ICA 2019 AACHEN

PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Physiological, psychological, and performance effects of office noise

Jenni RADUN[1]; Valtteri HONGISTO[1]; Henna MAULA[1], Ville RAJALA[1], Darin AL-RAMAHI[2], Mika SCHEININ[2]

[1] Turku University of Applied Sciences, Finland

[2] University of Turku, Finland

ABSTRACT

BACKGROUND. Colleagues' speech is a common disturbance in offices, especially in open-plan offices. Irrelevant speech influences cognitive performance and subjective ratings of acoustic satisfaction as well as environmental satisfaction. However, only few studies have examined simultaneously physiological, performance, and psychological consequences background speech has on humans.
AIM. The purpose was to compare psychological experiences, cognitive performance, and physiological responses in two sound conditions: speech and silence.
METHODS. We tested 21 subjects in the speech group and 19 subjects in the silence group (sound level of ventilation 35 dB L_{Aeq}). Speech was played at sound level 65 dB L_{Aeq}, which people were supposed to ignore while making cognitive tasks and answering questionnaires. The sound condition lasted on average for 48 minutes. Participants' performance, psychological experience and various physiological stress reactions (e.g. stress hormone levels, heart rate variability) were measured.
RESULTS. The speech group had lower performance and higher physiological stress level than the silence group. Speech was subjectively estimated more annoying and loading, but less tiring than silence.
PRACTICAL IMPLICATIONS. This study shows that speech influences experience, performance, and physiological stress level. Therefore, its influence should be minimized in offices, where work requiring concentration is needed.

Keywords: Irrelevant speech, Stress reaction, Office noise

1. INTRODUCTION

Noise and lack of privacy are the two most important disturbances in open-plan offices (1). Negative effects of poor acoustic environment in office are for example increased distraction, reduced privacy, increased concentration difficulties, and increased use of coping strategies (2). Irrelevant speech is one of the most disturbing type of noise in the office setting, since it has been shown to influence cognitive work performance and subjective disturbance (3). In addition, working under office noise can make people to exert, i.e. to put more effort into their task to keep the performance level as high as without the noise. Both noise and exertion can cause stress. For example, a study comparing a typing task in silence and in office noise, which included speech among other noises, found an increase in adrenaline levels when working under office noise (4). The study found no difference in typing performance nor in cortisol and noradrenaline levels, but after office noise condition people tried to solve less puzzles and they made less postural adjustments to their office furniture (4). Another study examining the influence of office noise found effects on memory of words, but no other effects on performance or cortisol or norepinephrine levels (5). One more study found

[1] jenni.radun@turkuamk.fi; valtteri.hongisto@turkuamk.fi; henna.maula@turkuamk.fi; ville.rajala@turkuamk.fi; [2] darin.al-ramahi@utu.fi; mschein@utu.fi

due to influence of office noise higher exertion in the head and contrary to expectations lower blood pressure (6).

Speech has been identified as more disturbing for performance than other noise types (7). Not many studies have examined how working under speech influences performance, psychological experience and physiological stress reaction.

The purpose was to compare psychological experiences, cognitive performance, and physiological responses in two sound conditions: speech and silence. We expect that speech increases stress level, reduces performance, and increases negative subjective ratings compared to silence.

2. METHOD

2.1 Participants

Forty people participated the study (22 females, age mean 25 years, min. 19 years, max. 37 years). All participants had normal hearing that was tested in the beginning of the experiment. All participants gave an informed consent before participating the study. The ethics committee of Hospital District of Southwest Finland approved the study (ETMK Dnro 20/1801/2018).

2.2 Sound conditions

There were two *sound conditions*: **silence** and **speech**. Silence was wideband noise presented at sound pressure level 35 dB L_{Aeq}. The condition corresponds to typical ventilation sound in open-plan offices. Speech was a radio dialogue at 65 dB L_{Aeq}. Both silence and speech had a one-third-octave spectrum that was interpolated from the standardized human speech spectrum (8). Silence was on the background during the whole experiment, except for the speech group, when speech was on during the experimental phase.

2.3 Participants division into sound conditions

Participants were divided into two experimental groups (two *sound conditions*) according to their gender and noise sensitivity (NS) score, which was asked when they registered themselves as volunteers. NS was measured with Weinstein's noise sensitivity scale (9). Based on our previous sample of 184 respondents, we defined the points, which divided observers into three equal groups: high, middle, and low NS. These points were used to divide the observers equally into different *sound conditions*. Table 1 presents the participants in different *sound conditions* in relation to their NS scores.

Table 1 – The number of participants in each *sound condition* and the distribution of high, middle and low noise sensitivity (NS) participants. The number in brackets represents participants from whom all blood samples were successfully acquired.

Sound condition	High NS	Middle NS	Low NS	Total
Silence	4 (4)	7 (5)	8 (6)	19 (15)
Speech	6 (3)	8 (5)	7 (6)	21 (14)
Total	10 (7)	15 (10)	15 (12)	40 (29)

2.4 Measures

2.4.1 Psychological (subjective) measures

After each task, the participants rated how much background sound irritated, bothered or annoyed them (*annoyance*) and how demanding or loading performing the tasks was (*workload*). The scale for both questions was from 0 "Not at all" to 10 "Extremely". The perceived fatigue was measured using Swedish Occupational Fatigue Inventory (SOFI), which gave three scales: *tiredness*, *lack of energy*, and *lack of motivation* (10).

2.4.2 Performance measures

N-back is a working memory task, where the participant responses whether the current stimulus is the same as n stimuli back (11). Three difficulty levels were used n = 0, 1, 2, and 3. Each time, 30+n repetitions of each difficulty level were performed.

Serial recall tasks are also working memory tasks examining how well the participants can keep a list of numbers in their mind. Digits from 1-9 were presented in a random order and participants were asked to write the correct order 10 seconds after the last digit was presented. 11 series were used. Two variations of the task were used: *visual serial recall* (VSR), where the numbers were presented visually on the display and *auditory serial recall* (ASR), where the participants heard the numbers from headphones.

2.4.3 Physiological (stress) measures

The physiological stress measures used were stress hormone concentration (*cortisol* and *noradrenaline*) determined from plasma, heart rate variability (HRV) measured with a heart rate monitor around participants' chest, and *blood pressure*. Plasma was taken from the peripheral venous access catheter that was placed in participants' arm in the beginning of the experiment. From HRV, the LF/HF relation was determined. It describes the activity of parasympathetic and sympathetic nervous system. The larger values mean greater sympathetic nervous system activity, which means more stress. This relation is here called $HRV_{LF/HF}$, which was calculated for periods of each cognitive task separately (VSR, ASR, and N-back).

2.5 Procedure

Procedure is described in Figure 1. Silence (35 dB ventilation sound = silence) was present in the room in every phase except in the experimental phase where the actual *sound condition* (silence or speech) was presented.

The experiment started at 11.45 each day and lasted on average for 3 h 19 min. Afternoon was chosen because diurnal variation in cortisol concentration is the largest in the morning. In the preparation phase, first the heart monitor and then the catheter were put on and hearing was tested. This was followed by the practice phase, where all tasks were explained and rehearsed. The baseline phase and experimental phase involved the same cognitive tasks and subjective estimations but the experimental sound was presented only in the experimental phase (silence or speech). Two participants were tested at the same time. The blood samples were taken 6 times during the experiment. Blood pressure was measured each time after taking the blood sample. In the questionnaire 1 (Q1), participants reported their current state and other background information. Psychological estimations related to sound were estimated several times during the experiment. *Annoyance* and *workload* were estimated after each task (8 times) (IQ1 and IQ2) and SOFI was filled each time after *N-back* task (4 times) (IQ2). In the restoration phase, participants filled questionnaires (Q2 personality and Q3 final questionnaire) with the silence in the background. The results from these two last questionnaires will not be reported in this article.

2.6 Statistical analysis

To reduce the influence of individual differences, the difference between experimental phase and baseline phase was estimated for the psychological and most physiological measures (experimental phase – baseline phase). However, cortisol concentration showed the expected diurnal changes in cortisol levels, but also there seemed to be large differences possibly due to excitement in the baseline phase. Therefore, with cortisol we used the restoration phase measurement as the reference (experimental phase - restoration phase). The performance measures showed more variation in performance in the baseline phase than in the experimental phase possibly due to excitement of the experiment as well as learning the tasks. Therefore, we examined the performance measures with a direct between groups comparison without comparing them to baseline performance.

The groups were compared with each other using repeated measures analysis of variance, if the experimental phase had more than one observation from each participant on that variable. In those cases, time was the within-subject variable, *sound condition* was the between-subject variable and noise sensitivity was the covariate. If there was just one observation on that certain variable from the experimental phase, then univariate analysis of variance was used with *sound condition* as the between-subject variable and noise sensitivity as the covariate. From the performance measures of *N-back* task, only *3-back* is reported here, since it was the only that filled the requirements of repeated measures analysis of variance. Greenhouse-Geisser correction was used, if the sphericity assumptions were not filled (ASR and VSR interaction).

Stage/ Time	Task
0 min	Recruitement questionnaire
Preparation phase	Informed consent
	Putting on catheter and heart rate monitor
30 min	Hearing test
Practice phase	Questionnaire 1 (Q1)
	Visual serial recall
	N-back
25 min	Auditory serial recall
Baseline phase	Visual serial recall
	Intermediate questionnaire 1 (IQ1)
	N-back (Time 1)
	Intermediate questionnaire 1 (IQ1)
	Auditory serial recall
	Intermediate questionnaire 1 (IQ1)
	N-back (Time 2)
50 min	Intermediate questionnaire 2 (IQ2)
10 min	**Break**
Experimental phase	Visual serial recall
	Intermediate questionnaire 1 (IQ1)
	N-back (Time 1)
	Intermediate questionnaire 1 (IQ1)
	Auditory serial recall
	Intermediate questionnaire 1 (IQ1)
	N-back (Time 2)
50 min	Intermediate questionnaire 2 (IQ2)
Restoration phase	Questionnaire 2 (Q2)
20 min	Questionnaire 3 (Q3)
Whole experiment: 3 h 20 min	Taking off catheter and heart rate monitor
	Receiving the reward
	End

Figure 1 – The procedure of the experiment. Red lines denote when the blood sampling took place and the grey area when the experimental sound was on.

3. RESULTS

Psychological measures are reported in Table 2, where the numbers describe the difference between experimental and baseline phases. Therefore, the results report whether the experimental phase was estimated differently between the *sound conditions*, when taking into account the baseline phase. Speech was considered more *annoying* than silence ($F(1,37)=33.0$, $p<0.001$). *Workload* was larger in speech ($F(1,36)=8.6$, $p=0.006$). Unexpectedly, *tiredness* was larger in silence ($F(1,37)=10.0$, $p=0.003$).

Performance measures are reported in Table 3. In *auditory serial recall* task, the last numbers were more difficult to remember during the speech than during silence ($F(4,152)=5.2$, $p=0.001$) (Figure 2). In *visual serial recall*, there was no similar effect ($F(5,170)=1.4$, $p=0.247$). In addition, the performance accuracy was lower in *3-back* task during speech than during silence ($F(1,37)=5.1$, $p=0.029$).

Table 4 shows the results of the physiological measures. Again, the numbers in Table 4 describe the difference between experimental and reference phases (either the baseline phase or the restoration phase) to reduce individual differences. The results report whether measurements in the experimental phase were different in the *sound conditions*, when taking into account the reference measurement. The difference in *cortisol* levels between the restoration phase and the experimental phase was higher in speech than silence ($F(1,27)=4.3$, $p=0.048$). Two physiological measures, *noradrenaline* and $HRV_{LF/HF}$, showed different interaction depending on the *sound condition* in relation to time. With time, *noradrenaline* level in the silence condition increased, while it stayed steady in the speech condition ($F(1,29)=7,8$, $p=0.009$) (Figure 3). N-back was the only task that was done twice during the experimental phase, which enables the examination of time in $HRV_{LF/HF}$. From first to second N-back tasks, $HRV_{LF/HF}$ increased in speech, while the value stayed the same in silence ($F(1,35)=6,2$, $p=0.018$) (Figure 4). This indicates that stress increased with time during speech.

Table 2 – The difference between psychological estimations in the baseline phase and the experimental phase. Negative value means that the value is higher in the baseline phase. Positive value means the opposite.

		Sound condition	
Variable	**Reference phase**	Silence (mean)	Speech (mean)
Annoyance*	Baseline	**0.18**	**4.91**
Workload	Baseline	**-0.35**	**1.03**
Tiredness	Baseline	**0.57**	**-0.75**
Lack of energy	Baseline	0.35	0.49
Lack of motivation	Baseline	0.14	-0.27

*$p<0.05$; **$p<0.01$; ***$p<0.001$

Table 3 – The difference in performance accuracy [proportion of correct answers (PCA)] between *sound conditions*.

	Sound condition	
Variable	Silence (mean)	Speech (mean)
***Auditory serial recall* (ASR)** ^{x}	**0.59**	**0.52**
Visual serial recall (VSR)	0.59	0.56
3-back*	**0.89**	**0.84**

*$p<0.05$; **$p<0.01$; ***$p<0.001$

x=The interaction between background noise and position was significant.

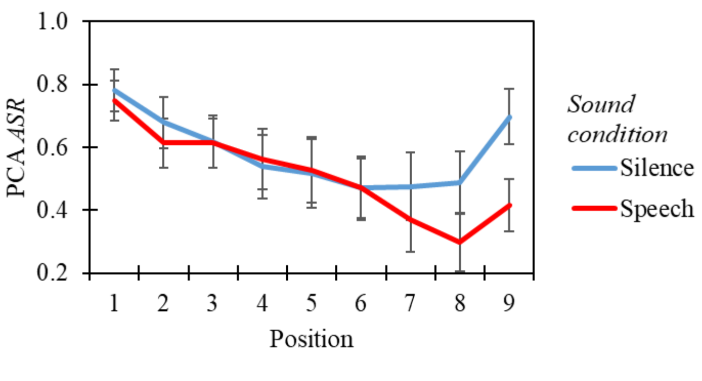

Figure 2 – The proportion of correct answers (PCA) per position of the digit for the two *sound conditions* in *auditory serial recall task (ASR)*. The error bars denote the 95% confidence interval.

Table 4 – Physiological measures in the two *sound conditions*. The means show the difference between the reference phase and the experimental phase. If the value is negative, the value in the reference phase is higher. If the value is positive, the value is higher in the experimental phase.

Variable	Reference phase	***Sound condition*** Silence (mean)	Speech (mean)
***Cortisol* [nmol/l] ***	Restoration	**-8.62**	**36.56**
***Noradrenaline* [nmol/l] x**	Baseline	**0.22**	**0.02**
Systolic blood pressure [mmHg]	Baseline	2.90	0.83
Diastolic blood pressure [mmHg]	Baseline	-0.49	-0.85
$HRV_{LF/HF}$ *ASR*	Baseline	-0.28	0.15
$HRV_{LF/HF}$ *VSR*	Baseline	-0.06	-0.32
$HRV_{LF/HF}$ *N-back* x	Baseline	**-0.13**	**0.04**

*p <0.05; **p <0.01; ***p <0.001

x=The interaction between background noise and time was significant.

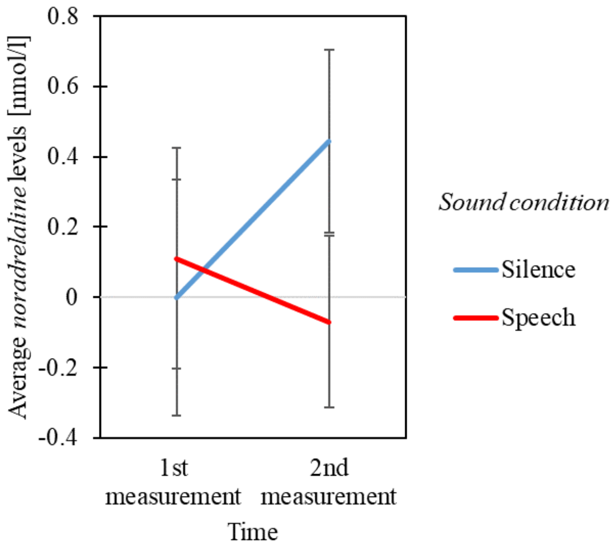

Figure 3 – Interaction for *noradrenaline* levels and time for the two *sound conditions*. The values represent the averages of the difference between the measurements in the baseline phase and the experimental phase.

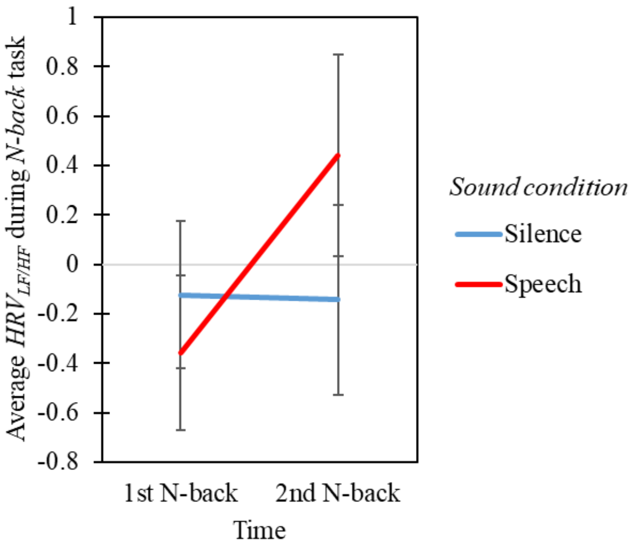

Figure 4 – Interaction for *$HRV_{LF/HF}$ N-back* and time for the two *sound conditions*. The values represent the averages of the difference between the baseline phase and the experimental phase.

4. DISCUSSION

Working in speech influences performance, psychological experience, and physiological stress measures. Speech was estimated more annoying and loading than silence, but it was also estimated as less tiring than silence. This might be due to the energetic radio dialogue used as speech. In speech condition, remembering the last words in *auditory serial recall* task was harder than in silence and the accuracy of *3-back* task was lower. The decrease in performance due to speech is in line with other research (7). Absence of the effect of sound condition on performance in *visual serial recall* was unexpected, since some studies have found an effect of speech on performance during visual serial recall task (12,13).

Speech increased *cortisol* levels. Previous research has found no effect of office noise on cortisol levels (4–6). However, in these studies, the background sound was office noise that contained only some speech, and in this study, speech involved an entire radio program (continuous dialogue). In addition, the level of speech was higher in our study than in previous studies (4) and (5), 55 and 51 dBA, respectively. Contrary to expectations, there was a statistically significant interaction in *noradrenaline* levels and time; however, we interpret the effect to be so small that it is not physiologically significant. The stressfulness of speech with time can be seen in *$HRV_{LF/HF}$ N-back*, which level rises with time during speech but not during silence.

5. CONCLUSIONS

Irrelevant speech corresponding to the sound level of normal conversation is considered annoying and loading, it decreases performance at least in tasks requiring cognitive working memory processing, and produces physiological stress reaction. With time, these effects can be harmful for employees' health and motivation. For these reasons, special attention should be given for reducing speech noise in offices. For this reason, Finland has set new building regulations concerning e.g. the room acoustic target values in open-plan offices (14).

ACKNOWLEDGEMENTS

The study was part of Anojanssi –project, which was funded by Business Finland, Turku University of Applied Sciences, Ministry of Environment Finland, Ministry of Social Affairs and Health Finland and collaborating companies and associations.

REFERENCES

1. Kim J, de Dear R. Workspace satisfaction: The privacy-communication trade-off inopen-plan offices. J Environ Psychol. 2013;36:18–26.
2. Kaarlela-Tuomaala A, Helenius R, Keskinen E, Hongisto V. Effects of acoustic environment on work in private office rooms and open-plan offices - Longitudinal study during relocation. Ergonomics. 2009;52(11):1423–44.
3. Haapakangas A, Hongisto V, Hyönä J, Kokko J, Keränen J. Effects of unattended speech on performance and subjective distraction: The role of acoustic design in open-plan offices. Appl Acoust. 2014;86:1–16.
4. Evans GW, Johnson D. Stress and open-office noise. J Appl Psychol. 2000;85(5):779–83.
5. Jahncke H, Halin N. Performance, fatigue and stress in open-plan offices: The effects of noise and restoration on hearing impaired and normal hearing individuals. Noise Heal. 2012;14(60):260.
6. Kristiansen J, Mathiesen L, Nielsen PK, Hansen ÅM, Shibuya H, Petersen HM, et al. Stress reactions to cognitively demanding tasks and open-plan office noise. Int Arch Occup Environ Health. 2009;82(5):631–41.
7. Szalma JL, Hancock PA. Noise effects on human performance: A meta-analytic synthesis. Psychol Bull. 2011;137(4):682–707.
8. ISO 3382-3. ISO 3382-3, Acoustics -- Measurement of Room Acoustic Parameters -- Part 3: Open Plan Offices. Geneva, Switzerland; 2012.
9. Weinstein ND. Individual differences in reactions to noise: A longitudinal study in a college dormitory. J Appl Psychol. 1978;63(4):458–66.
10. Åhsberg E, Gamberale F. Perceived fatigue during physical work: An experimental evaluation of a fatigue inventory. Int J Ind Ergon. 1998;21(2):117–31.
11. Owen AM, McMillan KM, Laird AR, Bullmore E. N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. Hum Brain Mapp. 2005;25(1):46–59.
12. Hongisto V, Haapakangas A, Varjo J, Helenius R, Koskela H. Refurbishment of an open-plan office - Environmental and job satisfaction. J Environ Psychol. 2016;45:176–91.
13. Haka M, Haapakangas A, Keränen J, Hakala J, Keskinen E, Hongisto V. Performance effects and subjective disturbance of speech in acoustically different office types - A laboratory experiment. Indoor Air. 2009;19(6):454–67.
14. Hongisto V, Keränen J. Open-plan offices - New Finnish room acoustic regulations. In: Euronoise 2018. Hersonissos, Crete, Greece; 2018. p. 1147–52.