Benefits of active noise-cancelling headphones in offices

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ABSTRACT

Active noise-cancelling (ANC) headphones are used in open-plan workplaces as an individual noise control device. This study examined the influence of different use settings of ANC headphones on a working person. 55 participants performed a serial recall task in an irrelevant speech setting. Irrelevant speech was separate sentences at the sound level of 52 dB L_{Aeq}. The experiment had five sound conditions: 1. No headphones, 2. Headphones, 3. Headphones+ANC, 4. Headphones+masking, 5. Headphones+ANC+masking. Masking sound was a wideband sound played from the headphones at a sound level of 51 dB L_{Aeq}. ANC headphones had a closed design so that wearing them attenuated speech to some extent. The subjective speech annoyance was lower in condition 5 than in condition 1. The sound condition did not influence the serial recall accuracy in general. However, the noise sensitive group had better accuracy in conditions 4 and 5 than in condition 1. Sound masking should accompany ANC headphones to achieve positive impacts with ANC headphones. ANC can bring an additional benefit, but only when masking sound is present.

INTRODUCTION

Noise and lack of speech privacy are considered the most disturbing environmental factors in open-plan offices [1,2]. The most common disturbing noise in offices is speech. Speech can also influence performance [3,4] and working during speech has been found to increase stress hormone levels [5]. Active noise-cancelling (ANC) headphones are increasingly used in open-plan office workplaces as an individually controllable noise control device. However, the use of ANC headphones has not been studied much in settings, which conform with real situations prevailing in the office. The worst condition is that a person hears intelligible speech. Very few studies have examined the effects of ANC headphones on performance [7]. None of previous studies have examined systematically the effects of headphones alone, ANC operation, and sound masking played via headphones.

Commercial ANC headphones can have closed on-ear, open on-ear, and in-ear design. Closed on-ear headphones are mostly used in offices. They also provide an inherent attenuation of 0–15 dB depending on frequency. The effect of this attenuation has been very little studied.

Our purpose was to examine how closed on-ear ANC headphones influence a working person during task irrelevant speech. We considered five use settings (*sound conditions*): 1. No headphones, 2. Headphones, 3. Headphones + ANC, 4. Headphones + masking, 5. Headphones + ANC + masking.

METHODS

Design

This was a laboratory experiment with repeated measures design. The independent variable was *sound condition* (5 levels). *Sound conditions* were made with ANC headphones and their different use settings while irrelevant speech was present. Dependent variables were serial recall accuracy and subjective speech annoyance. We collected also other dependent variables, but they will be published in a subsequent full paper. Noise sensitivity was a background factor.

Participants

57 volunteers participated in the study. The criteria to participate the study were normal hearing, speaking Finnish, age within 18–48 years, and normal health status. Two participants were excluded: one stopped the experiment and another could not wear the ANC headphones properly with the glasses. Therefore, the final number of participants was 55 (32 females mean age 23.7 years). The ethics committee of Turku University of Applied Sciences approved the study (statement 1/2020).

Sound conditions

Irrelevant speech was presented in the room via two loudspeakers during all five *sound conditions* at a constant level of 52 dB L_{Aeq} (A-weighted equivalent sound pressure level). The speech consisted of separate sentences from an audiobook presented in a mixed order.

Weak background noise was presented in the room via four loudspeakers at a level of 33 dB L_{Aeq}. It did not mask the speech but provided a typical noise caused by ventilation.

Sound conditions were made with headphones and their different settings. We chose closed on-ear ANC headphones available on the market (JBL TUNE 750BTNC). Wearing them reduced the level of speech by 10 dB L_{Aeq}.

Masking sound was wideband noise played from the headphones at a sound level of 51 dB L_{Aeq}. The spectrum of speech in the room conformed with standardized speech spectrum of ISO 3382-3 [6]. The spectrum shapes of masking in the room (33 dB) and masking in the headphones (51 dB) were equal and conformed with the spectrum used in many commercial sound masking systems (5 dB reduction per octave within 250–8000 Hz).

The *sound conditions* were:

1. No headphones: Without headphones, without ANC, and without masking sound
2. Headphones: With headphones, without ANC, and without masking sound
3. Headphones + ANC: With headphones, with ANC, and without masking sound
4. Headphones + masking: With headphones, without ANC, and with masking sound
5. Headphones + ANC + masking: With headphones, with ANC, and with masking sound

The objective acoustic conditions perceived by the participant had to be measured inside ear channels, since sound conditions 2–5 involved headphones. A head-and-torso simulator was used at the participants' position. The measured acoustic descriptors of the *sound conditions* are presented in Table 1. The values in Table 1 consider the diffuse field correction of the torso and, thus, represent the condition prevailing in a diffuse field without the torso.

Table 1: Measured acoustic conditions of sound conditions 1–5. L_{Aeq} is the A-weighted equivalent sound pressure level. STI is Speech Transmission Index (IEC 60268-1:2011). STI is an objective predictor of subjective speech intelligibility.

Sound condition	**STI**	**Masking L_{Aeq} [dB]**	**Speech L_{Aeq} [dB]**	**Total L_{Aeq} [dB]**
1	0.79	33	52	52
2	0.59	23	42	42
3	0.48	28	36	36
4	0.03	51	41	51
5	0.00	51	36	51

Measures

Serial recall accuracy. Digits from 1–9 were presented in a random order from the display and participants were asked to remember the correct order 10 seconds after the last digit was presented. 11 series were presented in each condition. First series was excluded from the analysis and the accuracy was calculated as the proportion of right numbers of all presented numbers (0–1).

Speech annoyance. After each task, the participants rated how much speech annoyed, bothered, or disturbed them [7] (*Speech annoyance*). The response scale was from 0 "Not at all" to 10 "Extremely". Here we examined only the annoyance estimation after the serial recall task.

Noise sensitivity. Weinstein's noise sensitivity was measured with 21-questions [8]. The respondents were divided into three *noise sensitivity groups* according to these scores. Group 1: Insensitive to noise N=18 (score ≤73), Group 2: Average sensitivity to noise N=15 (scores 74–77), Group 3: Sensitive to noise N=22 (score ≥78).

Procedure

The procedure is described in Table 2. The experiment lasted on average for 2 hours and 18 minutes. Every participant performed the experiment alone in a soundproof experimental room. During the experimental phase (marked with grey in Table 1), irrelevant speech was on. There were altogether three tasks but we focus on serial recall. Performing the tasks in one part lasted on average for 13 minutes (min. 11 min and max. 16 min). In the experimental phase, *speech annoyance* was asked after each task.

Statistical analysis

The *sound conditions* were compared using a repeated measures analysis of variance with noise sensitivity groups as the covariate. If the main effect of the *condition* was statistically significant (p<0.05), the differences between *conditions* were further examined with contrast comparing *sound conditions* 2-5 to *sound condition* 1. If the interaction with *noise sensitivity groups* and *sound condition* was significant (p<0.05), the *noise sensitivity groups* were further examined separately.

Table 2: The procedure of the experiment. The experimental part is marked with grey. During the experimental part, irrelevant speech was on. The *sound conditions* 1, 2, 3, 4, and 5 were presented in a random order in Parts A, B, C, D, and E.

Phase, duration	**Description**
Preparation phase, 25 min	Informed consent form, questionnaire, hearing test
Practice phase, 20 min	Rehearsal of orientation task, serial recall, N-back
Part A, 15 min	Orientation task, Serial recall, N-back, annoyance
Part B, 15 min	Orientation task, Serial recall, N-back, annoyance
Part C, 15 min	Orientation task, Serial recall, N-back, annoyance
Part D, 15 min	Orientation task, Serial recall, N-back, annoyance
Part E, 15 min	Orientation task, Serial recall, N-back, annoyance
End phase, 10 min	

RESULTS

Speech annoyance depended on *sound condition* ($F(3, 176)=3.3$, $p=0.017$, $\eta_p^2=0.059$) (Figure 1). Speech was less annoying during *sound condition* 5 than during *sound condition* 1 ($F(1, 53)=5.8$, $p=0.019$, $\eta_p^2=0.099$). *Noise sensitivity groups* did not rate *speech annoyance* differently ($F(1, 53)=2.5$, $p=0.116$, $\eta_p^2=0.046$), nor was there an interaction between *noise sensitivity group* and *sound condition* ($F(4, 212)=0.4$, $p=0.822$, $\eta_p^2=0.007$).

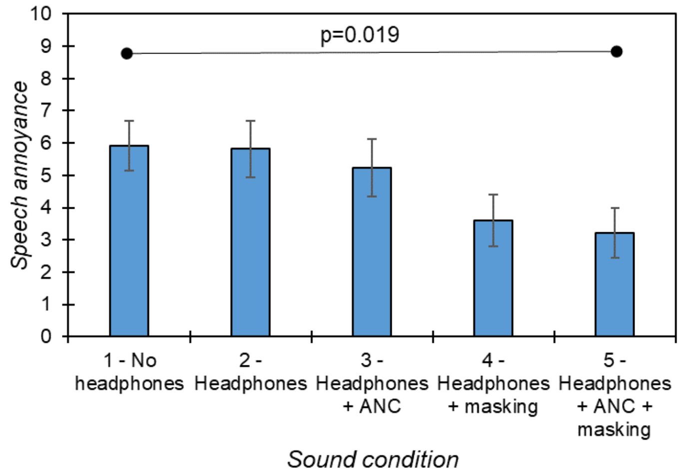

Figure 1: The mean *speech annoyance* estimation after serial recall task in different *sound conditions*. The error bars present 95 % confidence intervals.

Sound condition did not influence *serial recall accuracy* ($F(4, 212)=1.8$, $p=0.137$, $\eta_p^2=0.032$) (Figure 2), but there was an interaction between *sound condition* and *noise sensitivity group* ($F(4, 212)=2.5$, $p=0.041$, $\eta_p^2=0.046$). *Noise sensitivity groups* did not differ from each other in performance ($F(1, 53)=0.2$, $p=0.631$, $\eta_p^2=0.004$). Since the interaction was significant, we examined *noise sensitivity groups* separately.

Serial recall accuracy depended on *sound condition* in *noise sensitivity group* 3, i.e., among the most noise sensitive participants ($F(4, 84)=3.9$, $p=0.006$, $\eta_p^2=0.157$) (Figure 3). With *noise* *sensitivity group* 3, *sound conditions* 4 (F(1, 21)=15.8, p=0.001, η_p^2=0.430) and 5 (F(1, 21)=7.9, p=0.011, η_p^2=0.273) differed from *sound condition* 1. *Sound condition* did not influence *serial recall accuracy* of other *noise sensitivity groups* (Group 2: F(4, 56)=0.3, p=0.872, η_p^2=0.021; Group 1: F(4, 68)=0.9, p=0.448, η_p^2=0.052).

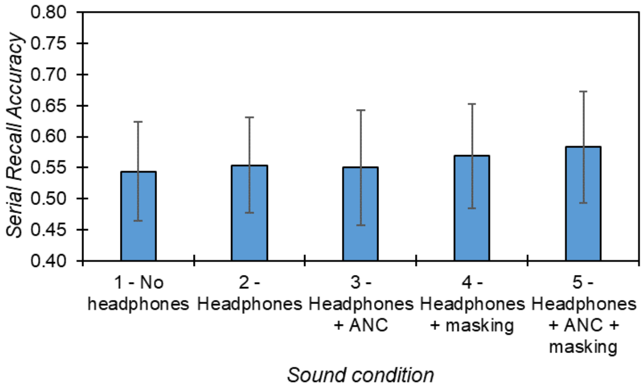

Figure 2: The mean accuracy of the serial recall task in different *sound conditions* for the whole sample. The error bars present 95 % confidence intervals. Accuracy ranges from 0 (no correct answers) to 1 (all correct answers).

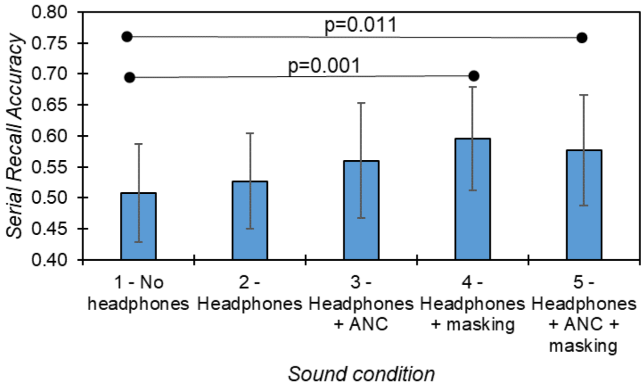

Figure 3: The mean accuracy of the serial recall task for *noise sensitivity group* 3 in different *sound conditions*. The error bars present 95 % confidence intervals. Accuracy ranges from 0 (no correct answers) to 1 (all correct answers).

DISCUSSION AND CONCLUSIONS

ANC function in on-ear closed headphones did not have an effect on annoyance due to speech nor work performance because we did not find a statistically significant difference between *sound conditions* 1 and 3. The finding regarding performance is in agreement with the review of Haapakangas et al. [3] showing that reducing STI value from 0.79 to 0.48 should not yet improve cognitive performance. However, the absence of effect on annoyance was unexpected and it contradicts the general belief that ANC headphones could protect people from annoying noise during office work. The probable reason for the absence of any effect is that ANC reduces only the sound pressure level of frequencies below 500 Hz while speech intelligibility, and STI, is mostly depending on frequencies above 500 Hz.

Because our preliminary STI calculations suggested only a minor influence of ANC function to STI, we tested also sound masking played via headphones. This was justified since commercial ANC headphones allow the playback of sound from external devices via Bluetooth or jack connector. When masking was played via headphones together with ANC operation (*sound condition* 5), subjective speech annoyance was statistically significantly lower than in *sound condition* 1 without headphones.

The accuracy of the serial recall task was affected by the *sound condition* only among the most noise sensitive participants, who improved their performance during *sound conditions* 4 and 5 (both involving masking) compared to the *sound condition* 1 without headphones. In offices, the use of closed headphones with sound masking might help noise sensitive persons to feel less annoyed and to perform better if the level of masking inside headphones is the same as the level of speech.

The study suggests that sound masking should accompany ANC headphones to achieve positive impacts with ANC headphones. ANC can bring an additional benefit, but only when masking sound is present.

Our study is limited to specific levels of speech and masking, see Table 1. People in the workplace are exposed to varying levels of surrounding speech and they can choose any masking sound level played via headphones. Thus, our conclusions cannot be generalized.

Acknowledgements

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