
# Research on community response to noise 2017 to 2021

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**ABSTRACT**

This contribution presents a review of the research progress on community response to noise in the years 2017 to 2021. The majority of the studies deals with transportation noise (separately and combined), followed by environmental noise or soundscape in general, wind turbine noise and other sources. In addition to noise annoyance and disturbances, the main criteria are soundscape perception and health-related quality of life. Further studies refer to the momentary assessment of short-term sound perception (noise, soundscape). Recently published studies predominantly support the assumption of an increase in transportation noise annoyance over time. Some studies investigated exposure metrics as supplements to average sound levels; others introduced new annoyance scales. Attention is drawn to non-acoustic factors that potentially affect noise responses, e.g. attitudes, other exposures, restorative environment. Also, within the 4-years period 2017 to 2021, a systematic review on environmental noise annoyance that informed among others the Environmental Noise Guidelines of the World Health Organization was published. These and other findings are discussed.

## INTRODUCTION

The subject area of ICBEN Team #6 refers to community response to noise and noise annoyance. It comprises noise responses such as disturbances (e.g. of communication, recreation), judgments of annoyance, (un-)pleasantness, but also effects of noise in self-reported health-related quality of life. Furthermore, the research on soundscape perception, i.e. on the evaluation of the acoustic quality of an environment as perceived by people, is one of the topics of Team #6. This paper gives an overview of the research in this area within the period from 2017 to the first quarter of 2021, focusing on trends, gaps and an outlook for future research.

## METHOD OF LITERATURE SEARCH

For the overview, we searched the literature in the databases EBSCO including PsycArticles, PsychInfo, Psyndex, Medline), Pubmed, Scopus, and BASE (Bielefeld Academic Search En-

gine), the latter one allowing the search of conference papers and “grey literature”. For the literature search, we used the following terms:

> (community OR neighbourhood OR neighborhood OR resident OR residential OR real life OR field OR natural setting ) AND ( noise OR soundscape OR vibration OR sound ) AND (response OR perception OR disturb* OR impair* OR interference OR annoy* OR quality of life OR health-related quality of life OR complain* ) AND ( survey OR interview OR questionnaire OR observation OR cross-sectional OR longitudinal OR cohort OR quasi-experiment OR quasi experiment OR cross-cultural).

We added relevant publications from our own archive and reference lists of identified papers to complement the pool of included publications. The papers were first screened by title and abstract, and from the included publications beside bibliographic data, we extracted the information on the population studied, the exposure, comparisons/control and context conditions, including non-acoustic factors, the outcome variables, and the main results.

## RESULTS

### Selection of papers

After the removal of duplicates, 1,671 papers were identified in the search and screened together with 73 additional publications. One thousand five hundred eighty-eight papers were excluded because of one of the following reasons: wrong topic (985), wrong outcome (358, including those addressed in other ICBEN teams), wrong population (192), acoustics, exposure only (21), no exposure (13), wrong year of publication (10), wrong exposure (5), wrong study/publication type (2; e.g. pure laboratory study/listening test), and wrong language (2). Altogether, 156 papers were included for further review in order to identify main trends in findings, research gaps, and challenges to address in future research.

### Reviews of studies on noise annoyance and soundscape

Several reviews on community response to noise have been published within the period of 2017 to 2021. For example, evidence reviews on environmental noise annoyance [1], and quality of life (HQoL) and well-being [2] have been prepared to inform the Environmental Noise Guidelines for the European Region published in 2018 by the World Health Organization (WHO) [3]. The meta-analyses that are done within the WHO review on environmental noise annoyance provided an update of generalised exposure-response functions for transportation noise annoyance (aircraft, road traffic, and railway noise), which together with exposure-response relationships for self-reported sleep disturbance, and road traffic-attributed risk of ischaemic heart diseases are implemented in the revised Annex III of the European Noise Directive 2002/49/EC (END) on the environmental noise-related health impact assessment for noise action plans in European agglomerations [4][5]. For HQoL the evidence was mixed, not allowing to establish any generalised exposure-response relationship [2].

More recent reviews and review updates studied health effects of different environmental noise sources, among them annoyance [6]-[8] and HQoL [9], focused on noise from aircraft [10][11], wind turbines [12]-[14], issues of soundscape research [15][16], on the impact of noise interventions [17] and in line with this on the role of non-acoustic factors of annoyance [18]-[20]. The reviews’ results confirm a clear association between noise exposure mainly assessed by average sound levels and noise annoyance and similar result patterns as the WHO

review [1]. Updates of meta-analysis on annoyance are recommended for transportation noise, particularly aircraft noise [7][10], and wind turbine noise [7][12].

The reviews on non-acoustic factors refer to personal, social (attitudinal), and situational factors that contribute to the explanation of annoyance [18]-[20]. The authors of these reviews agree that it is important to consider these contextual, non-acoustic factors in interventions aiming at minimising the adverse noise responses. In line with this, the WHO review on the health effects of noise interventions points out that most of the few included intervention studies refer to annoyance, showing that the change in annoyance cannot solely be explained by changes in noise exposure. The review authors recommend a focus of future research on the evaluation of the effects of interventions and propose a respective study protocol [17].

Regarding soundscape research, one review hints at the psychophysiological implications of soundscape [15]. The authors identified methods of quantifying heart rate, stimulus-locked experimental design, and passive listening as predominant methods of studying the psychophysiology underlying the soundscape, while pleasantness and arousal were the most psychological descriptors of soundscape evaluation. A large variety in findings regarding the link between physiological and psychological responses to soundscape was found. Two other reviews explore the use of mobile applications and smartphones for environmental noise and soundscape evaluation [16][21] and argue for standardisation of development and implementation of such apps within the series of ISO technical specifications on soundscape [22][23] in particular in ISO/TS 12913, Part II on data collection in soundscape research [23].

**Trend in annoyance**

The exposure-response functions presented in the WHO review on environmental noise annoyance [1] indicate for transportation noise annoyance a trend of an upwards shift of the curves for the percentage of highly annoyed (%HA) compared to older generalised exposure-response functions particularly used in Europe [24]. This shift seems to be strongest for aircraft noise, followed by the %HA curves for railway and road traffic noise. This trend in annoyance was already reported earlier, e.g. [25]-[28]. For aircraft noise annoyance, it is argued that the %HA per given average sound level ($L_{den}$) is elevated overtime only in studies at so-called 'high-rate change (HRC) airports' (airports with a "significant deviation in the trend of aircraft movements from the trend typical for the airport," [1], p. 5), which were more often published recently than in former times [29]. However, this only partly explains the shift in annoyance observed in [1]. The review authors could show that the HA%-curve for aircraft noise at low-rate change (LRC) airports is still elevated, although weaker than the curve derived from studies at HRC airports. Recently published studies, such as the US FAA Neighborhood Environmental Survey [30], the study around Hanoi Noi Bai Airport [31][32], the Swiss SiRENE study [33], or the German NORAH study [34], confirm the shift in annoyance over time for aircraft noise even at LRC airports, but also for railway noise [33][35]. However, other studies such as in the previous ICBEN period published Norwegian aircraft noise study [36][37], or the French study DEBATS [38] could not show evidence for a shift in %HA for aircraft noise over time, if the same definition of high annoyance (the same cut-off value on the response scale) were used.

There is a concern about the selection of studies included and methods used to model %HA against $L_{den}$ in the WHO review on annoyance and that other selections would lead to the conclusion of no change in the exposure-response relationship for aircraft noise annoyance over the decades and lower %HA per $L_{den}$ then presented in the WHO review [29]. A similar concern is expressed for road traffic noise [39]. It is clear that different input data and different methods might lead to different results. Because of this, within the framework of the WHO En-

vironmental Noise Guideline, the WHO Steering Group, the Guideline Development Group (GDG) and the Systematic Review Group agreed on a strict study protocol for the systematic reviews to be followed in the review process. The review authors together with members of the GDG responded to the concerns expressed, explaining the methodological issues of the systematic WHO evidence reviews [40]. However, the debate is ongoing [41][42] – see also a respective contribution to this ICBEN conference [43].

The debate cannot be described further in this contribution. It is likely that all discussants agree that there is a large variance in the level of annoyance at a given sound level. So general exposure-response functions will not be able to reflect the local situation. For local noise management, i.e. noise action plans according to the END [5], exposure-response information as tailored as possible to the situation in local communities would be more helpful for noise interventions that aim to minimise noise health effects, including annoyance. This includes considering both acoustic and non-acoustic factors that contribute to local noise annoyance.

**Study type of reviewed papers**

Cross-sectional studies are dominating in the empirical research of community response to noise (n = 66). Altogether 9 longitudinal studies, including four before/after intervention studies, were included. Other papers besides the reviews refer to experimental or simulation studies (n = 10) with residents (partly combined with cross-sectional surveys), to re- or meta-analysis of data on community response to noise (n = 20), to position papers or letters to editors in response to meta-analysis and systematic reviews (n = 16) or other methodological papers on the assessment of noise responses or perceived soundscape (n = 14).

**Population und Countries**

In most cases, the general adult population or exposed adult residents are studied (n = 121). Further, in particular in soundscape research, the evaluation of the acoustic environment of passers-by or visitors of locations (e.g. parks) are assessed (n = 14). Eleven studies refer to schoolchildren (n = 2), or students (school and/or university, n = 7) or university students and staff (n = 2). Four studies were carried out in hospitals, studying both staff and patients. Two studies assessed noise responses in particular of elderly residents.

Community response to noise and soundscape research is a worldwide topic. Thirteen papers are from North America (Canada, USA), two from Brazil. One study was conducted in South Africa, 21 papers report about studies in Asian countries and New Zealand, 76 about studies in European countries. Altogether 14 papers include studies from multiple countries. Five of them present comparisons of results from two or three countries, 9 publications refer to re- and meta-analysis of data from different countries. Thirty-two papers do not specify the location or report general analyses, statements or positions without reference to specific countries.

**Sources of sound exposure**

Transportation noise is still the most studied noise source, in particular aircraft noise (n = 59), followed by road traffic (n = 39), and railway (n = 23). Most of them study the noise effects on annoyance alone or together with self-reported sleep disturbances. The studies mainly confirm the findings described in the WHO review on environmental noise annoyance [1]. Among the studies on road traffic noise, one refers to community response to motorcycle noise, indicating that for the same $L_{Aeq}$ level, motorcycle noise is more annoying than the other sources of road

traffic noise, in particular at summer weekends [44]. The results suggest that seasonal average sound levels (at best summer Sunday $L_{Aeq}$ levels) would be better acoustic predictors of overall annoyance to motorcycle noise than yearly averaged sound levels.

The number of other sources being investigated has increased in the last 4-year period with 12 papers on wind turbine noise, 4 with noise from industry and 5 papers referring to neighbourhood noise, 3 papers study responses to construction noise, and 1 paper refers to shooting noise. Twenty-five papers refer to environmental noise in general or to a mixture of noise from different sources or to the environmental soundscape in general. Thirteen papers report findings related to effects of urban recreational spaces (n = 6), music in public space (n = 2), natural sounds, or judgment of the soundscape, including noise responses when having access to green or blue areas (n = 5). Thirteen papers report results on noise responses for other noise-related exposures, such as the impact of absorption from building facades on annoyance and perceived acoustic comfort [45] or responses to noise in a hospital [46].

Eight papers report results on combined noise [47]-[54]. Except for one [54], all other studies confirm previous results, indicating that the energetic summation of source-specific sound levels is not appropriate for predicting total noise annoyance. The annoyance equivalents model, which transforms the source-specific sound level to the sound level of a reference source (road traffic) that leads to the same percentage of highly annoyed people (%HA) before energetically summing up the levels [49], and the dominant source model are superior, in particular when the dominance refers to the effect (most annoyed or most sleep disturbed) and not to the exposure (loudest source) [50][51]. Total annoyance is predicted by the energetic sum of sound levels when the sounds from different transportation sources are presented simultaneously [54]. Adding contextual factors such as noise sensitivity [47][48], the visibility of the noise sources [48], the exposure to vibration, air pollution, coping activities, and judgment of the wider soundscape of the study area [53] to prediction model considerably increases the explained variance of total noise annoyance.

**Metrics of sound exposure**

The majority of studies use cumulative average sound levels ($L_{dn}$, $L_{den}$, $L_{night}$, $L_{Aeq,t}$) as metrics of sound exposure, in most cases modelled. In soundscape research, metrics relying on measurements (mostly $L_{Aeq}$) are more common. Measurements, in particular, refer to the period of soundwalks or interviews with residents or passers-by.

Some studies consider other metrics instead or in addition to average sound levels. For example, [55] could show that the intermittency ratio IR, which reflects the “eventfulness” of a noise situation [[55],p. 277], contribute to the prediction of annoyance in addition to $L_{den}$. Also, for aircraft noise, a re-analysis of data from socio-acoustic surveys around Swiss and German airports show that the prediction of annoyance is improved when adding a metric reflecting the number of events above a maximum sound level of 70 dBA ($\log N_{70}$) to the $L_{Aeq}$ [56]. The improvement in prediction by adding a number of events metric (here: $N_{60}$) is confirmed by results of a study on aircraft noise annoyance of school children and teachers in primary schools [57]. The study [56] found out that characteristics of the airport add to the prediction of annoyance. The fleet mix affected annoyance, in particular in areas with exposure to lower aircraft sound levels. From a methodological point of view, this suggests that multi-level regression models would improve the explained variance of community noise responses, with individual acoustic and non-acoustic predictors as first-level factors and the context (e.g. site, airport) and its characteristics as second-level factors.

**Noise annoyance as the most studied community response to noise**

Most studies have investigated noise annoyance as the main community response to noise (n = 97). Compared to this, only a few studies (n = 13) report results on further responses such as disturbance of activities at daytime (e.g. disturbances of communication, concentration, recreation). More often, the assessment of annoyance is combined with the assessment of self-reported sleep disturbances. For an overview on the latter one, see [58].

Within the period 2017 to 2021 for the assessment of noise annoyance, the 5-point verbal and the 11-point numerical response scale as recommended by ICBEN Team #6 [59] and as specified in ISO/TS15666 [60] have been widely used for different sources of environmental noise. The standard annoyance questions have been developed in further languages [61][62].

However, although ICBEN recommends using both scales in socio-acoustic surveys, in most cases (n = 46), only one of the two scales have been used, the 11-point scale in 23 cases, the 5-point scale in other 23 cases. In 11 further cases, both scales have been used.

By convention, since the synthesis of data on exposure-response relationships for noise annoyance by Schultz [63], the percentage of highly annoyed persons (%HA) has been used in exposure-response curves plotted against average sound level metrics such as $L_{dn}$, $L_{den}$, $L_{Aeq}$. Several re- and meta-analysis (e.g. [1], [63][64]) have defined people being highly annoyed when choosing the upper 27-29% categories of the response scale for their annoyance judgment. For the 11-point scale from 0 to 10, this means that the values 8 to 10 indicate high annoyance (HA). However, ICBEN has recommended specifying HA on the basis of the verbal 5-point scale with the values 4 (“very”) and 5 (“extremely”) indicating HA. The upper two categories of the 5-point scale comprise the upper 40% of the rating scale. Both definitions have been in use in the period 2017 to 2021. It is not clear for all cases which one has been used. Among those papers, where it was specified, we identified 9 papers using the 40%-definition (the upper two categories of the 5-point scale) and 17 papers using the 27% definition (values 8 to 10 on the 11-point scale). The ISO/TS15666 is currently under revision. The revision work will be presented in another contribution to this conference [65]. Among others, one of the recommendations is to specify in publications and study reports which definition of HA has been used in order to facilitate comparisons as well as re- and meta-analyses.

Some authors have suggested assessing the annoyance in a more reliable way using a score of several items to specify annoyance. For example, in studies on wind turbine noise, a composite score of annoyance to wind turbines is proposed, including the highly intercorrelating noise and visual annoyance [66]-[68] combined with reported stress symptoms [66]. It could be shown that the aggregate annoyance score correlated both with distance to the wind turbines and self-reported health [68]. In another study on transportation noise annoyance, the authors re-analysed survey data of the NORAH study and proposed a hierarchical structured multiple item annoyance scale (MIAS) consisting of altogether 7 items reflecting activity disturbances, the ICBEN 5-point annoyance item as a proxy for emotional responses and perceived lack of coping capacity as a valid and reliable measurement of noise annoyance [69]. The authors of the latter score could show that acoustic metrics correlate higher with the disturbance component of annoyance, whereas non-acoustic factors, in particular personal (e.g. noise sensitivity) and attitudinal ones (e.g. trust in authority) correlate higher with the annoyance factor ‘perceived lack of coping’ indicating different parts of the mechanism that lead to the development of the annoyance judgment and that contribute to the role of annoyance as a potential mediator of noise effects on further health outcomes.

There is an increasing interest in the study of personal, social, and situational factors that contribute to the prediction of annoyance ([18]-[20]). For example, two reviews emphasise the im-

portance of attitudinal factors (e.g. attitudes towards the source, trust in authority, perceived fairness) and discuss their importance (effect size) for annoyance and their modifiability [18][19]. Perceived control was found to mediate the effect of road traffic noise exposure on annoyance in the elderly [70]. It is argued that the attitudinal factors can be best addressed by communication and community engagement (e.g. when developing noise action plans) and that noise management should be encouraged to enhance the set of tools of noise interventions with measures of engagement and communication beyond tokenism. The authors of [20] point out the importance of wider determinants of health in particular greenery, access to quiet facades and areas, visual covering or acoustic masking of the noise sources with natural features, have beneficial effects in terms of minimising noise responses. In line with this, studies have confirmed previous findings of the restorative effect of access to urban/residential green areas (e.g. [71]. Results of soundscape research support these findings (e.g. [72]-[77]).

Recent studies have focused attention on the role of community response to noise, particularly noise annoyance, as a mediator of the impact of environmental noise on further health outcomes. Studies on the impact of aircraft noise show that psychological ill-health [78], self-related health status [79], the risk of hypertension [80] and the use of medication [81] were associated with noise annoyance, but also with noise sensitivity. Whereas in one of these studies, noise exposure was not found to be associated with psychological ill-health, in all cases, noise annoyance mediated the effect of noise exposure on the health outcomes. A mediating effect of aircraft noise annoyance was also found for the self-reported diagnosis of depression [82]. Bulgarian studies provide evidence of the restorative effects of green areas on mental health, mediated adversely by road traffic noise annoyance and sleep disturbance and positively by social cohesion and physical activity (e.g. [83]). These results indicate the importance of contextual environmental and social conditions for community response to noise and their relevance as health effects of environmental noise.

### Research on soundscape

In total, 14 studies were identified that examined the perception of the soundscape. The studies are quite diverse and investigate soundscape perception in various contexts as well as different characteristics of the soundscape such as pleasantness, loudness and comfort. An important step in research on soundscape perception is made by the recent development of a series of ISO technical specifications for the soundscape to facilitate research and provide a standardised approach. A first ISO technical specification standard related to soundscape was approved in 2014, presenting a definition of the soundscape as the “acoustic environment as perceived or experienced and/or understood by a person or people, in context” [22]. In 2018, a second ISO standard was released, providing specifications and protocols for data collection and documentation [23]. For the data analysis, a third ISO specification is currently being developed.

## DISCUSSION AND CONCLUSIONS

In the 4-years period 2017-2021, research on community response to noise and soundscape perception has been rather active. Transportation noise is still the most studied noise source, but research on other sources, e.g. wind turbines, has increased. Efforts of developing and revising ISO technical specification on the assessment of noise annoyance and soundscape research have been made. However, re- and meta-analyses of the exposure-response relationship for noise annoyance have been published that differ with regard to methodology, input

data and, therefore, results. It is proposed to consider developing recommendations also for the re- and meta-analysis of data on community response to noise, including the sources of data to be used in order to facilitate a common systematic approach for such analyses. In line with this, it is suggested to think about establishing a data repository hosted by an organisation, e.g. like ICBEN. Such a data archive could provide the data for re- and meta-analyses. The increased interest in the study of personal, social and situational, so-called non-acoustic factors and their role in minimising adverse noise effects leads us to recommend to continue and expand research efforts on the effects of noise interventions on community response and health outcomes, as empirical research on this is still scarce. For example, [17] proposed a study protocol for the scientific evaluation of the health effects of noise interventions. As there is raising research interest on the impact of both adverse as well as beneficial environmental context factors on community noise responses and the underlying pathways, it seems that the 'classical' research on community response to noise and the soundscape research are continuously moving together to research on the humans' perception and health effects of the acoustic environment. We can look forward to further research developments in this area.

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