The importance of meaning in ambient speech to eliciting cognitive performance effects

S. J. Schlittmeier[1], A. Assfalg[1], M. Hofmann[1], A. Liebl[2]

[1] Work, Environmental and Health Psychology, Catholic University of Eichstätt-Ingolstadt, Ostenstraße 25, D-85072 Eichstätt, Germany, sabine.schlittmeier@ku-eichstaett.de

[2] Department Acoustics, Fraunhofer Institute for Building Physics, Nobelstrasse 12, D-70569 Stuttgart, andreas.liebl@ibp.fraunhofer.de

INTRODUCTION

In open-plan offices employees have to perform demanding cognitive tasks in the presence of ambient speech due to conversations among colleagues or colleagues being on the phone. Ambient speech has been shown to impair cognitive performance at silent, concentrated work in laboratory studies. This holds true even if the background speech is irrelevant to the task at hand and is intended to be ignored by the listener. Many cognitive psychology experiments demonstrated this phenomenon, which is best explored in tests of verbal short-term memory, such as remembering a series of digits (see Hellbrück & Liebl 2008, for a summary). However, office work is far more than remembering single items in their correct order. A more typical example of office work is reading and text comprehension, as often written information needs to be processed and elaborated. Here, not only the serial order of the words needs to be stored, but the relation between the words must be elaborated to understand and derive information. Irrelevant background speech has been shown to impair performance in reading and text comprehension tasks (e.g. proofreading: Jones et al. 1990; Miles et al. 1988; reading comprehension, or text recall: Martin et al. 1988; Oswald et al. 2000). In these studies, however, the special importance of semantic content within ambient speech is striking; specifically, that irrelevant but semantically meaningful speech (e.g. mother tongue) reduced performance to a greater extent than semantically neutral speech (foreign language or reversed speech). In contrast to that, the semantic content of ambient speech is irrelevant to the extent of performance effects in tasks that solely rely on serial verbal short-term memory (e.g. Colle & Welsh 1976; Jones et al. 1990).

This pattern of results is explained by the 'interference by process' principle (e.g. Macken et al. 1999). This principle is based on the assumption that performance reducing sound effects arise due to the similarity of processes involved in the voluntary processing of the task on the one hand and the automatic and involuntary processing of ambient speech on the other hand. Because proofreading, text recall and reading comprehension require semantic processing, the semantic content of the background speech contributes to its detrimental impact. Analogously, the semantic content of background speech plays no role in tasks with minimal load on semantic processing like, for example, verbal serial recall. Here, unrelated verbal items (e.g. digits, consonants, words) are presented successively and have to be recalled afterwards in exact presentation order. This strict serial reproduction criterion ensures that successful task performance is achieved without semantic processing of the memorized items. Accordingly, mother tongue reduces serial recall performance to the same extent than unknown foreign language (e.g. Colle & Welsh 1976; Jones et al. 1990).

The present study consists of two experiments which tested the 'interference by process' principle (e.g. Macken et al. 1999) with respect to semantics by systematically varying both task characteristics and semantic content of background speech signals. The extent to which successful task performance relied on semantic processing was varied by using a reading comprehension task consisting of two subtasks. These subtasks differed regarding to the need to semantically process the presented information. The semantic content of background speech was varied differently in the two present experiments. In Experiment 1, the reading comprehension task had to be solved during semantically meaningful background speech (i.e., mother tongue) and during semantically neutral speech (i.e., foreign language). In Experiment 2, the semantic content of background speech was varied by step-wise reducing the coherence of mother tongue background speech. Here, coherent text, unrelated sentences, multiple word phrases (e.g. a rainy day, the girl's dress) or unrelated words were played-back.

EXPERIMENT 1

The reading task used in the present study is based on the German version of the reading span task (Daneman & Carpenter 1980) provided by Hacker and co-authors (Hacker et al. 1994, 2002). The present task comprises two subtasks that vary regarding to the extent to which they rely on the semantic processing of the presented information. Participants read four unrelated sentences. Afterwards, they are asked to recall the last word of each sentence (word recall). Then, four paraphrases of the four initial sentences are shown. Participants are asked to verify whether the information given in the to-be-remembered sentence (e.g. 'The judge went down the footbridge and jumped into the sea.') is represented in the paraphrase (e.g. 'The man jumped into the water.') or not (e.g. 'The judge jumped into the car.'). This sentence verification task cannot be solved without semantic processing of the to-be-remembered sentences. Less semantic processing is, however, necessary to solve the word recall task in which the last word of each of the read sentences is to be recalled (in this example: 'sea').

Accordingly, we expected semantically meaningful speech to reduce performance in the sentence verification task significantly more so than semantically neutral speech. In the word recall task, however, we expected background speech to reduce performance irrespectively of its semantic content.

Methods

32 students from the Catholic University of Eichstätt-Ingolstadt participated in Experiment 1 (M = 22.4 years, 19-29 years, 26 female, 6 male). All participants reported normal hearing and received a small allowance.

Four different sound conditions were included in Experiment 1. Narration in a foreign language was used as semantically neutral speech by ensuring that subjects did not know the chosen language. Unrelated sentences in the participants' mother tongue were used as semantically meaningful background speech. These two speech conditions were played back at L_{eq} = 55 dBA. A silence condition (pink noise at L_{eq} = 28 dBA) was included as an overall control condition to measure performance at baseline. Furthermore, the semantically meaningful speech was played back at L_{eq} = 35 dBA and, thus, was as loud as soft whisper. This condition was included since research has found that in a serial recall task (i.e., a simple reproduction task), the detrimental impact of background speech does not vary with its level (Colle 1980; Tremblay & Jones 1998).

In a trial of the reading comprehension task, four sentences were presented one after the other. Following these presentations, the two subtasks, word recall and sentence verification, were completed as described above. Twelve of these four-sentence trials had to be solved in a sound condition before the next sound condition with twelve more four-sentence trials of the reading task began. Succession of sound conditions was balanced over participants.

Results

The left panel of Figure 1 depicts mean error rates in the word recall task for each sound condition. Recall performance is significantly reduced during all speech condition compared to silence as t-tests verify ($p < .001$, two-tailed). Since speech conditions do not differ significantly from each other ($p \geq .157$, two-tailed), no differences in disturbance impact are found between semantically neutral and meaningful speech, or between loud and soft meaningful speech.

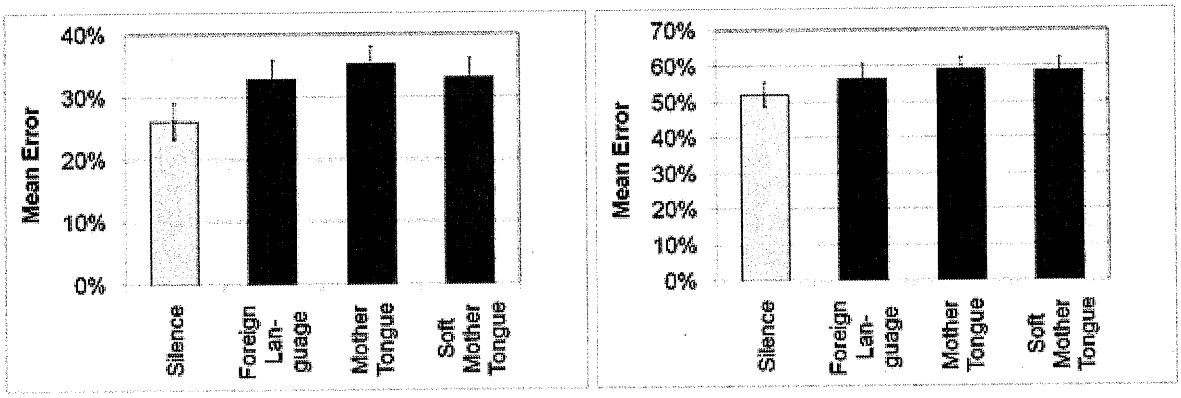

Figure 1: Impact of semantically meaningful speech (mother tongue) and semantically neutral speech (foreign language) on word recall performance (left panel) and sentence verification (right panel) in Experiment 1 (n=32). Error rate means with standard errors are plotted.

In contrast, semantically neutral speech (foreign language) reduces performance in the sentence verification subtask not significantly compared to silence ($p = .190$, two-tailed; Figure 1, right panel). Yet semantically neutral speech also does not differ significantly from meaningful speech conditions ($p \geq .376$), which reduce sentence verification significantly compared to silence ($p \leq .039$, two-tailed).

EXPERIMENT 2

In Experiment 2, the semantic content of background speech was reduced step-wise by reducing the coherence of the speech signal from coherent text to unrelated sentences to multiple word phrases and, finally, to unrelated words. According to the 'interference by process' principle (e.g. Macken et al. 1999, cp. Introduction), we expected performance in the sentence verification task to vary with the coherence of background speech due to the task's reliance on semantic processing. In the subtask 'word recall,' however, speech conditions are expected to reduce performance irrespectively of their coherence since semantic processing is not necessary for successful task performance in this condition. Since the latter sound effect pattern has been already verified for serial recall performance (e.g. Colle 1980; Ellermeier & Hellbrück 1998), we also included this task in Experiment 2.

Methods

24 students of the Catholic University of Eichstätt-Ingolstadt, Germany, participated in the experiment. All participants reported normal hearing and received a small allowance.

Performance was tested during six sound conditions: one silence condition (pink noise at L_{eq} = 25 dBA), which served as performance baseline, and five background speech conditions. The latter consisted either of coherent text, unrelated sentences, multiple word phrases, or unrelated words. Additionally the coherent text recording was superimposed with pink noise of equal level (signal-to-noise ratio, SNR = 0 dBA). To note, speech intelligibility remained perfect in this 'text control' condition and the semantic content of this speech signal was not reduced. All background speech conditions were presented at L_{eq} = 55 dBA.

The same reading task was used as in Experiment 1. Additionally, a verbal serial recall task was included. Here, the digits 1 to 9 were presented successively in a randomized order during the different background sound conditions. The participants were asked to recall the numbers after a short retention interval of 10 s in their exact presentation order.

Participants began with the serial recall task and after completing this task during all sound conditions, the reading task followed. Here, twelve four-sentence trials (cp. Experiment 1) were performed during a sound condition before the next sound condition started and the additional twelve trials were completed. Succession of sound conditions was counterbalanced over participants.

Results

In the serial recall task, each digit not recalled at its previously presented position is counted as an error. Mean errors are depicted in the left panel of Figure 2 for each sound condition. T-tests verify that all background speech conditions result in significantly more errors compared to silence (p < .001, two-tailed). This holds true independently of coherence of background speech, i.e. background speech conditions differ not significantly from each other (p ≥ .108, two-tailed).

The same result pattern is observed for word recall performance (Figure 2, right panel). Here, error rates are significantly higher during all speech conditions compared to silence (p < .001, two-tailed). Error rates during unrelated sentences are in tendency higher than during unrelated words, multiple word phrases and 'text control' (.053 ≤ p ≤ .103, two-tailed) while all other comparisons between speech conditions are non-significant (p ≥ .280, two-tailed).

Finally, analyzing performance in the sentence verification task reveals an unexpected non-effect of background speech conditions. Pooling error rates over all participants results in mean error rates between M=36 % and M=39 % per sound condition. According to this, there are no significant differences between sound conditions: speech conditions neither differed significantly from silence (p ≥ .27, two-tailed) nor from each other (p ≥ .29, two-tailed).

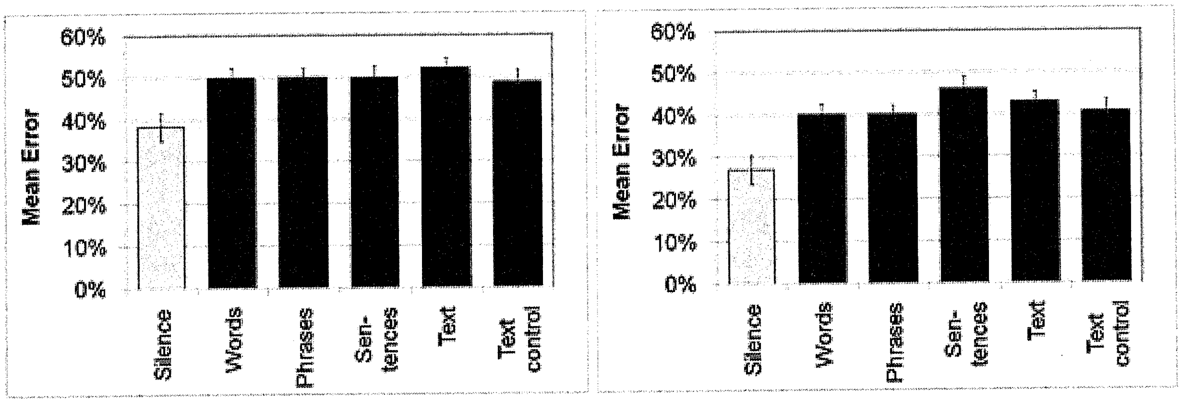

Figure 2: Impact of speech conditions varying in coherence on serial recall performance (left panel) and word recall (right panel) in Experiment 2 (n=24). Error rate means with standard errors are plotted.

CONCLUSIONS

At many office workplaces employees must perform verbal tasks, such as reading or writing text. Often they must do so in the presence of background speech due to conversations or phone calls among colleagues. The interference by process principle (e.g. Macken et al. 1999; cp. Introduction) suggests that a background sound reduces performance if the cognitive processes involved in the voluntary processing of the task compete with the automated processing of the ambient sound. Two experiments tested the interference by process principle with respect to semantic processing. Therefore the semantic content of ambient speech was varied as well as the extent to which performance in a given task relied on semantic processing. For experimental realization of the latter aspect, a reading span task encompassing two subtasks was used. These subtasks differed regarding the necessity of semantic processing for successful task performance: Whereas the subtask 'word recall' did not require semantic processing, the subtask 'sentence verification' could not be solved without semantic processing of the presented text. The semantic content of background speech was varied by playing-back mother tongue compared to foreign language (Experiment 1) or by step-wise reducing mother tongue's coherence from stringent text to unrelated words (Experiment 2).

The result pattern of Experiment 1 is in line with the interference by process principle. Semantically meaningful speech (i.e., unrelated sentences in mother tongue) reduced performance in the sentence verification subtask significantly in contrast to semantically neutral speech (i.e., narration in foreign language). In the subtask 'word recall', however, the two speech conditions caused a similar decline of performance compared to silence. Thus, the detrimental impact of background speech only varied with its semantic content if task performance relied on semantic processing. These findings of Experiment 1 also comply with the extant literature. Several studies verified that semantically meaningful background speech impairs reading comprehension and performance in other complex verbal task significantly more so than semantically neutral speech (e.g. Jones et al. 1990; Miles et al. 1988; Martin et al. 1988; Oswald et al. 2000). On the contrary, the detrimental impact of background speech on simple reproduction tasks has been shown to be independent of its semantic content (e.g. serial recall; cp. Colle 1980; Ellermeier & Hellbrück 1998).

Experiment 2 was based on a step-wise reduction of the semantic content of background speech by reducing its coherence from stringent text, to unrelated sentences, to multiple word phrases, and, finally, to unrelated words. As expected, all speech conditions significantly reduced performance in the subtask 'word recall'; however, speech conditions did not significantly differ from each other. This pattern of results was also found in the included serial recall task. All background speech conditions reduced performance significantly in this pure reproduction task, irrespective of the coherence of the background speech signal. In contrast to Experiment 1, however, background speech did not affect performance in the sentence verification subtask and, thus, reading comprehension. This surprising non-effect might be due to a small effect size of the disturbance impact of background speech on reading comprehension tasks. Thus, the effect might not show up when relatively small samples sizes are tested (n = 24 in Exp. 2 compared to n = 32 in Exp. 1).

The presented results do not fully support the 'interference by process' principle (e.g. Macken et al. 1999). However, Experiment 1 provides some evidence for the special role of the semantic content of background speech for its impact on reading comprehension. This experimental results are consonant with extent studies which also corroborate that performance in complex verbal tasks is impaired less if the semantic content of background speech is reduced (e.g. Jones et al. 1990; Miles et al. 1988; Martin et al. 1988; Oswald et al. 2000).

These empirical findings may provide a hint towards an approach to deal with acoustic disturbance in offices. In open-plan offices employees have to accomplish cognitive tasks in the presence of background speech. Reducing the intelligibility of background speech – e.g. by masking – may help employees to perform better. Reduced speech intelligibility implies that fewer words are understood compared to a highly intelligible speech signal indicated by high word identification rates. Considering that one or even several words that are crucial for the extraction of a sentence's informational content are not understood, less intelligibility can be equated with a diminished semantic content of the background speech signal (e.g. '__ go to __ in __.' or 'We go to __ in July.' instead of 'We go to London in July.'). Venetjoki et al. (2006) provide experimental evidence for these assumptions since these authors found less intelligible background speech to have less negative effects on proofreading compared to highly intelligible speech.

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Room acoustics and work performance - experimental study in a full-scale open-plan office laboratory

Annu Haapakangas[1], Valtteri Hongisto[1], Joonas Kokko[2], David Oliva[1], Jukka Keränen[1], Jarkko Hakala[1], Jukka Hyönä[2]

[1] Finnish Institute of Occupational Health, Indoor Environment Laboratory, 20520 Turku, annu.haapakangas@ttl.fi

[2] University of Turku, 20014 Turku, Finland, jukka.hyona@utu.fi

SUMMARY

The aim of the study was to show that the room acoustic design of an open-plan office that contains speech sounds has an effect on cognitive work performance, acoustic satisfaction and perceived workload. The study was carried out in an open-plan office (90 m^2). Four acoustic conditions, with different speech privacy levels, were built. The conditions were created by changing the acoustic environment using screens, absorbers, and a speech masking system. Speech was produced from empty workstations. In addition, a silent condition was used as a reference condition. Altogether 119 subjects participated in the experiment (a between-groups design). Subjects were exposed to the acoustic condition for nearly 4 hours. Performance was measured with several cognitive tasks which are essential for many kinds of office work. Questionnaires were used to gather information on acoustic satisfaction and subjective workload. The silent condition was the most beneficial acoustic condition. The condition with the lowest speech privacy was the least beneficial. The experiment has high practical relevance for the acoustic design guidelines as the acoustic conditions of this experiment can be realized in open-plan office workplaces.

INTRODUCTION

According to Hongisto (2005), cognitive performance decreases with increasing speech intelligibility. The result has high practical significance as it promotes noise control in open-plan offices where irrelevant speech is the most significant indoor environment problem (e.g., Kaarlela-Tuomaala et al. 2009). Speech intelligibility can be predicted very reliably by measuring the Speech Transmission Index, STI, between the speaker and listener. STI ranges between 0.00 and 1.00, with the highest values indicating perfect speech intelligibility and low speech privacy. In open-plan offices, a low STI (i.e. high speech privacy) is desirable in areas where tasks requiring high concentration and confidential conversations take place. STI can be reduced by reducing the signal-to-noise ratio of speech. This is done by reducing the level of speech (absorption, screens) and by increasing the background noise level up to 45 dBA (speech masking).

In previous experimental work (see review in Haka et al. 2009) the manipulation of STI has been done by electrical means. That is, different STI levels have typically been realized simply by changing the signal-to-noise ratio of speech. In these experiments, the STI (or speech intelligibility) has been kept constant during each sound condition. However, the STI strongly depends on the distance of the speech source (Figure 1). Therefore, an exact STI value cannot be determined for an open-plan office but it varies depending both on room acoustic conditions and the distance between a speaker and a listener. Literature lacks an experimental study where the exposure to speech is implemented using realistic open-plan office conditions where