Influence of active-noise-cancelling headphones on cognitive performance and employee satisfaction in open space offices

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Abstract

High speech intelligibility in open space offices leads to problems. As a result of the irrelevant sound effect it influences cognitive performance negatively. Roomacoustic measures do often not lead to improvements if an open space office design is to be maintained. For this reason a study was conducted to examine if active noise cancelling headphones influence cognitive performance and subjective feeling in an open space office. This was done with a cognitive task (serial recall) and a survey after every term. No significant difference between the condition with active noise cancelling headphones switched on and switched off as well as without headphones could be determined. However, active noise cancelling had an influence on subjective ratings. The background noise with active noise cancelling was rated as significantly less annoying, ability to concentrate significantly higher and the speaker distance was rated significantly larger in comparison with active noise cancelling switched off or without headphones.

Keywords: Sidetone, Irrelevant Sound Effect, Active Noise Cancelling Headphones, Active Noise Cancelling Headet, Open Space Office

1 INTRODUCTION

17 million Germans are employed in offices (1). Of these, only 58 % work in individual offices (1-2 persons). If it were up to the employees, office landscapes in Germany would look different: 95 % of all office workers would opt for a one- or two-person office if they had the choice (2). Despite this, companies are planning larger office landscapes mainly for economic reasons (1). Open space offices lead to many acoustical challenges. By using room acoustic measures, improvements can be achieved only partly. Although not only the reverberation time, but also the speech intelligibility of disturbing or irrelevant speech in offices is trying to be reduced, there are limited possibilities to influence the acoustic conditions of an open space office if an open structure is to be maintained. Not only subjectively, noise is seen as a major problem by employees in open space office environments – studies show significant impacts on health. The human autonomic nervous system is negatively affected by a noise level of 60 dB(A). Especially speech has negative effects – it leads to a loss of performance of the working memory (3) even at a level of 35 dB(A). This Irrelevant Sound Effect (ISE) was first investigated in 1976 by Colle and Welsh (4). It describes the decrease in short-term memory performance when irrelevant sounds are heard. The ISE affects many areas of the brain. Various studies show negative influences on memorizing numbers (5, 6), reading aloud (7), proofreading (8, 9) and solving arithmetic problems (10, 11). In addition, the effect has been explicitly demonstrated in office background noise in several studies (12, 13, 10, 11, 4). In order to reduce the ISE, Active Noise Cancelling (ANC) headphones are used more frequently in open space offices. For this reason, it was examined if ANC headphones can reduce the distracting effect of background speech and improve working memory performance. In addition, it was considered whether ANC headphones influence the subjective judgement on office noise or not.

2 METHOD AND EXPERIMENTAL DESIGN

2.1 Apparatus and stimuli

A listening test in the laboratory was chosen to evaluate the effects of ANC headphones in open space offices. For this, binaural recordings of an open space office were needed. Sentences from the "Oldenburger Satztest" (14) were first recorded in an anechoic chamber by a male speaker. For creating the listening test sound conditions, a typical 8-person office was chosen. The ceiling was out of concrete, the floor was carpeted. There were no screen walls between the workplaces. The reverberation time in the room met the requirements of room acoustic class C according to the German guideline VDI 2569:2016-02 - Entwurf (< 0.9 s). In the office, three typical speaker positions (distance to the listener: 2.79 m, 5.97 m, 11.57 m) were chosen. The voice signals were played back by a studio speaker (Yamaha MSP3), with a similar directivity as a human speaker. For each speaker position different sets of sentences with a voice level of 59 dB(A) at 1 m distance according to ANSI / ASA S3.5-1997 (R2017) (15) were used. Three sound conditions were recorded with the HEAD acoustics HMS III artificial head (equalization filter ID): One recording without ANC headphones, one with ANC headphones switched off and one with ANC headphones switched on.

The listening test was conducted in the High Performance Indoor Environment Laboratory of the Fraunhofer-Institute for Building Physics. The experimental program was created using PsyScope X Experiment Control System software. The headphone signal was output by an HEAD acoustics PEQ V frontend, which ensured the equalization of the binaural recordings and a calibrated headphone equalization for the Sennheiser HD 600 headphones as well as the calibrated playback level. The subjects were tested individually. A serial recall test was used to test cognitive performance. The subjects task was to memorize the order of nine visually presented random digits from 1–9 and recall them correctly after a retention interval of eight seconds on a 3x3 array on the screen. Each digit that was not correctly recalled at the right serial position was counted as an error. After a six-round exercise, the subjects completed 12 test trials per background sound condition. At the end of each condition, the subjects were asked to answer questions about the sound conditions (annoyance, ability to concentrate, speaker loudness, distance to speaker, long term disturbance, subjectively perceived performance). The questions were assessed after each sound condition by a five-point Likert scale (not at all, slightly, moderately, very, extremely) according to ISO/ TS 15666:2003 (16) and the scale for loudness ranking (not at all, slightly, moderately, very, strongly) according to DIN ISO 16832:2007-07 (17). In addition, the subjects were asked to enter the perceived distance to the speaker with one decimal and the subjectiveley perceived performance in %.

2.2 Experimental design and sample

A one-factorial experimental design with four factor levels (baseline condition: *silence*, headphones - with ANC: *ANCon*, headphones - without ANC: *ANCoff*, no headphones: *noHP*) and within-subjects-design was used. All subjects were presented with the same conditions – there was no control group. Background sound was varied in the four factor levels *silence*, *ANCon*, *ANCoff*, *noHP*. The sound conditions were presented in a randomized order. The dependent variable was the error rate (percentage of incorrectly entered numbers) in the serial recall task. Additionally the subjects were asked different question items to evaluate the subjective judgements. In the listening test data of $N = 21$ subjects was collected. The subjects were mostly students of different disciplines at the age of 21 to 69 years ($M = 28.52$ years, $Mdn = 25$ years). 11 female and 10 male subjects participated the study. They received a small stipend.

3 RESULTS

The data processing for the serial recall test and the subjective judgments took place in Microsoft Excel 2016. All further statistical analyses were then carried out with IBM SPSS statistics software (version 19). The significance level was chosen at $\alpha = .05$. There was an outlier correction. Data that deviated by more than 2.5 times the standard deviation from the mean was excluded from the evaluation.

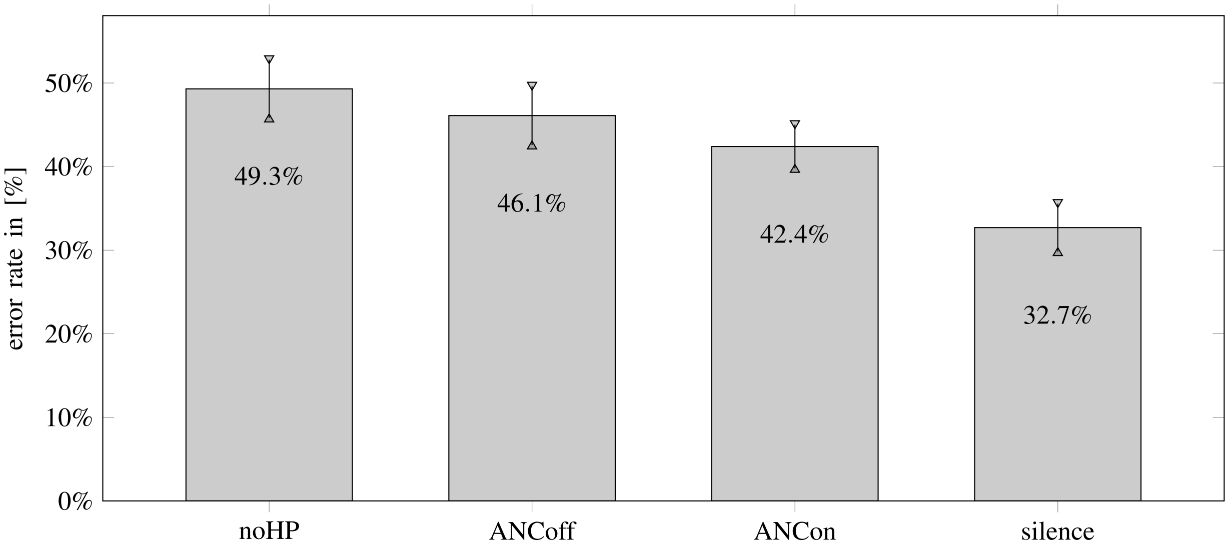

Figure 1. Mean error rates during the different sound conditions of the serial recall test. Means and standard errors are plotted.

3.1 Serial Recall

The error rates (incorrectly entered numbers) in the different conditions were measured. A one-way analysis of variance (with repeated measures) showed a significant main effect of the *headphones* factor on *error rate* ($F(3, 60) = 8.64$, $p < .001$, $\eta^2 = .30$). Significant differences were found in the comparison of error rates by calculating t-tests with a connected sample: *silence – noHP* ($t(20) = -4{,}01$, $p = .001$, $d = -0.88$), *silence – ANCon* ($t(20) = -3.048$, $p = .006$, $d = -0.67$) and *silence – ANCoff* ($t(20) = -2.858$, $p = .01$, $d = -0.62$). Although slightly lower error rates with headphones and with activated ANC than without headphones could be shown, all comparisons (*noHP – ANCon*, *noHP – ANCoff*, as well as *ANCon – ANCoff*) showed no significant differences. Furthermore Cohen's effect size value ($d = .06$ for *ANCon – ANCoff*, small effects also for the other comparisons) suggested low practical significance. The mean values are compared in figure 1. The results showed that headphones, whether with or without ANC, do not seem to significantly affect cognitive performance.

3.2 Subjective judgements

Annoyance The comparison of annoyance (see figure 2) in the various background sound conditions by a repeated measures analysis of variance showed a significant main effect of the factor *background noise* on the dependent variable *annoyance* ($F(3, 60) = 132.24$, $p < .001$, $\eta^2 = .869$). Comparing the perceived annoyance of background noise without headphones to headphones using paired t-tests with connected sample resulted in significant differences to *ANCon* ($t(20) = 4.176$, $p < .001$, $d = 0.91$) and to *ANCoff* ($t(20) = 2.682$, $p = .014$, $d = 0.59$). Between *ANCon – ANCoff* ($t(20) = -1.096$, $p = .286$, $d = -0.24$) no significant differences were found. Silence was perceived as significantly less annoying than any other sound condition.

Ability to concentrate The comparison of the subjectively perceived concentration (see figure 3) in the different background sound conditions by a repeated measures analysis of variance showed a significant main effect of the factor *background sound* on the dependent variable *concentration* ($F(3, 60) = 37.977$, $p < .001$, $\eta^2 = .655$). The comparisons *noHP – ANCon* ($t(20) = -3.005$, $p = .007$, $d = -0.66$) and *ANCon – ANCoff* ($t(20) = 2.121$, $p = .047$, $d = 0.46$) showed significant differences in perceived concentration.

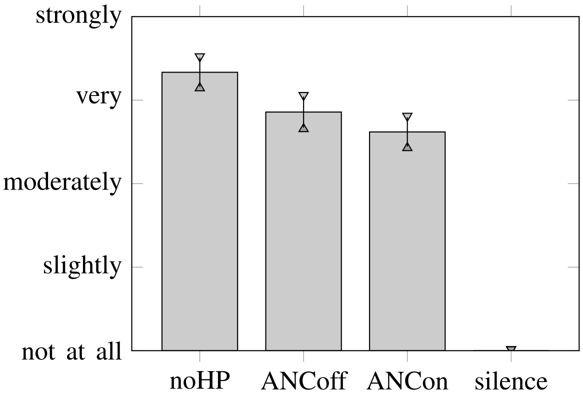

Figure 2. Mean annoyance ratings during the different sound conditions. Means and standard errors are plotted.

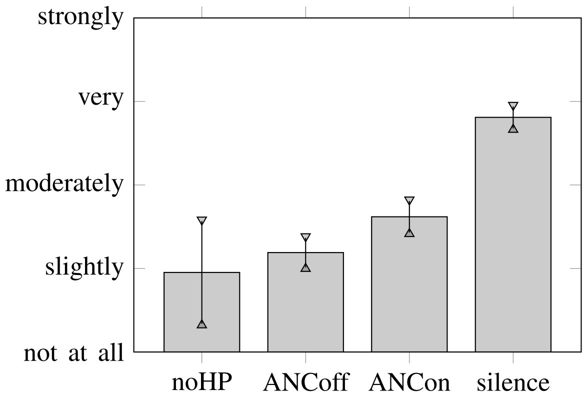

Figure 3. Mean subjective ability to concentrate during the different sound conditions. Means and standard errors are plotted.

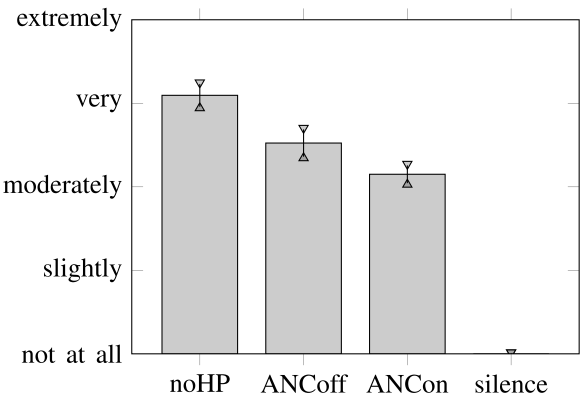

Figure 4. Mean speaker loudness during the different sound conditions. Means and standard errors are plotted.

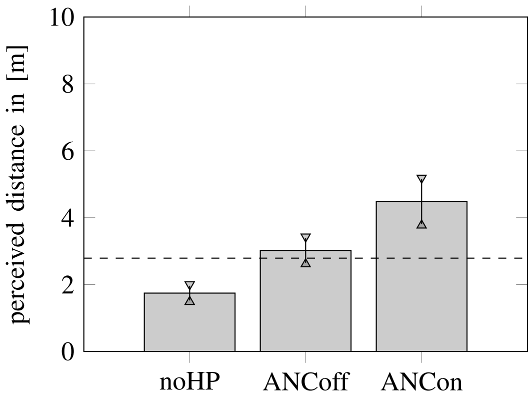

Figure 5. Mean perceived distance to speaker during the different sound conditions. Means and standard errors are plotted. The horizontal line showes the distance to the nearest speaker in the simulated office.

Speaker loudness The comparison of speaker loudness (see figure 4) in the different background sound conditions by a repeated measures analysis of variance showed a significant main effect of the factor *background noise* on the dependent variable *loudness* ($F(3, 57) = 163.369$, $p < .001$, $\eta^2 = .896$). The comparisons *noHP – ANCon* ($t(19) = 7.285$, $p < .001$, $d = 1.63$) and *noHP – ANCoff* ($t(20) = 3.873$, $p < .001$, $d = 0.85$) showed significant differences in the perceived loudness. Between *ANCon – ANCoff* ($t(19) = -1.926$, $p = .069$, $d = -0.43$) no significant differences were found.

Distance to speaker The comparison of the perceived distance of the speaker (see figure 5) in the different background sound conditions by a repeated measures analysis of variance showed a significant main effect of the factor *background sound* on the dependent variable *distance* ($F(2, 38) = 11.047$, $p < .001$, $\eta^2 = .368$). Paired t-tests revealed significant differences in the estimated speaker distance when comparing the condition

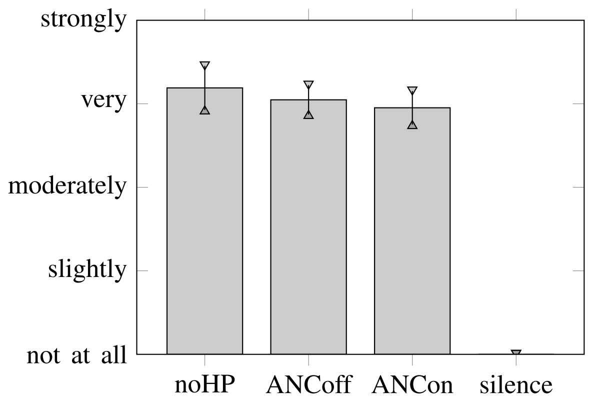

Figure 6. Mean long-term disturbance during the different sound conditions. Means and standard errors are plotted.

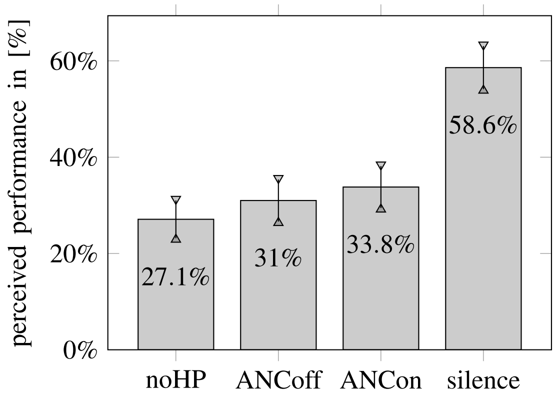

Figure 7. Mean subjectively perceived performance during the different sound conditions. Means and standard errors are plotted.

noHP with the conditions *ANCon* (t(19) = -3.773, p = .001, d = -0.84) as well as *ANCoff* (t(19) = -4.325, $p <$ .001, d = -0.97). There were also significant differences in the comparisons *ANCon – ANCoff* (t(19) = 2.179, p = .042, d = 0.49).

Long-term disturbance The comparison of the long-term disturbance (see figure 6) in the various background sound conditions by a repeated measures analysis of variance showed a significant main effect of the factor *background noise* on the dependent variable *long-term disturbance* (F(1.62, 30.76) = 65.573, $p < .001$, $\eta^2 =$ .775). There were no significant differences in the long-term disturbance in paired t-tests with connected sample *noHP – ANCon* (t(20) = 0.665, p = .514, d = 0.15), *noHP – ANCoff* (t(20) = 0.420, p = .679, d = 0.09) and *ANCon - ANCoff* (t(20) = -0.623, p = .54, d = -0.14). The long term disturbance at silence was perceived as significantly smaller than any other sound condition.

Subjectively perceived performance The comparison of subjectively perceived performance (see figure 7) in the various background sound conditions by a repeated measures analysis of variance showed a significant main effect of the factor *background sound* on the dependent variable *subjectively perceived performance* (F(3, 60) = 30.520, $p < .001$, $\eta^2 = .604$). Paired t-tests showed no significant difference in perceived performance in the comparisons *noHP – ANCon* (t(20) = -1.807, p = .086, d = -0.39), *noHP – ANCoff* (t(20) = -1.122, p = .275, d = -0.24) and *ANCon – ANCoff* (t(20) = 1.255, p = .224, d = 0.27). The subjectively perceived performance in silence was rated as significantly better than in any other sound condition.

4 DISCUSSION

Investigations aimed to examine how ANC headphones affect working memory performance while being affected by irrelevant speech sound. The error rate for the serial recall in *silence* was significantly lower than in all other conditions. This indicates a correct experimental setup and procedure, since the ISE was proven. In contrast, the error rate in the headphone conditions was not (neither in the condition *ANCoff*, nor in *ANCon*) significantly lower than in condition *noHP* although a tendency of lower error rates with ANC headphones could be shown while comparing the mean values. Also, there was no significant difference between *ANCon* and *ANCoff*. From this result, it can be concluded that ANC headphones do not seem to have an influence on the working memory performance. One possible reason could be that speech level – as long as speech is loud enough to be understood – is not relevant for the ISE, but only the speech intelligibility (18). Speech intelligibility can even increase with ANC headphones, as background noise is very well reduced up to 600 Hz, but speech is less well masked by the active algorithm due to its transients. Although no significant improvement in working memory performance was found, ANC headphones seem to improve the subjects subjective perception. The subjects rated the annoyance of the speech sound in condition *ANCon* as significantly less annoying than in *noHP* or *ANCon*. Ability to concentrate in the condition *ANCon* was rated as significantly better than in *ANCoff* or *noHP*. In terms of subjectively perceived privacy, ANC headphones may also be useful. The subjects rated the speaker loudness with headphones as lower, which is mainly due to the insertion loss of the headphones. However, there was no significant difference between *ANCon* and *ANCoff*. The significant difference between the perceived distance of the speaker (in the condition *ANCon* it was perceived as significantly farther away than in *ANCoff*) nevertheless indicates that there is an improvement caused by ANC. The results of the survey on long-term disturbance and subjective performance coincide with the results of the serial recall. There were no significant differences between *ANCon*/ *ANCoff* and *noHP*. The study shows that ANC only brings improvement in some areas in terms of subjective perception. However, no significant worsening by ANC was found in any area.

5 CONCLUSION

This study showed that ANC headphones do not seem to have significant impacts on cognitive performance while working in an open space office. The subjects also do not have the impression as their possibility to concentrate raises. For ANC headphones, however, there can still be practical uses in open space offices, as they reduce the annoyance of conversations between other employees and increase perceived privacy. These two factors have proved to be major disruptive factors in many office surveys conducted at the Fraunhofer IBP. In further research, a more comprehensive study could be performed to examine the effects of ANC headphones on people working in offices with different tests than the serial recall. Also, more subjects could be tested to detect smaller impacts of ANC headphones on cognitive performance as a tendency of lower error rates by conducting the serial recall test with activated ANC has been shown.

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