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Open-plan office noise: Cognitive performance and restoration

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ABSTRACT

The aim of the present study was to investigate cognitive, emotional, and physiological effects of two open-plan office noise conditions (high noise: 51 LAeq and low noise: 39 LAeq) during work in a simulated open-plan office, followed by four restoration conditions (river movie with sound, only river sound, silence, and office noise) after the work period. Students ($N = 47$) went through one practice session and two experimental sessions, one each with the low and high noise conditions. In each experimental session they worked for 2 h with tasks involving basic working memory processes. We also took physiological measures of stress (cortisol and catecholamines) and self-reports of mood and fatigue. Analyses indicate that the participants remembered fewer words, rated themselves as more tired, and were less motivated with work in noise compared to low noise. In the restoration phase the participants who saw a nature movie (including river sounds) rated themselves as having more energy after the restoration period in comparison with both the participants who listened to noise and river sounds. Remaining in office noise during the restoration phase also affected motivation more negatively than listening to river sounds or watching the nature movie. The findings bear on the appropriateness of open-plan office designs and the possibilities for restoration available in office settings.

1. Introduction

Research has often reported lower satisfaction, lower work productivity, and poorer health among the employees working in open-plan offices compared to traditional offices (see reviews by Navai & Veitch, 2003; Oommen, Knowles, & Zhao, 2008; Rashid & Zimring, 2008). Research has also indicated that the majority of the negative effects seem to be associated with an increase in background noise and ensuing distraction (Hedge, 1982). The results are, however, mainly from studies in field settings with self ratings of different work conditions rather than from laboratory studies with controlled conditions and objective measures of cognitive performance and acute stress effects (see review by De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005). Such studies can also aid the understanding of different sub-processes within working memory activated with office work. Such studies can also address relatively little studied issues concerning methods for recovery from work in office settings.

In the present experimental study we approached two main issues concerning open-plan offices. First we examined the effects of noise on basic working memory processes, self-ratings (mood and fatigue) and physiological measures of stress (saliva and urine samples). Second, we examined the effects of varying sound conditions on restoration at work.

1.1. Office noise effects on working memory and stress

Working memory (WM) processes are of crucial importance when working with complex tasks because they process information necessary for the task at hand and temporarily store and handle the needed information. WM has a limited capacity (Baddeley, 2002) and performance can decline if a task is performed in competing background noise (Banbury, Macken, Tremblay, & Jones, 2001; Jones, 1990; Sörqvist, Halin, & Hygge, 2009).

Noise appears to affect different WM tasks in different ways. For example, noise (such as irrelevant speech) impairs performance in proofreading (e.g., Smith-Jackson & Klein, 2009; Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006), serial recall (for a review, see Jones & Morris, 1992), mental arithmetic (e.g., Banbury & Berry, 1998; Schlittmeier, Hellbrück, Thaden, & Vorländer, 2008), reading comprehension (REFS), operation span, and tasks activating prior knowledge from long-term memory (Haka et al., 2009). Even if the majority of these tasks involved memory and seriation at some point (encoding and/or rehearsal), the studies particularly

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interested in the effects of open office noise have mainly taken a macro perspective on working memory. According to Roper and Juneja's (2008) categorization, only three of the 59 studies they reviewed included tasks which measure the subsystems of working memory and only five studies included tasks which measure the earlier unitary model of short-term memory. Thus, there is a need for further applied noise studies which make use of the different measures recently developed in working memory research.

One way to approach and investigate how WM is affected by noise applies the well known multicomponent model of working memory (Baddeley & Hitch, 1974; further developed by Baddeley, 2000). According to this model there are two modality-specific stores handling verbal or visual stimuli (i.e., the articulatory loop and the visuo-spatial sketchpad, respectively), together with one episodic buffer capable of multidimensional coding and one executive function that controls the other subsystems.

Another approach does not include modality-specific buffers such as the articulatory loop. Instead the focus is on the limited capacity of working memory and how a set of integrated processes can get disturbed by noise (Just & Carpenter, 1992). In the present study working memory will mainly be seen from different measures that have been developed to tap the integrated processes involved in complex tasks, rather than through further investigation of the hypotheses of working memory.

Earlier studies have indicated that task difficulty is important for the degree of disturbance by noise (e.g. Kjellberg & Sköldström, 1991), and depending on which task is performed, there seem to be different executive functions involved. Results from Miyake et al. (2000) suggest that updating (the ability to update information in WM), shifting (the ability to shift between mental sets) and inhibition (the ability to inhibit responses) are moderately correlated but clearly separable functions, and that it is possible to distinguish them according to their relative contribution to performance in complex tasks. We therefore employed tasks developed to tap these three basic functions, to explore whether these functions are differentially affected by office noise.

Further research (e.g., Friedman & Miyake, 2004) has also suggested that there are at least two inhibition mechanisms that must be distinguished. The first mechanism is *response inhibition*, which inhibits motor responses or distracting stimuli and can be tapped by tasks such as the Stroop task (e.g., Venetjoki et al., 2006), the Flanker task (e.g., Heitz & Engle, 2007) and the Sustained Attention to Response Test (SART; e.g., Manly, Robertson, Galloway, & Hawkins, 1999). The second mechanism is *cognitive inhibition*, which inhibits no-longer relevant information that was once activated in working memory and can be tapped by tasks that involve proactive interference (PI; e.g. Lustig, May, & Hasher, 2001). Therefore, tasks related to each of these mechanisms (i.e., SART and PI) were included in the present investigation of fatigue- and office noise effects.

Only a small number of studies have reported objective physiological assessments of the acute stress effects of office noise. These studies have mainly used measures of stress hormones, heart rate variability, blood pressure and activity in the trapezius muscles (e.g., Evans & Johnson, 2000; Kristiansen et al, 2008; Sloan, 1991; Waye et al., 2002). We were also interested in finding out whether our acute office noise exposure would show up in physiological measures, and whether physiological reactions mediate effects on cognitive performance during exposure to office noise. Hence, we include urine- and saliva samples to measure the changes in stress hormone production.

1.2. Restoration

If stress increases and performance declines while working in office noise, the question arises whether these changes can be moderated if a short restoration period is included, and whether the ensuing changes vary with the content of the restorative period.

Studies of restoration have mainly shown that nature environments are restorative to be in or to look at when cognitively fatigued (e.g., Berto, 2005; Hartig, Böök, Garvill, Olsson, & Gärling, 1996). These studies focused on the *visual* perception of the environment and not on the *sound* conditions per se. There are, however, some results indicating faster and more complete restoration (according to both performance and physiological measures) for participants exposed to nature movies with environmental sounds, in comparison to those exposed to other environments including sounds (Laumann, Gärling, & Stormark, 2001, 2003; Ulrich et al., 1991). Some studies have also shown a restorative advantage of natural versus urban settings in field conditions that included the sounds typical of each type of environment (Berman, Jonides, & Kaplan, 2008; Hartig, Evans, Jamner, Davis, & Gärling, 2003; Hartig, Mang, & Evans, 1991).

Khalfa, Bella, Roy, Peretz, and Lupien (2003) have also shown the restorative effects of positive sounds only. They compared recovery from sitting in silence with listening to soft music, and found that music promoted faster decline in salivary cortisol, measured after 15 min into the relaxation period. However, no studies (to the authors' knowledge) have investigated whether positive nature sounds by themselves can promote restoration and ensuing cognitive performance.

1.3. Aims and hypotheses

The aims of the present study thus were to further specify how noise in open-plan offices affects cognitive performance and acute stress, and to test whether it is possible to promote cognitive restoration with exposure to pleasant sounds and film-clips of pleasant nature environments after having been exposed to aversive sounds. Our hypotheses are as follows:

Hypothesis 1. Participants' *cognitive performance* will decrease more in high noise compared to low noise.

Hypothesis 2. Participants will have a larger increase of *stress hormones* from before to after the work session in high noise compared to low noise.

Hypothesis 3. Participants' *self ratings* of tiredness and motivation will decrease more with work in high noise compared to low noise.

Hypothesis 4. Participants will *restore* from fatigue (measured as performance on cognitive tasks, self ratings and cortisol levels) to differing degrees as a function of environmental conditions, including sound variations. More precisely, we expect the following order of restorativeness: a nature movie with nature sounds (positive stimuli for two senses), just nature sounds (positive stimuli for one sense), silence (no stimuli) and noise (negative stimuli).

2. Method

2.1. Design

To test these hypotheses we designed an experiment with two acoustic environments (low noise, high noise) varied within subjects and four restorative conditions (nature movie, nature sound, silence, noise) manipulated between subjects.

2.2. Participants

The participants were 47 persons with normal hearing and vision recruited from the University of Gävle (27 female; mean