# Consideration of objective measures of performance and subjective assessments under background speech in open-plan offices

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## SUMMARY

Short-term memory performance is important for activities in office environments and has effects on the efficiency of a company and employees' productivity. Negative effects of background speech on short-term memory performance have been shown in several laboratory studies (e.g. Banbury & Berry 1998). The Speech Transmission Index (STI) is considered to be a suitable physical set value to predict the decline of performance (Hongisto 2005).

However, the impact on subjective aspects such as perceived workload is rarely considered. It already has been shown that subjective assessment like disturbance and objectively measured performance do not necessarily match (e.g. Schlittmeier et al. 2008). Employees may be able to compensate for performance effects by an increase of effort but in turn perceived workload may increase (e.g. Yeh & Wickens 1988). In addition, a lack of perceived privacy, caused by background speech (among other factors) can influence mental workload and performance (e.g. Croon et al. 2005). This effect may not be immediately visible, but must be considered in the long term with respect to a decline of job dissatisfaction, which can cause absenteeism and even job termination. To avoid these consequences an exclusive focus on the loss of performance is not sufficient.

Therefore the reported results consider both the effects of background speech varying in intelligibility (STI) to objective and subjective measures. It is shown that subjective assessments, e.g. of workload, disturbance, territoriality as well as privacy and objective measures of performance correlate with the STI.

## INTRODUCTION

Physical characteristics of an office environment have effects on behavior, perception and productivity of workers (Crouch & Nimran 1989; Sundstrom et al. 1980). In open-plan offices several workstations are located in one spacious room and may be separated by internal boundaries like screens or shelves, while conventional workplace environments provide closed, private offices for employees. In open-plan offices, increased disturbances and distractions, an increased feeling of crowding and a loss of privacy may be the consequence (Crouch & Nimran 1989; Maher & von Hippel 2005).

Several studies demonstrated the relation between office noise and impaired cognitive performance (Banbury & Berry 1998), noise and decreased job satisfaction, lower motivation, higher perceived workload (Smith-Jackson & Klein 2009) stress and lower productivity (Sundstrom et al. 1994). Another issue of open-plan offices is the lower perceived privacy (Sundstrom et al. 1980, 1982; Crouch & Nimram 1989; Oldham & Brass 1979). One type of privacy is speech privacy which means the ability to have a conversation inside the workspace without being overheard and understood by people outside it (Sundstrom et al. 1986).

Irrelevant speech is the most disturbing noise, more than other types of office noise like telephone ringing and copiers. Schlittmeier et al. (2008) have proven that poorly intelligible speech has a significant lower impact on the disturbance of verbal short-term memory and mental arithmetic than highly intelligible speech. Background speech has no effect on verbal-logical reasoning performance. However, in all conditions, subjective disturbance ratings are similar, for example, poorly intelligible speech is rated as the least disturbing speech condition but still disturbing in comparison to silence. This shows that subjective assessment and objectively measured performance do not necessarily match.

To evaluate the impact of background speech of varying intelligibility the Speech Transmissions Index (STI) is used. The STI is a physical measure of speech intelligibility. It varies from 0 (completely unintelligible) to 1 (perfect intelligibility).

The model of Hongisto (2005) describes the relation of work performance and the STI. With increasing speech intelligibility (STI > 0.70) cognitive performance decreases. If the STI is low (STI < 0.20) the optimum performance is predicted. A linear relationship between STI and performance is assumed between STI values 0.20 and 0.70. Liebl et al. (2010) proved a strong relationship between cognitive performance (Serial Recall Task) and STI.

The goal of the present study was to examine the relationship between subjective assessments and the STI, which was systematically varied from 0.13 to 0.61, compared to the results found by Liebl et al. (2010). It is possible to describe acoustic environments in a more comprehensive way by considering both, objective performance and subjective comfort.

## METHOD

### Participants

A sample of 24 participants from German speakers was selected. They were aged 20 to 50 years (Md = 23 years) and reported normal hearing. A small allowance was paid for participation.

### Procedure

The design of the experiment was one-factorial with repeated measurement. The experiment was placed in a laboratory and presented by an Apple MacBook with the experimental software PsyScopeX. The experimental task (Serial Recall Task, see Liebl et al. 2010) was followed by the subjective ratings. After having processed the performance task, subjective ratings (perceived annoyance, perceived ability to concentrate and perceived difficulty) were evaluated. A dichotomous answer should be given to the question of privacy (request of increased distance to the sound source). The participants also estimated the perceived distance to the sound source in meters. Sounds were played via headphones (Sennheiser HD 600) using a CD-Player (Sony CDP-103) and an amplifier (AKAI AM-49). Over all participants the sequence of the experimental conditions was balanced. The duration of the experiment was approximately 2.5 hours.

## Sound scenarios

A room of 64 $m^2$ with standard workstations was used as an office mockup (Figure 1). Between adjacent workstations either no screens, absorptive (h = 1.70 m) or reflective screens (h = 1.70 m) were placed. The floor was carpeted and the ceiling absorptive (NRC = 0.70). At position 1 the sounds were played with a dodecahedron (h = 1.20 m) and were recorded by an artificial head (h = 1.20 m) at positions 2, 3 and 7.

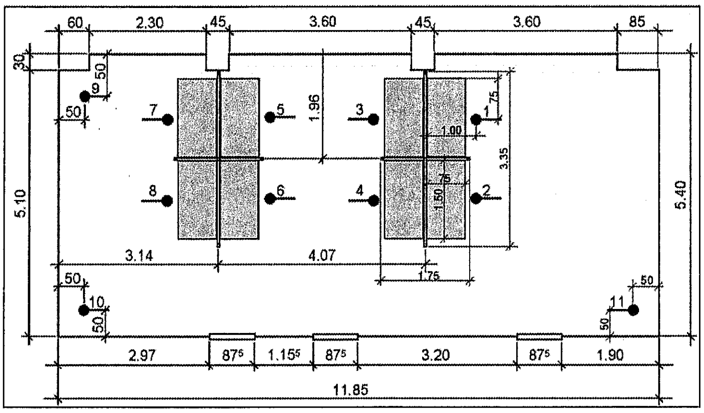

**Figure 1:** Sketch of the office mockup depicting the arrangement of workstations. Numbers 1 to 8 represent individual workplaces. Sound was played at position 1 and recorded at positions 2, 3 and 7.

An ANSI-specified speech spectrum with normal vocal effort was used to calculate the STI. With low level background noise the absorptive and reflective screens were not sufficient to create a broad range of STI values since the STI values at positions 2, 3 and 7 were very similar. By adding noise (39 dBA) and adapting the speech level, twelve sound scenarios with STI values from 0.13 to 0.61 were generated which were used in the experiment.

## RESULTS

The strong relationship between STI values and cognitive performance was proved by Liebl et al. (2010). The empirical data fit the model of Hongisto (2005), more errors were made with increasing STI.

Subjective ratings of the different sound scenarios also proved to correlate with the STI. Perceived annoyance significantly correlates with the STI values (r = 0.959, $p<0.01$). The higher the STI values, the higher the ratings of perceived annoyance (Figure 2).

Figure 3 shows the correlation between the estimated distance to the sound source and the STI. The higher the STI, the lower the distance is estimated (r = -0.940, $p<0.01$).

Figure 4 shows the violation of privacy (request of increased distance) as a function of STI values. If the STI is high, more participants intend to increase the distance to the sound source. The estimated distance to the sound source significantly correlates with the percentage of violation of privacy (request of increased distance) (r = -0.850, $p<0.01$) (Figure 5).

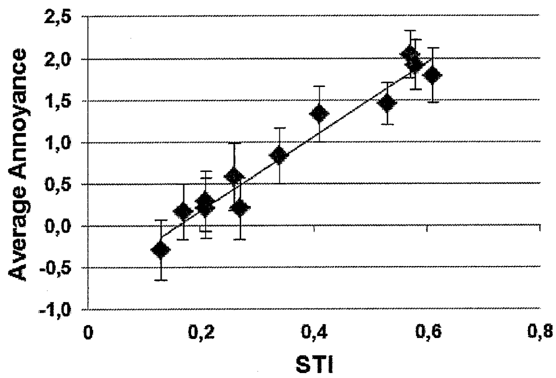


**Figure 2:** Average perceived annoyance as a function of speech intelligibility (STI)

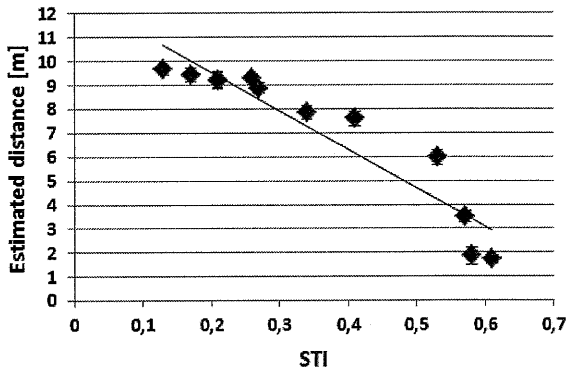


**Figure 3:** Estimated distance to sound source as function of speech intelligibility (STI)

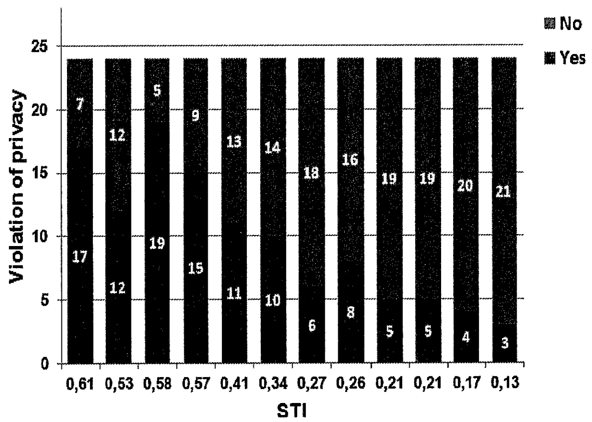


**Figure 4:** Violation of privacy as a function of speech intelligibility (STI)

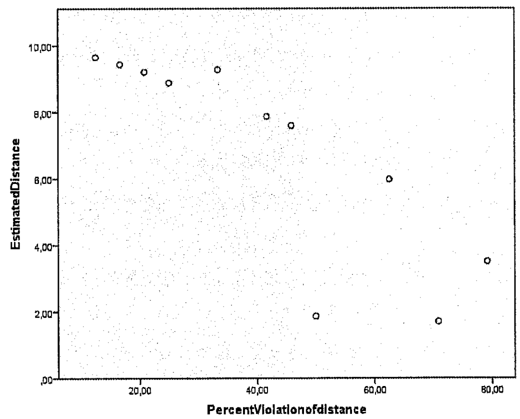


**Figure 5:** Estimated distance as a function of percentage of violation of privacy

## CONCLUSIONS

The results show a high correlation of subjective assessments with the STI value. Objective performance also highly correlates with the STI (Liebl et al. 2010). Speech intelligibility seems to be a good predictor of perceived acoustic comfort in open-plan offices. Higher STI values have a negative impact on the perceived assessments.

Estimated distance to the sound source correlates with the STI. But this relation can be a function of the method of calculation of the STI. In this experiment the STI was calculated by changing the signal-to-noise-ratio by keeping the same level of noise and decreasing level of speech signals. Because of the decreasing level of speech signals it is possible that the distance to the sound source was estimated farther. The lower a speech signal, the further away a sound source is positioned. In this case, privacy is not only related to speech intelligibility but also to the level. Probably the level is more relevant for perceived privacy. To generate the STI in another way – same level of speech and increasing noise – can be a possibility to get more information on the relation between STI, perceived distance and lack of privacy. Further investigations with regard to the level of signals would be very useful.

It is possible that another problem with the STI is the speech spectrum. An ANSI speech spectrum was used to create the STIs, but no other voices were used. In further questions male and female voices can be used for the creation of the STI.

In this study perceived privacy is rated by the request to increase the distance to the sound source only. For a more comprehensive approach it is advisable to evaluate privacy in a combined way using questionnaires, developed e.g. by Crouch & Nimran (1989) or a behavior-based questionnaire, together with ratings of the estimated distance to the sound source and further assessments.

In this study objective performance and subjective assessments both show an increasing disturbance with increasing STI. Therefore, it is recommended to consider both, objective measurements and subjective assessments in future investigations.

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