Acoustic comfort in open-plan offices: The role of employee characteristics

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Abstract

Purpose: To determine the extent to which employees' experiences of acoustic comfort, wellbeing, and productivity in open-plan offices are determined by specific characteristics (including demographic information, task characteristics, and personality traits).

Design/Methodology/Approach: A questionnaire was distributed to the occupants of three open-plan office sites, and was completed by 166 employees in total.

Findings: The results indicated that acoustic comfort in open-plan offices is largely determined by noise sensitivity. Higher noise sensitivity was associated with more negative ratings of acoustical quality, more perceived disturbance by speech, and more difficulties in concentration. More negative experiences were also reported by employees with lower interactivity with colleagues.

Practical Implications: There is significant inter-individual variability in experiences of acoustic comfort, wellbeing, and productivity in open-plan offices. As such, workplace practitioners should consider acoustic and behavioural solutions for introducing a greater diversity of functional workspaces within the office, so that employees can choose the most suitable working area for their requirements**.**

Originality/Value: Whereas the majority of past acoustics research has been laboratory-based, our study is conducted in real office environments with a representative sample of knowledge workers.

Within corporate real estate and facilities management, office 'improvements' are primarily driven by a cost reduction paradigm, in which productivity gains are sought through more efficient use of space (Haynes, 2007). In particular, this paradigm has underpinned the increasing global uptake of open-plan offices, which adopt various strategies to enable the allocation of fewer square metres per employee (e.g., shared workspaces, removal of interior walls), generating clear cost savings for organisations (Brennan *et al.*, 2002).

Purportedly, the transition to open-plan offices was also supposed to support increased interpersonal collaboration and knowledge-sharing within organisations. However, evidence for the effectiveness of open-plan offices relative to enclosed offices is weak, with a growing body of cross-sectional and longitudinal research indicating that communication actually worsens in open-plan offices (Bernstein and Turban, 2018; Kaarlela-Tuomaala *et al*., 2009; Kim and de Dear, 2013; Pejtersen *et al*., 2006), and numerous other indicators of environmental comfort, wellbeing, and productivity also suffer (Bodin Danielson and Bodin, 2008; Brennan *et al*., 2002; Kaarlela-Tuomaala *et al.*, 2009; Pejtersen *et al*., 2006).

In particular, background noise is the most common environmental complaint in open-plan offices (Bodin Danielsson and Bodin, 2009; Jensen *et al.*, 2005), particularly overheard speech from neighbouring workstations (Haapakangas *et al*., 2008; Jensen *et al.*, 2005; Mak and Lui, 2012). Background speech is particularly disruptive for knowledge workers because attending to it interferes with the articulatory rehearsal process in working memory (Gathercole and Baddeley, 1993), meaning that it more strongly disrupts cognitive task performance than other types of noise (Balazola *et al*., 2008; Haapakangas *et al*., 2014;

Haka *et al.*, 2009; Liebl *et al*., 2012). As such, relative to enclosed offices, open-plan offices are associated with an approximate tenfold increase in acoustic complaints (Pejtersen *et al*., 2006) and an estimated doubling in the amount of time wasted due to noise (Kaarlela-Tuomaala *et al*., 2009). In turn, acoustic discomfort contributes to dissatisfaction with the overall workplace environment (Lee et al., 2016), productivity loss (Mak and Lui, 2012), and increased workplace conflict (Bodin Danielsson *et al*., 2015).

However, it has been argued that these findings simply reflect the fact that the majority of open-plan offices are poorly designed. Research conducted in industry, on a database containing more than 250,000 occupant survey responses, concluded that whilst open-plan offices in general tended to be rated more negatively than enclosed offices, the small sub-sample of the highest-performing offices were almost wholly open-plan (Oldman and Rothe, 2017). This suggests that more effective workplace design could greatly alleviate many of the negative outcomes that are associated with open-plan offices. Indeed, given that organisations remain reluctant to relinquish the significant competitive advantages afforded by reductions in real estate costs, it has been recognised that the crucial challenge facing modern workplace practitioners is providing open-plan offices in which noise distractions are minimised (Haynes, 2008; Oseland and Hodsman, 2018).

To this end, it is crucial to recognise that the response to a noise source can vary significantly from employee to employee. A growing number of workplace theorists have argued that there is no such thing as good or bad workplace design *per se*, but rather workplace designs which are either aligned or misaligned to the needs of the occupants (authors, manuscript submitted for review; Gerdenitsch *et al.*, 2018; Haynes, 2012; Vischer, 2007). Thus, it is crucial to understand how the workplace requirements of different knowledge workers vary as a result of certain characteristics, so that workplace practitioners know how offices should be effectively designed and maintained for different groups of employees. In this study, we focus in particular on how employees' experiences of acoustic comfort, wellbeing, and productivity in open-plan offices are shaped by specific characteristics (including task characteristics, personality traits, and demographics).

Individual Differences

In previous research, various employee characteristics have been found to moderate employee outcomes in open-plan offices. These can be broadly divided into characteristics of the work being completed, the employee's personality traits, and also demographic characteristics.

Regarding the nature of the work, researchers have considered the *task complexity* (and, consequently, the degree to which focused concentration is necessary for its effective completion). For example, previous studies conducted in open-plan offices have found that environmental dissatisfaction is highest among those with high job complexity (Fried *et al.*, 2001), and that distractions and cognitive stress are highest amongst those with a high need for concentration (Seddigh *et al.*, 2014). This is thought to occur because the completion of complex mental activities places high strain on the cognitive system and leaves it susceptible to disruption, but places low strain on the perceptual system and leaves more capacity for the processing of irrelevant stimuli (Lavie, 2010).

Another important task characteristic is an employee's typical *interactivity* (i.e., the degree to which their role requires collaboration with colleagues). Evidently, the effective

completion of collaborative work necessitates a shared space where interaction, feedback, and knowledge-sharing are supported. Conversely, for those who complete mostly individual work, background speech is more likely to be task-irrelevant and a distraction. Indeed, it has been demonstrated that employees who perform a higher proportion of group work are more likely to rate the open-plan office as having a positive impact on their productivity, whereas those who perform mostly individual work rate it negatively (Haynes, 2008).

In terms of personality traits, *introversion-extraversion* has received significant attention. Numerous studies have indicated that introverts are most satisfied and productive under very low levels of background noise, whereas extraverts prefer noisier environments (Belojevic *et al.*, 2001; Cassidy and MacDonald, 2007; Dobbs *et al.*, 2011; Geen, 1984; Oseland and Hodsman, 2018). The explanation offered for this phenomenon is that extraverts naturally have lower psychophysiological arousal than introverts and need additional stimulation from the external environment to up-regulate themselves to an optimal level, whereas the same additional stimulation leads to a state of over-arousal for introverts (Geen, 1984).

A similar but distinct personality trait concerns an individual's natural responsiveness to stimuli in the external environment, termed 'sensory processing sensitivity' in general or '*noise sensitivity*' when relating specifically to auditory stimuli. It has been demonstrated that higher noise sensitivity leads to increased dissatisfaction and poorer cognitive performance in the presence of background speech (Haapakangas *et al*., 2014), higher annoyance ratings and physiological correlates of stress in response to other noise sources (Park *et al.*, 2018), and the increased use of coping strategies and higher estimated time wasted due to noise in open-plan offices (Kaarlela-Tuomaala *et al*., 2009). It is suggested that higher noise sensitivity results in more difficulty screening out irrelevant auditory stimuli, leading to greater disruption in work.

Finally, there is also some evidence to suggest that demographic characteristics such as *age* and *gender* influence acoustic comfort in open-plan offices. Younger employees report higher satisfaction in open-plan offices than older employees (Pullen, 2014), possibly because advanced age tends to increase sensitivity to auditory distractions (Horvath *et al*., 2009). Results relating to gender are slightly more unclear; past research has suggested that women are more likely than men to report noise disturbances in open-plan offices, but are also less likely to experience conflicts in these offices (Bodin Danielsson *et al*., 2015) and are more likely to rate workplace interactions positively (Haynes *et al.*, 2017). Due to this ambiguity, gender was also included as a potential predictor in the study, but was not included in the hypotheses.

Aims and Hypotheses

To summarise, the aim of the present study was to explore the extent to which certain employee characteristics are associated with acoustic comfort, wellbeing, and productivity in open-plan offices. The majority of past research in this area has been conducted in laboratory settings. Whilst this has provided researchers with high levels of control over variables, it remains unclear whether the findings generalise to real workplaces. As such, we decided to conduct this investigation within the context of real office environments, to improve the ecological validity of the findings.

In a previous study, we found that the perceived requirement for more open workspaces was predicted by lower sensory sensitivity, lower task complexity, higher extraversion, higher interactivity, and lower age (authors, manuscript submitted for review).

In particular, sensory processing sensitivity was the strongest predictor of these requirements. Here, we predict that the same characteristics will be associated with acoustic comfort, wellbeing, and productivity in open-plan offices, and that noise sensitivity will have the strongest impact upon the outcomes:

H_1: More positive ratings for the outcome variables will be predicted by: (a) lower noise sensitivity; (b) lower task complexity; (c) higher interactivity; (d) higher extraversion; and (e) lower age.

H_2: Noise sensitivity will have a stronger effect on the outcome variables than the other employee characteristics.

Method

Participants

Data were collected at three open-plan office sites in the United Kingdom. Each site was a regional office for a large facilities management organisation, housing knowledge workers completing typical office activities. The study employed a cross-sectional survey design, entailing the completion of a single questionnaire at one time only. Approximately 500 employees across the three sites were contacted by email with an invitation to complete the questionnaire, in exchange for entry into a prize draw to win a £20 Amazon gift voucher.

In total, 180 employees completed the survey (response rate ~35%). For the data analysis, entries with missing data (N = 14) were omitted, resulting in a final sample size of 166 (92 male, 74 female), with 42 to 79 respondents per site. 106 participants were aged 18-35, 42 were aged 36-50, and 14 were aged 51-64.

Physical and acoustic office characteristics

At each site, two of the researchers visited the open-plan office to perform detailed acoustic testing. Background noise levels for 8 hours were measured during the daytime (9am-6pm) and acoustic speech privacy parameters (ISO 3382-3:2012) were measured during night time without workers. The physical acoustics data was not used for analysis in the present study, but certain measurements are reported in Table 1 for the purposes of describing the research context. Specifically, the table shows the physical characteristics of each site, the measured background noise level ($L_{\mathrm{Aeq,8h}}$), the decay rate of speech ($D_{2,S}$), and the distraction distance (*rD)*.

Background noise levels varied from 52.1 to 56.5 dBA, which are similar to the levels reported by Kaarlela-Tuomaala *et al.* (2009). For $D_{2,S}$, measurements are interpreted with respect to the target values from a common industry standard (Finnish Association of Civil Engineers, 2008), which prescribes four levels of classification: Class A (Excellent), Class B (Good), Class C (Fair), and Class D (Poor). As shown, the speech privacy at each site was relatively poor, meeting only Class C or D criteria. This is mainly due to the fact that two of the sites had very low partitions (<0.4m from table) and the other site did not have any partitions.

Table 1: Physical characteristics and results of acoustic testing at each site

	Ceiling height (metres)	**Partition height (from table, metres)**	**Desk height (metres)**	**Desk size (metres)**	**LAeq,8h (dBA)**	**D2,S (dB)**	**rD (metres)**
Site 1 (N = 46)	2.7	0.38	0.72	0.8 x 1.2	56.3	5.7 to 7.2 *(Class C/D)*	12.2 to 15.0
Site 2 (N = 42)	3	No partition	0.72	0.8 x 1.4	52.1	4.2 to 7.9 *(Class C/D)*	9.7 to 10.8
Site 3 (N = 78)	2.45	0.33	0.72	0.8 x 1.6	56.5	7 to 7.9 *(Class C)*	10.6 to 12.7

Questionnaire

All questionnaire items and response scales are shown in Table 2. Additionally, descriptive statistics for the sample are provided, including the Cronbach's Alpha (α) for each multi-item scale, as well as the mean (*M*) and standard deviation (*SD*) for each measure. Where possible, survey items were taken from past research, although these were sometimes adapted to suit a common response format throughout the questionnaire.

The first group of items measured employee characteristics, which included demographic information, task characteristics, and personality traits. First, participants reported their *gender* and selected their *age* group from one of four categories (18-35, 36-50, 51-64, 65 and over). Next, two items were selected from the 'skill variety' sub-scale of Hackman and Oldham's (1975) Job Diagnostic Survey as a measure of *task complexity* (α = 0.8), as these directly related to perceptions regarding the difficulty of one's work. Three original items were used to measure *interactivity* (α = 0.78), as the only measure we found in previous research used a dichotomous rather than continuous response (Haynes, 2008). For the personality trait measures, four descriptors were taken from the Big Five Mini-Markers Extraversion sub-scale (Saucier, 1994) as a measure of *introversion-extraversion* (α = 0.79), and five items were taken from Weinstein's (1978) Noise Sensitivity Scale as a measure of *noise sensitivity* (α = 0.87).

The second group of items measured the outcome variables. For acoustic comfort, a single-item measure was adapted slightly from Kaarlela-Tuomaala *et al.* (2009) to measure *acoustical quality* in general, and an original item was included to measure *disturbance by speech*, to recognise the most commonly-mentioned noise in open-plan offices. In recognition of the fact that wellbeing is a multidimensional construct but is often operationalised in an overly vague and broad manner (Hanc *et al.*, 2019), we selected three specific dimensions including both negative and positive symptoms. A single-item measure was adapted slightly from Kaarlela-Tuomaala *et al.* (2009) to measure *difficulties in*

concentration and one additional item was used to measure perceived *stress.* Three original items were used to measure *work engagement*, derived from items on the Utrecht Work Engagement Scale (Schaufeli *et al.*, 2002). Finally, one item was adapted from Haynes (2008) to measure *office productivity,* defined as the perceived impact of the physical workplace upon productivity.

Statistical analyses

All data analysis was performed using R Studio. Specifically, the *lm* function from R's base package was used to create multiple regression models, the *Anova* function from the "car" package (Fox and Weisberg, 2011) was used to perform the multivariate hypothesis tests, and the *eta_sq* function from the "sjstats" package (Lüdecke, 2019) was used to generate partial eta-squared estimates for the predictors in the regression models.

Results

Descriptive Statistics

For descriptive purposes, means and standard deviations are shown for each of the employee characteristics and outcomes (Table 2). Additionally, a correlation matrix showing the interrelationships between the different outcomes is reported (Table 3). As shown, in the majority of cases the outcomes were significantly correlated with one another, albeit relatively weakly (all absolute r values ≤ 0.35). The strongest correlations indicated that increased concentration difficulties were generally associated with more negative ratings of acoustical quality (r = -0.35) and higher disturbance by speech (r = 0.32). Whilst the relationships between outcomes were generally as expected, non-significant correlations indicated that work engagement was independent of disturbance by speech (r = -0.02) and stress (r = -0.05) in the present sample.

Table 2: Full wording of the items used on the questionnaire, including descriptive statistics for all of the measures (N = 166).

SCALE	M	SD
Task Complexity (α = 0.8) "The job requires me to use a number of complex or high-level skills"; "The job is quite simple and repetitive*"; *[1=Strongly Disagree, 7=Strongly Agree]*	4.39	1.51
Interactivity (α = 0.78) "The job requires a high level of group work and regular communication with colleagues"; "The job is one where I spend most of the day talking with other people, either face-to-face or on the phone" *[1=Strongly Disagree, 7=Strongly Agree]* "What proportion of the time do you spend doing collaborative work (e.g. working in groups, talking on the phone, impromptu interactions with colleagues) compared to individual focused work"? *[1=Always individual, 7=Always collaborative]*	4.5	1.36
Extraversion (α = 0.79) "Generally, is it accurate or inaccurate that you are… (a) Shy*; (b) Talkative; (c) Outgoing; (d) Reserved*?" *[1=Very inaccurate, 7=Very accurate]*	4.83	1.09
Noise Sensitivity (α = 0.87) "I get annoyed when my neighbours are noisy"; "I get used to most noises without much difficulty*"; "I find it hard to relax in a place that's noisy"; "I get mad at people who make noise that keeps me from falling asleep or getting work done"; "I am sensitive to noise" *[1=Disagree, 7=Agree*]	3.94	1.49
Acoustical Quality "Overall, how satisfied or dissatisfied are you with the acoustical quality in your office?" *[1=Very dissatisfied, 7=Very satisfied]*	4.26	1.33
Disturbance by Speech "How disturbing do you find colleagues chatting in your office?"	3.41	1.78

[1=Not at all, 7=Extremely]		
Difficulties in Concentration "How often do you experience difficulties in concentration in your current working environment?" *[1=Never, 7=Frequently]*	3.87	1.39
Stress "How often do you experience stress in your current working environment?" *[1=Never, 7=Frequently]*	3.9	1.68
Engagement (α = 0.75) "How often do you experience… (a) enthusiasm; (b) complete absorption; (c) feeling energetic in your current working environment?" *[1=Never, 7=Frequently]*	4.37	1.08
Office Productivity "Overall, in your opinion, what impact does the physical environment in your current office have upon your productivity"? *[1=Very negative, 7=Very positive]*	4.28	1.21

*Item was reverse-scored prior to analysis

	Acoustical Quality	**Disturbance by Speech**	**Difficulties in Concentration**	**Stress**	**Engagement**	**Office Productivity**
Acoustical Quality	X	X	X	X	X	X
Disturbance by Speech	-0.32***	X	X	X	X	X
Difficulties in Concentration	-0.35***	0.32***	X	X	X	X
Stress	-0.24**	0.2**	0.2**	X	X	X
Engagement	0.21**	-0.02	0.14	-0.05	X	X
Office Productivity	0.25***	-0.25***	-0.24**	-0.16*	0.27***	X

Table 3: A correlation matrix showing the interrelationships between the different outcome variables
* $p \leq 0.05$; ** $p \leq 0.01$; ***$p \leq 0.001$

Regression Analyses

Multiple regression analyses were used to explore the associations between the employee characteristics and the outcome variables. Due to the inter-relationships amongst the outcomes, a multivariate multiple regression analysis was used to test the statistical significance of each predictor. A dummy variable to represent the site at which the data was collected was included in the regression model to control for any between-context variance.

The results of the regression analysis are displayed in Table 4. Specifically, Table 4 shows the *p*-values from the multivariate multiple regression analysis, and also shows summary statistics from each univariate regression model (the unstandardised coefficient (*B*) and partial eta-squared (η-*p2*) for each predictor to indicate the nature and size of the effect, and the R^2 for each model to indicate the overall variance in the outcome explained by the employee characteristics). Effect sizes are discussed with respect to Cohen's (1988) recommendations for statistical power analysis in the behavioural sciences.

The results of the multivariate analysis show that the strongest predictor of the outcome variables was noise sensitivity (F (6, 152) = 18.46, $p < 0.001$). In particular, there were large effects to indicate that higher noise sensitivity was associated with greater disturbance by speech and more difficulties in concentration. Additionally, a small effect was observed with respect to three of the other outcome variables, such that higher noise sensitivity was associated with more negative ratings of acoustical quality, higher levels of stress, and lower self-rated productivity.

Two other employee characteristics emerged as significant predictors of the outcome variables, task complexity (F (6, 152) = 2.57, p = 0.02) and interactivity (F (6, 152) = 2.18, p = 0.05). Contrary to expectations, results suggested that higher task complexity was actually associated with *higher* levels of work engagement and self-reported productivity. Regarding interactivity, the results indicated that higher interactivity with colleagues was associated with higher levels of work engagement. There were also small effects indicating that higher interactivity was associated with fewer difficulties in concentration, less disturbance by speech, more positive ratings of acoustical quality, and higher ratings of productivity.

The results also indicated several small effects in line with the hypotheses. Specifically, there was some evidence that higher age was associated with lower ratings of acoustical quality and higher disturbance by speech, and also that higher extraversion was associated with higher ratings of productivity. However, neither the multivariate hypothesis test for age (F(6, 152) = 1.04, p = 0.29) nor extraversion (F(6, 152) = 1.2, p = 0.31) were significant, so it cannot be concluded that these effects did not arise by chance.

Table 4: A table presenting summary statistics from the six multiple regression analyses, including the unstandardised beta (B) and partial eta-squared (p-η^2) for each predictor, the R-squared statistic for each regression model (R^2), and the p-values from the multivariate regression analysis.

OUTCOME

PREDICTOR		**Acoustical Quality**	**Disturbance by Speech**	**Difficulties in Concentration**	**Stress**	**Engagement**	**Productivity**	***p*-value**
Site = 2	**B**	0.006	-0.11	-0.01	0.42	0.07	-0.18	0.89
	***p*-η^2**	0.000	0.01	0.000	0.035^	0.016^	0.006	
Site = 3	**B**	-0.07	-0.23	-0.08	-0.15	0.11	-0.44	0.43
	***p*-η^2**	0.001	0.003	0.000	0.001	0.009	0.043^	
Gender	**B**	0.093	0.27	0.08	0.5	0.17	0.15	0.41
	***p*-η^2**	0.006	0.002	0.001	0.02	0.007	0.011^	
Age	**B**	-0.25	0.11	-0.05	-0.29	0.04	0.01	0.29
	***p*-η^2**	0.016^	0.016^	0.000	0.005	0.019^	0.002	
Task Complexity	**B**	0.079	-0.13	-0.1	0.06	0.21	0.11	0.02
	***p*-η^2**	0.007	0.008	0.014	0.006	0.11^^	0.023^	
Interactivity	**B**	0.068	-0.002	-0.15	0.07	0.19	0.05	0.05
	***p*-η^2**	0.011^	0.021^	0.045^	0.003	0.074^^	0.017^	
Extraversion	**B**	-0.018	-0.028	0.03	0.13	0.08	0.19	0.31
	***p*-η^2**	0.000	0.001	0.000	0.006	0.008	0.029^	
Noise Sensitivity	**B**	-0.2	0.77	0.35	0.15	-0.001	-0.11	<0.001
	***p*-η^2**	0.048^	0.38^^^	0.13^^^	0.018^	0.000	0.019^	

Model R²	0.08	0.41	0.18	0.09	0.21	0.13	

Effect size interpretation (Cohen, 1988): ^Small (0.01 ≤ p-η2 < 0.06); ^^Medium (0.06 ≤ p-η2 < 0.13); ^^^Large (p-η2 ≥ 0.13)

Discussion

The aim of this study was to investigate the extent to which employee characteristics were associated with acoustic comfort, wellbeing, and productivity in open-plan offices. In doing so, we aimed to identify the types of knowledge worker who were more or less suited to working in this type of environment. Multiple regression analyses were used to explore the relationships between the variables. The implications of the findings are discussed, and suggestions for future research are offered.

The results supported the hypothesis that noise sensitivity would have the strongest impact on the outcome variables (H_2). Specifically, participants with higher noise sensitivity tended to rate the acoustical quality of the office more negatively, were more disturbed by speech, had greater difficulties in concentration, were more stressed, and had lower self-rated productivity. The effect size was particularly strong in the case of disturbance by speech, where noise sensitivity alone accounted for almost 40% of the outcome variance. Thus, it can be concluded that the appropriateness of open-plan office for effective work performance is largely moderated by an individual's noise sensitivity.

These results are in accordance with previous findings on the influence of noise sensitivity in indoor environments (Haapakangas *et al.*, 2014; Kaarlela-Tuomaala *et al*., 2009; Park *et al*., 2018). At the physiological level, higher noise sensitivity heightens the response to auditory stimuli, characterised by both a stronger response to the stimulus (increased respiratory rate and electrodermal activity, decreased heart rate), and a slower return to baseline in the recovery phase (Park *et al*., 2018). At the cognitive level, this is manifest in increased involuntary attention to auditory stimuli and more difficulty in re-focusing following disruption, leading to greater noise disturbance and time wasted due to noise in open-plan offices (Kaarlela-Tuomaala *et al.*, 2009).

Regarding predictions made about the influence of the other employee characteristics (H_1) were only partially supported. There was evidence to support predictions that employees' interactivity with colleagues would be associated with certain outcomes. Specifically, it was confirmed that employees who interacted with colleagues less frequently tended to rate the acoustical quality of the office more negatively, were more disturbed by the speech of others, experienced more concentration difficulties, showed lower work engagement, and had lower self-rated productivity. This is in accordance with previous research indicating that employees who primarily perform individual work tend to rate the open-plan office as having a more negative impact on their productivity, compared to employees who primarily perform collaborative work (Haynes, 2008). Again, this highlights the fact that the open-plan office environment is more suitable for certain employees than others, in this case as a result of the type of work that they typically do.

However, other predictions contained within H_1 were not supported. Two unexpected effects emerged, both relating to task complexity. On the basis of research indicating that environmental dissatisfaction and stress in open-plan offices were highest amongst those completing more complex work (Fried *et al*., 2001; Seddigh *et al*., 2014), we had originally

predicted that higher task complexity would be associated with more negative ratings of all our outcome variables. However, task complexity did not exert a significant effect on four of the outcomes, and the effects on two of the outcomes were in an unexpected direction; higher task complexity was actually associated with *higher* work engagement and productivity.

Possibly, these results indicate that employees viewed the complexity of their work as a 'challenge demand' (i.e., work obstacles that are worthy of engagement, as they are linked to learning and higher achievement). Jobs with higher levels of challenge demands, as opposed to 'hindrance demands' (i.e., unnecessary obstacles which thwart personal growth and attainment), have been previously associated with higher levels of work engagement (Bakker and Sanz-Vergel, 2013) and job performance (Lepine *et al.*, 2005). Indeed, if there is a skill-demand imbalance (i.e., if the task is perceived as being too easy), then individuals are unable to enter the state of complete immersion termed 'flow' (Csikzentmihalyi, 1975; Engeser and Rheinberg, 2008). Thus, we suggest that any negative effects of the open-plan office environment for our sample were not strong enough to disrupt the natural relationship between challenge demands and more engaged and productive work.

Additionally, several of the predicted associations were not supported. For example, on the basis of past research (Belojevic et al., 2001; Cassidy and MacDonald, 2007; Dobbs et al., 2011; Geen, 1984; Oseland and Hodsman, 2018) it had been anticipated that higher levels of extraversion would be associated with more positive outcomes in open-plan offices. However, whilst there was a small effect to indicate that higher extraversion was associated with higher ratings of productivity, the results of the multivariate analysis indicated that introversion-extraversion was not a significant predictor. Similarly, age did not emerge as a significant predictor of the outcome variables, contrary to expectations.

Although in a previous study we had found that each of the employee characteristics was independently associated with requirements for workspace openness (authors, manuscript submitted for review), it is possible that the non-significant findings reflect certain variables accounting for the effects of others in the regression models. For example, it has previously been observed that the effects of age upon workplace requirements can be explained because older individuals tend to be more noise-sensitive than younger individuals (Horvath *et al.*, 2009). Similarly, it has been demonstrated that introversion-extraversion and noise sensitivity are not completely independent (Aron and Aron, 1997), and so previously-demonstrated effects of introversion-extraversion may actually have reflected an effect of noise sensitivity. In the present study, the inclusion of noise sensitivity in the regression models may have negated any additional predictive value of age and introversion-extraversion. Future research would help to clarify this.

Another possible contributing factor is the fact that our study was conducted in real workplaces whereas much of the past research was conducted in tightly-controlled experimental settings or, in the case of our previous study (authors, manuscript submitted for review), based upon perceived requirements rather than actual outcomes. This leaves open the possibility that real knowledge workers develop the capability to mitigate environmental demands in offices by exerting additional effort and/or by using various coping strategies. For example, some employees may have effectively coped with the open-plan office environment by using headphones. Whilst this may be effective in the short term, it is possible that the requirement for extra effort to meet the same goals will lead to emotional exhaustion and burnout in the longer term (Meijman and Mulder, 1998), so these results do not detract from the importance of providing more appropriate work settings where possible.

Finally, whilst it had been expected that the same characteristics which predicted acoustic discomfort would also predict stress, the results showed that the only characteristic which exerted an effect on stress was noise sensitivity, and this was a small effect with low practical significance. This suggests that stress was more strongly influenced by other (unmeasured) variables than acoustic comfort in our sample, and the impact of acoustic comfort on stress was negligible. Indeed, the correlation matrix for the outcome variables in the study shows that the relationships between stress and the two measures of acoustic comfort were significant but weak ($r < 0.25$). Additional workplace factors which might have influenced ratings of stress include, for example, high work pressure and long working hours (Bakker and Demerouti, 2014).

Practical Implications

The results of our study suggest that acoustic comfort in open-plan offices is significantly moderated by employee characteristics, with noise sensitivity in particular exerting a strong impact on participants' responses. Whilst it might be seen as relatively intuitive that higher noise sensitive is associated with greater acoustic discomfort, few studies have demonstrated this relationship within the context of the open-plan office and when concurrently examining the role of other employee characteristics. Furthermore, the fact that noise sensitivity is at least partially innate (Heinonen-Guzejev *et al.*, 2005) suggests that noise sensitive employees cannot simply adjust to the characteristics of the open-plan office in the same way that their less noise sensitive colleagues can.

This is crucial from a practical perspective because the role of individual differences is still largely ignored in much of workplace practice, meaning 'one-size-fits-all' designs are always likely to be misaligned to the needs of a significant proportion of the intended occupants. As such, the most salient implication of the present findings is the necessity of carrying out a detailed consultation of the needs of the workplace end users prior to any office relocation or renovation. The engagement process, which might involve surveys, interviews, and/or observations of current working practices, should be targeted towards a deeper understanding of the employees' characteristics and how these might affect their workplace requirements.

In the event that a significant proportion of employees are naturally more susceptible to visual and auditory distraction (i.e., due to high noise sensitivity and/or a high proportion of individual work), additional strategies will need to be considered to facilitate productive work. Historically this might have been supported through the provision of enclosed private offices, however the space efficiency benefits afforded by open-plan designs mean such designs are likely to remain prevalent. Nonetheless, certain acoustic design strategies can help to mitigate the inevitable presence of speech in open-plan offices. For example, practitioners might consider the use of sound-absorptive partitions between workstations, and the use of sound-masking systems through overhead speakers to reduce the intelligibility of background speech. These strategies would help to reduce speech transmission from neighbouring desks and help to increase individual privacy.

Additionally, workplace management strategies could also help to improve acoustic comfort in open-plan offices by giving employees more control over their working environment. Indeed, the perception of control over noise has been identified as an effective way of reducing noise disturbance for all individuals, regardless of personality type (Oseland and Hodsman, 2018). One way to facilitate this would be through the clear demarcation of

‘quiet zones’ (and the enforcement of explicit rules governing the use of these spaces) combined with the implementation of an activity-based working policy would be effective in ensuring that occupants are able to choose a space which suits their current requirements (i.e., a space for silence or a space in which speech is encouraged and is not seen as distracting). Additionally, organisations could allow employees to wear headphones whilst working, to cancel out the noise from surrounding workstations.

In this way, the implementation of flexible practices would allow employees to develop different strategies which would help them effectively cope with background noise, enabling them to work more productively. This would be particularly valuable in organisations where employee turnover is high, as the ever-changing nature of the workforce limits the extent to which the office can be designed to be aligned to the group of users.

Limitations

In terms of study limitations, it should be noted that several of the employee characteristics and outcomes were assessed using single-item measures or a small sub-set of items from existing scales, which potentially raises concerns regarding content validity. However, it has been demonstrated that single-item measures tend to correlate well with their multi-item counterparts, and often have practical benefits in reducing participant burden during the completion of the questionnaire (Gardner *et al.,* 1998; Hoeppner *et al.,* 2011; Wanous *et al.,* 1997). Indeed, the adoption of this approach in the present study was primarily motivated by the aim of improving response rates at each site by reducing the questionnaire length. As such, whilst it would be useful in future research to use full multi-item scales where possible, we do not regard the use of single-item measures in the present research as a major limitation.

Additionally, although we endeavoured to include a wider range of employee characteristics than had been typically considered in past research, it is nonetheless likely that additional unmeasured traits or characteristics also contribute to acoustic comfort and productivity in open-plan offices. For example, in Oseland and Hodsman’s (2018) recent study, neuroticism (i.e. the tendency to experience negative emotions and experience anxiety and apprehension) had the largest effect on various noise metrics, particularly difficulties in concentration. Another recent study conducted in open-plan offices found that the psychological need for privacy was the strongest predictor of general environmental satisfaction (Hoendervanger *et al.,* 2018). Given that there are often significant overlaps between the characteristics under investigation, it will be necessary in future research to ascertain exactly which traits are most strongly associated with the outcomes of interest, so that practitioners have a simple yet effective tool for understanding employees’ workplace requirements.

Finally, it should be acknowledged that we used a cross-sectional questionnaire with self-reported measures and investigated one type of office only. With this methodology we demonstrated that employees’ acoustic comfort in open-plan offices is largely determined by their noise sensitivity, and from this we inferred that employees who struggle to work productively in these offices will require more segregated workspaces. However, it will be necessary in future research to empirically validate such assumptions. For example, it would be useful to directly test the proposition that highly noise-sensitive employees are most productive in enclosed offices, or that strategies to reduce speech transmission in open-plan offices are particularly effective for highly noise-sensitive employees. It would also be

valuable if objective measures of wellbeing and productivity could be used in addition to subjective measures, in order to strengthen the evidence base.

Conclusion

The aim of this study was to explore the extent to which employees' experiences in open-plan offices are shaped by certain demographic, task-related, and personality characteristics. The results highlighted the importance of noise sensitivity, in particular. More noise-sensitive respondents tended to give more negative ratings of the acoustical quality of the office, were more distracted by speech, had greater concentration difficulties, and had lower self-rated productivity. More negative experiences were also reported by employees who had lower levels of interaction with colleagues.

These findings provide further evidence that individuals vary significantly in their workplace requirements, and that the design of open-plan offices needs to reflect this in order to enable the entire group of employees to work effectively. In particular, it is suggested that there needs to be greater consultation of the end users when considering workplace design and strategy solutions, and that particular attention needs to be paid to strategies aimed at minimising the disruption caused by overheard speech.

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