Journal of Environmental Psychology 72 (2020) 101503

Contents lists available at ScienceDirect

Journal of Environmental Psychology

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

Objective measures of cognitive performance in activity based workplaces and traditional office types

Helena Jahncke *, David M. Hallman

Faculty of Health and Occupational Studies, Centre for Musculoskeletal Research, University of Gävle, Sweden

ARTICLE INFO

Keywords:
Noise
Cognitive task
Memory
Cell office
Flex office
Open-plan office

ABSTRACT

Distraction from the background environment while performing concentrationdemanding tasks is a common issue for office employees in shared work areas. However, few field studies have been conducted on the effects of different office types and work areas on objective measurements of cognitive performance. The first aim of the present field study was to investigate, before relocation to an activity-based workplace (ABW), differences in performance on a concentration-demanding cognitive task between individuals in shared/open-plan offices compared to cell offices. The second aim was to investigate, after relocation, how performance differs (within-person) between different work areas within the ABW. This study included employees from five offices (n = 113), of which four relocated into an ABW. An acoustician measured the equivalent sound levels of the work areas. Data were analyzed using linear regression (aim 1) and mixed models (aim 2). Before relocation, employees working in shared/open-plan offices performed significantly worse (14%) than those in cell-offices, which had a 15 LAeq lower noise level. After relocation, employees performed significantly worse in the active zone without noise restrictions, compared to all other work areas. When shifting open-plan area from the active zone to the quiet zone cognitive performance increased significantly by 16.9%, and switching to individual working rooms increased performance by 21.9%. The results clearly demonstrate the importance for organizations to provide quiet areas or rooms with few distractions for employees working on tasks that demand concentration in an ABW. A daily drop in performance for each employee may be expensive for the organization in the long run.

1. Introduction

The office environment is essential for efficient performance in knowledge-based work. It is suggested that the office design and its use may explain up to 15% of turnover in a typical office organization (Leaman & Bordass, 1999). Important aspects of the office design concern both the indoor environment, for instance acoustics and lighting conditions; as well as architectural and/or interior design, such as the layout of rooms, workstation enclosure, color and view (Charles & Veitch, 2002; Rashid & Zimring, 2008). As the office layout is highly related to the office type (Bodin Danielsson, Chungkham, Wulff, 2014, pp. 139–147), the defining features are important when testing their influence on employees' performance. Haapakangas, Hallman, Mathiassen, and Jahncke (2018) analyzed the relation between different aspects in the work environment and self-rated productivity and found that privacy (i.e. satisfaction with perceived noise, acoustic privacy and visual shields) explained the largest proportion of variance (25%) in productivity among all environmental predictors tested. Therefore, daily performance may be strongly influenced by how well the office layout supports privacy aspects. However, few studies have measured performance objectively in different office types and addressed how much performance differs between different work areas.

1.1. Office design and performance

Research reviews of traditional open-plan offices — where the employees have their own work desk and share the office area with others — showed that this layout often causes complaints amongst employees about distractions, and consequently low ratings of work performance and productivity (Oommen, Knowles, & Zhao, 2008; Rashid & Zimring, 2008). On the other hand, few complaints about distractions are evident in traditional cell offices wherein people sit alone to work, hence this office type is often emphasized as the best for concentration-intensive work (Bodin Danielsson & Bodin, 2009; Kim & de Dear, 2013;

* Corresponding author. Centre for Musculoskeletal Research, Department of Occupational Health Sciences and Psychology, Faculty of Health and Occupational Studies, University of Gävle, SE-801 76, Gävle, Sweden.
E-mail addresses: helena.jahncke@hig.se, helena.jahncke@afaforsakring.se (H. Jahncke), david.hallman@hig.se (D.M. Hallman).

https://doi.org/10.1016/j.jenvp.2020.101503
Received 25 February 2020; Received in revised form 1 October 2020; Accepted 3 October 2020
Available online 8 October 2020

Seddigh, Berntson, Bodin Danielson, & Westerlund, 2014).

An office design that seems to become more common in today's working life is the flexible Activity Based Workplace (ABW). The ABW offers no fixed workstation for the employees; instead, the idea is that employees should switch between different work areas/rooms depending on the task they will perform (Appel-Meulenbroek, Groenen, & Janssen, 2011). For example, if a task requires concentration, an area or room with few distractions can be chosen. On the other hand, when work does not demand concentration, and focus is more on collaboration and the need for closeness to colleagues, an open-area for communication can be selected. A recent review found merely 17 articles addressing the ABW concept, of which only five studies were rated with high quality (Engelen et al., 2019). When summing up the results on performance, there was some support for improved performance (i.e. self-rated) in the ABW when compared to open-plan offices (Blok, de Korte, Groenesteijn, Formanoy, & Vink, 2009; Candido et al., 2016; Kim, Candido, Thomas, & de Dear, 2016; van der Voordt, 2004). In contrast, results on cell-offices were less consistent, showing positive, negative or no differences in performance compared with ABWs (Candido et al., 2016; De Been & Beijer, 2014; Meijer, Frings-Dresen, & Sluiter, 2009; Seddigh et al., 2014; van der Voordt, 2004). Instead of addressing the average performance/productivity for the whole ABW concept, research should aim for a more detailed analysis to understand which areas are suitable for concentration-demanding work and how much performance differs when switching between these work areas provided. As there is substantial research showing that privacy aspects are important for performance and productivity (De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005; Sundstrom, Burt, & Kamp, 1980) more focus is needed on noise and other distractions within research concerning office settings.

1.2. Environmental distractions and performance

Consistently, the most pronounced problem encountered in offices wherein employees share their work area with others, are environmental distractions, such as the distortions that come from task-unrelated background sound (see review, Navai & Veitch, 2003). Studies also show that the most disturbing noise usually comes from colleagues talking in the background and telephones ringing (Banbury & Berry, 2005; Sundstrom, Town, Rice, Osborn, & Brill, 1994). How noise distractions impact on performance in varying types of offices has mainly been studied with self-report data (De Croon et al., 2005; Engelen et al., 2019). Therefore, it is difficult to conclude whether, and how much actual performance is affected.

At a more theoretical level, experimental studies have investigated why objectively measured performance may decline when task-unrelated (irrelevant) stimuli is present, such as when colleagues talk in the background (see review, Banbury, Macken, Tremblay, & Jones, 2001). The most recent theories (i.e. the *duplex mechanism account*; Hughes, Vachon, & Jones, 2007) assert that auditory distraction is due to two mechanisms. First, the interference-by-process mechanism supposes that the involuntary processing of sound produces distraction on tasks that require similar processes. For example, the involuntary processing of a sequence of changing sounds results in a representation of the order of those sounds and this disrupts the deliberate process of imposing order on material (usually visual) that is to be remembered. Similarly, if the task requires processing the meaning of material to be read, then processing of the meaning of background speech will interfere (Marsh, Hughes, & Jones, 2008). The second mechanism is attentional capture and can occur when something unexpected (e.g., a deviant sound) happens with a stream of background sounds. This will capture attention away from the task at hand thereby resulting in an impairment to task performance (Cowan, 1995; Hughes et al., 2007).

Moreover, impairment of task performance can also occur due to visual distractions. For instance, visual distractors that are closer to the fovea where one tries to focus, impair performance less than distractors that occur in the periphery (Benson, 2008). Another study on visual distractors showed that static versus dynamic lighting (i.e. a constantly illuminated projection screen vs. a randomly travelling beam projected on the screen beside the participant) caused complaints but did not impair performance (Liebl et al., 2012). It can, however, be questioned whether all these experimental findings have ecological validity due to the tasks and use of laboratory settings.

Based on the theoretical development a few studies have used more ecologically valid simulated offices, with irrelevant stimuli in the background (e.g. recorded office noise), to test how people perform (Banbury and Berry, 1998). In this way researchers retain control over the environmental situation. As hypothesized, participants get fatigued with common noise levels for open-plan offices (e.g. 55 LAeq), and their performance is reduced by irrelevant stimuli (e.g., background speech) and this occurs to the rate that it is intelligible (Hongisto, 2005; Jahncke, Hygge, Halin, Green, & Dimberg, 2011; Keus van de Poll, Ljung, Odelius, & Sörqvist, 2014).

To the best of our knowledge, only one study has so far investigated performance with objective measures to compare different office types. Seddigh, Stenfors, Berntsson, Bååth, and Sikström (2015) undertook a cross-sectional study wherein they investigated the interaction between office-type and concentration demands in four organizations from varying sectors. The results showed higher performance in a free recall task for employees working in small compared to larger open-plan offices. Unexpectedly they also found a bigger drop in performance in cell-offices compared to open-plan offices when performance was compared to a quiet baseline condition. The employees in the cell-offices showed highest performance during the first baseline condition, when they were instructed to create a quiet condition, which also included curtailing distractions from their e-mails and phones. During the normal test condition (at time two) the researchers had no control over the type and frequency of distractions during the cognitive test and no indicator of noise levels. Therefore, it is possible that mechanisms other than the office type could explain the observed drop in performance in the cell offices.

In summary, research on how employees perform within different office types have so far adopted cross-sectional methodologies wherein self-ratings on perceived performance or productivity are taken. Within these designs it is impossible to make causal conclusions regarding the influence of a specific office type over time. Further, few studies have compared performance between different office types or work-areas within an office (i.e. ABWs) with objective measures. This is important as the relationship between perceived (subjective) performance and actual (objective) performance is seldom the same (Haka et al., 2009). Therefore, the present field study aims to investigate how performance of a concentration-demanding task differs between office types, in relation to the measured noise level at that specific office (i.e. the sound is measured, recorded and then replayed through headphones while the employees work at their regular desk).

As mentioned earlier, in open-plan offices you might, according to recent theories, expect increased exposure to changing sounds and infrequent, sudden, or unexpected sounds, which can produce interference by process and attentional capture, respectively. Therefore, our hypotheses are: 1) before relocation to ABW, performance will be higher in employees working in cell-offices compared to employees in shared/open-plan offices, and 2) after relocation to ABW, performance in different areas within the ABW will be proportional to the measured noise levels of the areas offered, with the best performance in cell-offices/rooms and worst in the open-plan area where communication is allowed, tested within-person.

2. Method

2.1. Design

The present study was conducted at the Swedish Transport

Administration during a change from traditional offices (i.e. open-plan offices, shared rooms of 2–3 employees, and cell offices) to ABWs. This organizational change was planned, initiated and implemented by the organization without interference from the researchers. Therefore, random allocation of participants was not conceivable. Four office sites at different geographical locations were included as intervention groups (offices A to D). Further, one office was included as a control group (office E) which worked in their traditional offices throughout the whole study. The control group was originally included for other aims of the overall project and these participants are only included in the analysis concerning the baseline-measures in the present study (hypothesis 1), as hypothesis 2 only concerns the circumstances within the ABW.

We measured performance at three time-points: (i) prior to relocating to new offices (baseline), (ii) 3 months after the relocation, and (iii) 12 months after the relocation. In this study, we analyzed data at baseline and 12-months. Data at 3-months were not included due to incomplete acoustical measurements and recordings.

The study was approved by the Regional Ethical Review Board in Uppsala, Sweden (Dnr. 2015/118). All participants provided written informed consent prior to participation in the study.

2.2. Selection of offices

The Swedish Transport Administration contacted the researchers for a scientific evaluation of the change from traditional offices to ABWs at four different geographical locations in Sweden.

Offices A and D relocated to another building with a newly constructed ABW, and all employees were invited to take part in the study.

Offices B and C were re-designed and renovated as ABWs. At Office B workers from only one floor out of six were included in the study, as employees on the other floors had already been temporary moved to other work areas, therefore baseline data could not be collected. At Office C only one department re-designed to an ABW and all employees from this department were invited.

Another office was further recruited as a control group (Office E) where the employees worked in either cell-offices, shared rooms or open-plan offices the whole study period.

At baseline, the open-plan offices varied somewhat in size and workstation design both between and within offices sites, however, typically the workstations had partial-height partitions (screens or cabinets) on one or two sides. Some employees shared rooms with 2–3 colleagues. In this study we grouped these two types of shared offices and denote it *shared/open-plan offices*.

The four ABWs also differed somewhat in size and design, with a total area that ranged from 775 to 14,714 m^2 according to company data. Within the ABWs the calculated area per employee ranged from 12 to 22 m^2. All ABWs included web-meeting rooms, project rooms, working rooms and conference rooms differing in insolation, size and equipment. They also contained open-plan areas accommodating 24 workers or more typically having both cubicles and touch down tables, and these areas were divided into quiet zones, project spaces, and zones with no noise restrictions. Furthermore, the ABWs contained one lounge area which could be used for work during non-lunch hours. Some ABWs also included prioritized workstations in open-plan areas or private rooms giving priority to employees with special needs. Photographs illustrating the different office sites from this study, including the control office, as well as further descriptions regarding the offices are provided in earlier publications (see Haapakangas, Hallman, et al., 2018; 2019).

2.3. Recruitment

Recruitment took part in collaboration with the organization. First, an e-mail was sent out to all employees by the person at each office-site assigned to be in charge of the study, informing the employees about the up-coming study and the responsible researchers. After about one week, the researchers distributed an e-mail containing more information about the study aim, procedures and ethical considerations. This invitation was distributed once, and those who did not answer and had not unsubscribed from the mailing list (i.e. by sending a reply) were reminded three times. These e-mails also contained a link to the questionnaire, however, the questionnaire data are not part of the scope of this study and are reported elsewhere (e.g. Haapakangas, Hallman, et al., 2018; 2019), except from data containing age, gender and a follow-up analysis of the average amount of switches between work areas before and after relocation.

2.4. Participants

We approached the employees (n = 901) by sending an email to all eligible employees who were not on parental/sick leave, with information about the study and a link to the questionnaire, and 57% responded. In the end of the questionnaire the participants were asked to participate in direct measurements of their work situation and performance. All the employees who reported an interest were also invited to take part (n = 121).

The inclusion criteria were employment at any of the five selected office sites and self-reported normal hearing and vision (eventually corrected with glasses or lenses). Exclusion criteria were sick leave, maternal leave, not moving to the ABW (for the intervention groups), reporting in advance that a major job change or retirement would take place during the study period. Finally, the study group at baseline consisted of 113 employees (86 intervention group; 27 control group). In total there were 53 women, 51 men, and 9 not reporting an answer; and the mean age was 47.6 (SD = 8.6) years. For age and gender distribution across different office types, see Table 1).

At the second follow up 64 (out of the 86) employees who shifted to ABW offices performed the cognitive task. People dropped out due to reporting not having time to take part in the study or due to problems during measurements. For a flow chart see Fig. 1. For the age and gender distribution, see Table 1. The participants who took part in the direct measurements of performance were rewarded with a Swedish lottery ticket after each measurement.

2.5. Cognitive task

We used a serial short-term memory task called *Serial recall,* which is commonly used within controlled experiments to capture the degree of noise interference (i.e. or disturbance from other distractions) while working (Jones & Morris, 1992; Liebl et al., 2012). The participants were told to remember a string of eight sequentially-presented one-digit numbers drawn from the set 1 and 9 and then to recall them in the correct order. The numerical sequences were random with the constraint that no sequence began with a 1 and that no more than two digits were presented in canonical (e.g., 1, 2) or reverse-canonical (e.g., 3, 2) sequence. The same (pseudo)random sequences were used for all participants. Each digit was presented for 350 ms at the computer screen, with a blank interval of 400 ms between each digit. Participants were directly told (i.e. without any retention interval) to write down the

Table 1
Gender and age distribution across office types, at baseline and follow-up measurements. Note: not all participants responded to these questions.

	Gender		Age
	Women	Males	M (SD)
Baseline (n = 113)			
Cell office	33	31	48.3 (8.0)
Shared/open-plan office	20	19	46.3 (9.6)
Follow-up, 12 months (n = 64)			
ABW	30	28	48.3 (8.6)

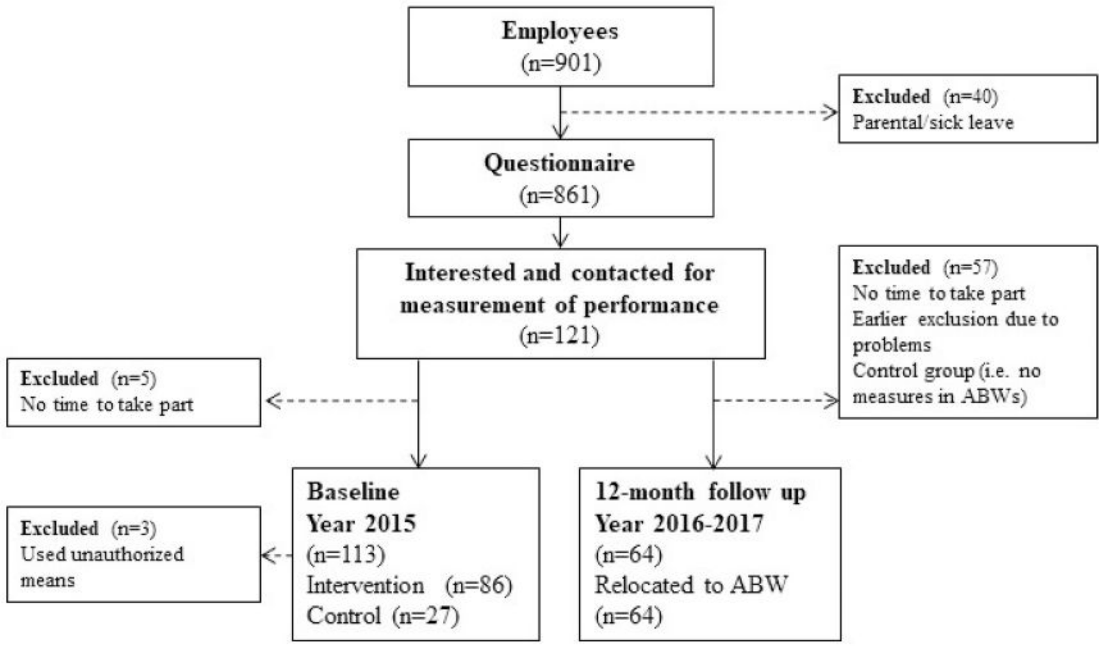

Fig. 1. Participant flow and exclusion/drop-outs. Baseline measures were performed in the employees' cell and open-plan offices. The 12-month follow up was performed only with employees who relocated to ABWs.

sequences in exactly the same order as they were presented. If the participants could not remember a given digit, they were told to write an "x" for that digit in the answer box. Each block consisted of 12 sequences and only numbers written at their correct positions were scored as correct. The maximum score was 96 points at baseline and the maximum score within the activity-based office for each work area was 96 points.

2.6. Office noise measurements and recordings

An acoustician made noise measurements (LAeq) and a sound recording in all office types at baseline; and after relocation she did the same procedure within each area of the ABW. She used a head and torso simulator (B&K 4100) to record the sound from each area/room representing the kind of work areas available at the office. Each site was measured during office hours to get the most representative sound image possible. The measurement time varies depending on the exterior condition and the variation in the sound image, where a more complex sound image was prioritized with longer measurement time (i.e. a silent single office was not measured all day to get the average sound level). All employees were told by their manager beforehand that the recordings were going to be made, and all present in the open areas and shared rooms gave a written consent for the recording.

The sound file was cut down to a short random audio clip corresponding to the average sound level during the day for each office site. The managers approved the sound clips before we included them within the study to ensure no sensitive content.

2.7. Procedure

The participants who took part in the direct measurements of performance were first informed about the ethical aspects of the study and given short instructions about the over-all procedure before they provided their written informed consent. At baseline, prior to relocation to the new offices, the employees borrowed a laptop to perform the tasks at their ordinary work desk (i.e. their cell office or shared/open-plan office). At follow-up measurement (12 months after moving in to the ABW) the participants who had relocated borrowed a laptop and rotated between given work stations within the ABW to accomplish the task in the different areas provided. The order of work stations was randomized between participants to control for learning effects on performance. One task was a background measure of working memory capacity, Operation span, and was only performed at baseline (i.e. not included for the purpose of this study). The main task, Serial recall, (described in section *Cognitive task*) tested concentration and memory. Both tasks took in all about 10 min to accomplish. The instructions about the tasks were displayed on the computer screen when the participants were installed by the desk. They were told to wear headphones during the whole session, although they might not hear any sound. Data were collected between May 2015 and January 2017. As the Serial recall task was carried out with several months apart, we expected minimal learning effects between the experimental sessions. The more direct learning effects were minimized through three practice sequences before the participants started the test each time.

2.8. Statistical analyses

Statistical analyses were conducted using IBM SPSS Statistics 24 (Armonk, NY: IBM Corp). In order to test Hypothesis 1, whether workers performed better in cell-offices than in shared/open-plan offices (before relocation), we made a linear regression with the open-plan office as reference condition and the number of correct answers in the cognitive task as dependent variable. We adjusted the model for eventual age and gender effects.

To test Hypothesis 2, whether there are differences in performance between the work areas of the ABW (after relocation), we made a Linear mixed model analysis with office area as fixed effect, referencing the noisy open-plan area (where communication was allowed), as reference condition. This is a within-person analysis, therefore there was no need to include age and gender as eventual confounders. The regression was followed up with pairwise comparisons to test the difference in performance between each work area within the ABW, and we adjusted for multiple comparisons (SIDAK).

The observed data of performance and the residuals from the models were normally distributed. For the regression model, we obtained the unstandardized regression coefficients (B); and for the Linear mixed model we obtained the estimates of fixed effects, all with a 95%

confidence interval (CI). The level for statistical significance was set to 0.05 for all analyses.

Further, a complementary analysis was performed to test whether the employees switch more between the workstations provided in the ABW, compared to how many switches they made in the cell and open-plan offices before relocation. The difference between the mean values of self-reported switches before and after relocation were tested with a one-sample *t*-test, and the level for statistical significance was set to 0.05.

3. Results

3.1. Cognitive performance in cell offices compared to shared/open-plan offices before relocation to ABW

Employees in the cell offices scored on average 54.1 (SD = 18.48) correct answers (scale 0–96) in the memory task, compared with 40.6 (SD = 14.98) for employees in the shared/open-plan offices (see Fig. 2). The linear regression model (see Table 2) showed that this reduction in performance ($B = -13.9$) for employees in the shared/open-plan office was significant, which corresponded to a reduction in performance of about 14% for employees in the shared/open-plan office. At the same time the measured average noise level (see Fig. 2) was higher for employees in the shared/open-plan office (50.1 LAeq) compared with employees in the cell office (34.8 LAeq). The regression model also showed that office type explained 13.4% of the variance in cognitive performance.

3.2. Cognitive performance in different work areas after relocation to ABW

After relocation to the ABWs, cognitive performance was assessed for each individual in different work areas of the ABW (i.e. web meeting room, project room, working room, quiet zone, lounge, project space, and active zone). Performance in the memory task ranged from 45 (SD = 14.10) correct answers (scale 0–96) in the active zone, to 65 (SD = 14.8) correct answers in the cell web meeting room and project room (see Table 3 for mean and SD values across all work areas).

The Linear mixed model on within subject effects indicated that work performance differed significantly between work areas in the ABW. Referencing the active zone, performance increased significantly in all of the other work areas (see Table 4). Follow up comparisons (see Table 5) showed that performance increased significantly when moving from the active zone to the individual working rooms (i.e. web meeting room, project room), which corresponds to an increase of 20.8% in performance. Further, moving from the active zone to the quiet zone improved

Table 2
Multiple linear regression analysis of the association between office type (cell offices, shared/open-plan offices) and performance in a serial recall memory task. Results are presented as Beta (B), Standard Error of B (SE), contribution to explained variance (R^2), and 95% Confidence interval. The model was adjusted for age and gender.

(n = 103)	*B*	*SE*	R^2	95% Confidence Interval		
				Lower Bound	Upper Bound	*p*
Constant	81.31	11.37		58.74	103.88	0.001
Shared/open-plan office (ref. cell office)	−13.89	3.46	0.134	−20.75	−7.03	0.001

Table 3
Average cognitive performance (M) and standard deviation (SD) at baseline in either cell offices (n = 45) or shared/open-plan offices (n = 31) for the non-moving locations, excluding Site E; and at follow-up 12 months after relocation to ABWs where all employees (n = 64) conducted the same cognitive task at different work areas within the ABW.

	Performance	
Office area	M	SD
Baseline (n=76)		
Celloffice (n = 45)	52.73	19.81
Shared/open-plan office (n = 31)	41.58	15.38
Follow-up, 12 months (n=64)		
Web meeting	65.3	16.56
Project room	65.5	14.82
Working room	59.4	14.44
Quiet zone	61.2	16.48
Lounge	55.9	16.15
Project space	57.9	16.45
Active zone	45.0	14.10

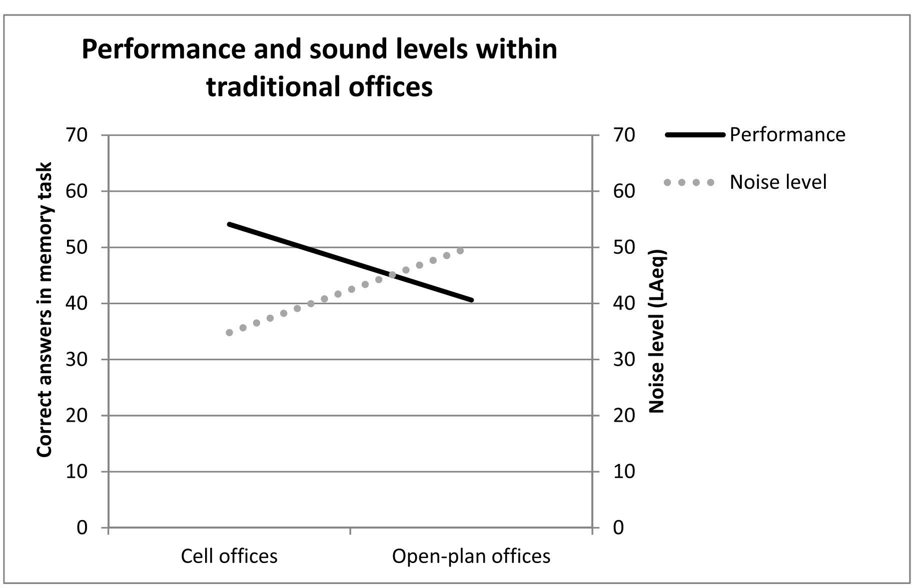

Fig. 2. Performance measured as correct answers in a serial recall memory task, for employees working in either cell offices (n = 64) or shared/open-plan offices (n = 39), and the average measured noise level (LAeq) of these office types (i.e. expressed as the mean for each office type across the five office sites).

Table 4
Linear mixed model of cognitive performance in different workspaces within the ABW, referencing the active zone (i.e. open-plan area with no noise restrictions).

(n = 64)	Estimate	95% Confidence Interval		
		Lower Bound	Upper Bound	*p*
Intercept	45.0	41.2	48.9	0.001
Web meeting	20.3	17.3	23.3	0.001
Project room	20.4	17.6	23.3	0.001
Working room	14.3	11.3	17.3	0.001
Quiet zone	16.2	13.4	19.1	0.001
Lounge	10.9	8.0	13.7	0.001
Project space	12.9	10.0	15.7	0.001
Active zone (reference)	0			

performance significantly, corresponding to an increase of 16.9%. Performance in the Lounge area was second worst and performance were significantly better in all other areas, except from the project space and the working room.

Further, an important thing to note is that performance also differed significantly between the different cell rooms, showing that the web meeting room and project room were associated with significantly better cognitive performance than the working room (see Table 5). Notably, performance also differed significantly between the different open-plan areas, showing that the quiet zone was better for the cognitive task than the active zone with no noise restrictions. Further, performance across the work areas seemed to decline with the increase in noise levels (see Fig. 3). The noise level increased from 32 LAeq in the top performance-category of cell-offices (i.e. the web meeting room and project room), towards 41–45 LAeq in the shared areas (e.g. quiet zone and lounge), and reached the highest levels of 49 LAeq in the active zone (see Fig. 3).

When so many work areas are provided it is also interesting to know whether the employees actually switch between the workstations provided in the ABW. We used questionnaire data at baseline, and 12-months after relocation to ABW (n = 441) to examine whether the employees actually switch between the workstations provided in the ABW, and whether the frequency of switches increased from baseline. The analysis showed that the employees switched work area on average almost two times a day in the ABW (M = 1.74, SD = 1.78), which was significantly fewer switches compared to baseline in the cell and shared/open plan offices (M = 2.58, SD = 2.71; $t(335) = -7.42$, $p < 0.001$). A

Table 5
P-values for the post hoc comparisons of cognitive performance in different work areas within the ABW. adjusted for multiple comparisons (SIDAK).

	Cell rooms			Open/shared areas			
Work area	Web meeting room	Project room	Working room	Quiet zone	Lounge	Project space	Active zone
Cell rooms							
Web meeting room	–	1.00	0.001	0.150	<0.001	<0.001	<0.001
Project room	1.00	–	0.001	0.079	<0.001	<0.001	<0.001
Working room	0.001	0.001	–	0.989	0.405	1.00	<0.001
Open/shared areas							
Quiet zone	0.152	0.079	0.989	–	0.006	0.469	<0.001
Lounge	<0.001	<0.001	0.405	0.006	–	0.979	<0.001
Project space	<0.001	<0.001	1.00	0.469	0.979	–	<0.001
Active zone	<0.001	<0.001	<0.001	<0.001	<0 .001	<0.001	–

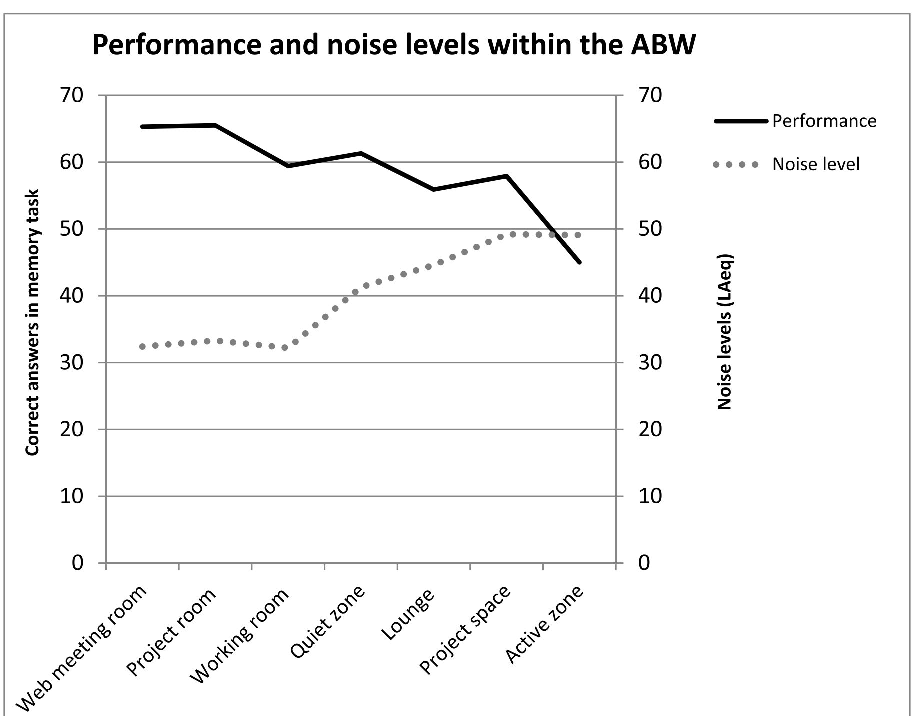

Fig. 3. Performance on a serial recall memory task in different work areas within the ABW among employees (n = 64) at four offices sites, and measured average noise level (LAeq) at the same work areas (the average measured at work areas in four offices).

"switch" was exemplified in the questionnaire as "changing from a project space to a meeting room (one switch), and go back to the project space (two switches)".

4. Discussion

The present study is one of the first studies to evaluate cognitive performance with objective measures in real occupational settings varying in layout, combined with noise level measurements. We examined whether employees in a large governmental agency in Sweden performed better in cell-offices compared to shared/open-plan offices, before relocation to ABWs. Further, after relocation we tested performance between work areas in the ABWs with different noise levels. We expected highest performance in quiet cell rooms and lowest performance in shared open-plan areas with no noise restrictions.

4.1. Performance in traditional office types

Our analysis showed that employees performed significantly better (14%) in the cell offices, compared to the shared/open-plan offices, in a task which required concentration (i.e. serial recall). This is consistent with several previous studies based on self-reported data, showing that participants report the lowest performance in shared open-plan offices (for reviews, see Oommen et al., 2008; Rashid & Zimring, 2008). As one of the main reasons behind the decision of moving to an open-plan office can be the possibility to save money, it is important to also consider the cost that can be expected for reduced performance due to a poorer acoustic environment. Inspired by an approximate cost estimation made by Jahncke (2012a, p. 136), a decrement of 14% would mean a loss of 247 h/year (1764 normal working hours/year in the USA * 0.14). This entails a cost of 6669 USD per employee/year (247 lost working hours * 27 USD, i.e. average salary per hour). For a company with 110 employees this means a cost of 733 590 USD per year. Having executives or knowledge workers with higher salaries will drive up the cost even more per year. Although serial memory may only be a smaller part of job performance, other studies considering different types of office tasks show that performance decreases around 8–10% for cognitively demanding tasks when exposed to intelligible background speech (i.e. search for information and memory-based tasks; Jahncke, 2012a, p. 136). On top of this are costs for increased risk for illness and sick leaves due to exhaustion, or other health related issues (Evans and Johnson (2000). We should, however, keep in mind that this calculation is still a vague estimate and there are many additional assumptions required which need further discussion.

In the present study, we also addressed the acoustic environment and found that the measured average noise level was 15.3 dB A higher in the shared/open-plan offices compared to the cell-offices. Concomitant increases in disruption of performance with an increase in noise level is consistent with the results from a simulated open-plan office study by Jahncke et al. (2011), who objectively measured a reduction in performance when the noise level increased with 12 dB A, from quiet office sound (39 LAeq) to noisy open-plan (51 LAeq). The aim of this field study was not to further test the theoretical explanations behind the reduction in performance. Rather the focus was on the consequences for employees being exposed to normal sound conditions in their own office. This included a combination of sound sources, such as phone signals and background speech. According to recent theories, deviant sound, such as sudden phone signals, can capture attention away from the task at hand, thereby also resulting in an impairment to task performance (Cowan, 1995; Hughes et al., 2007). Another theory states that performance can decline due to concurrent processing of the focal task and the background sound (Marsh et al., 2008). Further research is therefore needed to explore what actually caused the observed reduction in performance.

One solution that may help employees to handle distractions from background sound in shared areas is to provide back-up rooms. Haapakangas, Hongisto, Varjo, and Lahtinen (2018) made a study of two organizations relocating to open-plan offices that differed in the number and variety of quiet back-up rooms. The results showed that a high frequency of quiet backup rooms buffered against negative effects. For instance, if these backup rooms were perceived as easily accessible when needed, then they played a significant role in reducing the experience of distractions, reducing stress symptoms, heightening satisfaction with the open-plan setting overall, and led to better perception of collaboration (Haapakangas, Hallman, et al., 2018). The current study also confirmed the need for fewer distractions in open-plan areas. Our findings, though, support a relationship between the self-reported distractions and objective experience of diminished productivity in earlier studies of open-plan offices, through objective measures of employees' actual performance on a task that demands concentration.

4.2. Performance in ABWs when employees switch work areas

After relocation to the ABWs, the employees' performance was assessed in all types of work areas provided by these ABWs (i.e. web meeting room, project room, working room, quiet zone, lounge, project space, and active zone). Moving from individual web meeting and project rooms to the active zone led to a significant drop of 20.8% in performance. An important finding was that switching from the active zone without noise restrictions to another shared area, but this time one designated a quiet zone, led to a significant, 16.9% improvement in performance. These performance changes should also be related to the cost estimates performed earlier.

It is also important to note that performance differed significantly between the different cell rooms. The results showed that performance in the web meeting room and project room were associated with significantly better performance than the working room. This might be attributable to better insulation in the web meeting and project rooms designed for communication activities, with the aim of tempering any disturbance of surrounding areas or rooms. However, in the working rooms some participants mentioned that conversations could be overheard. We should therefore be aware of the differences between cell rooms in how well they support concentrated work. Note also, that performance in the individual working room was not significantly different to performance in the shared quiet zone that would be expected to contain more distractions. This result indicate that shared quiet zones are of similar importance as individual working rooms to facilitate performance in concentrated work.

In the current study the noise level increased from about 32 LAeq in the cell rooms, towards 41–45 LAeq in some of the shared areas (e.g. quiet zone and lounge), and reached the highest levels in the active zone of 49 LAeq. Performance across the work areas in the ABWs followed the decline consistently with this increase in noise levels. The highest level of 49 LAeq in the active zone is at a level approaching the 50 LAeq that is common of open-plan offices (Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006). Again these results support previous studies based on self-reported data, showing that participants report the lowest performance in shared open-plan areas (for reviews, see Oommen et al., 2008; Rashid & Zimring, 2008) and that performance drops during higher noise levels (Jahncke et al., 2011).

On the other hand, not all variance in performance can be explained by the noise level. It should be noted that the equivalent sound level is a vague measure that does not take into account all aspects of the sound sources that other studies have shown to influence performance more than the sound level, such as the intelligibility of speech mentioned earlier (Hongisto, 2005). Also, we cannot rule out the effects of other variables than noise occurring in shared office areas, such as visual distractions, spatial organization, architectonic details, ambient conditions, and view or visual access from the workspace (see review, Vischer, 2007). However, such factors are not easily controlled for in field studies.

Important to note is that the results of the present study clearly demonstrate that it matters for performance if employees switch to a quiet area when the task requires concentration. A follow-up analysis showed that the employees in the present study only shift work area about two times a day, which was even less than in the cell offices and open-plan offices before relocation. This is worrying, as a higher number of workspace switches per day, and a larger number of work areas used, has been related to a higher self-reported productivity in the ABW (Haapakangas, Hallman, et al., 2018). Research is still needed to determine whether objectively measured productivity would also increase by switching work area.

That it is rare to switch work areas in the ABW on a daily basis has been found by other studies as well. Moreover, Appel-Meulenbroek et al. (2011) report that the different work areas of the ABWs were not always used as intended. In their four case studies, 68% of employees never switched work area during an average day and 14% only switched once. The employees reported that they only chose a workstation that provided auditory and visual privacy when it was absolutely necessary. Instead, their personal preferences had a bigger effect on the use of certain types of work areas (Appel-Meulenbroek et al., 2011). People might therefore not be switching to the detriment of their performance on tasks due to their subjective beliefs or their preferences.

In a recent study (Babapour Chafi, Harder, & Bodin Danielsson, 2020) employees from two organizations were interviewed about their motives for avoiding different work areas in ABWs. The reasons for avoiding workstations in active zones was mainly due to exposure to stimuli (mainly noise distractions), while in quiet and semi quiet zones the reasons concerned lack of adherence to speech policies, demonstrating that the quiet zones were not quiet. The reasons for avoiding individual rooms were either due to a feeling of having to be available for others (i.e. especially experienced by managers), insufficient functionality (e.g. lack of needed equipment), and a feeling of expectation to use these rooms in a restricted manner. The employees reported that they preferred to work in areas that both supported their work and fulfilled their individual preferences. However, not using, or switching, workstations may be due to other factors as well, such as not having tasks that require a switch to other workstations, or a high people-to-workstation ratio, making it difficult to find a suitable workstation (Rolfö, Eklund, & Jahncke, 2017). Another possibility is that the time required to find a new space and to relocate and settle in is perceived too great. Hence, one might choose a space that is the least bad for the activities in the day, to avoid needing to move around.

In summary, organizations are challenged to find arrangements that match employees' preferences and work needs and the requirement to have well-defined and obeyed policies for different zones within the workplace. Since workplace switching has a significant impact on cognitive performance, perhaps organizations should encourage their employees to switch more often between the work areas they provide. Another direction for future research is to explore why people do not choose to relocate more often. The fact that they did not might suggest that the underlying concept of moving spaces for different activities does not fully account for the needs of employees, though this remains to be further explored.

4.2.1. Limitations

One of the strengths of this study is that the cognitive task was performed in the employees' normal work areas, and that the noise exposure was accounted for by using headphones with recorded office sound from the same area. However, we may underestimate the real effect on performance in the shared areas, as headphones can separate the participants from the real activity going around in the surroundings, such as conversations about one's own work or conversations directed at oneself. Although some participants would hear colleagues in the recordings, these sounds may not be perceived as in a natural situation. Moreover, conducting field studies also gives rise to several challenges, such as potential confounding factors that cannot be controlled for. Simple generalizations, such as one office type being better than another, are also problematic as there can be considerable variability in their layouts, ambient conditions, design features etc. Therefore, more studies are needed to enable a comparison of the current results across organizations, including an attempt to clarify how these cases vary in more detail. It would also be of interest to determine the effect of relocation to ABW on change in objective measures of performance in a traditional pre-post intervention design. However, we would like to emphasize that a long-term change in cognitive performance due to office design might be difficult to capture, and any effect could be due to a range of factors apart from the actual office design.

A more or less similar office concept can also give different effects due to the different initial situation of the employees, for example if the employees either relocate from an open-plan office or cell office into the ABW (van der Voordt, 2004). In the present study, we could not compare the baseline measures of performance with the measures of performance in the ABW, or the results with the control group after relocation. This was because we used a within-person design for the different areas of the ABW and a between-person design for the employees working in an open-plan office or cell office at baseline. No data from the ABWs was available for the control group, as they did not relocate (i.e. the control group was included for other aims beyond this study).

Another limitation is that the serial recall task was adopted from empirical studies that are deeply entrenched in adjudicating between different theoretical accounts of distraction. Therefore, its ecological validity is unclear. Office tasks may, however, require that employees keep pieces of information in memory, for example during identification and booking of train journeys, where rehearsal of digits in the right order is a central process to keep them memorized (Perham, Banbury, & Jones, 2007). Moreover, other studies testing the effects of background speech on different work tasks have found similar reductions in performance on tasks that for instance require memory, information search, arithmetics and writing (Jahncke, 2012b; Jahncke, Hongisto, & Virjonen, 2013; Keus van de Poll et al., 2014).

Furthermore, we tested performance during a limited period of time (i.e. 10 min). The real effects observed in the current study may thus be underestimated, as research has shown that it is possible to compensate for background sound during shorter exposure times by exerting extra effort (Kjellberg, 1997). A series of experiments also supports our underestimation of the effects. Although Banbury and Berry (1997) showed that people may habituate to continuous sound streams of office noise after 20 min exposure time, they also showed that dishabituation occurs as soon as there is a change in exposure, such as a short period of quiet. Therefore, in real office settings where exposure normally consist of more unpredicted variation of noise over prolonged periods of time, the negative effects on performance can be more severe.

Future research should focus more on the design and conditions of different office types, and the varying areas provided in the ABWs, to specify which characteristics are actually due to the effects on performance. There is also a need to examine the correlations between objective and subjective measures and to use other types of cognitive tasks to test if the results reported here are replicable. Further, COVID-19 will likely have a substantial impact on future office design, given that teleworking has increased drastically and will likely continue to be higher than normal in the future (Brynjolfsson et al., 2020). It is possible that this will also lead to even more organizations deciding to relocate to more flexible office designs. At the same time, awareness of the risk of infection, when many people sit together, may lead to offices being re-designed in a way that leads to a reduced risk of transmission of infections to others.

5. Conclusions

This study showed that before relocation employees performed best in cell offices and worst in shared open-plan areas. After relocation, the decline in performance followed the increasing noise levels at different work areas in the ABW. Performance declined most in the shared open-plan area wherein no noise restrictions were applied (i.e. the active zone). Performance also varied between office areas considered the same, for example, performance differed significantly between web-meeting rooms and project rooms when compared to other less insulated working rooms. Further, shifting between different shared open-plan areas, such as the active zone to a quiet zone, improved performance significantly.

Although one solution may not suit all, the results clearly emphasize that concentration-demanding work is best performed without background distractions. It is therefore important to offer work areas that support concentration-demanding tasks. However, merely providing such areas may be insufficient if employees do not have the impetus to switch work areas. Our results demonstrate that employees on average, only switch two times a day in the ABW and some intervention may be necessarily to encourage workplace switching. Such an intervention should focus on conveying the positive impact that a workplace switch can have for employees' performance and encourage employees to take responsibility for moving to a suitable area when the task requires it.

The more we will find out in future studies about when and why different office layouts and work areas influence employees' performance, the better help companies will receive for making more humane and cost-effective decisions.

Credit Author Statement

Helena Jahncke: Funding Acquisition, Project Administration, Conceptualization, Methodology, Investigation, Analysis, Writing - Original draft.

David Hallman: Conceptualization, Data Curation, Analyses, Writing – Review and Editing.

Declaration of competing interest

None.

Acknowledgement

We express our gratitude to the employees who took their time to be part of the study. We are also thankful to Kerstin Lundberg, Bo Johansson, Conny Jonsson and Niclas Lamberg at the Swedish Transport Administration who made the collaboration between our research group and the organization possible. Further, we would like to thank Johanna Edvinsson, Lina Persson, Per Gandal and Majken Rahm for assistance in data collection; Johan Odelius, Roger Johnsson and Caroline Åkerberg for the acoustical measurements; and Nisse Larsson and Per Gandal for their technical support during data processing. We are also thankful to John Marsh and the anonymous reviewers for comments on an earlier draft of this paper.

This work was supported by the Swedish Transport Administration (Dnr. 2015/43010); the Swedish Research Council for Health, Working Life and Welfare (Forte Dnr. 2009–1761), and the University of Gävle.

References

Appel-Meulenbroek, R., Groenen, P., & Janssen, I. (2011). An end-user's perspective on activity-based office concepts. *Journal of Corporate Real Estate, 13*, 122–135.

Babapour Chafi, M., Harder, M., & Bodin Danielsson, C. (2020). Workspace preferences and non-preferences in activity-based flexible offices, two case studies. *Applied Ergonomics, 83*, 1–10.

Banbury, S. P., & Berry, D. C. (1997). Habituation and dishabituation to speech and office noise. *Journal of Experimental Psychology: Applied, 3*(3), 181–195.

Banbury, S. P., & Berry, D. C. (1998). Disruption of office-related tasks by speech and office noise. *British Journal of Psychology, 89*, 499–517.

Banbury, S. P., & Berry, D. C. (2005). Office noise and employee concentration: Identifying causes of disruption and potential improvements. *Ergonomics, 48*, 25–37.

Banbury, S. P., Macken, W. J., Tremblay, S., & Jones, D. M. (2001). Auditory distraction and short-term memory: Phenomena and practical implications. *Human Factors, 43*, 12–29.

Benson, V. (2008). The influence of complex distractors in the remote distractor paradigm. *Journal of Eye Movement Research, 2*, 1–15.

Blok, M., de Korte, E., Groenesteijn, L., Formanoy, M., & Vink, P. (2009). The effects of a task facilitating working environment on office space use, communication, concentration, collaboration, privacy and distraction. *Proceedings of the 17th world congress on ergonomics*. Beijing: International Ergonomics Association.

Bodin Danielsson, C., & Bodin, L. (2009). Difference in satisfaction with office environment among employees in different office types. *Journal of Architectural and Planning Research, 26*, 241–257.

Bodin Danielsson, C., Chungkham, H. S., Wulff, C., & Westerlund, H. (2014). *Office design's impact on sick leave rates* (pp. 139–147). Ergonomics.

Brynjolfsson, E., Horton, J. J., Ozimek, A., Rock, D., Sharma, G., & TuYe, H. Y. (2020). COVID-19 and remote work: An early look at US data. In *Working paper series (27344)*. Cambridge: National Bureau of Economic Research. https://doi.org/10.3386/w27344.

Candido, C., Zhang, J., Kim, J., de Dear, R., Thomas, L. E., Strapasson, P., et al. (2016). Impact of workspace layout on occupant satisfaction, perceived health and productivity. In *Proceedings of the 9th windsor conference*. Windsor, United Kingdom.

Charles, K., & Veitch, J. (2002). Internal report No. IRC-IR-845. In *Environmental satisfaction in open-plan environments: 2. Effects of workstation size, partition height and windows*. Ottawa, Canada: Institute of Research in Construction.

Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford, England: Oxford University Press.

De Been, I., & Beijer, M. (2014). The influence of office type on satisfaction and perceived productivity support. *Journal of Facilities Management, 12*, 142–157.

De Croon, E. M., Sluiter, J. K., Kuijer, P. P. F. M., & Frings-Dresen, M. H. W. (2005). The effect of office concepts on worker health and performance: A systematic review of the literature. *Ergonomics, 48*, 119–134.

Engelen, L., Chau, J., Young, S., Mackey, M., Jeyapalan, D., & Bauman, A. (2019). Is activity-based working impacting health, work performance and perceptions? A systematic review. *Building Research & Information, 47*, 468–479.

Evans, G. W., & Johnson, D. (2000). Stress and open-office noise. *Journal of Applied Psychology, 85*, 779–783.

Haapakangas, A., Hallman, D., Mathiassen, S., & Jahncke, H. (2018a). Self-rated productivity and employee well-being in activity-based offices: The role of environmental perceptions and workspace use. *Building and Environment, 145*, 115–124.

Haapakangas, A., Hallman, D., Mathiassen, S., & Jahncke, H. (2019). The effects of moving into an activity-based office on communication, social relations and work demands – a controlled intervention with repeated follow-up. *Journal of Environmental Psychology, 66*, 1–8.

Haapakangas, A., Hongisto, V., Varjo, J., & Lahtinen, M. (2018b). Benefits of quiet workspaces in open-plan offices – evidence from two office relocations. *Journal of Environmental Psychology, 56*, 63–75.

Haka, M., Haapakangas, A., Keränen, J., Hakala, J., Keskinen, E., & Hongisto, V. (2009). Performance effects and subjective disturbance of speech in acoustically different office types–a laboratory experiment. *Indoor Air, 19*, 454–467.

Hongisto, V. (2005). A model predicting the effect of speech of varying intelligibility on work performance. *Indoor Air, 15*, 458–468.

Hughes, R. W., Vachon, F., & Jones, D. M. (2007). Disruption of short-term memory by changing and deviant sounds: Support for a duplex-mechanism account of auditory distraction. *Journal of Experimental Psychology Learning Memory and Cognition, 33*, 1050–1061.

Jahncke, H. (2012a). *Cognitive performance and restoration in open-plan office noise. Doctoral thesis* (p. 136). Luleå: Luleå University of Technology.

Jahncke, H. (2012b). Open-plan office noise: The susceptibility and suitability of different cognitive tasks for work in the presence of irrelevant speech. *Noise and Health, 14*, 315–320.

Jahncke, H., Hongisto, V., & Virjonen, P. (2013). Cognitive performance during irrelevant speech: Effects of speech intelligibility and office-task characteristics. *Applied Acoustics, 74*, 307–316.

Jahncke, H., Hygge, S., Halin, N., Green, A., & Dimberg, K. (2011). Open-plan office noise: Cognitive performance and restoration. *Journal of Environmental Psychology, 31*, 373–382.

Jones, D., & Morris, N. (1992). Irrelevant speech and serial recall: Implications for theories of attention and working memory. *Scandinavian Journal of Psychology, 33*, 212–229.

Keus van de Poll, M., Ljung, R., Odelius, J., & Sörqvist, S. (2014). Disruption of writing by background speech: The role of speech transmission index. *Applied Acoustics, 81*, 15–18.

Kim, J., Candido, C., Thomas, L., & de Dear, R. (2016). Desk ownership in the workplace: The effect of non-territorial working on employee workplace satisfaction, perceived productivity and health. *Building and Environment, 103*, 203–214.

Kim, J., & de Dear, R. (2013). Workspace satisfaction: The privacy-communication tradeoff in open-plan offices. *Journal of Environmental Psychology, 36*, 18–26.

Kjellberg, A. (1997). Noise. In H. A. Waldron, & C. Edling (Eds.), *Occupational health practice* (4th ed., pp. 241–256). Oxford: Butterworth Heinemann.

Leaman, A., & Bordass, B. (1999). Productivity in buildings: The 'killer' variables. *Building Research & Information, 27*, 4–19.

Liebl, A., Haller, J., Jödicke, B., Baumgartner, H., Schlittmeier, S., & Hellbrück, J. (2012). Combined effects of acoustic and visual distraction on cognitive performance and well-being. *Applied Ergonomics, 43*, 424–434.

Marsh, J. E., Hughes, R. W., & Jones, D. M. (2008). Auditory distraction in semantic memory: A process-based approach. *Journal of Memory and Language, 58*, 682–700.

Meijer, E. M., Frings-Dresen, M. H., & Sluiter, J. K. (2009). Effects of office innovation on office workers' health and performance. *Ergonomics, 52*, 1027–1038.

Navai, M., & Veitch, J. A. (2003). *Acoustic satisfaction in open-plan offices: Review and recommendations (IRC-RR-151)*. National research council Canada: Institute for Research in Construction.

Oommen, V. G., Knowles, M. K., & Zhao, I. Z. (2008). Should health service managers embrace open plan work environments? A review. *Asia Pac J Health Manag, 3*, 37–43.

Perham, N., Banbury, S. P., & Jones, D. M. (2007). Reduction in auditory distraction by retrieval strategy. *Memory, 15*, 465–473.

Rashid, M., & Zimring, C. (2008). A review of the empirical literature on the relationships between indoor environment and stress in health care and office settings. *Environment and Behavior, 40*, 151–190.

Rolfö, L., Eklund, J., & Jahncke, H. (2017). Perceptions of performance and satisfaction after relocation to an activity-based office. *Ergonomics, 61*, 644–657.

Seddigh, A., Berntson, E., Bodin Danielson, C., & Westerlund, H. (2014). Concentration requirements modify the effect of office type on indicators of health and performance. *Journal of Environmental Psychology, 38*, 167–174.

Seddigh, A., Stenfors, C., Berntsson, E., Bååth, R., & Sikström, S. (2015). The association between office design and performance on demanding cognitive tasks. *Journal of Environmental Psychology, 42*, 172–181.

Sundstrom, E., Burt, R., & Kamp, D. (1980). Privacy at work: Architectural correlates of job satisfaction and job performance. *Academy of Management Journal, 23*, 101–117.

Sundstrom, E., Town, J. P., Rice, R. W., Osborn, D. P., & Brill, M. (1994). Office noise, satisfaction, and performance. *Environment and Behavior, 26*, 195–222.

Venetjoki, N., Kaarlela-Tuomaala, A., Keskinen, E., & Hongisto, V. (2006). The effect of speech and speech intelligibility on task performance. *Ergonomics, 49*, 1068–1091.

Vischer, J. C. (2007). The effects of the physical environment on job performance: Towards a theoretical model of workspace stress. *Stress and Health, 23*, 175–184.

van der Voordt, T. J. M. (2004). Productivity and employee satisfaction in flexible workplaces. *Journal of Corporate Real Estate, 6*, 133–148.