Transferability of the results from laboratory basic research on cognitive impairment by background sound to real life offices

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ABSTRACT

The Irrelevant Sound Effect (ISE) is considered to be of great practical importance to real-life work tasks, like in open-plan offices. The knowledge about the physical parameters determining the ISE has also been implemented in national and international standards determining the physical set values for the acoustic design of open-plan offices. However, it may be questioned whether this phenomenon, which stems from basic research in cognitive psychology, can easily be generalized to office environments. Simplifications and means of control applied to laboratory experiments guarantee for reliability and internal validity of the experimental results. However, external validity may be questioned. Details of the real life environment must be properly considered. This paper focusses on the relevance of specific sound conditions. Results are reported which address the relevance of the number, gender and location of speakers for the ISE to arise.

Keywords: open-plan offices, cognitive performance, validity I-INCE Classification of Subjects Number(s): 63

1. INTRODUCTION

It has often been shown that presentation of background sound, in particular background speech, leads to an impairment of verbal short-term memory performance, even so the memory task is presented visually and the background sound is supposed to be ignored (for a review see 1, 2, 3). The term Irrelevant Sound Effect (ISE) was chosen for this phenomenon (4). It is triggered by a combination of memory tasks where items have to be remembered in strict serial order and background sounds which are acoustically changing. This is termed the changing-state effect (5). The ISE is explained by the interference by process account of auditory distraction, which relies on the assumption that serial processing of the items of the memory task collides with the automated serial processing of the background sound (6, 7). Recently the phenomenon could be analysed more accurately by separating between changing-state and deviation effects as different means of auditory distraction. This finding has been termed the duplex theory of auditory distraction (8, 9).

The ISE is considered to be of great importance to everyday performance at workplaces like open-plan offices (5). This led to an implementation of physical set values for the acoustic design of open-plan offices in the ISO 3382-3, which are connected to physical parameters determining the ISE. The intelligibility of speech produced by colleagues at distant work stations in an open-plan office is considered to be connected to the decline of performance. Based on a review of empirical studies of background speech on cognitive performance, Hongisto (10) developed a model for the prediction of the disturbance impact of background speech as a function of the so-called speech transmission index (STI). The STI determines the quality of speech transmission on its path from the speaker to the listener (11). This measurement for the intelligibility of speech can vary between 0 and 1, where 0 is “absolutely unintelligible” and 1 is “perfectly intelligible.” It is assumed that with increasing STI – and thus increasing intelligibility of the background speech – the disturbance impact increases. The distraction distance (r_D) is used as an easy to handle measure for the evaluation of the acoustic quality of open-plan offices. It describes the distance in meters, where the STI falls below a value of 0.5. From this distance to the speaker, the disturbance impact should be lower and it should decrease even further

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as distance further grows. The radius of distraction (r_D) is connected to the STI – and thus to speech intelligibility – as it describes how well a speech signal's intelligibility is attenuated on its spatial way to the listener's ears due to the acoustic room characteristics and the existence of sound absorbing as well as insulating materials or sound masking respectively.

There is also a remark within the ISO 3382-3 which indicates that the negative impact of background speech may diminish or even vanish, if multiple speakers are present. This assumption is based on basic research findings on the ISE. It was shown by Jones and Macken (12) that the ISE is diminished if at least four speakers are present and that error rates continue to decline when the number of speakers is raised to 5 or 6. Similar results have been reported by Kilcher and Hellbrück (13), who found reduced error rates with 8 background voices. A study by Kittel, Wenzke, Drotleff and Liebl (14) tried to transfer these findings to an experimental setup which is closer related to a real workplace setting. Here, it was tested whether the babble of 6 distant speakers can mask a disruptive speaker who is placed close to the receiver. Therefore an open-plan office was simulated and the auralised acoustics were presented to test persons in a laboratory experiment. The results showed a significant trend towards an improvement of verbal short-term memory performance when the number of babble voices increased from 1 to 6. However, it is important to mention that the same voice data was used for the speaker and the babble voices, additionally the latter were all located at the same position in the simulated open-plan office. This means that the frequency characteristics were identical and the babble voices could not be locally separated thus the masking effect may be exaggerated as compared to a situation with different voices at different locations.

It may be concluded so far that the knowledge about the ISE is mainly based on basic research in cognitive psychology and it relies on experiments, where the effects of single speakers or artificial sounds were tested. Recommendations for the design of workplaces are derived from these results. However, acoustics in open-plan offices usually comprise multiple different speakers which are locally separated within the office. Thus two experiments are reported which investigate the relevance of the number, gender and location of speakers for the ISE to arise or rather to diminish.

Experiment I is aligned to the investigation by Kittel et al. (14) but the number of babble voices is raised to 12 and the male speaker voice is contrasted to a female speaker voice.

Experiment II explores the role of spatial location by contrasting the effect of 1 speaker voice and 5 babble voices in one location to the effect of 5 babble voices with a horizontal separation by an angle 60° each.

2. EXPERIMENT I

2.1 Participants

A total of 19 students (7 female, 12 male) from the University of Stuttgart aged between 20 to 28 years (Md = 23) voluntarily took part in the experiment. A small allowance was paid for participation.

2.2 Materials

The acoustics of an open-plan office was simulated using ODEON room acoustics software. The modelled room is characterized by a spatial decay rate of speech ($D_{2,S}$) corresponding to 4 dB (A) and by a sound pressure level of speech at a distance of 4 m ($L_{p,A,S}$) corresponding to 50 dB (A). The distraction distance (r_D) is 6.2 meters. A background noise with a decrement of 5 dB per octave band and a total level of 38.9 dB (A) was applied. The speaker was placed at a distance of 2 meters from the receiver. The babble voices were all positioned at the same location 8 meters away from the receiver. For both the speaker voice and the babble voices unrelated sentences of the German HSM speech intelligibility test (15) were used. The male speech signals were adjusted to correspond to the sound power spectrum of normal speech according to ISO 3382-3. Since the HSM speech intelligibility test is only available with a male speaker the sentences were also read by a female speaker and recorded. Figure 1 depicts the simulated open-plan office.

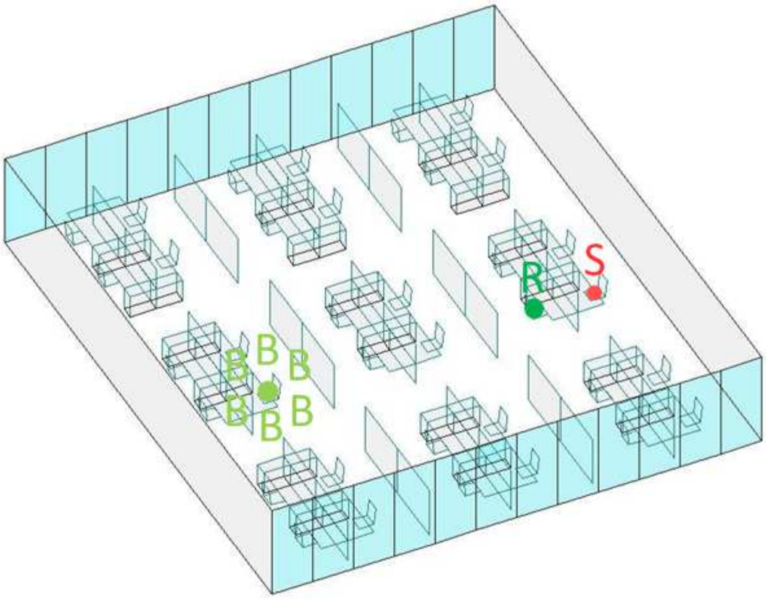

Figure 1 – Schematic view of the simulated open-plan office (R = Receiver, S = Speaker, B = Babble)

In total 10 sound scenarios were tested which are described in table 1. The sound level of the speaker voice was adjusted to 49.6 dB(A) and the background noise was 38.9 dB(A). The sound level of the babble voices increased with a growing number of babble speakers corresponding to a real multiple speaker situation.

Table 1 – Description of sound scenarios (Scenario 1 is the reference condition, which is silence. Scenario 4 was generated without the background noise)

Scenario	Number of babble voices	Speaker voice	Sound level babble voices (dB(A))	Total sound level (dB(A))	Signal to noise ratio (dB(A))	STI
1 (Silence)	-	-	-	-	-	-
2	0	male	-	50.0	10.7	0,61
3	1	male	42.9	51.0	5.2	0,49
4	1	male	42.9	50.7	6.7	0,53
5	1	female	42.9	51.0	5.2	0,51
6	2	male	45.9	51.6	2.9	0,43
7	4	male	48.9	52.6	0.3	0,35
8	6	male	50.7	53.5	-1.4	0,30
9	6	female	50.7	53.5	-1.4	0,37
10	12	male	53.7	55.5	-4.1	0,23

2.3 Procedure

The experiment was conducted in the indoor environment laboratory of the Fraunhofer Institute for Building Physics. Each participant performed a digit span task under presentation of a balanced order of all background sound scenarios. A random sequence of the digits 1 to 9 was presented. Each digit was shown individually for 300 ms and the interstimulus interval was 700 ms. The digits had to be remembered in the strict order of presentation after a retention interval of 8000 ms. Participants also had to rate the perceived loudness and annoyance of every sound scenario and the NASA-TLX (16) questionnaire was used. Additionally a sentence intelligibility test was applied. The experiment was run on iMAC computers using Psyscope version X B57 for the digit span task and the speech intelligibility test. The software Limesurvey was used for the questionnaires. All sounds were presented via Sennheiser HD 280 Pro headphones.

2.4 Results

Figure 2 depicts the observed error rates during processing of the digit span task under presentation of the different sound scenarios. Performance during silence is best and it is worst if only the speaker is audible. The data of the subjective ratings and intelligibility test is not reported here.

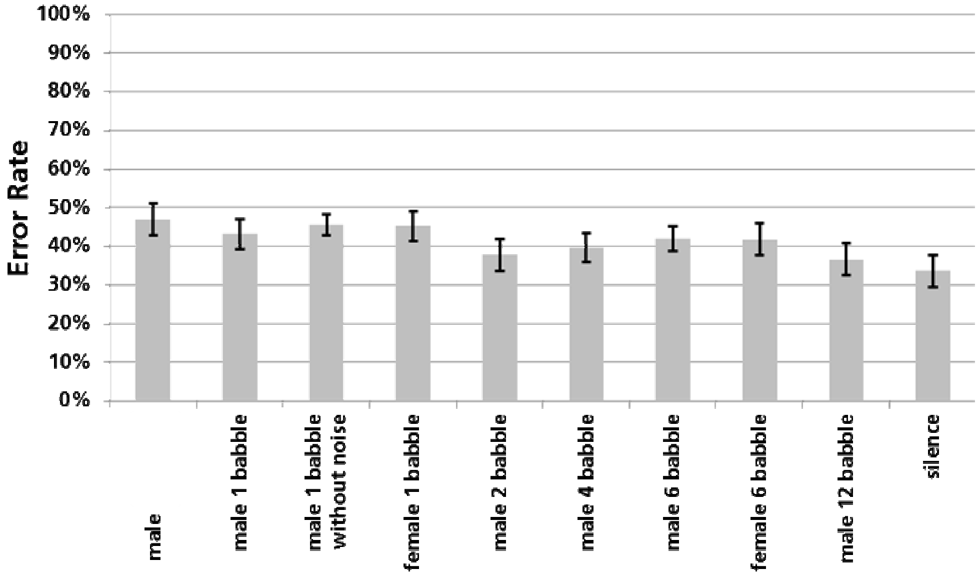

Figure 2 – Mean error rates and standard errors in the digit span task depending on sound scenario

A single factor (Sound) repeated measures ANOVA was conducted and revealed a statistical significant effect of the factor Sound ($F(9, 162) = 4.62$; $p < .01$; $\eta 2 = .204$). One-tailed t-tests with Bonferroni-Holm correction were calculated to compare every condition to the silence condition. The results are shown in table 2.

Table 2 – Results of pairwise comparisons (t-tests)

Comparison	t	df	p
silence – male	-8.14	18	<.01
silence – female 1 babble	-4.85	18	<.01
silence – male 1 babble without noise	-4.62	18	<.01
silence – male 1 babble	-3.86	18	<.01
silence – female 6 babble	-2.51	18	<.05
silence – male 6 babble	-2.29	18	<.05
silence – male 4 babble	-1.99	18	>.05
silence – male 2 babble	-1.36	18	>.05
silence – male 12 babble	-1.27	18	>.05

It is surprising to see that there are no significant differences between silence and male 4 babble as well as silence and male 2 babble but that there are significant differences between silence and male 6 babble as well as silence and female 6 babble. A stepwise decrease of error rates connected to the stepwise increase of babble voices was expected. However, the largest abatement of error rates is observed when 12 babble voices are presented. There is also no significant difference between male 6 babble in comparison to female 6 babble ($t(18) = -0.43$; $p > .05$) which points to minor importance of the speech spectrum with regard to the ISE.

3. EXPERIMENT II

3.1 Participants

A total of 21 students (9 female, 12 male) from the University of Stuttgart in the age of 19 to 46 years (Md = 24) voluntarily took part in the experiment. A small allowance was paid for participation.

3.2 Materials

Figure 3 depicts the experimental setup in the indoor environment laboratory. In total 4 sound scenarios were tested which are described in table 3. The speaker voice and 5 babble voices were either presented in one location from an angle of 0° or the 5 babble voices were horizontally shifted by an angle of 60° each.

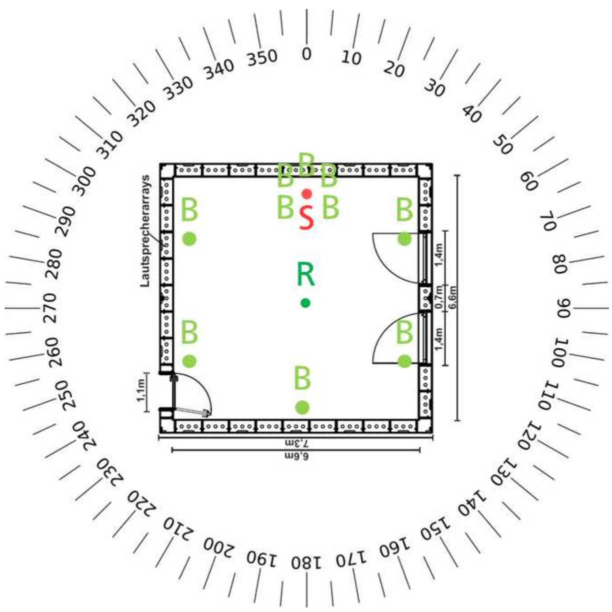

Figure 3 – Schematic view of the experimental setup in the indoor environment laboratory (R = Receiver; S = Speaker, B = Babble)

The sound level of the speaker voice was adjusted to 48.0 dB(A). The 5 babble voices were adjusted to add up to 48.0 dB(A) which means their individual level was about 41.0 dB(A). The level difference between speaker voice and single babble voices was applied to account for the assumed differences in distances between a close speaker and more distant babble voices. However, since the five babble voices add up to 48.0 dB(A) a signal to noise ratio of 0 dB(A) between the speaker and the babble voices is realized when they are all presented from an angle of 0°.

Table 3 – Description of sound scenarios (Scenario 1 is the reference condition, which is silence)

Scenario	Description	Total sound level
1	Silence	-
2	1 speaker voice (0°)	48.0
3	1 speaker voice (0°) and 5 babble voices (0°)	51.0
4	1 speaker voice (0°) and 5 babble voices (60°, 120°, 180°, 240°, 300°)	51.0

3.3 Design and Procedure

The experimental task corresponds to Experiment I and also the same questionnaires were applied. The order of presentation of the different sound scenarios was again balanced. The sounds were presented with the 3 D audio system based on the principle of wave field synthesis. Participants were seated in the middle of the room.

3.4 Results

Figure 4 depicts the observed error rates during processing the digit span task under presentation of the different sound scenarios. Performance during silence is best and it is worst if only the speaker is audible.

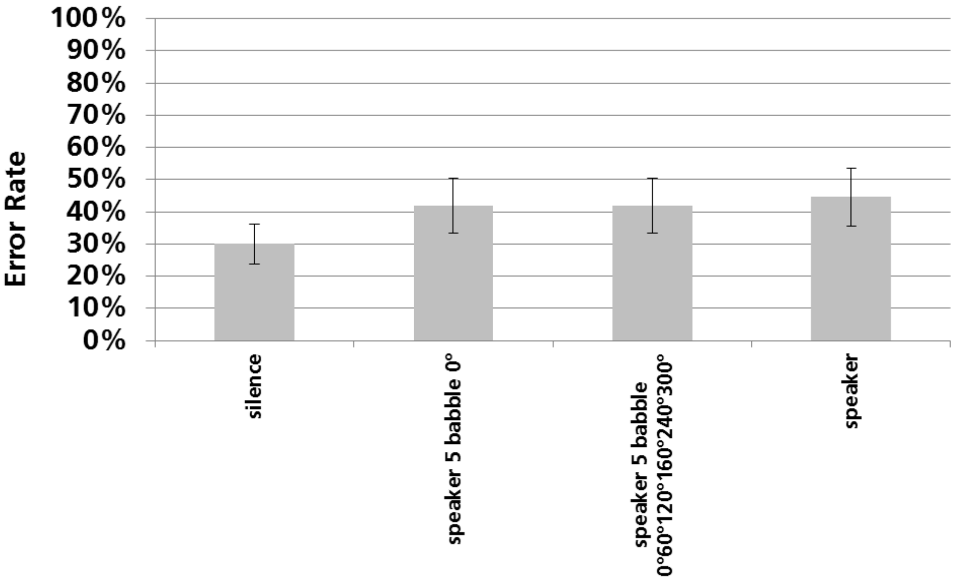

Figure 4 – Mean error rates and standard errors in the digit span task depending on sound scenario

A single factor (Sound) repeated measures ANOVA was conducted and revealed a statistical significant effect of the factor Sound ($F(2.1, 41.3) = 12.41$; $p < .01$; $\eta 2 = .383$). One-tailed t-tests with Bonferroni-Holm correction were calculated to compare every condition to the silence condition. The results are shown in table 4.

Table 4 – Results of pairwise comparisons (t-tests)

Comparison	t	df	p
silence – speaker	-5.31	20	< .01
silence – speaker 5 babble voices (60°, 120°, 180°, 240°, 300°)	-3.84	20	< .01
silence – speaker 5 babble voices (0°)	-3.47	20	< .01

It is surprising to see that there is a significant difference between silence and speaker 5 babble 0°. So there is no hint towards a relief from the ISE by the babble voices. There is also no significant difference between speaker 5 babble 0° in comparison to speaker 5 babble 60°120°180°240°300° ($t(20) = 0.23$; $p > 0.5$) which was expected from the findings reported in literature so far.

4. CONCLUSIONS

It was shown in Experiment I that the presence of distant babble voices can diminish the disruption of verbal short-term memory caused by a speaker. However, the pattern of results is inconsistent since there is no linear relationship between the number of speakers and the diminution of error rates. There is also no difference between a male and a female speaker voice but this might be due to the fact that six babble voices were not enough to establish a reduction of the ISE. It may be concluded at this point that the number of speakers necessary to achieve a distinct effect is higher than was reported in literature so far.

In Experiment II no difference was found between the single speaker voice and the single speaker voice accompanied by the 5 babble voices. There is no relief from the ISE and the local separation of the babble voices yielded no additional effect. This result is unexpected. However, it follows from Experiment I that a higher number of babble voices might be necessary to establish a reduction of the ISE. So it is necessary to conduct further experiments with a higher number of babble voices to further investigate the relevance of spectral differences and location of speaker and babble voices.

From a practical viewpoint the reported results somehow question the STI as a physical set value for the evaluation of the acoustic quality of open-plan offices. A radius of distraction (r_D) < 4m can hardly be achieved in open-plan offices with usual room acoustical measures. However, the results of Experiment I indicate that even lower STI values than 0.5 are necessary to establish a stable relief from the ISE. It follows from this that the STI value which is used to determine r_D should be smaller than 0.5. Then again r_D will increase dramatically beyond 4 m and hardly any workplace within a usual open-plan office will be placed outside r_D. Additionally it seems that the relief from the ISE by babble voices is something that will hardly be found in the field, because such a high number of concurrent babble voices can only be found in very large offices with a high rate of communication work. It may be concluded from this that the findings from basic research laboratory experiments cannot easily be transferred to workplace settings. The specific characteristics of the workplace settings must be reconsidered and investigated.

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