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Noise at work: Subject-orientated approaches to noise exposure and soundscape design of workplaces

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Abstract

Human factors and ergonomics sciences have been dealing with noise as workload for several decades in Europe. For this purpose, a comprehensive investigation of instruments already exists. Labour inspectors measure sound levels and they are using sound pressure measurement methods. Average levels indicate a health hazard and DIN norms regulate employment conditions. Sensory perception as a cognitive instrument of subjective perceived workloads caused by noise is less a component of human factors and ergonomics sciences and DIN standards. This article searches for interdisciplinary connections to open the focus on subjective perceived noise stress levels. Starting from this approach, the article highlights the thesis that noise in workplaces can, in addition to the assessment of the human factors and ergonomics sciences, reduced and changed by sensor sensible and subject orientated methods of sound studies and critical psychology.

Keywords：Sensory Epistemology, Soundscape Design, Sound Studies, Perception, Workload

1 Introduction

Sound can be described as a complex term for various acoustic and musical phenomena. Accordingly, sound is part of physics and cultural semantics. For physicists, sound is not a medium, but silent sound waves, and air is the medium that transmits sound. Sound in a vacuum is physically impossible. For acousticians, however, sound is a periodic vibration that contains audible information. Sound is therefore a relational term that can be shifted to two sides. I.e. whether sound is noise or music is related to aesthetics on the one hand and aisthesis on the other.[1]

Human factors and ergonomics sciences is also concerned with sounds, tones, frequencies when it comes to the analysis of workplaces and the assessment of noise. The measurements and assessments are carried out by means of sound pressure measurement methods in which the intensity of sound pressure at the workplace determines health hazards. I.e. the sound pressure is an objectively detectable physical event. Noise, on the other hand, cannot be described by sound pressure measurement methods, because the measurement methods analyses the sound sources. This is at least problematic for the description, assessment and analysis of the effects of noise, as no subjective data on the psychosocial risks of noise can be collected using the sound pressure measurement method. Noise stress depends more on personal assessments and sensitivities. This article therefore looks for epistemological and methodological connections to analyse subjectively perceived noise stress via the act of hearing.

In the following, therefore, mainly aesthetic aspects of sound are in the foreground. Here, however, it is less about physical processes that accompany the excitation of the sense of hearing, but rather about subjective listening experiences and what contributes to the interpretation of what is heard. With special consideration of the soundscapes of workplaces, these

[1] Ernst 2008, 1

aspects are shown. A subject-oriented approach is intended to extend the methods of noise stress assessment available in human factors and ergonomics sciences with the help of sound study methods. Based on this approach, this article discusses the thesis that hearing can be regarded as instrument to analyse workplaces. This perspective includes, in addition to the analysis of noise, the ability to design the existing soundscape of a workplace in a subject-oriented manner.

An essential difficulty in this context especially and in exploring the sensual experiences of sound in general is the capturing of the subjectivity of listening experiences and their evaluations. [2]This becomes clear when listening experiences must be assessed in the context of psychoacoustics: For example, when police officers ring the doorbell and must investigate complaints about noise pollution. This means that noise need not automatically be perceived as disturbing and "how someone perceives or interprets a sound event depends on conditioning, experience and knowledge, which in turn are influenced by many aspects such as age, personality, education, environment and culture".[3] This means that auditory perception is filtered, determined by prejudices, patterns of perception or by a cultural coding of sound. The question is not only how spaces of work can be designed in terms of sound, but how these sounds in their diversity can be understood as something to be designed.

Therefore, the next chapter will focus on historical aspects of sound research to open different approaches to sound perception. This chapter is followed by a chapter with actually studies to noise and health hazards. The forth chapter describes how sensual perception can be used as an instrument to subsequently dock subjective methods of hearing on perspectives of human factors and ergonomics sciences. The conclusion provides concrete considerations on how a subjective or participatory soundscape design at the workplace is possible.

2 A brief history of sound studies and their research topics

Sound studies consist primarily of capturing auditory phenomena. In contrast to human factors and ergonomics science, less noise levels are documented, but rather the soundscapes of social environments and the effect of auditory phenomena.

When Thomas Alva Edison invented the phonograph in 1877, it was possible for the first time to make sound recordings of the environment. The first field recordings were then made in the context of ethnomusicology and comparative musicology. First reviews of the soundscape of workplaces took place in the early 19th century. Friedrich Engels describes the sound of the "narcotizing" drones of machines and the factory as follows:

"[...] the engine moves unceasingly; the wheels, the straps, the spindles hum and rattle in his ears without a pause, and if he tries to snatch one instant, there is the overlooker at his back with the book of fines. This condemnation to be buried alive in the mill, to give constant attention to the tireless machine is felt as the keenest torture by the operatives, and its action upon mind and body is in the long run stunting in the highest degree".[4]

In the 1960s, scientific investigations into health and safety measures against deafness were carried out. Since hearing protection was introduced, workers could have been able to regulate the volume himself. Since 2006 (cf. DIN 15905-5), hearing protection must be worn at a volume of 85 dB(A) throughout Europe.

In the meantime, sound studies have reached different sciences. The "World Soundscape Project" by the Canadian composer R. Murray Schafer in the 1970s provided significant impulses for the development of sound studies. This project had set itself the task of documenting the acoustic ecology of certain places (forest, city, factory, etc.) by means of field

[2] Hannoschöck 2009, 38
[3] Spehr 2008, 201f
[4] Engels 1845, 126

recordings and thus making it possible to investigate the effect of the soundscapes on the individual emotions. Regarding the sound of workplaces, Schafer criticizes above all the structural conditions of hearing, since everyday working life offers hardly any intentionally designed soundscapes. According to Schafer, acoustic design problems of industrial soundscapes combine with social problems such as noise stress or hearing loss.[5]

As a profession, sound studies lie across existing research disciplines and has transdisciplinary and methodologically innovative approaches that are as artistic as they are scientific: Research disciplines in design theory, cultural studies, communication theory as well as sound research in the context of sonification, bioacoustics or sound ecology can be found.[6] In sound studies, the question arises as to what influence sounds have on perception. In other words, one goal of sound studies is to focus on the "contingency of sound design, its dependence on conditions such as spatiality, culture and individual experience, its designability and thus to make it comprehensible and teachable".[7] Accordingly, the materiality of sounds is not only historically, socially and culturally coded, but also shaped by science, technology and its instruments and listening practices.

3 Work, noise and health problems

Noise pollution is currently verified by labour inspectors. However, the sound noise limits are not regulated by subjective listening experience, but by measurable and comparable sound levels. There are many standards, guidelines and legal provisions relating to the design of health and safety at work (cf. DIN EN ISO 11690-1).[8] Noise protection regulations define the emission limit values for noise in such way that people are not significantly disturbed in their well-being by emissions above the limit values. According to the VDI guideline "Assessment of noise at the workplace", an exceedance of 70 dB(A) for simple or predominantly mechanised office activities and 55 dB(A) for predominantly intellectual activities is regarded as measurable factors influencing well-being. The limit values are 85 dB(A). The common goal of noise protection regulations is that people should not be disturbed in their well-being by too loud noise emissions. When setting limit values, less subjective listening experience are important, but rather measurable sound levels enable a risk assessment. These objective measurement results have the advantage of making soundscapes comparable. The importance of noise as a health risk in Europe is further illustrated by the following study:

- Approximately 60 million employees throughout Europe are affected by considerable noise pollution at the workplace.
- 28% of EU workers are so exposed to noise that communication is difficult.[9]

While health-impairing soundscapes are certainly dependent on the intensity, exposure time and frequencies of sound events, the perception of the soundscape and the associated noise pollution can also be attributed to subjective sensations. The survey by the Lucerne University of Applied Sciences and Arts (2010), with 1230 respondents in 116 Swiss companies, points to a quiet working atmosphere as the most important criterion for a health-preserving workplace. Half of all respondents in open-plan offices feel affected by background talks and telephone calls.[10] The quantitative meta study by Oommen et al. identifies three problem areas based on 59 different studies on the effects of open-plan offices: Lack of privacy (constant visibility and audibility, feeling of being monitored), distraction by poor acoustic conditions (conversations from others, loud telephone calls, no possibility of retreat) and lack of the personal design of the workplace (no possibility of personal appropriation).[11] Therefore, from an occupational psychology point of view, it is also problematised that workload concepts concentrate on concrete work contents and working conditions. The ability to work

[5] Schafer 2010, 45
[6] Schoon 2011
[7] Schulze 2008, 11
[8] Guidelines are not described here in detail, for more information's see Liebl/Kittler 2016, 17-24
[9] Hecker 2008, 13
[10] SBiB 2010
[11] Oommen et al. 2008, 37

is recorded only under the aspect of measurable functional impairment. In doing so, the operational conditions of work and above all the feelings and wishes of the employees are neglected.[12] According to this, only a contextualization of the subjective perception of work demands offers a framework that enables valid evaluations and opens creative scope for reducing stress factors. With these aspects it becomes clear how important sustainable and creative strategies are in dealing with noise.

In summary, it can be concluded that an acoustic design of workplaces is only possible through the capturing of subjective feelings. However, to include subjective meanings for the design of soundscapes, insufficient actual acoustic states must be recognized. In addition to human factors and ergonomics sciences and medical regulations, it is particularly important for the well-being of employees to record their subjectively perceived sources of noise stress below limit values and take their design wishes seriously. This means that the effects of noise must not only be examined individually, but also structural noise protection are required. These gaps in relation to capture and evaluate noise stress can be closed by epistemological approaches to listening experiences. This open research aspect will now be discussed in the following chapter.

4 Subjective perception as method of soundscape design

Starting from sensual perception, this chapter explains the thesis that hearing can be regarded as a constitutive of knowledge: In other words, by reflecting processes of perception or empirical experience, listening forms a preliminary stage of logic, which is described as a content-related and factual meaning of the environment. According to Peres, the process of logical conclusions based on experiences contains two essential steps: 1. "sensual recognition" and 2. "sensual representation".[13] This is relevant for the assessment of noise stress in so far as it is possible to compare listening experiences and, if necessary, to derive forecasts from experience in the recognition and presentation of the sensory. Before the method of sensual cognition is applied to the assessment of noise, the sensual cognition process is described in general in the following:

According to the psychologist and founder of critical psychology Klaus Holzkamp, however, a representation of reality can only take place through the real and possible cognitive activity of individuals. I.e., the sensual experience and understanding of perception is a prerequisite for "the appropriate understanding of people's practice".[14] Perception is therefore not only an individual practice, but also a processing of what is perceived. I.e., hearing lies accordingly in a transition area between perception and processing. What is heard is accordingly subjective and exists "only in the mind of the thinker".[15] Whether noise is pleasant or unpleasant differs in subjective perception: A jackhammer at an avant-garde band concert can trigger well-being and ectase if the sound source is one's own favourite music. However, a jackhammer can just as easily cause tension or anxiety in everyday life. This makes it clear that it is not necessarily the sound characteristics but rather the subjective handling of noise that is a decisive factor for noise stress. This means that noise is not necessarily to be measured in volume levels, but rather has psychological and social assessment criteria.

At the same time, the researchers themselves, their methods, preconceptions and conceptual categories are in the context of sound assessments. Accordingly, self-relations are established which are accompanied by perceptions, sensations and repetitive hearing processes. Schulz summarizes this epistemological approach as follows: "I, as a hearing creature, move in the world and use my creative hearing, my creation of sounds as an auditory way to gain knowledge".[16] Accordingly, sound and sensory research is combined with questions of perception and self-perception: scientific knowledge is also a form of creative research, because sensual perception and individual sensitivity become a method and the access to

[12] Maschewsky 1983, 124; Frosch et al. 2014
[13] Peres 2011, 11ff
[14] Holzkamp 1973, 12
[15] Holzkamp 1973, 34
[16] Schulz 2011, 29

knowledge can be investigated and composed beyond the effects of auditory phenomena. This means that sound research perspectives are framed by hearing itself, by the cultural nature of hearing. Thus, sensations are theory-able.[17]

In summary, perception is a moment of human subjectivity and subjectivity has a recognizing character. If this moment is now represented scientifically, sensual perception becomes an instrument of knowledge. When sounds serve as a mediation between the environment and the listener, hearing always includes a socio-spatial component.[18] This means that the social space is opened through the subjective experience and the experience of hearing. Accordingly, the listeners constitute the social space through the background of their biographical approaches and their meanings, which will attach to the social space. Thus, local conditions, perceptions and interpretations become the focus of hearing.[19] Finally, it can be concluded that sensual perception has an orderly character and orientation function. The partial controllability of the conditions of perception are pre-structured by experience. The art of sensual knowledge consists of reflecting on the construction of perception and its social integration, as well as developing methods that make this epistemological approach possible. It must be clarified how sensual knowledge can be instrumentalized or methodologized for human factors and ergonomics sciences so that general conclusions become permissible and verifiable. The following chapter is dedicated to this aspect.

5 Conclusions for a risk assessment of noise at work and soundscape design of workplaces

Risk assessments offer current possibilities for capturing the relationships between subjectively perceived noise exposure, physical parameters as well as the development of noise protection. Health hazard is the source of work-related health impairment. The purpose of risk assessments is to minimize health-risking workloads. They also function as a workload monitor or early warning system.[20] Current risk assessments at the workplace are regulated by various laws and guidelines in Europe and assess work equipment, work safety, hygiene, working hours and workplace design.[21] The determination of the workloads is implemented by means of different work-scientifically tested questionnaires and screenings (e.g. ISTA, VERA, BASA 2 and many more). An assessment of psychosocial risks, including noise stress, is now provided for in Section 5 (3) of the German Occupational Safety and Health Act of 2013.

Overall, however, research gaps can also be identified in the practice of risk assessment: These are due, among other things, to incorrect identification of psychosocial burdens and imprecise human factors and ergonomics sciences measurements, because many of the established procedures do not meet the specific requirements and needs of employees, companies and sectors in every respect .[22] The final report of the Commission "Work of the Future" states: "In the last decades [...] no fundamental progress has been made in the further development of this so important instrument [the risk assessment]".[23] In addition to higher implementation rates, the Commission proposes above all a model development for recording health hazard assessments: "Since forms of exposure are varied, situation-dependent and cannot be uniformly described and quantified, standards must be specified for specific sectors or activities". [24] Finally, these criticisms also point to gaps in epistemological research: Capturing the complexity of individual sensations and stressors. This research gap or the complexity of the risk assessment of noise becomes particularly clearer when people affected by noise stress describe their feelings:

[17] Schulz 2011,14ff
[18] Truax 2000
[19] Reutlinger 2008
[20] Jürgens et al. 2017: 156; Hahnzog 2015
[21] Beck/Splittgerber 2016, GDA 2016
[22] Beck/Lenhardt 2009, 75; Janetzke/Ertel 2016, 81
[23] Jürgens et al. 2017: 156
[24] Jürgens et al. 2017: 156

"Today we have an infinite amount of space [in the open-plan office], but because there is so much space, of course the whole background noise just also becomes too loud. Um, and when they then talk to someone like that in a one-on-one conversation with an occupational physician, who then also says, ok well, you can actually only make recommendations, but you can't tell a company or an entrepreneur how to close things down. (...) When they come from smaller units and then enter a large room, um, which is really not only a large room, but actually also a large room, because there are no sound-absorbing walls or partitions, where they have an uncanny noise level, where people can, um, Yes, and I'm saying that they don't feel at ease, that they can't concentrate where you're partly aware, so even the colleague 50 meters away - when he calls Asia louder or hears something - can't even hear what's going on in detail. If you then, I say once to the next superiors go and say: 'We must absolutely talk about it, maybe to do certain things, that we bring this, the noise level just to the bottom'. Um, and nothing happens according to the slogan, 'the owner just doesn't want that', because he thinks it's nice when everything is kept in Betty Ford white and everything is so nice and clear, nä, to see. (...) I think that the nervous strain that has now led to my situation could not have been avoided by other architecture or would probably have occurred. But the feel-good effect also before, um, the little thing that it has made for me now, um, would certainly have been much better if one had felt comfortable at work. So that one would have had a somewhat calmer atmosphere".[25]

On the one hand, these sensations indicate the complexity of noise stress. On the other hand, these sensations also show how difficult risk assessments are without the help of subjective feelings. A link between subjective sensations and risk assessments is the soundscape design of workplaces. In the context of psychoacoustic and participatory research methods, the field of soundscape design takes up the possibility of dealing with problems in noise stress assessment and sonic design wishes at workplaces. To design workplaces, Schulz (2010) proposes that these social spaces be designed not only aesthetically, but also in terms of their sonic resonance conditions, and that these designs should be based on the hearing impression of the people who work at these social spaces.[26] On the one hand, this means that auditively designed architecture is therefore not only reserved for concert halls but can also be an elementary aspect in the design of functional utility rooms. On the other hand, it is critical to state that no generalizable planning variables can be derived from individual sensations, "so that it is necessary to establish the connection between subjectively perceived noise exposure and physical measured variables".[27]

Abrass (2015) describes in this context a target-group-specific soundscape design, which asks the expectations of the users of the location to be designed, to then clarify how a target-group-specific soundscape should be designed.[28] Four basic principles or implementation steps are described in this context. In a procedure for designing soundscapes, the following questions must be clarified by target group step by step:

1. Which people enliven the place? What are their activities, where and when do they take place? What expectations are placed on the location?
2. Which acoustic conditions are relevant for the place and how should this place sound?
3. Which noises are intentional or unintentional?
4. Which sound design measures or structural artefacts can create the desired soundscape?

Both in the first and in the last two steps, the special features of the sound cap design become visible: Essentially, the soundscape design is based on 1) an actual/target comparison and 2) measures to determine how the actual/target deviations can be corrected. This makes 3) target groups have become the focus of noise assessments. In these assessments, the sole aim is no longer to contain noises that are too loud, but 4) to determine and develop those noises that are desired by the

[25] Helmut, quoted after Paulus 2012, 335f
[26] Schulz 2011, 25f
[27] Liebl/Keitel 2016, 57
[28] Abrass 2015, 40ff

target groups. From this it can be deduced that the task of risk assessments is now to reflect perception, sensations and their social integration and to develop methods that enable subjective or sensual and socio-spatial approaches.[29]

In the following, these basic principles of soundscape design will be critically reflected upon and deepened based on methodological approaches and empirical studies on the subject.
Central problems of soundscape design are that people may have difficulties describing their perceptions, that different people perceive the same sound event differently or that there are conflicts of interest between user groups. In these cases, notation procedures of a) psychoacoustics and b) sound studies provide orientation and c) participation methods and architectural design measures can reduce conflicts:

a) Psychoacoustics is already used in human factors and ergonomics sciences and investigates the relationship between objective-physical stimulation and the emotional effect of the sound event. The most important criteria here are sensory variables such as volume level, loudness, timbre, fluctuation level or sharpness of a sound. In psychoacoustic hearing tests, for example, test subjects are asked to classify sounds along reproducible scales (blunt to sharp tones) or to describe sounds using property words (e.g. powerful, clean, spongy, soft, warm, annoying, metallic, etc.). Psychoacoustic tests have the advantage that listening experiences can be validated and individual hearing ability can be assessed in a medical context.[30]

b) Socio-spatial hearing methods by sound studies have been used for several decades in hearing education[31]. Schafer (2002) has documented more than one hundred methods. Here you will find instructions on sound diaries, participating audio observations or questionnaires for describing soundscapes using notation methods. These methods and procedures open theoretical and practical starting points for capturing noise pollution at the workplace. Characteristically, soundscapes can be divided into "Hi-Fi" (less background noise) and "Lo-Fi" (noise pollution). Operational "Lo-Fi" sounds, for example, are characterized by a dense carpet of sounds in which many signal sounds are swallowed, differentiated hearing is more difficult and the spatial perspective is lost. This increases the perception of noise. In this context, extensive description patterns or notation patterns of soundscapes exist to detect unwanted or disturbing sound sources and to assign meanings to undifferentiated sounds. Thus, for example, the soundscapes of an office can be described by assigning and characterizing disturbing sound sources (also below limit values). [32]

c) Participation methods can help in the case that there may be conflicts of interest between user groups. Based on psychoacoustic findings, Brown (2011) and Abrass (2015) propose in this context to bring desired soundscapes to the foreground to completely or partially cover up unwanted sounds. Based on these findings, participation methods are used to create acoustic acceptance for a workplace. The auditory contrasting, contextualization and adaptation by means of the expectations of the users also means an improvement of the functional side of the workplace, because users like to spend time in these self-designed rooms. Abrass describes successful design processes in Brighton and the redesign of Nauener Platz in Berlin. In other words, these participation procedures are not only concerned with reducing noise, but also with redesigning the spatial conditions by means of structural measures in such a way that the soundscape is supported by all users.[33]

[29] Brown 2011
[30] Bruß 2014
[31] Westerkamp 1974
[32] Schafer 2002,34f, 230ff;
[33] Abrass 2015, 55

d) Current studies on the structural-acoustic design of workplaces also show effective design measures. Pieren (2011) is explicitly dedicated to the design of soundscapes in open-plan offices and uses sound design models to show how speech intelligibility, noise, shielding and reverberation can be optimized by zoning specific activities (telephoning, meetings, concentrated work, etc.) and structural artefacts (e.g. sound screens, noise curtains, sound absorbers) together.[34] Acousticians at the University Ostwestfalen-Lippe are currently experimenting with masking noises in a research project. In other words, they want to develop self-controlling audio devices for offices that adapt to the soundscapes and drown out background noise with natural sounds such as from water, wind or birds.[35]

In summary, hearing-sensitive scientific approaches refer to the perspective of not reducing the acoustic environment to individual sound events. Rather, they are based on a socio-spatial understanding to assign different meanings to sounds and to take employees as a measure of the positive and negative evaluation of the acoustic environment. The four basic principles of sound cap design show

1. an orientation towards people's senses
2. soundscapes are based in an interdependency with humans
3. laws of perception
4. socio-spatial design strategies.

This allows potential target groups to be actively involved in risk assessment and their perceptions of ambient noise and their expectations of the design of their workplace can be considered.

6 Resumé

Workers in open-plan offices, but also in metalworking factories, road construction, etc. know the effects of unwanted sounds, ranging from psychological effects such as "annoyance", reduction of the ability to concentrate to psychosomatic illnesses. Certainly, these effects depend on the intensity, exposure time and frequencies of the auditory phenomena, but the perception of the soundscape and the associated noise pollution can be attributed to the individual constitution of the person. Therefore, from an occupational psychology point of view, it is problematised that workload concepts concentrate on concrete work contents and working conditions and that the ability to work is only recorded under the aspect of measurable work situations that cause illness. In doing so, the operational conditions of work and above all the feelings and design wishes of the employees are neglected. This means that workloads caused by noise must be contextualised so that descriptions or measurement data allow comparisons, conclusions or derivations. According to this, only the contextualisation of the subjective perception of workloads caused by noise stress provides a framework for evaluation and opens creative scope for reducing subjectively perceived stresses.
Since the sensations of noise exposure are subjective, these sensual experiences can also serve as an instrument of knowledge for assessing noise exposure. In risk assessments, psychosocial noise stress factors must therefore be considered, because not only a too loud machine causes noise stress, but also the rattling of keyboards or the unwanted conversation in open-plan offices can be annoying. A reduction in noise levels therefore does not necessarily improve better working conditions or minimize health hazards.

In this context, there is a considerable backlog of scientific studies on noise and stress factors. Additional investigations and procedures are required to shed light on the possibilities of influencing spatial acoustic parameters through structural

[34] Pieren 2011, 7
[35] Kob 2016

measures and furnishings as well as the capturing of noise sensations to be able to carry out comparative meta-analyses.[36] This also includes a capturing of subjective sensations and design wishes to create environmental conditions that make salutogenetic working conditions possible. The development of auditory spatial interpretations can help to create an understanding of the living and working environment of employees. However, this means a continuation of human factors and ergonomics sciences analysis towards subject-oriented procedures.

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