Comparison study of three Speech Masking Sounds on Employees' Task Performance in Open-Plan Office environments

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Summary
This pilot study aims to investigate the impacts of three speech masking sounds (water stream, pink noise, instrumental music) on occupants' performance as well as to draw conclusions about potential correlations between the actual performance and the perceived disruption by nearby speech, efficiency of each masking sound and stress. Ten participants were tested under four different noise conditions, three of which included the aforementioned masking sounds and one unmasked background speech. Typical office sounds were also added to the background to resemble the audible environment of an open-plan office (OPO). A five-minute short-term memory test, which was designed to examine the participants' cognitive performance, followed by a short questionnaire for subjective evaluations were conducted in this within-subject design study. The results indicated that there was no main effect of sound condition to the participants performance or subjective responses. However, two evaluations of marginal statistical significance were identified with regard to the efficiency of the masking sound during pink noise and instrumental music as well as the perceived stress during unmasked speech and instrumental music. Although further investigations are still required, this pilot study has already highlighted the potential impact of different masking sounds on individuals' performance.

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1. Introduction

The open-plan office design (OPOD) was introduced in 1960s and it remains one of the most popular office configurations in today's workstations[1]. Although it offers an attractive and cost-effective solution for businesses, compared to traditional cellular offices, the detrimental effect of noise by sources such as conversations, machine noise, keyboard typing, phones, background music etc. on occupants' performance is well-documented [2]–[4].

In order to achieve acceptable levels of speech privacy in OPOs a degree of sound masking is required, and its necessity had already been identified in Hardy's early office design guidelines [5]. However, it is recommended that artificial sound masking should only be applied in offices with background noise levels below 40 dB(A) [6].

The aim of this study is to address the effect of 3 speech masking sounds (Water Stream, Pink Noise, Instrumental Music) on employees' performance in open-plan office environments and draw conclusions about potential correlation between the objective performance and the subjective impressions of each participant during their exposure to each of those conditions. Overall, the following research questions were examined:

1. Is there an improvement in the participant's performance while working in office environments which include speech masking sounds than when exposed to unmasked speech environments?
2. Is there a difference in the participants' perceived stress levels when working in office environments where nearby speech is completely unmasked?
3. Are there any potential correlations between the participants' performance and the

subjective evaluations tested at the end of each condition?

2. Background

Among all the noise sources identified in OPOs, background speech has repeatedly been reported as the most distracting source [7], [8]. In particular, the semanticity of the speech is considered to be the main factor that causes greater distraction than non-meaningful speech [9], [10]. On this basis, the *Speech Transmission Index (STI)* is used to quantify the speech intelligibility of a space. It shows the average amount of speech information available to a listener's ear. The assessment of the signal is based on a scale from zero to one, with the former denoting that no information is available to the listener, while the latter indicates that intelligibility is perfect [11].

According to Hongisto [12], a model showing the relationship between decrease in performance and STI has been proposed. Based on this model the International Standard ISO 3382-3 (2012) offers STI target values that are alleged to be suitable for open-plan offices [13]. In short, the negative effects of speech on work performance start to die out rapidly if the STI is below 0.5 and disappear when the STI falls below 0.20.

The auditory distraction and the subsequent decline in performance seems to be highly associated with the degree of uncontrolled audition of irrelevant sounds in the surrounding soundscape. This is called the irrelevant sound effect (ISE) and is incorporated within the *changing-state hypothesis and* the *interference-by-process theory*, an extensive description of which can be found in Yadav *et al* [14]. In particular, studies have shown that the ISE is one of the main factors which causes disruption of serial memory. Serial memory refers to temporary storage of information for use in the very near future and completion of tasks, and it is highly associated with activities related to employees' tasks in the offices [6].

With regard to the masking effect, the extent to which masking occurs depends on the frequencies and amplitudes of the masking sound and background speech in this case. With respect to frequency, it is recommended that the speech spectrum should fall within the masker's response curve [15], [16]. It is also recommended that the masking sound level should be within the range 40 dB(A) to 45 dB(A), so that the masking system is not considered an additional source of distraction[17].

Previous studies have examined the effectiveness of pseudorandom masking sounds such as white, pink and brown noise [7], [16], [18], [19]. Veichte *et al*.[16] came to the conclusion that an efficient masker should follow the speech spectrum which is approximated as a -5dB doubling per octave within the frequency range 125-8000 Hz. When compared to legato and staccato music, pink noise was found to be more efficient in reducing the negative impact of office noise in [19]. Similar results were obtained in studies [6] and [23] in which people performed better in pink noise than in conditions which included instrumental or vocal music.

Water sounds have not extensively been used as speech maskers in offices but their contribution to the improvement of urban soundscapes has been established in [21] and [22]. Studies which included sounds of water in simulated office environments indicated that subjects achieved better scores in short-term memory tasks when exposed to water waves superimposed with multiple voices than in conditions with continuous noise or water with a single voice [23] and when exposed to plain water waves than in unmasked and masked speech conditions [6],[27]. Subjective evaluations observed by Hongisto *et al*.[18], who conducted a long-term experiment in an OPO comparing three water based masking sounds (WBMS) with pseudorandom masking, showed that the results were in favour of the latter. However, further research is required to confirm the reliability of those results due to technical and methodological issues associated with this study. This trend, however, is already supported in [23].

Music has often been defined as a partial masker since its structure consists of phrases as well as pauses, during which background speech is intelligible[25]. Several studies have investigated the effect of music as a speech masker and the results are fairly consistent. More specifically, Miller [25] states that "*...most music is inoffensive...*", which is supported by the majority of the studies showing that instrumental music does not improve the impairment in cognitive performance caused by background irrelevant speech and yields worse scores in performance when compared to water or continuous noise [6], [19], [20], [25], [26]. It should be noted, however, that music with clear temporal and spectral structure as opposed to legato music, is shown to reduce serial recall performance [26].

3. Method

3.1. Participants

10 individuals 23 to 38 years old (5 Females, M=27, SD=5.4), volunteered for the experiment. Four participants had no previous experience in open-plan offices, whereas the rest had a mean of 3.6 years of experience (SD=3.6). All subjects reported normal hearing, five of which had undertaken a hearing test in the past.

3.2. Design & Procedure

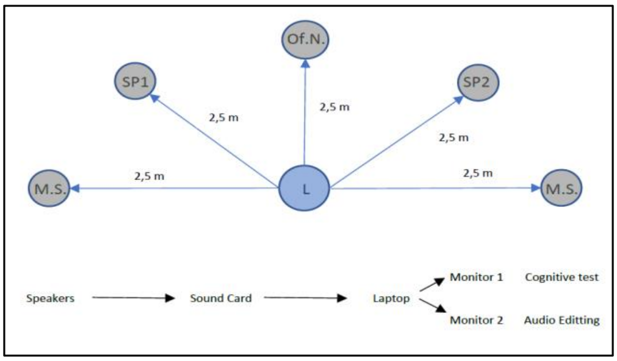

Figure 1: Experimental Plan and Apparatus. Abbreviations: M.S: Masking System, SP: Speech, Of.N.: Office Noise, L: Listener

The experiment was carried out in a usability laboratory, set out as an office. The room had a number of desks aligned at the perimeter of the room and two desks in the centre of the room which were used to conduct the experiment. Five active loudspeakers were placed at a radius of 2.5 m from the participants in a hemispherical arrangement as shown in figure 1.

Two loudspeakers, immediately on the left and right of the participant, were used for the speech masking sounds, another pair of loudspeakers placed on the right and left diagonal facing the participant were used for the irrelevant background speech signals, simulating a colleague working approximately 2.5m from the participants' desk. (the conversations would interchange between the two speakers trying to achieve a more realistic OPO environment) and lastly, the loudspeaker located directly in front of the participant's position was used to emit office background sounds.

An HP 250 G5 Notebook PC was used connected to the M-Audio Fast Track C600 sound card. The speech and masking sounds were produced by four loudspeakers having mouth like directivity (Genelec 6010) whereas the office background sounds by a dodecahedron OmniPower Sound Source by B&K.

3.3. Noise Conditions

Four noise conditions were compared, three of which included speech masking sounds (Water stream, Pink Noise, Instrumental music) plus background speech and one control condition which was unmasked background speech. All conditions included background office sounds on a separate channel (speech from colleagues in the vicinity, keyboard typing, phone ring tones, printers) so that the audible ambient environment resembled that of an open-plan office.

The sound signals for the speech masking sounds were either retrieved from electronic sources or created digitally. More specifically, the signal used for the water stream was the *"England: A river spring in spring"* uploaded on Freesound by kernowrules, the instrumental music was retrieved from YouTube under the following word string "Relaxing Background Music for Yoga" uploaded by Meditation Relax Music, the office background noise was "*Office Ambience*" retrieved from Freesound (Copyright 2013 Iwan Gabovitch), and Pink Noise was created in Audacity at a sampling rate of 44100 Hz at 24bit.

Finally, the background speech was taken from the Audio Practice Tests available in '*Telephoning in English'* [27], The audio file was edited in Cubase 5 in such a way that the participants would listen to one side of the two-way telephone conversations; reported as one the most distracting sound stimuli in such environments [14], [28]. Different speech material was used for each condition that the subjects were exposed to so that there was no repetition of the same conversation throughout the entire test. The material comprised meaningful sentences and parts of actual office conversations.

Hongisto (2005) suggests that the decrease in performance depends on the STI of the background speech rather than the total sound level. Other studies, however, contradicted these findings by noticing differences in performance which were more likely related to the sound level of exposure in the tested conditions [2], [29]. Hence, one of the objectives of this study was to keep the STI and total sound pressure level (SPL) of each sound condition as similar as possible for all the test conditions so that any change in the participants' performance would be linked solely to the sound stimuli in each case.

The sound pressure levels were recorded with a NTi XL2 sound level meter at the position and height of the participant's ears, and the STI measurements were carried out in accordance with IEC 60268-16 (2011) following the STIPA method which is a simplified direct method of obtaining STI measurements suitable for the measurement of natural speech (room acoustic transmission) as well as sound systems [11].

Table I shows the recorded levels for each of the four configurations tested in this study. All levels represent equivalent A-weighted sound pressure levels of 15 second measurement interval. The background level within the room, in the absence of masking or office background sounds was 36 dB(A) and the background office sounds and background speech were set at 47.5 dB(A) and 49.4 dB(A) respectively.

Table I: Equivalent A-weighted SPLs of the Test Conditions & STI. Abbreviations: L_m=masking, $L_{ofn,m}$= office BG noise and masking, L_T= total SPL level, STI= Speech Transmission Index

Conditions	L_m	$L_{ofn,m}$	L_T	STI
C1: «Speech»	-	-	51.6	0.6
C2: «Water stream»	44.5	49.2	52.3	0.42
C3: «Pink Noise»	44	49	52.2	0.37
C4: «Instrumental Music»	47.7	50.6	53	0.43

3.4. Cognitive Performance Test

A within-subject design was used in this study and the whole procedure for each participant lasted approximately 30 minutes. Subjects were exposed to 4 sound conditions. The order of presentation is shown in Table *I*.

Each condition comprised a five-minute cognitive test followed by a short questionnaire. Short breaks were given at the end of each condition

In order to test cognitive performance, participants were given a serial recall task in which they were required to recall a certain number of digits presented on a computer screen in the order of appearance,. The digits were presented in a random order with each digit appearing only once in a sequence. This serial short-term memory task is related to the type of activities included in the daily cognitive load of typical office workers [14], [30]. This task was designed to have an adjustable level of difficulty.

If the participants recalled the whole sequence correctly, the number of digits in the subsequent problem increased by one, with the maximum number of digits to memorise set to eight, whereas in the opposite case it decreased by one. The length of the task for each test condition was set to 5 minutes and the final score was the number of sequences that the participant recalled correctly with no errors or omissions. .

3.5. Questionnaires

Questionnaires were handed out at the beginning of the experiment in order to collect demographic and work background information for each subject.

Additional questionnaires were filled by the participants at the end of each test condition as a means to capture the subjective impressions of each condition and establish a degree of correlation, if any, with the performance rates obtained during the corresponding cognitive tests. Individual statements were rated on a Likert scale 1–5 (strongly disagree – strongly agree) and were made up of the following:

I1) Nearby intelligible Speech was disruptive,

I2) The masking sound was effective in diminishing the negative effects of nearby speech,

I3) I was stressed while performing under this sound condition.

The last questionnaire which was handed out after the fourth condition included an additional item (I4) at which participants were asked to rate the conditions which included speech masking sounds on a scale from 1 to 3 in an order of preference from the most to the least satisfying condition to work in.

3.6. Data Analysis

The data was analyzed with IBM SPSS Statistics 24 for Windows. Data normality was tested with the Kolmogorov-Smirnov test. For the normally distributed data two-tailed t-tests were conducted for paired comparisons and repeated - measures ANOVA to determine the variance between the different conditions. Mauchly's test of sphericity was taken into account for the homogeneity of variance of the F values. The effect size was estimated with the partial Eta-squared in the ANOVA analysis and the Cohen's *d* in the t-tests.

Non-normally distributed data was analysed by means of nonparametric tests. Those were Friedman's test for analysis of variance and Wilcoxon's signed-rank test for paired comparisons using as effect sizes Kendell's W and r respectively.

4. Results

The results are presented in three sections. Data collected from the cognitive test which is associated with the first research question and the main effect of each sound condition to the participants' performance is shown first, followed by the analysis of the subjective measures retrieved from the questionnaires and finally by correlations between the performance results and the subjective evaluations.

4.1. Performance Results

Results in the working memory task indicated that the overall performance was not affected by sound condition ($F_{(3,27)} = 0.367, p = 0.78, partial\ \eta^2 = 0{,}04$).

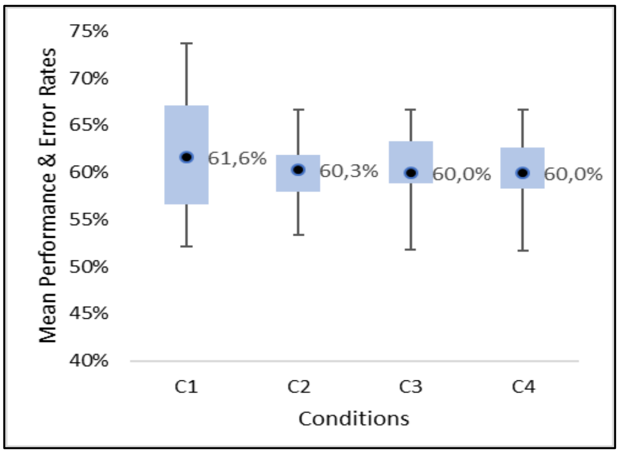

Figure 2: Mean Performance and Error Rates per Condition

More specifically, compared to unmasked speech the error rates were lower in C2 ($t_{(9)} = 0.81, p = 0.44, d = 0{,}26$) than in C3 ($t_{(9)} = 0.73, p = 0.49, d = 0{,}23$ or in C1 ($t_{(9)} = 0.71, p = 0.5, d = 0{,}22$). However, there was no statistically significant difference between the conditions as indicated by the analysis (see *Figure 2)*.

4.2. Subjective Evaluations

Data analysis indicated that there was no significant main effect of sound condition on the subjective measures of the questionnaire items [I1: ${\chi^2}_{(3)} = 2{,}661, p = 0.45, W = 0.09$, I2: ${\chi^2}_{(3)} = 3{,}92, p = 0{,}14, W = 0.2$, I3: ${\chi^2}_{(3)} = 4{,}015, p = 0.26, W = 0.13$]. Of marginal significance, however, were the results obtained by the paired comparison of C3 and C4 ($Z = -1.823, p = 0.07, \mathrm{r} = -0.41$) regarding the perceived efficiency of the masking sound in diminishing the negative effects of nearby speech (I2), as well as C1 and C4 on the third questionnaire item with regard to the perceived stress during those conditions ($Z = -1.725, p = 0.08, \mathrm{r} = -0.39$), both having a medium to large effect size according to Cohen's interpretation guidelines.

The order of overall masking preference as rated by the individuals, however, brings instrumental music in the first place, as 90% of the participants claimed that it was the most satisfying sound condition to work in, followed by water stream (70% of the participants), and lastly by pink noise which was chosen as the least satisfying condition compared to C2 and C3 by 60% of the partakers in this experiment.

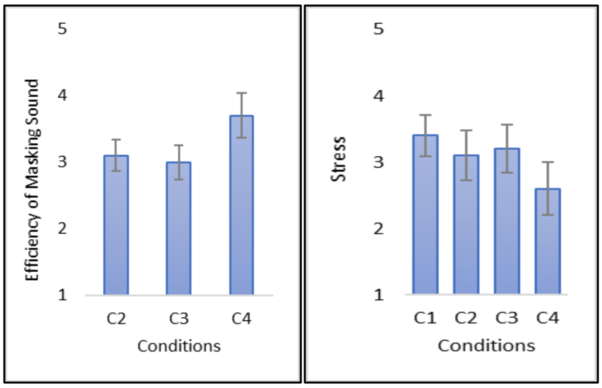

Figure 3: Graph on the left: I1 - Perceived Efficiency of Masking Sound and standard errors, Graph on the right: I3 - Perceived stress and standard errors for each condition.

4.3. Comparisons Between Objective and Subjective Measures

Although the data yielded no statistically significant differences between the effect of sound conditions and the participants' performance or subjective responses, the two-scaled graph in *Figure 4* shows how the mean performance and the subjective measures are linked. Three elements were identified.

As discussed in section 4.1, participants marked slightly higher scores in the cognitive whilst exposed to the unmasked speech condition. However, the perceived stress during this condition was given a mean value of 3.4, which seems to be the highest mean value in absolute terms for this parameter. The opposite effect was noted for C4 (instrumental music) as stress had the lowest ratings

($\bar{x}_{(m)} = 2.6$) although the overall performance was the lowest. Yet, only a marginal difference was observed for the subjects' stress evaluation between those two conditions according to the corresponding Wilcoxon's sign-rank test ($Z = -1.725, p = 0.08$).

Also, almost identical performance in the cognitive test was observed for C3 and C4 ($\bar{x}_{(p)} = 59.96\%, \bar{x}_{(m)} = 59.95\%$). However, music was rated as slightly more efficient by the individuals with respect to diminishing the negative effects of speech (marginal statistical difference).

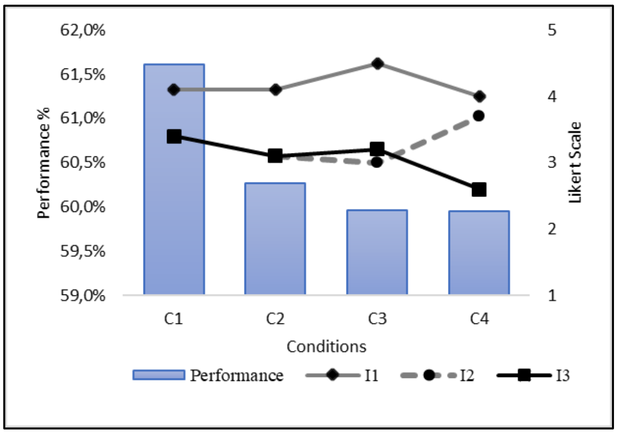

Figure 4: Mean Performance Values & Overall Subjective Evaluations

Finally, although individuals achieved slightly better scores at the serial recall task when exposed to water stream compared to pink noise and instrumental music (see *Table II)*, the former was regarded as less satisfying compared to instrumental music.

Again, it should be highlighted that these correlations are potential trends derived from the current results and data analysis, as there was no statistical significance to show distinct differences.

5. Discussion

The findings in this pilot study showed that there was no main effect of sound condition to the participants' performance. Office noise and background speech are sounds of distinct temporal and spectral characteristics. BG speech was presented at a SPL level of 49.4 dB(A) simulating a colleague working approximately 2.5 m from the participants' desk. In contract, the masking sounds in this experimental study were specifically chosen to have steady-state elements in order to fill the "gaps" created by speech, since according to the changing-state hypothesis an increase in the auditory distraction is observed with the degree of segmentation of a sound stream[14]. Hence, the results showed that none of the above conditions potentially succeeded in overcoming the ISE caused by nearby speech.

Previous studies have shown that instrumental legato music had no effect in reducing the detrimental impact of nearby speech or office noise on cognitive performance [6], [19], [20], [25], [26], despite peoples' evaluations which tend to follow an opposite trend. The current results seem to be in line with the aforementioned, since instrumental music was rated as the most satisfying condition to work in compared to pink noise and water stream, although there was no significant difference in the participants' performance for the above conditions.

No statistically significant variation was also observed in the subjective evaluations of the questionnaire items. However, marginal significance was noted when comparing the perceived efficiency of the masking effect of pink noise and instrumental music (I2). This could be owed to the subjects' preference over music, since the error rates in the serial recall task were identical for those two conditions.

It should be noted, however, that pink noise was played at a lower sound pressure level compared to music. That was intentionally designed as such, because the directivity of the speakers as well as the proximity of the participant to them created the impression that pink noise very prominent and acoustically uncomfortable at a higher volume in the test room. It should also be noted that the spectrum of the instrumental music superimposed to the office noise recording is really close to the speech spectrum for frequencies up to 1000 Hz meaning that music should be more efficient in that particular range, whereas the combination of pink and office noise identically follows the speech spectrum curve for frequencies over 2000 Hz.

Table II. Means and Standard Deviations in brackets per condition per question.

	Unmasked Speech	*Water Stream*	*Pink Noise*	*Instrum. Music*
I1	4.1 (0.7)	4.1 (0.9)	4.5 (0.5)	4.0 (1.1)
I2	-	3.1 (0.7)	3.0 (0.8)	3.7 (1.1)
I3	3.4 (1.0)	3.1 (1.2)	3.2 (1.1)	2.6 (1.3)
I4	-	2^{nd}	3^{rd}	1^{st}

Results of similar significance were also marked in the comparison of unmasked speech and instrumental music with regard to the perceived stress whilst undertaking those tasks (I3). Since the perceived disturbance from nearby speech did not yield any significant difference between those two conditions (p=0.79), this could be accounted to the fact that during the first condition (unmasked speech), there was no significant familiarity with the cognitive task apart from the 2 minute trial that preceded the formal test procedure, whereas towards the end of the test and the fourth condition (music) individuals possibly felt more confident with the task. It should, therefore, be stressed that a randomized order of presenting the different conditions to the participants might have been more suitable in this case. Also, another possible explanation for the lower ratings regarding the perceived stress during C4 could be the relaxing elements of meditation music and the subsequent feeling of greater acoustic comfort which is generally induced in the presence of music, as it has been suggested by a study in urban open spaces[31].

In the absence of a control condition that would test cognitive performance in silence, there is no way of testing the degree to which background irrelevant speech has impaired the individuals' performance. It is rather unlikely though that the soundscape in today's workstations is characterised by absolute silence, in which case masking systems would be of no use. Another limitation of this study is the arrangement of the speakers during the laboratory session. Masking systems tend to be located above a suspended ceiling and not in the individuals' visual field for psychological reasons and for a more even distribution of sound within the space. This was not implemented in the current study.

In addition, it is very likely that the above results might have revealed greater statistical differences if the number of participants was increased. Different subjective responses after prolonged exposure to the conditions have also been reported according to Schlittmeier [20]. In that particular study, although music was initially preferred among pink noise or masked music, it was considered the least preferable after an hour of exposure.

6. Conclusions

The majority of studies, if not all, have tested participants' cognitive performance under the effect of various masking sounds as well as background speech, multiple backgrounds voices or office noise. The present pilot study attempted to investigate the degree of impairment in cognitive performance of 10 individuals through a serial recall memory task for one unmasked speech condition and three masked speech conditions (water stream, pink noise and instrumental music) in the presence of office background sounds which included verbal and non-verbal elements superimposed in all four conditions. The results indicated no main effect of sound condition to the participants performance or subjective responses. Only two marginally different evaluations were given for two questionnaire items. Further examination and extension of the sample size is required for the generalisation of the results to a wider population.

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