Journal of Environmental Psychology 44 (2015) 16–33

Contents lists available at ScienceDirect

Journal of Environmental Psychology

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

Simultaneous effects of irrelevant speech, temperature and ventilation rate on performance and satisfaction in open-plan offices☆

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A R T I C L E I N F O

Article history:
Received 19 February 2014
Received in revised form
24 March 2015
Accepted 19 August 2015
Available online 28 August 2015

Keywords:
Cognitive performance
Indoor environment
Noise
Air quality
Room temperature
Open-plan offices

A B S T R A C T

The aim of this study was to investigate how irrelevant speech, temperature and ventilation rate together affect cognitive performance and environmental satisfaction in open-plan offices. In Condition A, neutral temperature (23.5 °C), low intelligibility of speech (high absorption and low masking sound level) and high fresh air supply rate (30 l/s per person) were applied. This was contrasted to Condition B with high room temperature (29.5 °C), highly intelligible speech (low absorption and high masking sound level) and a negligible fresh air supply rate (2 l/s per person). Sixty-five participants were tested. In Condition B, performance decrement was observed especially in working memory tasks. Based on subjective assessments, mental workload, cognitive fatigue and symptoms were higher and environmental satisfaction was lower in Condition B. It was concluded that special attention should be paid to the design of whole indoor environment in open-plan offices to increase subjective comfort and improve performance.

1. Introduction

Scientific interest towards subjective satisfaction in open-plan offices has increased because open-plan office has become the most usual office solution, mostly because of its high space efficiency (De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005). Moreover, open-plan offices are also assumed to improve organizational productivity due to the enhanced exchange of information and communication and increased teamwork (Allen & Gerstberger, 1973; Hundert & Greenfield, 1969).

However, many studies have shown that there are disadvantages in open-plan offices if the design of the indoor environment (IE) is inadequate. Increased cognitive workload (De Croon et al., 2005), concentration problems and fatigue (Haapakangas, Helenius, Keskinen, & Hongisto, 2008; Pejtersen, Allermann, Kristensen, & Poulsen, 2006) and the lack of speech privacy (De Croon et al., 2005) have been reported. Open-plan offices have also been associated with decreased job satisfaction (De Croon et al., 2005). Decreased satisfaction with IE has been indicated to have a connection with decreased job satisfaction (Veitch, Charles, Farley, & Newsham, 2007). The amount of annual sick leave has also been shown to be greater in open-plan offices, as assessed by employees' self-ratings (Bodin Danielsson, Chungkham, Wulff, & Westerlund, 2014; Pejtersen, Feveile, Christensen, & Burr, 2011).

One of the most commonly mentioned causes for these problems is poor acoustic conditions, i.e., disturbance caused by colleagues' speech and poor speech privacy (Danielsson, 2005; Frontczak et al., 2012; Haapakangas et al., 2008; Pejtersen et al., 2006). Improper thermal conditions and poor air quality have also been reported as producing discomfort in open-plan offices (Haapakangas et al., 2008; Pejtersen et al., 2006). On the other hand, overall improvement of the IE can significantly increase environmental satisfaction in open-plan offices (Hongisto, Haapakangas, Helenius, Keränen, & Oliva, 2012). That is, differences between open-plan offices can be significant regarding on the quality of IE.

The effects of IE on work performance and various components of environmental satisfaction have been studied in several

☆ This manuscript was submitted for publication to the Journal of Environmental Psychology on **17**th **February**, **2014**. The revision version of the manuscript was send on **8**th **October**, **2014**. The second revision was send on **22**nd **December**, **2014**. The third revision was send on **23**rd **March**, **2015**. This manuscript, or parts of it, has not been submitted to other journals.

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http://dx.doi.org/10.1016/j.jenvp.2015.08.001

laboratory experiments. However, most of the previous laboratory studies have focused on the effects of a single factor of IE. In the present study, we simultaneously manipulated three IE factors in order to examine their joint effects on task performance and environmental satisfaction. Fig. 1 depicts how our study was designed as a follow-up study to three previous studies each separately examining the effects of a single factor of IE. We next summarize the evidence for the effects of each factor examined separately.

1.1. Effects of office noise

Office noise, especially irrelevant speech having sufficiently high intelligibility, has been shown to decrease performance in serial recall (e.g., Haapakangas et al., 2011; Haka et al., 2009), information search (Jahncke, Hongisto, & Virjonen, 2013), proofreading (e.g., Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006) and counting tasks (e.g., Buchner, Steffens, Irmen, & Wender, 1998). Our experiment was preceded by an experiment conducted in the same laboratory, which showed that the room acoustic design, where the intelligibility of irrelevant speech could be reduced, improved work performance (Haapakangas, Hongisto, Hyönä, Kokko, & Keränen, 2014).

Moreover, subjective assessments confirm the negative impact of highly intelligible irrelevant speech; speech and other office activity sounds negatively affect subjective well-being, acoustic satisfaction and self-estimated performance (Evans & Johnson, 2000; Haapakangas et al., 2014; Haapakangas et al., 2011; Haka et al., 2009).

It is important to study how different room acoustic solutions usually applied in open-plan offices can be used to reduce the negative effects of irrelevant speech. The effects seem to mainly depend on speech intelligibility (Ellermeier & Hellbrück, 1998; Hongisto, 2005; Jahncke et al., 2013) and not on the loudness of speech (Colle, 1980). Performance is expected to decrease with increasing Speech Transmission Index, STI (Hongisto, 2005). Subjective speech intelligibility can be objectively evaluated by measuring STI which ranges from 0.00 to 1.00, with large values representing highly intelligible speech (ISO 3382-3). STI can be reduced in open-plan offices by simultaneous application of high room absorption, high screens between desks and the use of masking sound (Bradley, 2003; Keränen & Hongisto, 2013; Virjonen, Keränen, & Hongisto, 2009). By reducing the STI values below 0.30, it can be expected that the negative effects on performance can be significantly reduced (Haka et al., 2009; Jahncke et al., 2013; Keus van de Poll, Ljung, Odelius, & Sörqvist, 2014) compared to a situation where the STI is above 0.50, which is, unfortunately, very typical in open-plan offices (Keränen & Hongisto, 2013; Virjonen et al., 2009).

Our study involved an acoustic manipulation where the two most important factors of acoustic design were considered

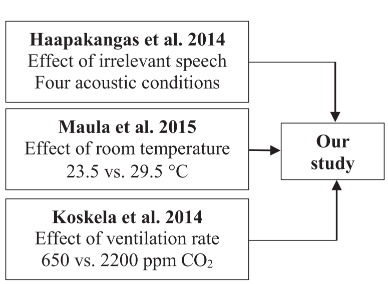

Fig. 1. Our study was preceded by three experimental studies in the same laboratory where the effects of the three IE factors were examined separately.

simultaneously: sound masking and room absorption. Absorption was used to reduce the reflection of sound from room surfaces and to reduce the overall speech level. Sound masking was used to reduce the signal-to-noise ratio of speech. Successful application of masking sounds in the office has been reported by Hongisto (2008) and Hongisto et al. (2012).

1.2. Effects of high room temperature

Room temperature can affect cognitive performance (see e.g., reviews of Hancock, Ross, & Szalma, 2007; Pilcher, Nadler, & Busch, 2002). However, the results of these reviews cannot be directly applied to office environments because the examined thermal conditions differed from usual thermal conditions in offices. The desirable room temperature in offices is between 21 °C and 25 °C depending on outside temperature, clothing, activity level and cultural differences. However, much higher temperatures, up to 35 °C, can be found in offices having insufficient cooling capacity or no cooling at all. When neutral temperatures (21–25 °C) have been compared to higher ones (above 26 °C), cognitive performance has been observed to decline at higher temperatures in short-term free recall tasks (Hygge & Knez, 2001), addition and visual tasks (Lan, Wargocki, Wyon, & Lian, 2011) and working memory tasks (Häggblom, Hongisto, Haapakangas, & Koskela, 2011). Maula et al. (2015; Fig. 1) performed an experiment before our study in the same laboratory environment. They found that high temperature (29 °C) affected the performance in working memory demanded N-Back task. However, temperature did not affect psychomotor, attention or long-term memory tasks. These results are consistent with the suggestion of Hancock et al. (2007) that the performance effects of room temperature are task-sensitive.

Subjective assessments yield a more uniform picture of the effects of room temperature. High temperature has been reported to negatively affect mood, energy, motivation, concentration and the assessment of air quality (Lan et al., 2011; Maula et al., 2015). High temperature has also been found to increase self-rated intensity of somatic symptoms compared with neutral temperature (Lan et al., 2011).

1.3. Effects of air quality

Air quality is affected by the ventilation rate and emissions from the building, furniture and occupants (Wargocki, Bakó-Biró, Clausen, & Fanger, 2002). In the majority of laboratory experiments investigating the effects of air quality on performance, the air quality has been reduced by artificial material emissions, such as by installing old and polluting carpets in the room. The combination of artificial material emission and small ventilation rate has marginally decreased performance in typing and negatively affected subjective assessments of air quality and well-being (Wargocki, Wyon, Sundell, Clausen, & Fanger, 2000). Similar results have been found for high material emissions with a constant ventilation rate (Wargocki, Wyon, Baik, Clausen, & Fanger, 1999).

When office buildings are renovated, furniture and decoration are likely to be changed and old material emission sources are usually removed. The emissions from new furniture and surface materials can cause relatively high concentrations of volatile organic compounds (VOCs) for a couple of months. The combination of high material emissions from new materials and small ventilation rate has been found to decrease objectively measured performance in typing, addition and memorization tasks and to reduce the acceptability of perceived air quality (Park & Yoon, 2011). In comparison, a previous study (Koskela, Maula, Haapakangas, Moberg, & Hongisto, 2014, Fig. 1) carried out in the same laboratory as our study investigated the situation where the