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The indoor sound environment and human task performance: A literature review on the role of room acoustics

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ABSTRACT

A substantial amount of studies have addressed the influence of sound on human performance. In many of these, however, the large acoustic differences between experimental conditions prevent a direct translation of the results to realistic effects of room acoustic interventions. This review identifies those studies which can be, in principle, translated to (changes in) room acoustic parameters and adds to the knowledge about the influence of the indoor sound environment on people. The review procedure is based on the effect room acoustics can have on the relevant quantifiers of the sound environment in a room or space. 272 papers containing empirical findings on the influence of sound or noise on some measure of human performance were found. Of these, only 12 papers complied with this review's criteria. A conceptual framework is suggested based on the analysis of results, positioning the role of room acoustics in the influence of sound on task performance. Furthermore, valuable insights are presented that can be used in future studies on this topic. While the influence of the sound environment on performance is clearly an issue in many situations, evidence regarding the effectiveness of strategies to control the sound environment by room acoustic design is lacking and should be a focus area in future studies.

Contents

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1. Introduction

People working indoors are continuously subjected to sound. Whether working alone in a private office, or amongst a large number of colleagues in an industrial setting; a complete absence of sound never occurs. Conversations of colleagues, loud industrial noise or the continuous hum of HVAC installations can be distracting [1], cause stress [2], fatigue [3] or even hearing loss [4], all of which might result in a decrement of task performance. Sound though, can also be stimulating or cause a positive mood change which might in turn result in a performance increase [5]. Already in the early 20th century, studies on the relation between sound and people's performance were conducted [6], and the increasing popularity of open-plan offices in recent years has boosted this field of research [7].

The substantial amount of research dedicated to the effect of sound on human performance, mainly originates from a cognitive psychology point of view. For example, many studies are performed in which people's susceptibility to distraction by noise is used to understand the processes in the human brain [8]. The results of these studies are then introduced as evidence to support psychological theories about selective attention [9], interfering processes [10,11] and arousal [12]. Building on the increasing knowledge about the impact of sound on performance, the current review takes a complementary perspective. Rather than focusing on understanding cognitive processes, we are taking a room acoustic point of view following the working principles of evidence-based building design [13]. Furthermore, the scope of this study is limited to the effect of natural sound sources occurring in working environments on task performance. We consider this an important step in defining the prerequisites of a good indoor environment, a topic for which the awareness of its importance has grown in recent years [14,15]. A good sound environment should not lead to any physical, physiological or psychological changes in a person's body that could negatively affect his or her health. Furthermore, the sound environment should allow a person to be in, or should even contribute to obtaining, the most suitable state of mind for a specific activity. What we consider to be lacking in the literature is an overview of the effect of sound on human performance which can be, in principle, translated to room acoustic parameters and adds to the knowledge about the influence of the built environment on people. While letting a person perform a serial recall task when being subjected to either speech at 85 dB(A) or 'silence' in a laboratory experiment (for an example see [16]) does provide insight in cognitive processes, it does not help define guidelines for an optimal acoustic (working) environment. These extreme levels are not representative of natural working conditions; moreover, room acoustic interventions or design decisions alone would not allow to realize such large differences between conditions. The question arises to what extent the current body of evidence on the effect of sound on task performance can be used to gain insight in the role of room acoustics.

The present paper reviews to what extent the current evidence on the effect of sound in the work environment on human performance can be used to aid room acoustic design decisions. To answer this question, it is desirable to clearly specify what effect (passive) room acoustics can have on the relevant quantifiers of the sound environment in a room or space. Based on this, the results can be identified of those experimental studies in which the difference between experimental conditions can, in principle, be attributed to room acoustic modifications. A secondary objective of this review is to derive implications for future research from the results. The meta-analytic synthesis conducted by Szalma and Hancock [17] in which the results of 151 papers on the effect of sound on human performance were reviewed will form the starting point in the search for literature.

2. Search strategy and selection of papers

2.1. The effect of room acoustics on the indoor sound environment

For this review's purpose, sound level and speech intelligibility are considered the most important quantifiers of the sound environment that are affected by room acoustics and for which the effect on human performance has been investigated and published. Inclusion and exclusion criteria for the selection of papers which do not take room acoustics into account are based on a theoretical approach of the maximum effect of room acoustics on these quantifiers. Other effects of acoustics on the sound environment, such as the existence of a flutter echo which can make one's own voice sound unnatural and uncomfortable, or a change in the spectral distribution of sounds due to frequency specific sound absorption, are too dependent on the source type and the positions of source and receiver, and will therefore be considered to be outside the scope of this review. Studies on the effect of actual room acoustic changes are included.

The inclusion and exclusion criteria that are used to select articles are shown in Table 1. The following sections provide a motivation for the inclusion criteria related to sound levels and speech intelligibility and an explanation of the review procedure.

2.2. Motivation for the inclusion criteria related to sound levels and speech intelligibility

2.2.1. Reduction of overall sound level in a room of a fixed size due to sound absorption

Replacing a sound reflecting ceiling with a ceiling with a high sound absorption coefficient, adding wall panels or absorbing elements in the room and the use of soft furnishings are typical ways to increase the total amount of sound absorption. The sound pressure level difference $\Delta L_p(f)$ due to adding sound absorbing material to a room, assuming a diffuse sound field, can be calculated by using the following formula (1). The total amount of room absorption area in m^2 before (S_1) and after (S_2) the intervention has