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Writing performance in open-plan study environments: a laboratory study

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ABSTRACT

An increasing number of students work in open-plan study environments (OPSEs). OPSEs can be characterized by young users, a variable occupancy rate and a mix of individual and group activities. The occupancy rate, activities of students in an OPSE as well as the acoustic parameters of an OPSE determine the intensity and intelligibility of background speech. Especially this irrelevant speech appeared to be very disturbing in a recent OPSE field research [1]. The aim of this study is to analyze the influence of background speech characteristics in combination with reverberation time on writing performance, an important task in an OPSE. Computational modelling and auralization are used to simulate an OPSE. Four signals were composed by combining two different reverberation times with two different speech conditions. One signal was a silent control condition. Forty-two subjects had to write five short essays while being exposed to these acoustic sound signals via headphones. Results on writing speed, keystrokes per minute, show that the situation with much background speech and a high reverberation time has the most detrimental effect on writing performance.

INTRODUCTION

Due to new ways of learning in higher education there is a growing importance of a diversity of learning settings [2]. Not only the well-known formal classroom or lecture hall setting but also more informal learning settings are desirable in higher education nowadays. These informal learning places are diverse, they vary from corridors and coffee shops to libraries. Informal learning spaces, intended and designed for students to accommodate individual study activities as well as small group activities, further named open-plan study environments (OPSEs), are subject of this paper. Although OPSEs are designed to accommodate study activities a recent study on 5 OPSEs [1] showed that 38% of the surveyed students were disturbed by background noise. The most disturbing sound sources were intelligible and unintelligible speech and students were mostly disturbed when performing complex cognitive tasks like studying for an exam, reading and writing. From those activities writing proved to be the most performed activity in an OPSE and therefore the activity that will be tested in this research.

Earlier studies showed the influence of irrellevant background speech on writing performance [3] [4] [5]. One theory to explain these negative effects of background speech is that the processes needed to unintendedly analyze the semantical content in the background speech signal are interfering with similar intended processes needed for writing, the so called theory of interference- by- process [6] [7].

In the writing performance studies in literature one or more voices in combination with white or pink noise were used as background sound signals. In the present study also the room acoustic parameter reverbration time is taken into acount. The intellegibility of speech in a room expressed by the speech tranmission index (STI) value depends on the reverberation time and the background noise level in a room [8]. Therefore, in this experiment both parameters reverberation time and background speech are studied in relation to writing performance.

MATERIALS AND METHODS

Participants

A total of 42 Dutch students (27 male and 15 female) from Avans University of Applied Sciences aged 18 to 27 years (mean=20.7) participated in this study. The students received a cinema ticket or an internet voucher as compensation for participation.

Materials

Five sound conditions were composed, four comprising different background sounds and one silent condition. The four acoustic environments comprising background sounds were created by an auralization based on impulse responses computed for two room acoustic models of the 3rd floor of the Vertigo building, an open-plan study environment of the Eindhoven University of Technology with a volume of 2750 m^3. The commercial software Odeon (version 12.12) was used for acoustic computational modelling and auralization. One model of the open-plan study environment was calculated with sound absorbing walls, ceiling and floor (Table 1) which resulted in a very absorbing OPSE (reverberation time T_{30}=0.6s) and a second model was calculated with acoustical reflecting walls, ceiling and floor (Table 1) which resulted in a very reverberant OPSE (T_{30}=2.3s).

Table 1: Most important materials and absorption coefficients used in the Odeon models.

Materials	Absorption coefficient					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sound absorbing model:						
Ceiling: sound absorbing ceiling	0.40	0.85	0.99	0.90	0.99	0.99
Floor: carpet	0.05	0.10	0.30	0.70	0.90	0.75
Walls: perforated panels	0.39	0.94	0.92	0.68	0.69	0.58
Reverberant model:						
Ceiling: concrete	0.02	0.03	0.03	0.03	0.04	0.07
Floor: linoleum	0.02	0.02	0.03	0.04	0.04	0.05
Walls: unperforated panels	0.08	0.11	0.05	0.03	0.02	0.03

In both models, 3 and 14 talkers were implemented producing background speech. As a result, 4 sound conditions were created:

- absorbing OPSE (T=0.6s) with 3 talkers
- absorbing OPSE (T=0.6s) with 14 talkers
- reverberant OPSE (T=2.3s) with 3 talkers
- reverberant OPSE (T=2.3s) with 14 talkers

The positions of the listener and the 14 talkers are illustrated in Figure 1.

The background speech consisted of stories of students about their studies and work. The stories were recorded in a highly sound absorbing setting. By convolving the recorded speech signals with the binaural impulse responses calculated using the Odeon software a stereo sound signal was composed suitable for playback through headphones. The speech signals were adjusted to the sound power spectrum of normal speech according to ANSI 3.5 [8]. The sound signal in the control situation was a pink noise signal at the same background noise level as in the OPSE without people. The sound levels of the separate sources (talkers) at the receiver position as well as the total sound levels of the different conditions calculated by Odeon are described in Table 2.

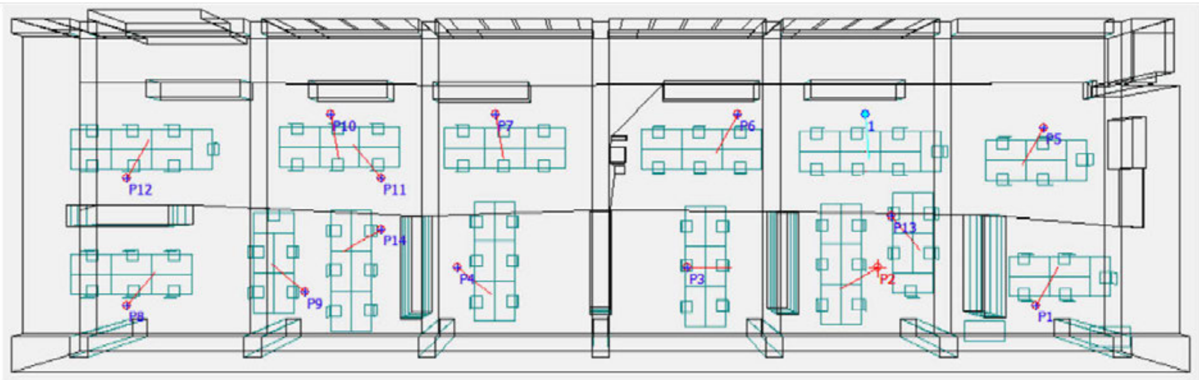

Figure 1: Positions of receiver (1) 14 sources (P1-P14), with the lines indicating the listening and talking direction.

Table 2: Description of the sound sources (talkers) in the absorbing and reverberant model of the OPSE Vertigo floor 3.

Talker	Talkers in model		Gender	Sound level at receiver 1 calculated by Odeon (dB(A))	
	3	14		absorbing model	reverberant model
1		*	male	39.3	54.3
2		*	male	46.5	54.5
3		*	female	44.4	53.7
4	*	*	male	39.5	51.5
5		*	female	45.9	54.6
6		*	female	44.2	53.2
7		*	female	39.7	51.3
8	*	*	female	31.8	48.5
9		*	female	28.9	48.0
10		*	female	39.8	49.9
11		*	female	33.5	49.8
12	*	*	male	33.7	48.2
13		*	male	47.5	54.9
14		*	female	28.8	47.8
control - pink noise				30.0	
14 talkers				53.8	63.7
3 talkers				41.1	54.4

Design and Procedure

A within-subjects design was used and a silent control condition was added. The analyzed depending variable was the total number of key-strokes per minute (including deleted characters), the so called fluency. The independent variables were five sound conditions composed of two reverberation times and two different occupancies and a silent condition.

The participants carried out the test individually in a small quiet room in front of a laptop. The room was situated in a back-office of Avans University of Applied Sciences and had a window looking out to the street. The participants wore headphones (Sennheiser SD280 Silver) during the whole experiment.

After a short oral introduction a training phase of 2 minutes was started to get used to the procedure. The participants had to write stories related to the following five themes displayed on a computer screen: study, hobby, holidays, previous study, future plans. For each theme, the writing time was set to 5 minutes.

The themes were presented in the same order to all the participants. The five sound conditions were presented in a counterbalanced sequence using a Latin Square design. The participants were asked to write as quickly and as accurately as possible. Afterwards they filled in a short questionnaire about their experiences during the writing experiment and the reduced version of the NoiseQ sound sensitivity questionnaire developed by Griefahn (2008) [9]. The whole experiment lasted about 45 minutes for one participant. InputLog [10] was used to analyze the writing data, a key logger that observes the writing process.

RESULTS

Fluency

The total number of keystrokes per minute in relation to the different noise conditions is illustrated in Figure 2.

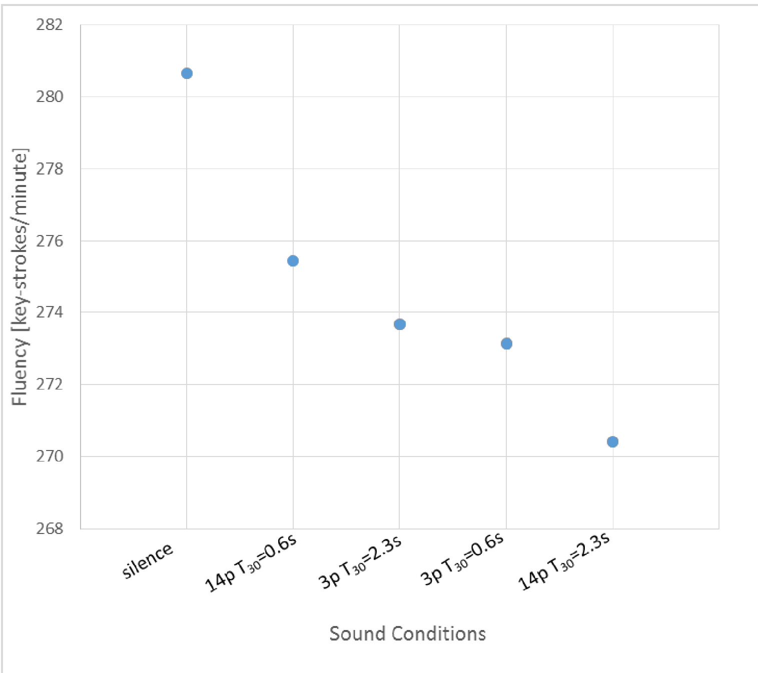

Figure 2. Mean fluency for the five different sound conditions

A repeated measures analysis of variance (ANOVA) across the five sound conditions revealed no significant effect of the sound condition ($p = 0.124$). A follow-up pairwise comparison t-test showed significant differences between the silent condition and the reverberant condition (T_{30}=2.3s) with 14 talkers ($t(42)=2.533$, $p=0.015$) and between the silent condition and the reverberant condition (T_{30}=2.3s) with 3 talkers ($t(42)=2.069$, $p=0.045$). The differences between all the other conditions were not significant ($p>0.05$).

Questionnaire

The results of the questionnaire showed that the participants of the experiment experienced a detrimental impact of the background noise on their writing performance. The differences between the mean values of the effects of background sounds were verified with the Friedman test. The values ($\chi^2(39)=6.222$, $p<0.045$) showed significant differences. The participants expected the writing speed (mean=3.0 on a 4 point scale, SD=0.963) to be influenced the most, then the quality of the story (mean=2.62, SD=0.795) and spelling the least (mean=2.49, SD=0.914). Post hoc pair wise comparisons by the Wilcoxon signed rank test including the Bonferroni correction, revealed a significant difference between the expected influence on writing speed and spelling ($Z = -2.370$, $p = 0.018$).

Estimated STI values

Although in literature a significant influence of irrelevant background speech on writing performance was found [3][5] in this study only a significant influence on fluency was found between the silent condition and the reverberant conditions. In the study of Keus van de Poll [3], a decrease in writing performance was established between STI values of 0.23 and 0.34, and no further significant decrease in performance was found when the STI was exceeding 0.34. One voice was mixed with pink noise to create different STI values [3]. In an OPSE the situation is different, there are multiple background voices, where nearby voices are masked by various other voices. In such a condition, the computation of the STI is less straightforward.

An approximation of the STI was made by means of an estimation of the background noise. The background noise level due to the irrelevant speech was based on measuring the $L_{Aeq,}$ and L_{95} of the different sound conditions. The L_{95} is the sound level that is exceeded 95% of the time. The L_{95} has been widely adopted to quantify background noise levels of fluctuating signals.

The estimated STI values were calculated between the nearest and loudest voice (speaker 13) and listener 1 by Odeon using the measured L_{95} and L_{Aeq} values as background noise, see Table 3.

Table 3. Estimated STI values in four different sound conditions between speaker 13 and listener 1.

	3 persons speaking	14 persons speaking
L_{95}		
T_{30}=0.6s	0.72	0.43
T_{30}=2.3s	0.43	0.22
L_{Aeq}		
T_{30}=0.6s	0.59	0.31
T_{30}=2.3s	0.34	0.16

The estimated STI values based on L_{Aeq} and L_{95} can be discussed, as speech as background noise is a different sound source than noise from e.g. trains, cars, industry or pink or white noise. Nevertheless, comparing the estimated STI values of the sound conditions one may expect, according to literature [3] [11], the following ordening of writing productivity from most productive to less productive (in order of increasing STI values): 14 persons reverberant, 14 persons absorbing, 3 persons reverberant, 3 persons absorbing. Comparing this order to Figure 2 the most reverberant and multiple speaker situation does not meet the expectation. This sound condition proved to be the least productive sound condition instead of the most productive sound condition as can be seen in Figure 3.

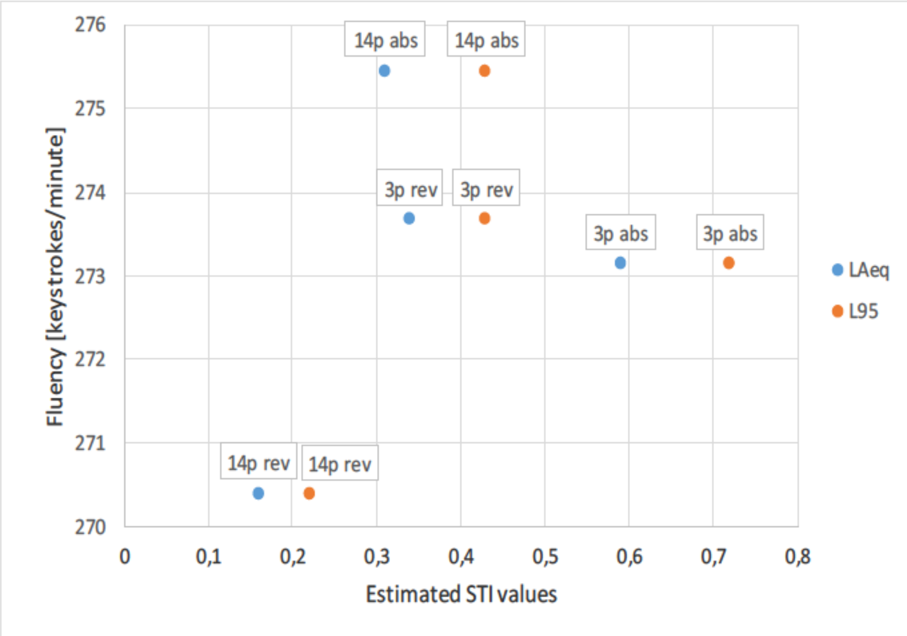

Figure 3. Writing performance for estimated STI values sound conditions.

DISCUSSION

Although no significant effects of the different background sound conditions were found, there were significant differences between the silent situation and the reverberent situations which indicates an impairing of writing performance by background speech in a reverberant condition.

The absence of significant differences between the different background sound conditions can be the result of:

- The background sound conditions.
  the range of estimated STI values in this research was, based on L_{Aeq} background noise, $0.16 \leq STI \leq 0.59$ and based on L_{95} background noise, $0.22 \leq STI \leq 0.72$. In the research of Keus vd Poll [3] the significant differences in her studie were found when $STI<0.34$ [3] and no significant differences were found in the same range in the present study.
- The writing assignment.
  the writing assignment seems to be a less complex assignment than in comparable writing tests in literature [3] [5]. A less complex writing assignment might be less influenced by background speech and might induce a higher fluency or smaller differences of fluency between the sound conditions.
- The test condition.
  a window with a view on the street was situated in the test room, this might have been a distractive effect on the students and might have been influencing the significance of the results.

The use of the L_{Aeq} and L_{95} as the background sound level to determine the STI should be studied. The STI proved to be a good predictor of productivity [11] [3] and therefore an important parameter to calculate in room acoustics. Further research will be done to check the reliability of these approaches to determine the background sound from speech needed to calculate the STI value.

The unexpected detrimental influence of the high reverberation time in combination with a high occupancy on writing performance could be the result of the higher sound level. A higher reverberation time not only reduces the speech intellegibility but also increases the sound level. Further reseach will be done on this phenomenon.

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