess exposure to the AE on a population-level. For acoustic indices, their functionality and effectiveness in reflecting relevant constructs in the urban environment in relation to humans needs to be further investigated. For example, it is necessary to investigate whether and which indices could represent biophonic sounds in the urban environment. In addition, models need to be developed to predict relevant indices at high spatial resolution.
For the questionnaire approach, instruments need to be developed that measure perceived constructs of the AE for non in-situ situations. Furthermore, the challenges of context dependency need to be addressed and methods to relate results to the built environment need to be established.

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