Applied Acoustics 86 (2014) 1–16

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Effects of unattended speech on performance and subjective distraction: The role of acoustic design in open-plan offices

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ARTICLE INFO

Article history:
Received 25 October 2013
Received in revised form 19 March 2014
Accepted 16 April 2014
Available online 27 May 2014

Keywords:
Speech Transmission Index
Cognitive performance
Speech intelligibility
Masking
Acoustic satisfaction
Noise effects

ABSTRACT

Unattended background speech is a known source of cognitive and subjective distraction in open-plan offices. This study investigated whether the deleterious effects of background speech can be affected by room acoustic design that decreases speech intelligibility, as measured by the Speech Transmission Index (STI). The experiment was conducted in an open-plan office laboratory (84 m^2) in which four acoustic conditions were physically built. Three conditions contained background speech. A quiet condition was included for comparison. The speech conditions differed in terms of the degree of absorption, screen height, desk isolation, and the level of masking sound. The speech sounds simulated an environment where phone conversations are heard from different locations varying in distance. Ninety-eight volunteers were tested. The presence of background speech had detrimental effects on the subjective perceptions of noise effects and on cognitive performance in short-term memory and working memory tasks. These effects were not attenuated nor amplified within a three-hour working period. The reduction of the STI by room acoustic means decreased subjective disturbance, whereas the effects on cognitive performance were somewhat smaller than expected. The effects of room acoustic design on subjective distraction were stronger among noise-sensitive subjects, suggesting that they benefited more from acoustic improvements than non-sensitive subjects. The results imply that reducing the STI is beneficial for performance and acoustic satisfaction especially regarding speech coming from more distant desks. However, acoustic design does not sufficiently decrease the distraction caused by speech from adjacent desks.

1. Introduction

Acoustic problems of open-plan offices have been widely documented in the literature. These problems are not only manifested as increased noise complaints (e.g., [1]), but have also been associated with a variety of negative outcome variables, such as noise-related stress [2], decreased environmental satisfaction [3], decreased job satisfaction [3], impaired concentration [4], and decreases in self-estimated work performance [5]. However, the environmental problems of open-plan offices are not confined to office noise. Open-plan offices have also been associated with increased complaints about most indoor environmental factors (e.g., [6,1]), lack of privacy (e.g., [7]), decreased satisfaction with the overall environment [5], increased cognitive workload [7], increased prevalence of different symptoms [1], and increased sickness absence [8]. Therefore, it is difficult to separate the effect of acoustic conditions on work performance and well-being from other factors that may confound the perception and the impact of the acoustic environment.

In recent years, a growing number of researchers have adopted an experimental approach to study the effects of open-plan office noise on performance. In this approach, performance effects are tested with different cognitive tests in laboratory settings employing methods from experimental psychology. A few of these studies have tested office noise exposure *per se* using noise that consists of a variety of office sounds [9–11]. However, most studies have focused on the effects of background speech (e.g., [12–17]). The latter approach is motivated by several reasons. Firstly, speech sounds tend to be mentioned as the most distracting noise source by office workers (e.g., [5,18]). Secondly, basic cognitive research has repeatedly demonstrated that background speech impairs cognitive performance, and that these effects are larger than those produced by non-speech noise (for a meta-analysis, see [19]). Thirdly, the practical relevance of this research area has increased since the publication of a new international room acoustic

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http://dx.doi.org/10.1016/j.apacoust.2014.04.018
0003-682X/

measurement standard for open-plan offices [20] in which reducing the distraction of background speech is the most essential idea.

The present study focuses on the role of room acoustic design in decreasing cognitive and subjective distraction that is caused by background speech.

1.1. Speech intelligibility and cognitive performance

Unattended background speech has been shown to affect several cognitive tasks, such as short-term memory [21], mental arithmetic [22], reading comprehension [23], proofreading [24], and writing performance [25]. According to the interference-by-process account, the performance disruption depends on the interplay between the properties of the sound and those of the task (e.g., [26]). More specifically, performance disruption is caused when the processes engaged by the automatic processing of the sound overlap with those needed in the focal task. Thus, the meaningfulness of speech is only seen as relevant in tasks requiring semantic processing [26], whereas the acoustic variation of speech explains the decrements observed in serial memory [27], regardless of whether the speech is comprehensible or not [24].

Unlike with some other noise sources, the performance impairment caused by speech does not depend on the sound pressure level, but rather on the intelligibility of speech [28,29]. While the effects of speech on performance have been extensively researched, few researchers have focused on the role of speech intelligibility. The latter studies show that performance in several cognitive tasks deteriorates with increasing intelligibility (e.g., [13,14,22,29]). Similarly, speech intelligibility predicts a variety of subjective responses, such as acoustic satisfaction [12,30], perceived disturbance [13,22], subjective habituation [17], and subjective workload [12].

The method of determining speech intelligibility has differed between studies, varying from subjective listening tests [15,22] to the signal-to-noise ratio [28,29,31] and the Speech Transmission Index (STI) [12–14,17,32]. While the first two methods provide valuable information about the effect of speech intelligibility in general, the latter approach is more beneficial for applied research because the STI is commonly used in evaluating and designing room acoustics. The STI is also a key quantity in the new international measurement standard [20]. By using the STI, cognitive laboratory experiments can be linked to predicting how acoustic conditions affect performance in office environments.

The STI is an objective descriptor for subjective speech intelligibility (STI 0.00 = not intelligible, STI 1.00 = perfectly intelligible). In practice, the STI of speech depends on absorption, screens, background sound level, and the distance between a speaker and a listener [33]. According to the model proposed by Hongisto [34], cognitive performance deteriorates with increasing STI. Performance is expected to start to decline above STI 0.20 and reach the maximum decrement when STI 0.60 is exceeded. The steepest decline is expected in the range of STI 0.30–0.50. Hongisto [34] concluded that in order to decrease the detriments of background speech, the STI should be below 0.50. This idea is included in the ISO 3382-3 standard [20] as distraction distance (r_D) which defines the distance at which the STI falls below 0.50.

However, the STI-performance model [34] may be somewhat debatable because the model was based on only three experimental studies available at the time. Later studies have given some support to the model by showing that the steepest decline in performance occurs somewhere between STI 0.38 and 0.62 [12,13]. However, recent findings by Jahncke et al. [14] and Keus van de Poll et al. [32] suggest that the maximum deleterious effect on performance might already be reached at STI 0.34. The inconsistency of these studies may be explained by the use of different tasks, as it seems likely that the STI-performance relation is to some degree task-specific [14]. Other methodological differences between the studies may also account for the results. Given the divergent findings and the small number of studies conducted, the relationship between the STI and cognitive performance requires more research. This knowledge would also be beneficial for evaluating whether the acoustic criteria adopted in the ISO 3382-3 standard [20] are sufficient in terms of the desired effects on background speech distraction.

1.2. Limitations in studies on speech intelligibility

Most of the studies on the STI and speech intelligibility have, to a varying degree, attempted to provide practical implications for office environments. However, there are several aspects in which the ecological validity of experiments on the STI-performance relation can still be improved.

As far as speech material is concerned, most speech intelligibility studies have used continuous speech either comprising of very simple successive sentences with no plot [14,22] or a story in the native [32] or a foreign language [29]. A few studies lack the description of the sound materials used [15,31]. However, the meta-analysis of Szalma and Hancock [19] has shown that intermittent background speech causes greater performance impairment than continuous speech. Background speech is also more distracting when it represents half of a dialogue, as in overhearing a phone conversation [35]. Both intermittent speech and one side of a phone conversation are characteristic of many open-plan offices, whereas monologue-like speech is not. In some tasks, constant speech can also be habituated [36], which may lead to imprecise conclusions if used to represent open-plan office noise. Three studies [12,13,17] have used intermittent speech with short pauses of varying length between sentences but the speech was designed to be calm and uninteresting, which may represent some but not the most distracting office discussions.

Another factor that may affect performance effects of speech is the location of the speech source. A few studies suggest that performance is affected most when speech originates from the same direction where visual attention is actively engaged in [37,38], although this may not be true for all tasks [24]. In open-plan offices, the location of the speech source varies, as does the distance to different speakers present in the room. The speech intelligibility studies have usually used speech from one static location, typically in front of the subject, and presented the speech via loudspeakers or using a headphone simulation [14,15,17]. Some studies have used headphones without specifying the perceived speech location [29,32]. Only two studies have used multiple locations for speech sources [12,13]. Schlittmeier and Hellbrück [31] have used open-plan office noise that was recorded with an artificial head, presumably including variation in sound direction and distance, but they reported no details to describe the sound material. However, none of the studies have intentionally varied the STI within a test condition which would simulate open-plan offices where the distance to different speakers varies.

The effect of the exposure time has also been neglected in speech intelligibility experiments. The single speech conditions have typically lasted for less than an hour (e.g., [12,14]), while the longest duration seems to have been 1.5 h at the most [15]. The performance effects of noise in general tend to attenuate with longer exposure times but this may not apply to background speech [19]. In open-plan offices, one working period between breaks might last for three-to-four hours. While it is possible that the effect of background speech could be adapted to over time, it is also conceivable that cognitive or subjective impacts of noise might increase as a result of an emerging stress response or decreasing compensatory resources.