Multimodal detection of noise-related stress in a simulated work environment

Elizabeth (Libby) Sander[1], Cecilia Marques[2], Oliver Baumann[2], James Birt[2], Mathew Stead[3]

[1] Bond Business School, Bond University, Gold Coast, Australia.

{lsander@bond.edu.au}

[2] Faculty of Society and Design, Bond University, Gold Coast, Australia.

{cecilia.marques@student.bond.edu.au; obaumann@bond.edu.au; jbirt@bond.edu.au}

[3] Resonate Consultants, Adelaide, Australia

matthew.stead@resonate-consultants.com}

Abstract
Covid-induced changes in the workplace present a timely opportunity for human resource management practitioners to consider and remediate the deleterious effects of noise, a commonly cited complaint of employees working in open-plan office environments. There is little experimental research comprehensively investigating the effects of noise on employees in terms of their cognitive performance, physiological indicators of stress, and affect. Employing a simulated office setting, we compared the effects of a typical open plan office auditory environment to a quieter private office auditory environment on a range of objective and subjective measures of well-being and performance. While open plan office noise did not reduce immediate cognitive task performance compared to the quieter environment, it did reduce psychological well-being as evidenced by self-reports of mood, facial expressions of emotion, and physiological indicators of stress in the form of heartrate and skin conductivity. Our research highlights the importance of using a multimodal approach to assess the impact of workplace stressors such as noise.

Keywords: Open office, acoustic noise, simulation, stress, psychophysiology

1 Introduction

Research has shown that noise in OPOs can result in reduced cognitive performance [6], and psychological and physiological well-being [7]. Although perceived noise level and noise distraction are common complaints in surveys of employees working in open plan offices, objective levels and properties of the office acoustic environment are seldom measured or manipulated. In a recent review of the effects of office environments on employee well-being, Colenberg [2] found only four such studies and called for further research on the effects of objective acoustic properties on office occupants. We respond to this call in the current research by experimentally manipulating the acoustic environment at two levels: higher noise at a level typical of open plan offices and lower noise at a level typical of private offices. Further, we go beyond occupant opinion surveys to measure the effects of noise on objective performance and physiological stress responses in addition to self-reports.

Offices are never entirely silent. In enclosed private offices, steady background noise comes from ventilation and computer fans, with intermittent noise from the keyboard, phone, and computer of the occupant, plus the possibility of passing footsteps or conversations outside the office door. On average, the background noise in a private enclosed office is about 39db(A) [5]. In open plan offices, noise sources from computers are magnified by the number of people present, by shared facilities such as copy machines and elevators, by footsteps, paper shuffling, drawer opening and closing by other occupants, and by phone and face to face conversations held by others in the room. These noises may be exacerbated by high occupant density and the typically "hard" acoustical properties of OPOs. On average, the background noise in an OPO is on average between 52 and 58db(A) [3].

This paper uses a repeated measures experimental design in which the same individuals work under two noise conditions which are carefully manipulated to simulate typical open plan and private office noise levels, bearing the advantage of reducing variability and increasing statistical power. This allows causal conclusions to be reached about the effects of the objective auditory environment and well-being indicators. In addition, we collect both objective and subjective measures of a range of relevant outcomes which research suggests may be affected by noise exposure. These include a total of nine indicators covering cognitive performance, a number of physiological measures of the stress response, and both subjective and objective measures of affective responses. Some of these measures require special instrumentation and cannot be collected in field settings. Our use of a comprehensive multimodal approach for assessing responses to noise allows for a nuanced understanding of how environmental stressors may affect some types of outcomes but not others. Taken together, existing field surveys of employee perceptions of Indoor Environmental Quality plus laboratory-based research demonstrating causal effects of specific auditory environments on objectively measured outcomes will best support the decisions and recommendations of HR experts considering workspace design post-COVID.

We posed three hypotheses regarding the effects of noise on three categories of outcomes: cognitive performance, physiological stress responses, and affect.

Hypothesis 1: Cognitive performance will be lower in the open plan office noise condition than the private office noise condition.

Hypothesis 2: Physiological stress will be greater in the open plan office noise condition than the private office noise condition.

Hypothesis 3: Affective reactions will be more negative in the open plan office noise condition than the private office noise condition.

2 Method

2.1 Design, Procedure, and Treatment

Participants completed a cognitive performance (proof-reading) task under two conditions: simulated open plan office background high noise vs. simulated private office low noise. The order of the two conditions was counter-balanced across participants, to avoid bias due to fatigue and training effects. Participants were tested individually in the same room. In the high noise condition, a combination of typical open-plan office sounds was played to the participants while they were engaged in the proof-reading task. The soundscape included people speaking, walking, printing papers, ringing telephones, and keyboard typing noises. The sound was presented via a Bluetooth JBL Flip 3 portable speaker that was mounted vertically on a stand above head height, that was placed in the middle of the room approximately 210 cm away from the participant) to create a non-directional sound effect. The average sound pressure level was 59.1 dB (A) (measured at the participants' head location, via a Casella CEL-63X sound pressure meter and expressed as an equivalent sound level). The choice of this sound level was based on literature demonstrating that typical values for background noise in open plan offices range from 52 to 58 dB(A) [3]. In the low noise condition, the room was much quieter during performance of the proof-reading task, with an average sound pressure level of 36.3 dB (A) (resulting from air-conditioning and computer fan noise).

To obtain physiological measures of stress, a SHIMMER ™ 3 GSR+ optical pulse oximeter was placed on the participants' right ear lobe to measure heart rate and two GSR electrodes were placed over the arch of the participant's right foot to measure skin conductivity. Each participant underwent both task conditions (high noise vs. low background noise), each lasting 10 minutes in a counter-balanced order. Eight minutes were allocated to the proofreading task, and the remaining 2 minutes were allocated for the completion of the self-report measure of positive and negative affect.

2.2 Participants

Forty healthy subjects with an age range of 17-44 years and a mean age of 22.65 years (SD=6.15) participated in this study. Participants consisted of 34 female and 6 male undergraduates and post-graduate students recruited predominantly from a psychology subject pool. Due to technical faults (i.e. poor signal quality), there are only 38 data sets for the two heartrate measures.

2.3 Measures

2.3.1 Cognitive Performance

To measure cognitive performance in an ecologically valid way, a proof-reading task was employed, as such a task is similar to many clerical tasks performed by knowledge workers in offices. For this, two different text excerpts (4200 words each) from On the Origins of Species were used. In total, 80 typographical errors were introduced in each text, on average one error for every three lines of text. The performance measure was the number of correctly identified errors.

2.3.2 Heart rate

We captured the heart rate of the participants, which is simply the number of beats of the heart per minute. The positive correlation between heart rate, as a measure of physiological arousal, and stress is well established; the higher the heart rate, the greater the impact of the stressor on the individual (e.g.[8]).

2.3.3 Electrodermal activity

Electro-dermal activity (EDA), measured in microsiemens (µS), quantifies electrical skin conductance from the sweat glands in the palms of the hand, soles of feet or fingertips. Electro-dermal activity is an autonomic and involuntary bodily response whereby the individual sweats more in stressful situations, although this increased sweating may be imperceptible to the human eye (typical skin conductance levels are within the range of 1-20 µS). The two components of EDA are the *skin conductance level*, a slow changing (tonic) time interval measure of skin conductance, and skin conductance response, which captures abrupt (phasic) increases or peaks. The skin conductance level was measured by averaging the low pass filtered (at 6Hz to remove phasic signals) signal. *Skin conductance response* was measured in form of GSR peaks per minute. Both measures are widely used indicators of physiological stress, with higher levels being indicative of increased stress [1].

2.3.4 Self-reported Positive and Negative Affect

In each of the two conditions, participants reported their mood immediately after the proofreading task using the Positive and Negative Affect Schedule (PANAS). High positive affect (PA) reflects the experience of happiness, enthusiasm, and alertness. High negative affect (NA) refers to experiences of stress and displeasure, such that high NA is indicated by states such as nervousness, hostility, and distress.

2.3.5 Facial Expression of Emotion

Automated facial expression analysis is a relatively novel instrument in research, however it has promise as a means of objectively assessing emotions in research settings. The first empirically validated approach to classifying emotions based on facial expressions was called the facial action coding system [4]. The emotions recognized by the facial action coding system were based on the six universal facial expressions [4]. In the current study, facial expressions were recorded by a high-definition webcam and analysed using iMotions (Version 8.1.1) AFFECTIVA. The program includes a real time analysis of facial features (such as eyebrow furrow and upper lip movements), and an analysis based on the basic emotions of anger, fear, disgust, sadness, and joy. The software employs an algorithm which has analysed over seven million faces.

3 Results

Data were analysed by paired-sample t-tests on each dependent variable with a MANOVA for the potentially correlated physiological indicators. The current study has nine dependent measures in total: cognitive performance (errors detected on the proof-reading task), skin conductance response, skin conductance level, heart rate, facial emotions (anger and disgust), self-reported affect (positive and negative mood).

3.1 Cognitive Performance

We used a paired t-test to compare the two conditions (high noise vs low noise) for differences in cognitive performance levels as measured by the proofreading task. There was no statistically significant difference ($t(39)=1.09$, $p=.283$) in the average number of errors detected in the experimental condition ($M=11.00$, $STD=4.99$) compared to the control condition ($M=10.33$, $STD=4.73$).

3.2 Electrodermal activity

We assessed the data for difference in tonic and phasic skin conductance across the two conditions. Phasic skin conductance response was significantly higher ($t(39)=2.08, p=0.044$) in the open plan office noise condition ($M=3.06$, $STD=2.69$) than in the low noise condition ($M=2.47$, $STD=2.47$). For tonic skin conductance level, there was no significance effect of the noise condition ($t(30)=1.78$, $p=.083$), though the mean trended higher in the high noise condition ($M=11.91$, $STD=10.65$) than the low noise condition ($M=10.52$, $STD=10.54$).

3.3 Heart rate

Comparing the two conditions for differences in heart rate, we found that heart rate was higher in the high noise condition ($t(37)=2.61$, $p=.013$) ($M=76.83$, $STD=13.46$) than in the low noise condition ($M=75.49$, $STD=12.69$).

3.4 Self-reported Positive and Negative Affect

We used two paired t-tests to compare the noise conditions for differences in positive and negative affect. Positive affect was significantly lower in the high noise condition ($t(39)=3.26$, $p=0.002$) ($M=17.3$; $STD=6.27$) relative to the low noise condition ($M=20.3$, $STD=6.82$). Negative affect was significantly higher ($t(39)=3.59$, $p=0.001$) in the high noise condition ($M=16.05$; $STD=4.87$) relative to the low noise condition ($M=12.85$, $STD=3.59$).

3.5 Facial Expression of Emotion

We used two paired t-tests to compare the two conditions for differences in the percent of time in which the facial expression of anger and disgust were present. We detected significantly ($t(39)=2.24$, $p=0.031$) more disgust expressions in the high noise ($M=0.17\%$, $STD=0.27$) than in the low noise condition ($M=0.08\%$, $STD=0.16$). It should be noted that, given the 8-minute duration of the proof-reading task, this translates to an average duration of disgust expression of ~1 second in the high noise condition, which is not present in the silent condition. So, despite the statistical significance the effect is very subtle. Conducting the same contrast for facial expression of anger, we detected no significant effect ($t(39)=0.989$, $p=0.329$).

4 Discussion

Our results demonstrated that exposure to open plan office noise significantly affected a number of the physiological and psychological variables as expected. Hypothesis 1, that cognitive performance would be compromised by open plan office noise, was not supported. Hypothesis 2, that physiological measures would show that participants experienced greater stress under open plan office noise than quiet working conditions was supported by significant effects for two measures, and trends in the hypothesized direction on the other two. Hypothesis 3, that affect would be more negative under open plan office noise, was supported by both self-report mood measures and one of the two facial recognition measures of emotion.

These results are fairly convincing given that the work period in the study was only 8 minutes in each condition. In actual work settings, workers in open plan offices are exposed to noise continuously during the day and we would expect that effects on stress and affect would be greater. The short duration may also explain the non-significant results for cognitive performance. Participants may have exerted compensatory effort to sustain their performance over the short term. Given the significant results on both self-reported mood and stress, it is likely that the increased cognitive load of maintaining focus under distraction would deplete resources and damage performance following longer exposure.

Our study has highlighted the importance of using a multimodal approach in assessing the psychological impact of workplace stressors. The sole reliance on a task performance measure would have suggested that the office noise had no detrimental effect, whereas the affective self-report and physiological measures provided clear evidence for increased stress in the noise condition. Further, the objective physiological effects of noise complement the self-report mood effects and help to demonstrate that employees are not merely complaining but actually being affected by the auditory environment.

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