The physiological, psychological, and performance influences of speech and wideband steady-state noise

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ABSTRACT

Speech is thought to be disturbing and stressful, when performing tasks requiring concentration. Steady-state noise without any special characteristic is thought to be less disturbing. We studied the difference of two conditions: speech and steady-state wideband noise. Both conditions were presented at normal speech level (65 dB L_{Aeq}) and spectrum. A between-group laboratory study examined the influence of these conditions on human performance, physiology, and psychological outcomes. Speech and noise conditions had 21 and 19 participants, respectively. Psychological (annoyance, workload, and fatigue) and physiological (stress hormones, heart rate variability HRV) stress were measured, while participants were performing tasks requiring constant attention (visual and auditive serial recall and N-back). Speech was rated more annoying, loading, and less tiring, but it did not deteriorate performance more than wideband noise did. Speech differed in one physiological measure from wideband noise – with time HRV showed more physiological loading. Our study shows clear extra effect of speech on subjective variables, minor effect on physiological stress. There is a clear need for further research comparing human reaction to speech and wideband steady-state noise having similar energy.

INTRODUCTION

Noise and lack of privacy are among the two most usual sources of dissatisfaction in open-plan offices [1]. In the office setting, one of the most disturbing type of noise is irrelevant speech [2], which also influences cognitive work performance [3]. Speech has been identified more disturbing for performance than other noise types [4]. To understand the extra effect of speech, speech has to be compared with a sound having the same sound level, but without the special characteristic of speech. The most relevant comparison is steady-state wideband noise that resembles ventilation noise. Similar sound is also used in most commercial sound masking applications.

To understand possible extra effects of speech on human, we compared psychological experiences, cognitive performance, and physiological responses in two sound conditions: speech and steady-state wideband noise both presented at the same sound level. We expect to see the extra effect of speech in increased stress level, reduced performance, and increased negative subjective ratings compared to noise.

Detailed results are presented in wider perspective by Radun et al. [5].

METHODS

Participants

Forty people participated in the study (26 females, age mean 26 years, min. 19 years, max. 42 years). All participants had normal hearing. All participants gave an informed consent before participating in the study. The ethics committee of Hospital District of Southwest Finland approved the study (ETMK Dnro 20/1801/2018).

Sound conditions

Sound conditions were **noise** and **speech**. Noise was steady-state wideband noise presented at sound pressure level 65 dB L_{Aeq}. Speech was a radio dialogue at 65 dB L_{Aeq}. Both sounds conditions had a one-third-octave spectrum that was interpolated from the standardized human speech spectrum [6].

Participants division into sound conditions

Participants were divided into two experimental groups (two sound conditions) according to their gender and noise sensitivity score, which were asked when they registered themselves as volunteers. Noise sensitivity was measured with Weinstein's noise sensitivity scale [7]. The total number of participants was 19 in noise and 21 in speech conditions.

Measures

Psychological 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 [8].

Performance measures. N-back is a working memory task, where the participant responses whether the current stimulus is the same as n stimuli back as fast and as accurately as possible. 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 one by one 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.

Physiological measures. The physiological measures used were stress hormone concentration (cortisol and noradrenaline) determined from plasma, and heart rate variability (HRV) measured with a heart rate monitor around participants' chest. Plasma was taken from the peripheral venous access catheter that was placed in participants' arm in the beginning of the experiment. For HRV, the low frequency/high frequency (LF/HF) ratio was determined for periods of each cognitive task separately (visual serial recall, auditory serial recall, and N-back). LF refers to heart rate variability on frequencies 0.04-0.15 Hz and HF to frequencies 0.15-0.4 Hz. Larger LF/HF values mean greater sympathetic nervous system activity, which means more stress.

Procedure

Procedure is described in Table 1.

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. The experiment consisted of preparation, practice, baseline, experimental, and restoration phases. In the preparation phase, first the heart monitor and then the catheter were put on and hearing was tested. In the practice phase, all tasks were explained and rehearsed. The baseline phase and experimental phase involved the same cognitive tasks (VSR, ASR, and N-back), and subjective estimations. The experimental sound was presented only in the experimental phase. In the restoration phase, participants filled questionnaires (personality and final questionnaire). The results from these two last questionnaires are not be reported in this article.

The blood samples were taken 6 times during the experiment. Psychological estimations related to sound were estimated several times during the experiment. Annoyance and workload were estimated after each task in baseline and experimental phases (8 times) and SOFI was filled in the end of baseline and experimental phases (2 times).

Table 1: The procedure of the experiment. The experimental sound (speech or noise) was on during experimental phase.

Stage/time	Tasks+Blood tests
Preparation phase, 30 min	
Practice phase, 25 min	Blood test 1
Baseline phase, 50 min	VSR, N-back, Blood test 2
	ASR, N-back, Blood test 3
Break, 10 min	
Experimental phase, 50 min	VSR, N-back, Blood test 4
	ASR, N-back, Blood test 5
Restoration phase, 20 min	Blood test 6
End phase	

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, in addition to the expected diurnal changes in cortisol levels, but also there seemed to be large differences in the baseline phase in cortisol concentration possibly due to excitement. Therefore, the restoration phase measurement was used as the reference (experimental phase - restoration phase) for cortisol concentration analyses. In addition, 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 using mixed measures analysis of variance, if the experimental phase had more than one observation on that variable. In those cases, time was the within-subject variable, sound condition was the between-subject variable. 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. 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.

RESULTS

Working during speech was rated to be more annoying ($F(1, 38)=4.3$, $p=0.044$) and workload larger ($F(1, 38)=6.4$, $p=0.016$) than working during noise (Figure1 a and b). Unexpectedly, tiredness was larger during noise than during speech ($F(1, 38)=10.9$, $p=0.002$) (Figure 1c). There were no difference between sound conditions regarding the lack of energy ($F(1, 38)=0.1$, $p=0.731$) or lack of motivation ($F(1, 38)=0.8$, $p=0.389$).

In serial recall tasks, the mean accuracy was slightly lower during speech than during noise (ASR: speech 0.52 and noise 0.58; VSR: speech 0.56 and noise 0.62). However, these differences were non-significant (ASR: $F(1, 38)=2.0$, $p=0.167$; VSR: $F(1, 38)=1.7$, $p=0.195$). The sound conditions did not differ from each other in 3-back accuracy (3-back: $F(1, 38)=0.0$, $p=0.863$).

The sound conditions did not differ in cortisol concentration ($F(1, 28)=1.1$, $p=0.303$) nor in noradrenaline concentration ($F(1, 32)=3.8$, $p=0.061$).

HRV did not show significant main effects of sound condition (VSR: $F(1, 38)=0.1$, $p=0.779$; ASR: $F(1, 38)=0.0$, $p=0.838$; N-back: $F(1, 37)=0.7$, $p=0.424$). However, HRV showed different interaction depending on the sound condition in relation to time. From first to second N-back tasks, LF/HF value of HRV measurement increased during speech, while the value stayed the same during noise ($F(1, 38)=7.9$, $p=0.008$) (Figure 2). This indicates that stress increased with time during speech.

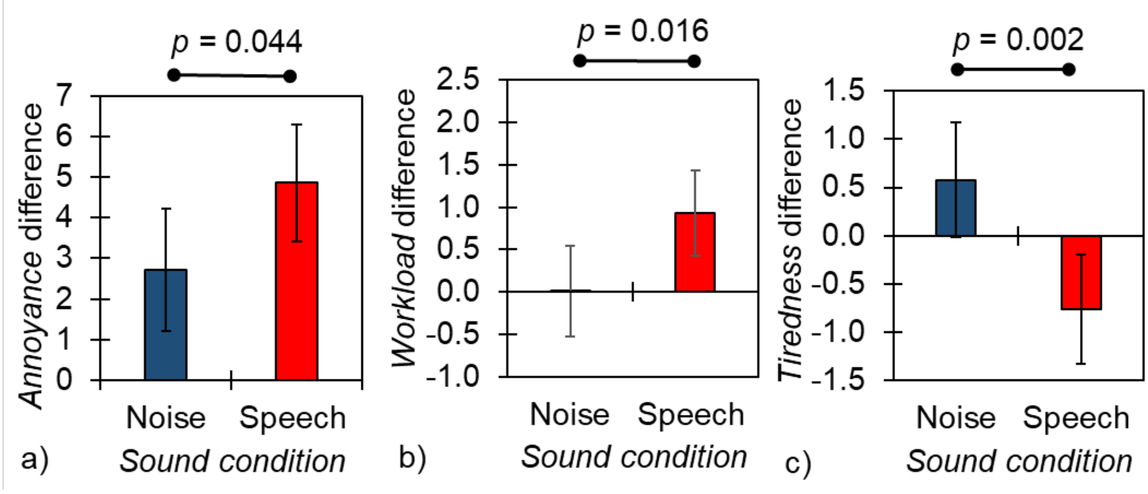

Figure 1: Annoyance (a), workload (b), and tiredness (c) differences compared to baseline phase in the studied sound conditions. The error bars show the 95 % confidence intervals.

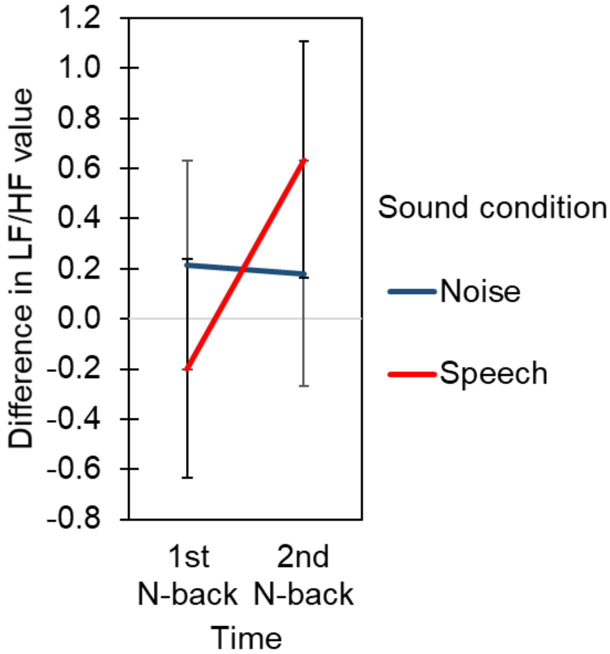

Figure 2: N-back task's HRV LF/HF value differences compared to baseline phase as a function of time in different sound conditions. The error bars show the 95 % confidence intervals. Positive difference indicates increased stress.

DISCUSSION AND CONCLUSIONS

Speech caused higher noise annoyance and workload compared to noise. Speech was less tiring than noise, which might be due to the energetic radio dialogue used as speech. Unexpectedly, performance did not differ significantly in sound conditions. This seems to be against Haka et al. [9], who found with a within-group design that performance in serial recall task was worse during speech (48 dB L_{Aeq}) than wideband steady-state noise (48 dB L_{Aeq}) containing only small proportion of 39 dB speech. The lack of effect in our study might be partly due to between-group design in our study, which might cause more variation in results and even though the means show differences to the expected direction, these differences are not significant. In addition, there were no differences between sound conditions in cortisol and noradrenaline concentrations. The only physiological measure showing differences between sound conditions was HRV (LF/HF) that increased with time during speech but not during noise. This indicates that working during speech might cause slightly more physiological stress with time than working during noise at the same sound level.

Our study shows that the extra effect of speech on human compared to noise having similar energy was clear only for our subjective variables. A minor extra effect was also found in physiological stress. However, the effect was absent for cognitive performance. This finding justifies further research in this field since precise knowledge of possible extra effects of speech is very important both from psychological and engineering point of view. It is possible that the type of speech material (independent sentences, story, conversation, liveliness) also affects the outcomes and might require special control in further experimental work.

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