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Effect of variation in noise absorption in open-plan office: A field study with a cross-over design

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ABSTRACT

Noise has repeatedly been shown to be one of the most recurrent reasons for complaints in open-plan office environments. The aim of the present study was to investigate if enhanced or worsened sound absorption in open-plan offices is reflected in the employees' ratings of disturbances, cognitive stress, and professional efficacy. Employees working on two different floors of an office building were followed as three manipulations were made in room acoustics on each of the two floors by means of less or more absorbing tiles & wall absorbents. For one of the floors, the manipulations were from better to worse to better acoustical conditions, while for the other the manipulations were worse to better to worse. The acoustical effects of these manipulations were assessed according to the new ISO-standard (ISO-3382-3, 2012) for open-plan rooms acoustics. In addition, the employees responded to questionnaires after each change. Our analyses showed that within each floor enhanced acoustical conditions were associated with lower perceived disturbances and cognitive stress. There were no effects on professional efficiency. The results furthermore suggest that even a small deterioration in acoustical room properties measured according to the new ISO-standard for open-plan office acoustics has a negative impact on self-rated health and disturbances. This study supports previous studies demonstrating the importance of acoustics in work environments and shows that the measures suggested in the new ISO-standard can be used to adequately differentiate between better and worse room acoustics in open plan offices.

1. Introduction

In relation to other ambient factors, the impact of unwanted sound or noise is probably the most studied when it comes to office environments (Boyce, 1974; De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005; Leather, Beale, & Sullivan, 2003; Leder, Newsham, Veitch, Mancini, & Charles, 2015; Navai & Veitch, 2003; Nemecek & Grandjean, 1973; Pejtersen, Allermann, Kristensen, & Poulsen, 2006; Sundstrom, Burt, & Kamp, 1980; Sundstrom, Town, Rice, Osborn, & Brill, 1994; Veitch, Charles, Farley, & Newsham, 2007; Veitch, Farley, & Newsham, 2002; Warnock, 2004). Noise has been suggested to cause interruption, irritation and lowered performance among employees (Roelofsen, 2008), and is one of the most common reasons for complaints in open-plan office environments (Kaarlela-Tuomaala, Helenius, Keskinen, & Hongisto, 2009). However, this study addresses something that is less known about noise, namely, how better or worse acoustical conditions in open-plan offices affect employees' perception of disturbances, cognitive stress, and professional efficacy.

Why noise is a common reason for complaints can be explained by the *changing state hypothesis* (Jones, Madden, & Miles, 1992), which suggests that sounds varying over time cause more disruptions. A sound that is constant in intensity or timbre should therefore cause fewer disturbances than sounds that constantly change their characteristics. A more uniform sound source can be created by filtering out high frequency sound, so called low-pass filtering (Jones, Alford, Macken, Banbury, & Tremblay, 2000) or by introducing new sources of sound, which either can be competing voices (babble-effect) or speech neutral masking noises, e.g. from ventilation (Loewen & Suedfeld, 1992). Increasing the number of sounds beyond a critical level causes the overall degree of

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variability in sound to drop, hence the overall result is a more even sound level where peaks and troughs from individual sound sources are cancelled out (Perham, Banbury, & Jones, 2007). The degree of variability might also be expected to drop when reverberation time increases. For example, Beaman and Holt (2007) found that a reverberation time, i.e. the time it takes for sound to attenuate, of 5 s led to the same low amount of error in conducting an immediate recall test as in the quiet control condition. However, in an office environment the reverberation time seldom approaches 5 s but varies in lower ranges (between 0.4 and 1 s). Perham et al. (2007) investigated if more realistic differences in reverberation time can affect performance on a cognitive test measuring serial recall. They compared one quiet condition with two different noisy conditions. The two noisy conditions were comprised of noise from various sources in an office recorded in a room with a reverberation time of either 0.7 or 0.9 s. The respondents conducted the test while listening to the noises through headphones. Although they found an effect on performance between the quiet condition, where no noise was played, and the two noisy conditions, performance on the test did not differ between the two noisy conditions. Further analyses revealed that speech intelligibility did not differ between the two noisy conditions, and the authors concluded that "at least for typical office reverberation times, lower reverberation times do not increase intelligibility" (Perham et al., 2007, p. 843). It has also been found that different noise types, for example speech, music, and office noise in general, in comparison with quiet conditions, negatively impact different cognitive outcomes, such as memory performance, reading comprehension, and proofreading (see Hongisto, 2005 for an overview).

Noise has also been extensively studied in field studies. Ringing telephones, air conditioning, and office machinery have all been suggested to cause disturbances in office environments. Human speech (Boyce, 1974; Pierrette, Parizet, Chevret, & Chatillon, 2014; Sundstrom et al., 1994) and its intelligibility is another common distracting factor. It is measured by the Speech Transmission Index (STI), which ranges from 0, meaning that the speech is not understandable, to 1, meaning that the speech is fully comprehendible. When STI exceeds 0.2 it begins to cause a decrease in performance with the highest decrement occurring around 0.6 (Hongisto, 2005). Furthermore, field studies also show that distractions and noise are present also in cell offices (Seddigh et al., 2015), even if open-plan office environments usually are associated with more noise and distractions (Kaarlela-Tuomaala et al., 2009; Seddigh, Berntson, Bodin Danielson, & Westerlund, 2014). Consequently, it would be more relevant to investigate the impact of different sound intensities or certain aspects of noise rather than comparing its presence with absence.

In addition, another study by Pierrette et al. (2014) could not find any association between the A-weighted sound pressure level dBA (LeqA) and the perception of noise in the office as high or annoying. The authors emphasised the relevance of measuring behavioural outcomes to appraise the appropriateness of the noise in open-plan office environment instead of relying overly much on objective acoustical measures. This conclusion corresponds well with the definition of noise not as the particular type or magnitude of the sound, but rather as the perception of the sound by the listener, i.e. to what extent the sound is experienced as noise (Roelofsen, 2008).

Additionally, knowledge workers – that is workers who create, develop, manipulate, disseminate or use knowledge to provide an outcome – depend to high degree upon processing information (Bosch-Sijtsema, Ruohomäki, & Vartiainen, 2010; Janz, Colquitt, & NOE, 1997). According to the Load theory of selective attention and cognitive control (Lavie, Hirst, de Fockert, & Viding, 2004) unwanted stimuli such as noise need to be first processed and then actively inhibited in order to not distract the person who is exposed to noise. Therefore, for knowledge workers noise competes for the same cognitive capacities that process task related information (see also Diamond, 2013; Seddigh et al., 2014). Hence, lower in comparison to higher noise levels in office environments should lead to fewer problems for knowledge workers.

Furthermore, another relevant theory concerning supportive design (Ulrich, 1991) suggest that while certain physical characteristics may not affect employees negatively per se, they may intensify the negative impact of some other factor in the environment (Evans, 2001). Leather et al. (2003) found such effect and reported that high noise together with high job strain, in contrast to low job strain, was associated with lower job satisfaction, lower organisational commitment and increased rate of symptoms of infectious diseases. Low noise regardless of the level of job strain did not have a large effect on these measures. A comparable suggestion to the interaction of noise level and job strain can be made for the joint effect of open-plan office environments and noise levels. That is, even if the open-plan office environments per se do not affect employee health and performance, bad acoustical conditions in these environments might.

It is important to investigate the total acoustical condition in the office rather than focussing on any single aspect that may affect the acoustical condition. Namely even if wall panels can affect the acoustical condition in an office environment, in research settings it is important to focus on the actual acoustical condition in the office instead of the presence or absence of panels per se. In fact in a recent study Leder et al. (2015) found that larger workstations in open-plan offices were associated with greater satisfaction with privacy, however the degree of enclosure of the workstation by partial-height partitions was not associated with the same outcome measure. Furthermore, in order to more thoroughly understand the impact of noise on office workers health and performance, different types of measures should be used. Except behavioural outcomes, we believe that a more comprehensive mapping of the objective sound environment, rather than too much reliance on a single sound measure, could give a more extensive understanding of how objectively measured sound is associated with the perception of noise. This idea is in fact raised in the International Standard of room acoustic parameters (ISO-3382-3, 2012), which suggests that rather than relying too much on single measures, such as reverberation time, a combination of measures including STI and background noise levels should be focused on in order to receive a more complete evaluation.

Hence, the purpose of the present study is to test the effect of different acoustical environments on employee ratings on indicators of disturbances, health, and performance. This is done by a crossover design that compares two different types of sound absorbents installed in contrasting sequences on two similar floors within the same office building. In order to obtain a comprehensive understanding of the room acoustics, we collected objective acoustical data in accordance with the international standard regarding room acoustics parameters (ISO-3382-3, 2012). We also collected behavioural measures, in order to understand how the acoustical environment impacts on the employees.

1.1. Aims and hypotheses

In this study the aim was to investigate if enhanced or worsened room acoustic characteristics in open-plan office environments are reflected in changes in the employees' own perception of disturbances, health and/or performance. The manipulation consisted of different acoustic elements in the office building, where one condition enhanced the acoustic environment (better condition) and one worsened the acoustic environment (worse condition) as