# Effect of speech intelligibility on task performance - an experimental laboratory study

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## ABSTRACT

The aim of this study was to examine the effects of speech varying in intelligibility on cognitive performance and subjective perceptions of sound environment disturbance. 37 subjects performed a series of tasks in three conditions in which speech transmission indexes were 0.10, 0.35 and 0.65. These correspond to cellular office, well-designed open office and unsatisfactory open office, respectively. The experiment was conducted in an office laboratory in which the direction of the speech source varied. The sound environments were presented at 48 dBA. Performance deteriorated in condition 0.65 compared to the other two conditions in a serial recall task ($p < .05$) and in a complex working memory task ($p < .001$). Proofreading performance did not differ in different conditions but the task was experienced as easier in the condition with lowest STI value than in the other two ($p < .05$). Questionnaire measures showed consistent, statistically significant differences between all three situations: the higher the STI value was, the more it was experienced to disturb performance and draw attention away from the task ($p < .001$). Similarly, the ease of habituation and the pleasantness of sound were rated higher as the STI value declined ($p < .001$). Self-rated work efficiency declined with ascending STI values ($p < .05$). Continuous background noise was not experienced to disturb performance in any condition. This supports the use of continuous masking sound in minimizing speech intelligibility, i.e. increasing speech privacy in open offices.

## INTRODUCTION

Office surveys have shown that speech is experienced as the most distracting noise source in offices (e.g., Haapakangas et al. 2008). The problem is particularly great in open offices. Earlier laboratory experiments have shown that the disruptive effects of speech are not produced by the level of speech but speech intelligibility (Colle 1980; Ellermeier & Hellbrück 1998; Venetjoki et al. 2006; Schlittmeier et al. 2008).

According to Hongisto et al. (2007), speech intelligibility in open offices varies greatly but it can be lowered by proper acoustical design. Research is needed on the effect of speech intelligibility on task performance in order to encourage investments in acoustic improvements. However, there are only a few published studies that have studied the effect of speech on cognitive performance with varying levels of speech intelligibility.

Speech intelligibility can be evaluated with Speech Transmission Index (STI). For example, STI value 0.50 expresses roughly that 50 percent of syllables are correctly heard. STI can be easily determined between office workstations using acoustical measurements. The first experiment that used STI as a descriptor of irrelevant speech was published by Venetjoki et al. (2006). It was found that proofreading performance deteriorated significantly in STI 0.80 compared to STI 0.00. Later, similar experiments have been conducted by Schlittmeier et al. (2008).

The aim of this experiment was to show how the level of speech intelligibility affects cognitive performance. Speech was expected to deteriorate performance more in higher levels of speech intelligibility. The study focused on the STI range from 0.10-0.65 because the acoustic conditions of offices are typically in this area. The study also aimed to validate the model of Hongisto et al. (2008) that predicts the deterioration of performance as a function of STI.

## METHODS

### Subjects and test setup

A repeated measures design with three speech conditions was used. Altogether 37 students took part in the experiment in December 2007. The three speech conditions were STI 0.10, STI 0.35 and STI 0.65.

A group of four participants was tested at a time. Experiments were conducted between 8.15 a.m. and 12.30 p.m. The experiment included a practice session and three test sessions lasting for about 55 minutes each. Each situation was followed by a 5-minute break. The order of speech conditions was counterbalanced across subjects, as was the presentation of different speech samples and test versions in different speech conditions.

Subjects performed five tasks: a serial recall task, a complex working memory task, a proofreading task, a visual short-term memory task and a reading comprehension tasks. The latter two were mainly included as filler tasks to increase the length of test sessions and were being piloted for future experiments. The serial recall task was conducted following classic procedures in which digits from 1 to 9 are presented on a computer screen in random order. Subjects' task is to recall the digits in the same order. The number of digits recalled in correct serial positions is measured.

The complex working memory task was modified from the operation span task developed by Turner and Engle (1989). In the task, subjects had to state whether simple arithmetic calculations, presented on a computer screen, were true or false. Each calculation was followed by a presentation of a word that the subject had to memorize. At the end of each equation-word pair list, subjects were asked to recall the presented words in the same order. The number of words to be remembered increased from 3 to 8. The total number of correctly recalled words was measured.

The proofreading task was the same as in our earlier study (Venetjoki et al. 2006). It was a pen-and-paper task in which subjects looked for mistakes in the text. Half of the errors were spelling errors whereas half required semantic processing.

Each speech condition was followed by a questionnaire that assessed subjective perceptions of the sound environment. A 5-point Likert scale was used in most questions. Disturbance of other environmental factors was included in the questionnaire that was presented after the last sound condition. Background information was gathered with a separate questionnaire before practice session.

### Speech conditions

The investigations were carried out in an office laboratory (Figure 1). Three speech conditions were used:

- STI=0.10 - corresponds to a private office room with the door closed. Speech intelligibility is extremely low.

- STI=0.35 - corresponds to a very good open office or a private office room with opened doors. Speech intelligibility is reasonably low.
- STI=0.65 - corresponds to a typical open office without adequate acoustic design. Speech intelligibility is nearly perfect.

STI values were obtained by changing the relative sound pressure levels of speech and masking as shown in Figure 2. However, the total sound pressure level was constant in all speech conditions, $L_{A,eq}$=48 dB.

Special effort was made to create an office-like environment. All factors of indoor environment were monitored during all experiments. Typical values are given in Figure 1.

Indoor environment:

| | |
|---|---|
| Lighting: | 410 lx |
| Temperature: | 23 °C |
| Sound level: | 48 dBA |
| Input air rate: | 63 l/s |
| $CO_2$: | 700 ppm |

**Figure 1:** The office laboratory (30 m$^2$) contains 8 workstations. Four subjects were tested simultaneously and they sat in the middle. Speech was produced from four other workstations in random sequences. Masking sound was produced from four loudspeakers hidden above the suspended ceiling.

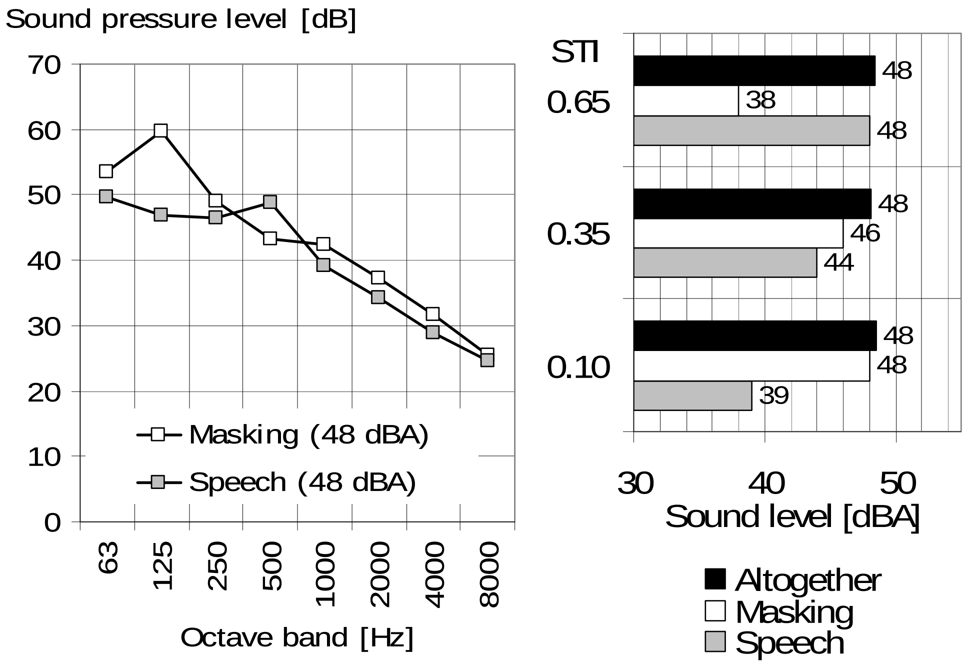


**Figure 2:** The spectrum of speech and masking was constant in each sound condition. The relative A-weighted sound pressure levels in three speech conditions 0.65, 0.35 and 0.10.

## RESULTS

Data was analyzed with SPSS 16.0 program using variance analysis of repeated measures.

### Performance measures

Task performance was affected by speech intelligibility in the serial recall task ($p < .05$) and in the complex working memory task ($p < .001$). In the serial recall task, the contrast comparisons showed a significant decline in the percentage of correctly recalled digits in STI 0.65 compared to other two speech conditions (Table 1). The performance did not differ between STI 0.35 and STI 0.10.

**Table 1:** Serial recall task. The table shows the percentages of digits recalled in correct serial position in different speech conditions.

| Speech condition | Mean | SD |
|---|---|---|
| STI 0.10 | 56,4 | 13,7 |
| STI 0.35 | 55,9 | 14,0 |
| STI 0.65 | 51,5 | 14,6 |

A similar pattern emerged for the complex working memory task (Table 2). The number of correctly recalled words did not differ between STI values 0.10 and 0.35 but performance deteriorated significantly between STI 0.35 and STI 0.65 ($p < .01$). Proofreading task was not affected by different levels of speech intelligibility but the task was experienced as easier in STI 0.10 than in the other speech conditions ($p < .01$).

**Table 2:** Complex working memory task. Percentages of correctly recalled words in different speech conditions are shown.

| Speech condition | Mean | SD |
|---|---|---|
| STI 0.10 | 83,2 | 9,7 |
| STI 0.35 | 82,6 | 8,8 |
| STI 0.65 | 76,7 | 12,2 |

### Subjective ratings

Analyses of questionnaire measures showed consistent, statistically significant differences between all three speech conditions. The results for perceptions of speech conditions are shown in Figure 3. The higher the STI value was, the more the sound condition was experienced to disturb performance and draw attention away from the task ($p < .001$). Similarly, speech condition was perceived more pleasant and easier to habituate to as the STI value declined ($p < .001$). Self-rated efficiency also declined with ascending STI values with a significant deterioration in STI 0.65 in comparison to the other two speech conditions ($p < .01$).

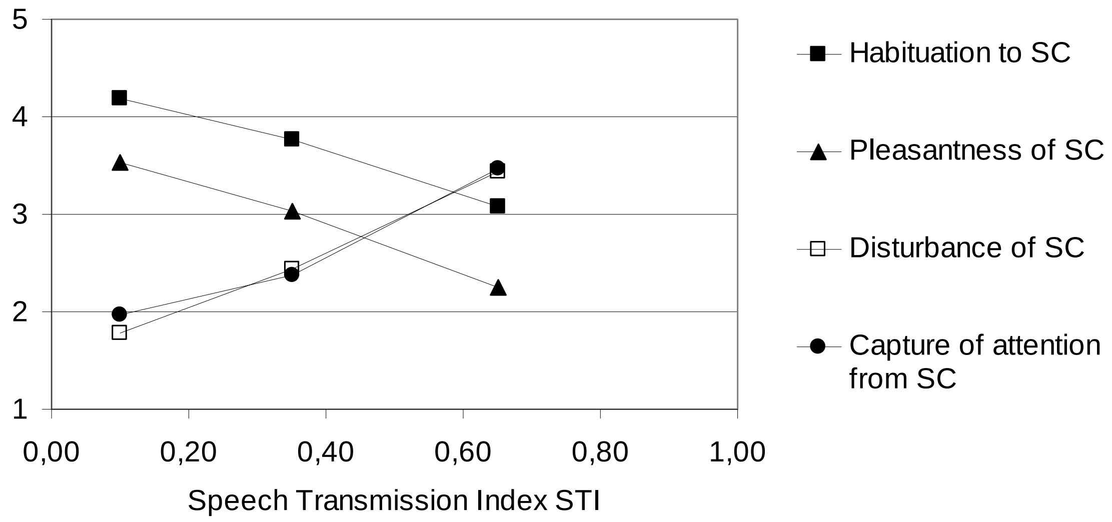


**Figure 3:** Subjective ratings of the qualities of speech conditions (SC). The figure shows average values on a scale from 1 (not at all) to 5 (very much).

The subjective disturbance of different sound sources is shown in Figure 4. Speech was the most distracting sound in all speech conditions. The disturbance of speech increased with growing STI-values ($p < .001$). The perceived disturbance of the sound level followed the pattern of disturbance from speech, increasing with ascending speech intelligibility ($p < .001$) although the actual sound pressure level was the same in all speech conditions. It must be noted that, in speech condition STI 0.10, the sound pressure level of speech was 9 dB below the sound pressure level of masking (Figure 2). Yet, speech was experienced as the most disturbing sound source even in this condition and the difference between the disturbance of speech and masking noise was statistically significant ($p < .01$). The disturbance of masking noise did not differ in different speech conditions.

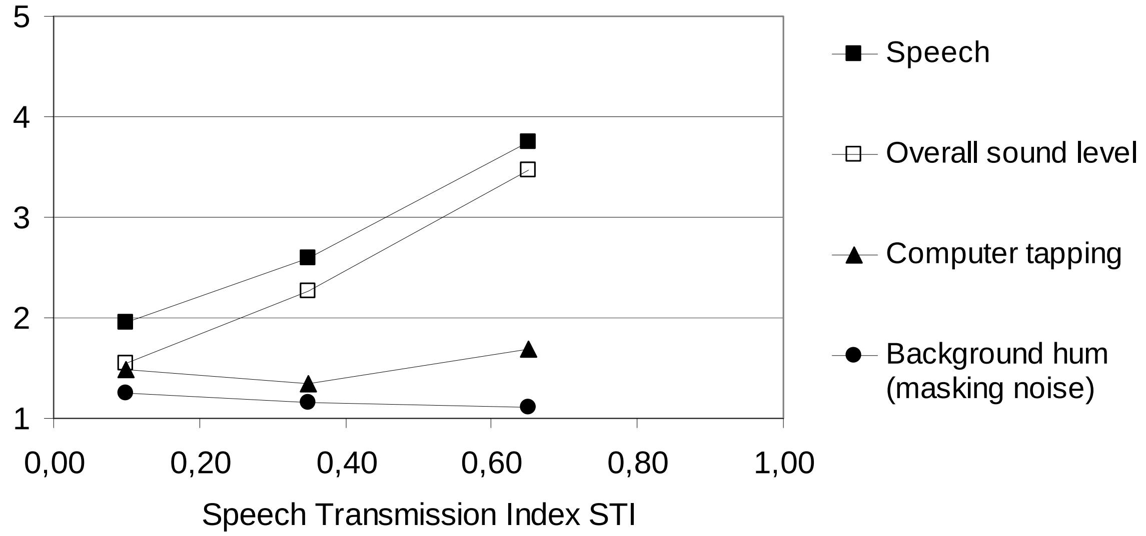


**Figure 4:** Distraction caused by different noise sources on a scale from 1 (not at all) to 5 (very much). Mean values for each condition are shown.

## DISCUSSION

The present study demonstrated the deteriorating effects of intelligible speech on cognitive performance. As in other similar studies (e.g., Schlittmeier et al. 2008), serial recall deteriorated in the speech condition in which speech was most intelligible. The performance in a complex working memory task followed a similar pattern but the degree of deterioration due to intelligible speech was slightly bigger than in the serial recall task. The working memory task taps into both the storage and the processing functions of working memory whereas serial recall only requires short-time storage of information. Such tasks are generally better predictors of complex cognitive abilities than simple digit recall tests (Daneman & Merikle 1996) and complex working memory tasks may therefore have more relevance when the purpose is to find measures that capture cognitive processes essential in real office work.

Speech transmission index proved to be a good predictor of both performance loss and subjective disturbance. It is important to note that performance in the situation corresponding to private room conditions (STI 0.10) did not differ from the speech condition corresponding to well-designed open office conditions (STI 0.35). The drop in performance occurred between 'good open office' condition (STI 0.35) and 'poor open office' condition (STI 0.65). This is in line with Hongisto's (2005) model that predicts that performance starts to deteriorate when STI exceeds 0.30.

Unlike performance tests, the subjective disturbance ratings showed consistent differences between all three speech conditions. Schlittmeier et al. (2008) who observed similar differences between objective and subjective measures, have suggested that the experienced disturbance might cause participants to invest more effort in performing tasks. This could amplify differences in subjective perceptions while reducing differences in performance between different conditions. It is likely that noise affects performance via several routes. Disturbance of cognitive mechanisms, such as working memory, represents a direct link between environmental conditions and performance effects. It is possible that subjective perceptions of disturbance predict long-term effects of noise that may indirectly influence performance, e.g. motivational effects and stress. However, this question cannot be answered in laboratory settings alone.

Speech intelligibility did not affect all tasks in the same way. Contrary to expectations, proofreading performance was not affected by different levels of speech intelligibility. A few possible explanations exist for this. In our earlier experiment (Venetjoki et al. 2006), proofreading performance differed between STI values 0.00 and 0.80 but a narrower range of STI values was used in the present experiment. Proofreading may be less sensitive to changes in speech intelligibility than short-term and working memory tasks because it allows more flexible use of different strategies. For example, in proofreading, one can compensate temporary disruptions of attention by stopping and going back in the text. In serial recall and working memory tasks, the pace of information processing is to a large degree set by the test program. Thus, the disturbing effect of intelligible background speech may be compensated in proofreading by changes in strategies and enhanced effort. The finding that the task was experienced as more difficult with higher STI-values supports this possibility.

Another explanation concerns the method of presenting speech samples. In our previous experiment (Venetjoki et al. 2006), speech was produced from loudspeakers that were in front of the subject and visible. In the present experiment, open office conditions were better simulated by producing speech from adjacent workstations and varying the direction of speech source randomly. Even with equal STI values, the listening experience differs depending on the speech production method. This may complicate the comparison of different experiments. Other studies have typically produced speech monaurally or binaurally using headphones. In real open offices, rooms are reverberant, the speaker's direction is changing, listening is binaural and the speech enters, not directly, but via room reflections to the listener. These issues should be taken into account when speech production is planned for experiments on speech intelligibility. It would also be important to investigate whether the way of presenting speech confounds the relation between STI and performance.

Finally, the results have practical relevance for acoustic design of offices. It is suggested that more appropriate conditions for individual work performance can be created in open offices by lowering speech intelligibility, e.g. by using masking noise. The subjective disturbance ratings showed that masking noise was not experienced to disturb participants at all.

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## REFERENCES

Colle HA (1980). Auditory encoding in visual short-term recall: effects of noise intensity and spatial location. J Verbal Learn Verbal Behav 19: 722-735.

Daneman M, Merikle PM (1996). Working memory and language comprehension: A meta-analysis. Psychon Bull Rev 3: 422-433.

Ellermeier W, Hellbrück J (1998). Is level irrelevant in irrelevant speech? Effects of loudness, signal-to-noise ratio, and binaural unmasking. J Exp Psychol: HPP 24: 1406-1414.

Haapakangas A, Helenius R, Keskinen E, Hongisto V (2008). Perceived acoustic environment, work performance and well-being - survey results from Finnish offices. In: 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, July 21-25, Mashantucket, Connecticut, USA.

Hongisto V (2005). A model predicting the effect of speech of varying intelligibility on work performance. Indoor Air 15: 458-468.

Hongisto V, Virjonen P, Keränen J (2007). Determination of acoustic conditions in open offices and suggestions for acoustic classification. In: 19th International Congress on Acoustics, Madrid, Spain, Sept 2-7, 2007.

Hongisto V, Haapakangas A, Haka M (2008). Task performance and speech intelligibility - a model to promote noise control actions in open offices. In: 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008 July 21-25, Mashantucket, Connecticut, USA.

Pejtersen J, Allermann L, Kristensen TS, Poulsen OM (2006). Indoor climate, psychosocial work environment and symptoms in open-plan offices. Indoor Air 16: 392-401.

Schlittmeier SJ, Hellbrück J, Thaden R, Vorländer M (2008). The impact of background speech varying in intelligibility: Effects on cognitive performance and perceived disturbance. Ergonomics 51: 719-736.

Turner ML, Engle RW (1989). Is working memory task dependent? J Memory Lang 28: 127-154.

Venetjoki N, Kaarlela-Tuomaala A, Keskinen E, Hongisto V (2006). The effect of speech and speech intelligibility on task performance. Ergonomics 49: 1068–1091.