Effect of modified brown masking noise delivered through earphones on open-plan office worker's concentration, task performance and attitudes – a multi-methods study.

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Effect of modified brown masking noise delivered through earphones on open-plan office worker's concentration, task performance and attitudes – a multi-methods study.

The aim of this study was to investigate the attitudes of workers in an open-plan office towards concentration, task performance and co-worker interaction when wearing earphones with masking noise and when not wearing earphones. The earphones with masking noise were evaluated over the course of a working day and the level of the office noise varied between 51 and 59 dBA. The spectrum of the masking noise was brown noise modified by a PC audio controller and earphones (the spectrum of the modified brown noise was substantially different to that of brown masking noise). The questionnaire based quantitative study (*Study 1, n = 28)* indicates that disturbance to concentration and task performance is reduced by modified brown masking noise thereby confirming previous studies. However all the participants in the qualitative study, which involved both open ended questionnaire and focus group interviews, (*Study 2, n = 28 for open ended questionnaire and 12 for focus groups*) identified that they would not use earphones with modified brown masking noise to counteract office noise. An important reason for this is that modified brown masking noise obscured nearby relevant conversations, which participants identified as being crucial to the success of their overall work task. Other participants rejected the brown masking noise delivered through earphones as it caused irritation and discomfort. It is recommended that future studies into the effectiveness of masking noise in open-plan offices should include consideration of the relevance of nearby conversations. Future studies should also consider other types of masking noise and should measure the level and duration of the masking noise.

Keywords: open-plan office; brown masking noise; office worker; intelligible speech; relevant speech; earphones

Practitioner Summary: This paper reports on a multi-methods study into the use of modified brown masking noise delivered through earphones to counteract the negative effects of noise on open-plan office workers. It was found that modified brown masking noise delivered in this way was rejected by all participants.

1 Introduction

Since the 1970's open-plan office layouts have effectively replaced private offices. Open-plan offices provide both reduced commercial cost and improved worker communication (Loewen and Suedfeld 1992). However longitudinal studies identified that the acoustic environment in an open-plan office, particularly intelligible speech, leads to increased concentration difficulties, reduced task performance and reduced co-operation between workers (Kaarlela-Tuomaala et al. 2009; Liebl et al. 2012). This paper sets out to provide evidence regarding the value of masking noise including a follow-up to determine the attitudes of users willingness to adopt masking noise. The latter is essential if any performance benefits are going to be realised.

Laboratory and field experiments have demonstrated that the detrimental effect of office noise on worker attitude and performance can be significantly reduced through the use of masking noise (Ellermeier & Hellbrueck, 1998; Venetjoki et al. 2006; Hongisto 2008; Haka et al. 2009; Haapakangas et al. 2011). For instance the experimental study performed by Haka demonstrated that the performance of operation span tasks, serial recall and long term memory tasks were all improved when masking noise was used; and the field study performed by Hongisto (2008) indicated that masking noise significantly reduced disturbance of worker attitudes towards concentration caused by office noise. Masking noise achieves this improvement through reducing the intelligibility of nearby speech (Haapakangas, Kankkunen, et al. 2011). Tasks which involve semantic processing are disrupted by the involuntary interpretation of the meaning of the irrelevant speech. Reducing the intelligibility of the irrelevant speech will lead to the reduction of involuntary interpretation. This will in turn lead to the reduction of the level of task disruption. A similar benefit to task performance is likely to be achieved by tasks that are disrupted by phonological similarity (through reducing the creation of irrelevant auditory objects in the sub-vocal rehearsal process), or by the diversion of the locus-of-attention. In all three cases reduction in speech intelligibility results in reduced disruption to the task. Kaarlela-Tuomaala et al. (2009, p. 1442) also identified that the level of effect of office noise on office worker performance and attitudes is strongly influenced by the job type. For instance job types requiring mainly individual effort should have low levels of intelligible speech typified by private offices or open-plan offices with higher levels of masking noise; whilst job types requiring team interaction would benefit from open-plan offices with lower levels or no masking noise.

Consequently masking noise has been identified as providing value in terms of office worker attitude and performance in open-plan offices. To date masking noise has been generated by loudspeakers (Haapakangas et al. 2011). However there appears to have been no consideration as to the use of earphones rather than speakers to deliver masking noise. Earphones would provide individual office workers with all the benefits of masking noise delivered through speakers. In addition they would provide the worker with the added advantage of selecting masking noise only when prevailing noise levels and task difficulty demanded it. When the prevailing noise or task levels were low then the masking noise can be switched off and the communication benefits of working in an open-plan office resumed. Consequently the general aim of our study was to investigate the use of earphones to deliver masking noise to improve office worker performance and attitudes. The specific aims of our study was to investigate the effects of masking noise delivered through earphones on a) professional office workers attitudes towards concentration when exposed to specific office sounds, b) professional office workers ability to perform specific tasks when exposed to general office sounds, and c) professional office workers attitude towards their workspace including co-worker interaction.

One of the few studies regarding the use of headphones to deliver music was reported by Oldham, Cummings and Mischel, 1995. This study identified improved worker performance and satisfaction when headphones with music were used by 256 workers in the office of a retail company. These improvements were attributed to masking of distracting background noise together with worker control over their working environments. Since earphones are functionally identical to headphones, as both deliver sound to an individual user directly to their left and right ears, then the study by Oldham would lend support to the use of earphones to deliver masking sounds to office workers. In our study we use a constant masking noise rather than music. This was because constant masking sound is a more effective masking noise than instrumental or vocal music (Haapakangas et al. 2011). Our study also differs from that of Oldham in that the participants in our study were all professional office workers.

The hypothesis being tested by the quantitative study is that workers attitudes towards concentration, task performance and co-worker interaction are all improved by modified brown masking noise delivered by earphones. There are three research questions addressed by the qualitative part of the study. These are 1) Does the use of modified brown masking noise delivered through earphones reduce the detrimental effects of office noise on concentration, task performance and co-worker interaction? 2) What are the disadvantages of

modified brown masking noise delivered through earphones? and 3) Do the advantages of modified brown masking noise delivered through earphones outweigh the disadvantages?

2 Materials and Methods

2.1 Design

This multi-methods study consisted of two parts. Study 1 was a quantitative investigation into the effect of modified brown masking noise delivered through earphones on office workers concentration, task performance and workspace. Study 2 was a qualitative investigation into attitudes of office workers towards modified brown masking noise delivered through earphones. Study 1 utilised a questionnaire before and after using modified brown masking noise delivered through earphones and Study 2 used open ended questions and two focus group interviews.

2.2 Participants

The participants were drawn from a single large open-plan office. This office was occupied by over 120 workers. All participants were aerospace professionals working either in engineering, project management or commercial. They were qualified to at least degree level and had worked in the office for at least 6 months. 105 workers were selected at random and invited to complete the first questionnaire of which 76 completed questionnaires were returned (72% return rate). 59 of these participants were male and 17 were female. The mean age of the participants was 45 and the standard deviation was 11. The participants were chosen to be evenly distributed throughout the office layout. The second questionnaire was completed by 28 participants drawn from the 76 participants in the first questionnaire. 26 of these participants were male and 2 were female. The mean age of these participants was 44 and the standard deviation was 11. These 28 participants also completed the open-ended questions of Study 2 and 12 of them participated in the focus group.

2.3 Work type and concentration level

Of the 28 participants in the second questionnaire 71% classified their work type as being ‘individual workers’, 4% classified this as ‘collaborative workers’, and 25% were neither individual nor collaborative task workers. ‘Individual workers’ were those that spent over 60% of their time working individually and ‘collaborative workers’ spent over 60% of their time collaborating with co-workers.

Of the 28 participants in the second questionnaire 85% considered that their work required moderate concentration; 11% required high concentration, and 4% required moderate/low concentration.

2.4 Sound conditions

The noise level within the office used in the study was measured using a Bruel & Kjaer Type 4436 noise dose meter. The microphone was located at a typical office workers seated ear position (1.2m above floor). Twenty second SPL samples, $L_{A,eq,20s}$, were measured throughout the course of a day [Table 1]. Noise levels ranged from an L_{min} of 51 dBA during relatively quiet periods when only babble was present to an L_{max} of 59 dBA when nearby conversations took place. Measurements performed on successive days identified similar ranges of L_{min} and L_{max}. These noise levels were similar to those measured in the open-plan offices used by Kaarlela-Tuomaala et al. (2009, 1434).

[Table 1 near here]

Table 1: Sound level measurements recorded over the course of a day in the open-plan office used during the study.

Conventional masking noise is a continuous pseudorandom noise which is superimposed on office noise and which has the effect of reducing the intelligibility of unwanted (irrelevant) speech (Ellermeier & Hellbrueck 1998). There are four main types of continuous masking noise; a) white masking noise which has equal power in the frequency band between 40 Hz and 60 Hz as it has between 400 Hz and 420 Hz, b) pink noise which is linear when plotted on a linear graph and has the same power over the frequency band from 40 to 60 Hz as it has in the frequency band 4000 to 6000 Hz, c) brown noise has a Gaussian probability distribution, and d) red noise is any signal with a power density proportional to $1/f^2$ (Colors of noise 2015). Noise with a spectrum of between -5dB per octave to -7dB per octave is considered to be close to brown noise (Hongisto, Oliva and Rekola, Subjective and objective rating of spectrally different psuedorandum noises - Implications for speech masking design 2015). A recent study has identified -7dB per octave as being an acceptable masking noise (Hongisto 2015). Of the eleven spectrally difference noises evaluated brown noise (-7dB per octave) resulted in the highest satisfaction. The intention was consequently to utilise brown noise in our study. The brown noise that was utilised was generated via the web page at http://www.simplynoise.com/ using a Hewlett Packard Compaq Elite 8300 computer fitted with a Realtek High Definition Audio sound controller. The earphones that were used were of the type that is inserted into the ear canal. These are also referred to as ear buds or

inner-ear headphones. The spectrum of the .wav music file used to create the Brown noise was extracted using the audio analysis tool Audacity. The resulting spectrum is shown in Figure 1. Also shown in Figure 1 is the -7dBA line. The spectrum of the brown noise wav. file is very close to that of the -7dBA line and is therefore close to brown noise. The spectrum of the sound emitted by audio controller and the sound emitted by the earphones is shown in Figure 2. This was measured by the Noise and Vibration Environmental Test Laboratory using a Brüel and Kjær 4231 Sound Calibrator, a Knowles Miniature Microphone, a Knowles Miniature Microphone, two Edirol R-09HR digital recorder (one to replay the brown noise and the other to record the output from the microphone preamplifier), a B&K Pulse Analyser and a Dell Laptop computer. The spectral characteristic of both the audio controller and the earphones have changed the spectral content of the brown noise from the wav. file (Figure 2). The resulting spectrum is distinctly different from brown masking noise and is consequently referred to as modified brown masking noise. Modified brown masking noise is realistic as office workers would use this combination of webpage/computer/earphones to listen to masking noise.

[Figure 1 near here]

Figure 1: Spectrum of the brown noise .wav file used in this study.

[Figure 2 near here]

Figure 2: Spectrum of the audio controller and the earphones produced using the brown noise wav. file.

2.5 Procedure

Study 1 was performed in two phases. Both phases used questionnaires to collect office workers attitudes towards office noise in terms of concentration, task performance and workspace. In the first phase the participants completed the first questionnaire when not wearing earphones. In the second phase the participants completed the second questionnaire after they wore earphones with modified brown masking noise for one day and earphones with no masking noise on another day. To counteract any order effect half the participants wore earphones with modified brown masking noise first whilst the other half wore earphones with no masking noise first. Participants were instructed only to wear their earphones when they felt that the level of office noise was such that it would cause distraction to their concentration and/or task performance. They were also instructed to adjust the volume to be loud enough to mask any offending office sound but not loud enough to cause

discomfort. The volume of the masking noise was adjusted using the speaker symbol on the Windows© task bar and/or the volume provided by www.simplynoise.com. The second phase of the study commenced within one week of the end of the first phase and was completed within one month. The results of the questionnaires were then analysed as described under the analysis section.

The participants of the focus groups (Study 2) were randomly drawn from the twenty eight participants in the second phase of Study 1. The participants in the focus groups were invited to discuss three main questions; "What are the positive aspects of using masking noise delivered through earphones in the office environment?", "What are the negative aspects of using masking noise delivered through earphones in the office environment?" and "Do the positive effects outweigh the negative effects; or do the negative effects outweigh the positive effects". Participants were not limited to these specific questions but were invited to introduce any issue that they felt relevant. Both focus groups commenced with a round the table introduction by each participant which included their views on the above questions. This was followed by a general discussion led mainly by the participants with occasional prompting by the moderator. Each focus group lasted approximately thirty minutes. In total one hundred and seventy five comments were recorded and subsequently included in the thematic analysis.

2.6 Ethical considerations

The study was performed in accordance with the British Psychological Society Code of Human Research and was approved by the Department of Psychology Ethics Committee (University of Derby).

3 Study 1

3.1 Method

3.1.1 Design

A longitudinal survey design was utilised in the present study. The study commenced by measuring the effect of office noise on the performance of workers in an open-plan office when the workers were not wearing earphones. This measurement was then repeated after the workers had used earphones with modified brown masking noise for one day, and earphones

with no masking noise for another day (repeated measures design). Workers performance was measured in terms of a) their ability to concentrate in the presence of typical office noises, b) their level of disturbance whilst performing specific tasks and c) their attitudes to their workspace. The independent variable was 'wearing earphones with modified brown masking noise' or 'not wearing earphones'. The dependant variable was office workers performance.

3.1.2 Questionnaires

Two questionnaires were used. The first questionnaire was completed by participants when they were not wearing earphones. This questionnaire performed three functions which were a) measure office workers performance in terms of concentration, task performance and workspace, b) characterise the population from which participants were drawn and c) identify volunteers for the full study. The second questionnaire was completed by participants after they had worn earphones with modified brown masking noise and had worn earphones with no masking noise. The second questionnaire also measured office workers performance in terms of concentration, task performance and workspace. Participants who completed the second questionnaire had also completed the first questionnaire.

The questions regarding the performance of office workers in terms of concentration, task performance and workspace followed those utilised by Kaarlela-Tuomaala et al. (2009); Hongisto (2008); Haapakangas et al. (2008). These have a Cronbach's α of >0.8. A Cronbach's α larger than 0.75 is considered to have good reliability (Cooligan (2009, 195)).

The questionnaires included a briefing guide and debriefing guide which were designed so that participant's responses would not be biased. They also utilised coding to allow questions in the first questionnaire to be matched to corresponding questions in the second questionnaire for each individual participant, whilst maintaining the participant's anonymity. Participants returned their completed questionnaires to a collection box in order to maintain their anonymity.

3.1.3 Statistical Analysis

The frequency distributions of the sets of data were analysed using the Kolmogorov-Smirnov test and found to be significantly non-normal. Consequently the tests of statistical differences between the three conditions were accomplished using Friedman's ANOVA. The three

conditions were earphones with modified brown masking noise, earphones with no masking noise and no earphones. The Wilcoxon test was used to follow up the findings of the Friedman's ANOVA. A Bonferroni correction was applied to counter the potential increase in type 1 errors introduced by multiple comparison analysis; so as 3 comparisons are being made all effects are reported at a .0167 level of significance (Field 2005). One-tailed tests were used as previous research indicates that masking noise will only decrease and not increase the negative effects of office noise on participants' attitudes. Two levels of analysis were performed. Firstly, the overall themes of concentration, task performance and workspace were analysed. This was achieved by averaging the results of all the questions within a theme. Secondly the significance of individual questions within the themes was analysed. The analysis of themes provided an overview of participant's attitudes towards the effect of office noise on concentration, task performance and workspace. The analysis of individual questions provided participant's specific attitudes towards various types of office noise, various types of tasks and various aspects of their workspace.

3.2 Results (Study 1)

3.2.1 Analysis of themes

a) Comparison of 'wearing earphones with modified brown masking noise' to 'not wearing earphones'.

Wearing earphones with modified brown masking noise significantly reduced the disturbance of office workers concentration caused by office noises [$T = 66$, $p<.0167$ ($p= .001$)].

Wearing earphones with modified brown masking noise also significantly reduced the disturbance of overall task performance caused by office noises [$T = 55$, $p<.0167$ ($p= .001$)].

Wearing earphones with modified brown masking noise had no significant effect on the influence of office noises on overall worker interaction (i.e. workspace).

This is illustrated in Figure 3.

b) Comparison of 'wearing earphones with no masking noise' to 'not wearing earphones'.

'Wearing earphones with no masking noise' had no significant effect on a) disturbance of concentration due to overall office noises, b) disturbance to overall task, and c) overall co-worker interaction (i.e. workspace). This is illustrated in Figure 3.

[Figure 3 near here]

Figure 3: Participants' attitudes to overall themes of concentration, task performance and workspace.

3.2.2 Analysis of individual questions

The analysis of the individual questions are summarised in Figure 4, Figure 5 and Figure 6 and described below. The analysis of individual questions followed that utilised by Kaarlela-Tuomaala (2009).

3.2.2.1 Disturbance of office workers concentration by specific office sounds

Disturbance of office workers concentration was significantly reduced when wearing earphones with modified brown masking noise in comparison to not wearing earphones for '*Nearby speech and laughter'* [T = 18, p< .0167 (p= .001)] and '*Telephone ringing tones'* [T = 53, $p\leq$ .0167 (p= .014)]. Disturbance was not significantly reduced for '*General speech and laughter'*, '*Movement in corridors'*, '*Shared office equipment'* and *'Sounds caused by work'*.

[Figure 4 near here]

Figure 4: Disturbance of office workers concentration by specific office sounds

3.2.2.2 Disturbance of office workers perceived performance of specific tasks

Disturbance of office workers performing certain specific tasks was significantly reduced when wearing earphones with modified brown masking noise in comparison to not wearing earphones for *'Reading, studying'* [T = 18, $p\leq$.0167 (p= .001)], *'Planning, creative work'* [T = 40, $p\leq$ .0167 (p= .004)], *'Counting / spreadsheets'* [T = 49, $p\leq$ .0167 (p= .009)] and *'Text processing, writing'* [T = 42, $p\leq$ .0167 (p= .002)]. Disturbance was not significantly reduced for tasks involving *'email and internet'*.

[Figure 5 near here]

Figure 5: Disturbance of office workers perceived performance of specific tasks

3.2.2.3 Office workers attitude towards workspace (e.g. co-worker interaction)

Office workers attitude towards their workspace whilst wearing earphones with modified brown masking noise was not significantly different to their attitude whilst not wearing earphones for *'Direct and pleasant cooperation with co-workers'*, *'Ease by which co-workers can be approached'*, *'Information flow among colleagues'* and 'Efficiency of cooperation between co-workers'.

[Figure 6 near here]

Figure 6: Office workers attitude towards workspace (e.g. co-worker interaction)

4 Study 2

4.1 Method

A qualitative approach was utilised in order to capture rich detailed information on the human factor (Kraemer and Carayon 2007, 145). Quantitative research can only support empirical laws whilst a qualitative approach will provide an understanding as to the why and how; specifically why and how the use of modified brown masking noise provided benefit or hindrance (Gibbs, 2002; Cooligan, 2009; Willig, 2008).

4.1.1 Data Collection

Data was gathered using open-ended questions and two focus group interviews. Open-ended questions were used to draw out participant's views regarding two specific issues; the advantages and disadvantages of using earphones with modified brown masking noise; and whether the advantages of using earphones outweighed the disadvantages. The open-ended questions were contained within the questionnaire that was completed by the twenty eight participants in the second phase of *Study 1*. Focus group interviews were used as they utilise the interaction between participants to challenge, extend, develop and qualify particular attitudes expressed by individual participants (Willig 2008). As such they are more likely to reveal underlying explanations as to why particular attitudes are held than would be achieved with individual semi structured interviews (Cooligan 2009). The focus groups were run in accordance with guidelines provided by Kandola (2013).

4.1.2 Materials

The focus group discussion was audio recorded using a digital Dictaphone. The recording was subsequently transcribed into textual data and analysed with the replies to the open-ended questions.

4.1.3 Procedure and Analysis

Analysis was accomplished through the use of Template Based Thematic Analysis. This method has "a high degree of structure in the processing and analysing of textual data with the flexibility to adapt to the needs of a particular study" (King 2013). The analytical process utilised in our study combined that defined by King (2013) and Waring & Wainwright (2008). It consisted of the following steps:

1) Identify a-priori themes from available research papers and use them as the basis of a QSR NVivo 10 Project [Table 2]
2) Insert the answers to the open-ended questions as a 'source' in the NVivo project
3) Gather data through the use of the two focus groups interviews
4) Transcribe focus group interviews into text
5) Enter transcript of focus groups into the NVivo project as two sources
6) Perform a first pass coding of the open-ended questions. Modifying the template through reading the sources, making connections and populating corresponding themes and subthemes. This is accompanied by insertion of new themes, deletion of unused themes and merging of non-exclusive themes
7) Repeat step 6 with the first focus interview transcript, and then with the second focus interview transcript
8) Verify that themes identified are correct through repeating and checking analysis performed in step 6 and 7, and through comparison against sources
9) Create the final template [Table 3]
10) Interpret and present the template analysis in the form of a summary narrative.

[Table 2 near here]

Table 2: A-priori themes and sub-themes in hierarchical order.

[Table 3 near here]

Table 3: Final themes and sub-themes in hierarchical order.

4.2 Results (Study 2)

4.2.1 Summary Narrative.

The purpose of this summary narrative is to draw together the main issues that were identified by the Template Based Thematic Analysis. The most important issue that was identified was that none of the participants would voluntarily use modified brown masking noise delivered through earphones to address office noise. This was for two distinctly different reasons which appeared to correspond to two distinctly different types of office workers. The first type of office worker rejected the modified brown masking noise delivered through earphones because it prevented them from maintaining awareness of discussions that occurred between colleagues in their immediate vicinity. The second type of office worker rejected the modified brown masking noise delivered through earphones because they perceived earphones with modified brown masking noise as being too irritating and uncomfortable. Seven participants exhibited the attitudes of the first type of office worker. This was made up of six participants in the first focus group and one in the second focus group. Five participants exhibited the attitudes of the second type of office worker. This was made up of one participant in the first focus group and four in the second focus group.

The view of the first type of office worker is typified by the following comment from one of the participants; "In an open-plan office you never work entirely alone, you often gain information by overhearing colleagues. With earphones on you either miss this interaction or strain to hear it." This comment represented a consensus of opinion held by this type of office worker which was that it is better to continually monitor interactions between co-workers and risk some distraction to the task at hand [2.1.1 and 2.1.2; these numbers correspond to the themes in Table 3].

The second type of office worker had the general belief that their colleagues and managers understood and accepted that the participant's main task was an isolated one. Colleagues would deliberately involve the participant if and when the topic of group discussion was of relevance to them but at other times the participant was free to work in isolation from their co-workers [2.1.1]. However these participants rejected modified brown masking noise delivered through earphones for several other reasons. The main reason concerned the volume and tone of the modified brown masking noise. The volume at which the modified brown masking noise had to be set at in order to counteract loud noises caused by laughter and speech was considered by participants to be unpleasantly irritable, oppressive and uncomfortably loud. The other reason was the physical comfort of the earphones

themselves (e.g. their insertion into the ear canal and obstruction to arm movement caused by the wire).

5 Discussion

5.1 Rejection of earphones as a means of delivering modified brown masking noise

The purpose of our study was to investigate the attitudes of professional workers in open-plan offices towards office noise and how this is affected by modified brown masking noise delivered through earphones. Workers that participated in the study performed individual tasks which required moderate levels of concentration. Study 1 indicated that wearing earphones with modified brown masking noise, in comparison to not wearing earphones, had a significant positive effect on office workers ability to concentrate when exposed to two types of office noise and a positive effect on office workers ability to perform four task types. As these office sounds and tasks are common in open-plan offices then this might be taken to indicate that office workers would significantly benefit from wearing earphones with modified brown masking noise. However this conclusion is not supported by Study 2 which indicated that office workers would not use the modified brown masking noise delivered through earphones. This was either because it prevented office workers from overhearing and potentially benefiting from nearby relevant co-worker conversations, or it was perceived as being too irritating due to its tone and volume. It is noted that there are many types of masking noise; the outcome of this study may have been different if a more effective or more comfortable masking noise had been used.

5.2 Comparison to study using headsets

A study into the effect of headsets on employee work response was performed by Oldham et al. (1995). This is a similar to our study in that both studies injected masking sounds directly to participants' ears rather than via loud speakers. Oldham found that for relatively simple jobs both performance and worker satisfaction improved. However, Oldham et al. also found that for relatively complex tasks performance was reduced and there was no benefit to worker satisfaction. Oldham et al. also identified that headsets would have an adverse effect on individuals performance effectiveness when their jobs required substantial interaction with co-workers'. Consequently there is some similarity between the results of the study by Oldham et al. and the results of Study 2 (qualitative). However the difference in

masking noise used (Oldham used music) and differences in definitions of task complexity both prevent a more precise comparison being made between Oldham's study and our study.

5.3 Rejection of earphones due to masking noise level, type and physical comfort.

The participants in Study 2 exhibited two main attitudes. The first attitude was the rejection of modified brown masking noise delivered through earphones due to it blocking nearby relevant conversations, as discussed in detail above. The second attitude was the rejection of modified brown masking noise delivered through earphones due to the unpleasantness of the sound itself or the comfort of using earphones. There are two potential reasons why these participants found the modified brown masking noise unpleasant. Firstly, the actual spectrum of the modified brown masking emitted by the earphones was distinctly different from brown masking noise used and found to be acceptable in previous studies (Hongisto, Oliva and Rekola 2015). On reflection masking noise such as those investigated by Haapakangas, Kankkunen, et al. 2011 may have been more acceptable to the participants. Secondly the typical volume of the masking noise needed to mask nearby speech may be too loud. The latter issue arises from a) volume levels above 45 dB are considered to be too loud for office workers (Veitch et al., 2002 as cited by Navai, and Veitch, 2003 and Hongisto et al. 2014) and b) the sound level of nearby speech in the office used in our study reached 59 dBA (also, Hongisto et al. 2004 and Virjopnen et al 2009 as cited by Haka et al. 2009 have identified that the volume of speech from the nearest workstation in open-plan offices is typically between 45 and 55 dBA). Consequently if the participant sets the volume of the masking noise to match that of nearby conversation then it is likely to be perceived as being unpleasant. Ideally in future studies the volume level of the masking noise set by the participant would be recorded to allow the impact of a) and b) above to be evaluated.

It is possible that other types of masking noise (Haapakangas, Kankkunen, et al. 2011 and Hongisto, Oliva and Rekola 2014) or more physically comfortable earphones would have resulted in a more beneficial effect on office noises, and consequently would not have been rejected by participants. However even if this type of office worker was placated in this way there remains a substantial proportion of participating office workers (over half) who would reject masking noise due to its detrimental effect on awareness of co-workers conversations.

5.4 Participants job type

Job type is likely to have an impact on office workers response to masking noise (Oldham et al. 1995 and by Kaarlela-Tuomaala, 2009). The study by Oldham et al. (1995) into the use of headphones to deliver music as a masking noise found a clear difference in the

perceived benefits between jobs requiring simple interactions with co-workers and jobs requiring substantial interaction with co-workers. Helenius and Hongisto, 2004 considered office workers who had university or academy level education dealing with the development of administrational tools, Hongisto, 2008 considered office workers working in a telephone exchange and Hongisto et al. 2012 considered office workers who provided customer service support and were educated to Bachelor level education. Office workers in all of these studies did not appear to have a requirement for a high level of interaction with co-workers. All three studies found that office workers benefited from masking noise. Our study considered professional office workers who did have a requirement for a high level of interaction with co-workers. This was due to the office workers in our study all participating in different aspects of the same projects, thereby necessitating high levels of co-worker interaction. The difference in outcome between our study and previous field studies may therefore be linked to the level of co-worker interaction required by job type.

5.5 Number of participants

The qualitative study performed by Kraeme and Carayon, 2007 utilised 16 participants with 2 focus groups consisting of 8 participants, and the qualitative study performed by and King (2013) utilised 20 participants with 4, 6 and 10 participants in each focus group. The present study utilised 28 participants in the open-ended questions and 12 participants in the focus groups. Consequently the qualitative part of the present study is considered to be compatible to these other studies in terms of number of participants.

5.6 Limitations and future research needs

Our study has weaknesses which are discussed below. Despite these limitations we believe that valuable insight into the use of earphones to deliver masking noise, for a specific type of office worker, has been achieved. We also believe our study identifies valuable suggestions for future research into the use of masking noise in open-plan offices.

Limitations in our study include the reliability and validity of the qualitative study. The techniques proposed by King (2014) to address reliability and quality, of creating an audit trail and employing reflexivity, have been implemented. Another limitation was the number of participants, duration of the trial and the number of focus groups. Ideally this would have been larger in order to ensure that the full range of office workers views were identified, however the limitation was imposed largely by the number of offices workers that were willing to participate beyond the completion of the first questionnaire. This limitation might be addressed through streamlining the questionnaires, or through other participant

incentives such as payment or entry into a prize draw. The technique of 'theoretical saturation' as identified by Taylor and Bogdon 1998 as cited by Kraemer & Carayon, 2007 might also be usefully employed to provide assurance that the number of participants and focus groups was sufficient. Theoretical saturation is where further data collection and analysis does not identify any new themes. The duration of the trial of one day may be too short to allow participants to become accustomed to using masking noise. The field study by Helenius and Hongisto, 2004 identified that participants still retained their initial resistance to higher levels of masking noise more than one month after it had been introduced. Future field studies should if possible extend their duration over several months. The number of times that earphones were worn and the duration of their use may also provide useful insight if this was recorded during future trials. However the mechanism for measuring this data should itself not cause further distraction to the participant. There are many types of masking noise which have varying levels of effectiveness and perceived quality. The results of this study may have been different if a more effective or more comfortable masking noise had been used. Future studies into the use of earphones to deliver masking noise should consider other masking noises. Haapakangas, Kankkunen, et al. 2011 identified recorded spring water sound to be a very effective masking noise.

Finally the questionnaires utilised in our study were susceptible to being biased by the participant subjective impressions of the task being considered. The use of objective performance tests would have provided additional data to verify the results of the questionnaire (Schlittmeier, et al. 2008).

Counterbalancing of the order of the experimental sound was beneficial to our study in that it minimised order effects that may have otherwise influenced the results.

It is recommended that future studies into the use of masking noise to improve workers attitudes and task performance in open-plan offices should a) consider all types of office workers, in terms of 'individual' or 'team' workers, and required interaction with co-workers, b) include monitoring of nearby relevant conversation as a second task c) consider other types of masking noises d) control the level and measure the duration of the masking noise (this is to permit comparison to other recent studies) and e) utilise qualitative methods, as well as quantitative methods, in order to fully capture the why and how masking noise delivered through earphones provides benefit or hindrance to office workers. Future studies should also include representation of other physical environmental factors that influence

office worker performance and attitudes such as thermal, lighting and desk density (Kim and de Dear, 2013 and Hongisto et al. 2016).

6 Conclusions

The participants in our study were professional office workers in an open-plan office who performed individual tasks requiring moderate levels of concentration. Study 1 (quantitative) identified that these office workers felt that their ability to concentrate and perform specific tasks was improved by the modified brown masking noise delivered using earphones. Consequently the alternative hypothesis is supported. However Study 2 (qualitative) identified two disadvantages of modified brown masking noise delivered through earphones. These are loss of awareness of nearby conversations or irritation and discomfort caused by earphones with modified brown masking noise. These disadvantages were considered to overshadow the advantages to the extent that the office workers who participated in the study fully rejected the use of earphones with modified brown masking noise. Those office workers who rejected earphones playing modified brown masking noise due to it reducing their awareness of nearby conversations did so because they considered achieving their overall task was more important than improving the performance of the immediate task at hand. The masking noise utilised in this study was brown noise modified by the spectral characteristics of the PC audio card and earphones. The spectrum of the modified brown masking noise was substantially different from brown noise; but is realistic as office workers would potentially use this combination of webpage/computer/earphones to listen to masking noise. Participants were able to decide when masking noise was required and set its volume level (i.e. the duration and level of the masking noise was not measured during the study, though it should be in future studies). There are also many types of masking noises with various levels of masking effectiveness and perceived comfort; future studies should consequently consider other types of masking noises. This study also highlights the importance in future studies of including consideration of offices workers need for active interaction with background speech.

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