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Auditory Distraction in Open-Plan Study Environments in Higher Education

Proefschrift

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Summary

Due to new ways of learning in higher education not only classrooms and lecture halls but also informal learning spaces are becoming increasingly important. Students need environments to work on assignments individually or in groups. This research focusses on informal learning spaces, intended and designed for students to accommodate individual study activities, as well as small group activities. These study areas will be referred to as open-plan study environments (OPSEs). OPSEs have a floor plan with large open spaces and no, or only a few, enclosed rooms. This open-plan concept shows much architectural resemblance to open-plan offices, a very popular office design for many years. However, office employees have a lot of complaints about the well-being in their open office environment, and in particular disturbing noise is one of the biggest problems. Although research shows that learning activities can be negatively influenced by noise, and noise disturbance can be expected in OPSEs, there is little research into the acoustics of OPSEs and no room acoustic recommendations are available. Hence, the objective of this research is to gain more insight into the influence of the sound environment on students' performance and well-being in these study environments. Based on the research results, this study aims to make a first step towards acoustic recommendations for OPSEs.

To investigate how students are disturbed by background noise in an OPSE, a field study was conducted in five OPSEs in higher education (Chapter 2). Almost five hundred students participated in a survey to reveal correlations between student tasks, acoustic parameters, noise disturbance and noise sources. Also, room acoustic parameters were measured. This study showed that 38% of the students were much to very much disturbed by background noise. Students were mostly disturbed by intelligible background speech when working on cognitive tasks. Only weak correlations were found between room acoustic parameters and disturbance.

Subsequently, three experimental studies were conducted to investigate correlations between the parameters of representative sound scenarios and the disturbance and performance of students working on a student task. A selection of student tasks was made based on the results of the field study. Sound scenarios were composed by auralization of binaural room impulse responses, obtained by computational modelling of an existing OPSE. Different sound scenarios were created by varying the reverberation time of the OPSE, the number of talkers in the OPSE and the language of the background speech. These variations of parameters resulted in sound scenarios with different intelligibility of the background speech at the listener position.

Firstly, a collaboration task was studied (Chapter 3), the most frequently performed task in an OPSE. This experiment was conducted at the University of Gävle, Sweden. Students worked in pairs to solve 'spot the difference' puzzles, by using the 'DiapixUK' collaboration task. The semantic content (language) and reverberation time were varied in the sound scenarios. No significant influence of the sound scenarios on performance was found. However, it was shown that sound scenarios with a longer reverberation time were the most disturbing

for students. while more intelligible and meaningful speech was not. We interpreted this as a result of an increased difficulty of interpersonal communication, a collaboration sub-task. As a result of an increased reverberation time, the signal-to-noise ratio decreased between the participants due to the increased level of the background speech. The interference of semantic processes showed to be less important for this task.

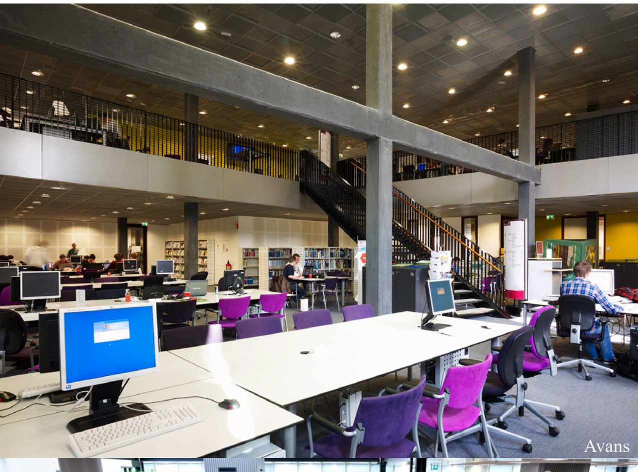
Secondly, the influence of background speech on a writing task was analyzed (Chapter 4). Students had to write five short stories about different landscapes. The sound scenarios varied in number of background talkers (3-14) and reverberation time. The results showed a significant decrease in writing performance of the participants while exposed to the most intelligible background sound scenario, the absorbing environment with only three talkers.

Finally, the most disturbed task in an OPSE, studying for an exam, was analyzed (Chapter 5). Students had to study a text and after a period they had to answer questions about the text. In the period between studying and answering the questions, they had to do logical reasoning and mental arithmetic tasks. The sound scenarios varied in number of background talkers (3-14) and reverberation time. A significant sound effect on self-estimated performance and disturbance was found but not on performance. The absence of a detrimental performance effect is probably a result of focusing due to task engagement in combination with task difficulty, both aspects working as a 'shield against distraction'.

We can conclude that in all experiments the quiet sound scenario was the most preferred sound environment. The interference of intelligible speech on semantic task performance was only shown in the writing experiment, and not in complex tasks where sub-tasks demand different sound conditions. In addition, other factors like sound sensitivity and the importance and difficulty of a task influenced performance and disturbance. A first important step towards recommendations is the recognition of serious sound disturbance in OPSEs. Furthermore, activity based OPSEs, with sections acoustically optimised for specified student tasks, would be a start to develop OPSEs where students are less disturbed by noise and perform better.

Contents

CHAPTER 1



OPSEs

1 | Introduction

"Education is the most powerful weapon which you can use to change the world"
Nelson Mandela

Nelson Mandela argued education to be the most powerful weapon to change the world. He wanted to change people's racist ideas but he also believed education to be the engine of personal development and hence a way to escape poverty and inequity [1]. Universities indeed not only provide knowledge transfer, they also educate students to develop a learning, inquiring, entrepreneurial and responsible attitude [2]. Students have to be prepared for lifelong learning to keep up with, or be responsible for a continuously changing and developing society. Therefore, education will evolve, and new ways of learning must be supported by appropriate new learning facilities. This thesis will focus on the quality of a special learning facility in higher education: open-plan study environments.

Formal learning spaces in schools and universities, such as classrooms and lecture rooms, are meant for courses or other prescribed learning activities. In addition, informal learning environments can be used by students to work on their individual or group assignments and prepare for exams. These informal learning places are diverse: libraries, individual and collaborative study areas, lobbies, atria, corridors, lounges, coffee shops, canteens, restaurants and outdoor places such as meadows [3]. This research focusses on specific informal learning spaces, intended and designed for students to accommodate individual study activities, as well as small group activities, such as individual and collaborative study areas, which will be referred to as: open-plan study environments (OPSEs).

OPSEs in higher education have become more important over the years. Despite existing knowledge about disturbance and loss of performance by background noise in other open work environments, there has been little research on auditory distraction in OPSEs. Furthermore, research also shows that learning activities can be negatively influenced by noise, nevertheless there are no recommendations or requirements for architects or acoustic consultants to design acoustically comfortable OPSEs. Therefore, this thesis presents a study on the influence of the sound environment on student performance and well-being in OPSEs, with the aim to make a first step towards acoustic recommendations for OPSEs.

This introduction will start with a short review on the acoustics of educational spaces and open-plan offices, two indoor environments which are strongly related to open-plan study environments.

1.1 The acoustic environment of educational spaces

1.1.1 Acoustic research on schools and universities

The acoustic environment is one of the many factors of the physical environment of schools and universities that influences students' performance and well-being. It has been shown that inadequate temperature control, lighting, air quality and acoustics will have a detrimental effect on performance and well-being of students [4]. Research on the acoustic environment of schools and universities in relation to performance and disturbance of students has been done for decades. However, these studies have been conducted mostly for classrooms in primary [5,6], secondary [7,8] and higher education [9,10]. The focus of these studies is diverse. Many studies investigated the influence of noise on pupils' performance (e.g. [6,11]), others researched the disturbance of students due to noise exposure at schools [7,8]. In addition, studies on noise levels and room acoustic parameters (e.g. *STI*, T_{30}, *EDT*) were conducted, often to describe the quality of the acoustic environment [7,9,12] or to investigate improvement measures [13,14].

Besides a large amount of research on the acoustics of classrooms, a limited amount of research on noise in open-plan school environments has been carried out. Studies on open school environments are mostly performed on open plan classrooms in primary and secondary schools [14]. Open plan classrooms became very popular in the 1960s and 1970s due to new progressive educational methods in the 60s [15]. Instead of traditional teaching, with a teacher in front of a group of students sitting behind desks, a more informal and less authoritarian student-centred approach was introduced [16]. To accommodate this type of education, open classrooms around a shared resource area became popular. However, later in time (1970-1980s), criticism on this educational approach and classroom design led to a return to traditional classrooms. Most criticism was raised regarding the poor acoustic quality of the open classrooms, which led to noise problems [14]. Now, in the 21st century, new classroom designs are coming up while educators and designers want to build flexible and future proof classrooms. These new classroom designs often have large, flexible open spaces to accommodate different learning methods and working group sizes [17]. Although the classroom designs are renewed, the open spaces could still lead to similar acoustical problems as in the 1960s and 1970s.

While the importance of open learning environments in universities is evident, there is very little research on the acoustics of open learning environments in higher education [18]. To prepare students in higher education for a continuously changing and developing society, students have to develop new competences. They have to take responsibility of their own learning process to be prepared for lifelong learning, needed in a rapid changing society. Students have to learn to collaborate with each other, use networks and make use of information and communication technology (ICT). Therefore, changed educational methods are needed to achieve all these new learning objectives. Furthermore, changes in the university environment are required to facilitate these new ways of learning [19]. Not only classrooms but also informal learning places become more important. Students work outside the classroom in open environments on individual and group tasks. Research of Beckers [18] on 697 students showed that students prefer quiet learning spaces, which indicates the importance of a good acoustic design. Nevertheless, there is a lack of research on the acoustics of open study environments in higher education.

1.1.2 The influence of the sound environment on performance and disturbance

Noise

Noise in schools and universities can be divided in two categories, external environmental noise and internal classroom noise. Important external environmental noise sources are road, rail and air traffic noise but also industrial noise and noise from people outside the school [20]. The internally produced noise levels depend on the sound sources inside the room such as heating, ventilation, and air conditioning (HVAC) noise and noise generated by the teacher and students. The internally produced noise levels are strongly related to the students' and teacher's activities [9,21].

Most research on classrooms for primary and secondary education has been performed on external environmental noise. This is mostly done in field studies, testing effects of long-term noise exposure on childrens' cognitive performance. The exposed children are compared to children with low noise exposure, or a reduction of environmental noise in the same classroom has been studied. These studies have demonstrated that children exposed to aircraft noise at schools show less reading ability, decrease of attention and motivation, poor memory, and less performance on standardized tests than children not exposed to aircraft noise [20,22,23]. One of the most comprehensive studies on noise and childrens' cognition is called RANCH (Road Traffic Noise and Aircraft Noise Exposure and Children's Cognition and Health). In this project the effect of traffic and aircraft noise on 2844 children (age 8-10 year) attending 89 primary schools was studied near three airport locations: Schiphol (The Netherlands), Heathrow (London), and Barajas (Madrid). This study showed a significant linear effect between aircraft noise exposure and reading comprehension and recognition memory. The aircraft noise was measured inside and outside the school in dB(A) while testing the children. No correlation was found between road traffic noise exposure and reading comprehension [24,25,26]. Follow-up analyses showed the importance of noise exposure at schools by aircraft noise, while night-time noise exposure at home and sleep disturbance had no additional effect on cognitive performance when day-time noise exposure at school had been taken into account [27].

Research on the effect of environmental noise on academic performance or disturbance of students in higher education facilities such as university classrooms or open plan informal learning places is, as far as we know, not discussed in literature.

Research on the effect of indoor sounds on performance and disturbance in classrooms has been conducted less than research on external environmental noise. However, nowadays there exists an increasing number of studies on indoor sound, probably due to the new popularity of open learning environments. A comparison between noise levels in open plan and enclosed classrooms at primary schools showed little difference in noise levels [14]. However, the noise levels in open school environments are perceived as more disturbing [28]. This could be the result of lack of control over intrusive noise coming from other groups in the open school environment [29]. In one of the first studies on open space schools the influence of noise from other classbases (i.e., another class) in the same open space on reading performance was measured and no influence was found on reading errors, only on reading speed. The noise also affected disturbance and speech communication [29]. In a study on how children perceived their sound environment it was found that noise from other children was the most disturbing sound. In open schools, noise from other teaching areas was found as most disturbing [28,29]. Another research on semi-open-plan primary schools also found children to be significantly affected by speech from children and teachers from other groups. Especially in a listening situation they were very disturbed and could not hear their own teacher well enough [30].

Only few studies have been performed on the effect of indoor sounds on academic performance and disturbance due to indoor sounds in higher education. A research on the acoustic environment of informal open learning spaces in higher education showed that environments were perceived as more suitable for learning when the sound level from ventilation systems in an unoccupied situation was low. On the other hand, when assessing occupied spaces, students preferred environments with more occupant-generated noise and more reverberation. This unexpected result was probably related to sound privacy, because more noise and a longer reverberation time will result in less intelligible speech and supports conversational privacy [31].

Room Acoustics

The indoor sound environment students perceive will be the result of sound sources (noise) and the room acoustic characteristics of the environment [32]. The sound environment in a classroom should be optimal to discriminate words, to understand spoken language and to remember the content of the information [33]. Research on the room acoustic environment of schools and universities has mostly been focusing on the reverberation time. The reverberation time is a measure of the time required for the sound level to decrease 60 dB in an enclosed area after the source of the sound has stopped. The reverberation time is depending on the volume and shape of the classroom, the total acoustic absorption area and the placing of absorption materials and structures to diffuse the sound.

The Speech Transmission Index is a widely used acoustic measure to describe the intelligibility of speech in a classroom. It describes speech intelligibility between a source (speaker) and a receiver (listener). The *STI* has values between 0 and 1, whereby 1 is an excellent speech transmission. The noise level and the reverberation time are the most important parameters that determine speech intelligibility in a room [34]. The less reverberant the room, the lower the noise level and the better signal-to-noise ratios (*SNR*). A high signal-to-noise ratio is required to discriminate the signal. Especially young children and students with another mother tongue need a high signal-to-noise ratio [14,35].

Research on reverberation time, signal-to-noise ratios, and *STI* values in occupied and unoccupied primary [6,14,28,36], secondary [7,8] and university classrooms [9,10,37,38] has been done to describe the acoustic quality. However, only a few studies on university classrooms took into account the relation between the acoustic environment and performance and disturbance [35,39].

Measurement results

Noise and room acoustic parameters in schools and universities can be charted by measurements. Until recently relatively few data have been published on classroom noise in primary, secondary and higher education, suitable to perform profound analyses [20]. Even less data was collected on open plan school environments. Most of the collected data comprised noise levels, presented as single number quantities without further details [9,40]. However, due to an increase of interest worldwide in school acoustics, more research was initiated and therefore more data has been published [11,25,26]. Measured data on noise levels include teacher's speech levels, background levels in empty classrooms and occupied classrooms. In a study on open plan classrooms by Weinstein [29], intrusive sound levels from adjacent 'quiet' classbases were measured of 45-49 dB(A), and 56-66 dB(A) for active adjacent classbases [29].

Noise levels at university classrooms have only been published in a few studies [9,10,37,38]. Data on informal learning spaces at universities are rarely published [31]. The measurement results for the different studies on sound levels in university classrooms showed a wide range of equivalent A-weighted sound levels. For closed unoccupied university classrooms, noise levels between 32 and 48 dB(A) were measured, and for occupied classrooms levels between 35 and 70 dB(A) [9,10,37,38]. Noise levels in informal learning spaces were only measured by Scannell *et al*. [31]. For unoccupied spaces levels between 32 and 55 dB(A) were measured and for occupied places levels between 38 and 77 dB(A) [31]. Besides of the sound levels in schools also the reverberation time have been measured. Reverberation times measured in unoccupied enclosed secondary school classrooms varied between 0.4 and 0.9 s and in open classrooms between 0.5 and 0.7 s [7].

Acoustic parameters in higher education have been published in a few studies [10,37,38]. In those studies, the *STI* values in unoccupied university classrooms vary between 0.4 and 0.8, which stands for fair to good speech intelligibility. The measured reverberation time in unoccupied university classrooms shows a much larger spread, 0.7-2.0 s measured by *EDT* [37], and 0.3-1.8 s measured by T_{30} [10,38]. In occupied classrooms the reverberation time measured by T_{30} is much shorter due to the absorption from the students, 0.2-0.9 s [10]. Scannell *et al.* [31] measured the reverberation time ($T_{30,\ 1000\mathrm{Hz}}$) in open informal learning spaces: 0.3-2.8 s with an average of 1.0 s. The large spread in reverberation time was a consequence of the diversity in the volume of the spaces.

1.1.3 Standards and recommendations

Acoustic standards and recommendations for open and enclosed classrooms and informal learning spaces are depending on the country [41-48]. Considering maximum noise levels, most of the recommended values are for closed classrooms and are expressed in single number quantities, measured and averaged over time and weighted to the sensitivity of the human ear: L_{Aeq} in dB(A). The maximum recommended values vary between 30-50 dB(A) for closed unoccupied classrooms and between 30-45 dB(A) for open unoccupied classrooms. Only three countries have recommendations for a maximum noise level in open classrooms: England, Denmark and Sweden. There are no maximum noise levels recommended for occupied open or enclosed school environments or open informal learning spaces [48].

The most researched room acoustic parameters are the reverberation time (*EDT* or T_{30}) and the speech intelligibility (*STI* or SI). Background noise in combination with reverberation time (*EDT* or T_{30}) are determinative for speech intelligibility. In literature it is recommended that the speech-to-noise ratio should be at least 15 dB in a classroom, in combination with a maximum reverberation time of 0.5 s [40,49,50]. Children younger than 11 years old even need an *SNR* ratio of 20 dB [14]. In open plan classrooms a reverberation time of 0.4 s is recommended [28,51]. For open classrooms also a minimum *STI* value of 0.6 is recommended for intelligibility within a classbase, and a maximum of 0.2 between classbases [51]. Standards for *EDT*, T_{30} and *STI* in educational buildings vary for each country, and some countries do not have standards for educational buildings at all. The recommended maximum reverberation time for unoccupied closed classrooms varies between 0.4 and 0.9 s, while the maximum reverberation time for open classrooms varies from 0.3 until 0.8 s. There are only five countries with recommendations for open classrooms: England, Denmark, Sweden, Norway and Iceland. There are no recommendations for occupied classrooms or informal learning spaces. Recommendations for *STI* values in classrooms are only formulated for open classrooms in three countries; England, Denmark and Iceland. It is recommended to obtain an *STI* value of at least 0.6 [48].

It can be concluded that there is a lot of research on school acoustics and there are acoustic standards for classrooms in some countries. However, there is very little research on OPSEs and no standards or recommendations on these important learning environments in higher education do exist.

1.2 The acoustic environment of open-plan offices

Another approach to gain more insight into the acoustics of OPSEs could be to study literature regarding the acoustic environment of other open work environments. Of course, it must be realized that the users of OPSEs and student tasks are very specific and differ from other open-plan work environments, such as open-plan offices. A brief literature review of the acoustic environment of open-plan work environments, in particular open-plan offices, will be reported in the next section.

1.2.1 Acoustic research on open-plan offices

Open-plan work environments are very popular nowadays, especially open-plan offices. The advantages of open-plan work environments are diverse, probably the most important benefit is economical; a higher occupant density, an increased net usable area and adjustability of the work environment will lead to financial advantages [52]. Also communication and interaction between colleagues or fellow students has been mentioned as an advantage, although that has never been scientifically proven [53,54].

Most research on open-plan work environments has been conducted on open-plan offices. The first open-plan office concepts were developed around the 1960's in Germany and later in the United States [55,56]. Nowadays, in most countries the open-plan office is a very popular concept. In addition to the aforementioned advantages, many office workers also experience many disadvantages of the open-plan office concept. The biggest complaints of office workers are about the lack of visual and acoustic privacy, interruption by colleagues and increased distraction by noise [53,57].

Two important research methodologies are used to investigate the perception of the acoustic environment in open-plan offices; field research and laboratory experiments. Field research can be performed in various ways, for instance by a case study or by comparing different offices (a cross-sectional survey) or longitudinal studies. In a study of Kaarlela-Tuomaala *et al.* [53] a literature review on cross-sectional surveys was done. It showed that noise coming from colleagues and lack of privacy were the most important factors for dissatisfaction. It also showed that literature disagreed about the communication advantage of open-plan offices [53,58-61]. A longitudinal study on relocated office workers from Kaarlela-Tuomaala *et al.* [53], from a private office to an open-plan office, showed comparable negative effects such as decrease of privacy, more disruption during work and an increase of concentration difficulties. In a study of Kim and de Dear [57] an analysis was made over the office building subset of the CBE occupant Indoor Environment Quality (IEQ) issues survey database. Five categories of office lay-outs were compared: enclosed private offices, enclosed shared offices, cubicles with high partitions (>1.5 m), cubicles with low partitions (<1.5 m), open-plan offices with no partitions. Enclosed private offices were clearly more preferred than open-plan lay-outs. And from all IEQ aspects sound privacy scored the lowest on satisfaction and the highest in percentage dissatisfied office workers. Furthermore, it was remarkable that open-plan office concepts using cubicles (partitions by screens) were less favourable than open-plan offices without partitions [57]. Also, in a study of Pierrette *et al.* [62] it was shown that office workers in an open-plan office concept were very much disturbed by noise, and especially by background speech from colleagues. In this research it was shown that the overall sound level did not cause disturbance. A research on refurbishing an open-plan office by Hongisto *et al.* [63] showed noise and lack of privacy to be the most disturbing factors in an open-plan office. After the refurbishing, both aspects decreased significantly, however, they remained the most disturbing factors of the indoor environment after renovation.

Laboratory experiments were used to study task performance in open-plan environments. Most of the experiments were not especially designed for tests concerning open-plan offices or other open-plan work environments, but the research questions were often related to the noise problems in open-plan offices. Within the field studies in open-plan offices, disturbance of office workers was clearly demonstrated. However, to establish the influence of noise on performance, more conditioned laboratory experiments studies were needed. In an experimental setting the sound condition can be manipulated and therefore it is possible to study the influence of the sound environment on performance. In this way the influence of background speech (irrelevant for the task of the office worker), a typical problem if more people are working in an open-plan office environment, on performance was studied [64-69].

1.2.2 The influence of the sound environment on performance and disturbance

The influence of noise on performance and disturbance of workers in open-plan offices is depending on different aspects [32,62]. The most important aspects are the characteristics of the sound environment but also characteristics of the people and their work in those open-plan offices:

- sound sources causing the noise
- type of tasks being performed
- the room acoustic parameters of the open-plan office
- personal factors of the office workers

Sound sources

The sound sources in an open-plan office can be diverse. In a research of Pierrette *et al.* [62] five sound sources were included in a standardized questionnaire to assess the disturbance by noise in open-plan office environments. These sound sources were: operation of office equipment, ringing telephones, intelligible conversations of co-workers, unintelligible conversations of co-workers and people walking by. In a case study, the most frequently heard sound source was intelligible conversations from other office workers, this was also perceived as the most disturbing sound source [62]. Also, in other field studies intelligible conversations were indicated as most disturbing [62]. In a field research of Goins *et al.* [70] the same kind of sound sources were mentioned, also in this study speech from co-workers was indicated as the most disturbing sound source. In this research also outdoor noise was taken into account as most people in an office like to work near a window. However, the analysis showed that outdoor noise was not a significant problem, indoor noise sources were about 10 times more prevalent than outdoor noise. Also, other field studies showed speech to be the most disturbing background sound in an open-plan office [53,58].

In laboratory experiments, testing the influence of background noise on performance, intelligible speech showed to have a detrimental effect on performance. The intelligibility of the background speech showed to be of importance in relation to the degree of performance reduction through speech [65,67,71-74]. But not for all tasks the influence of the intelligibility of background speech is important.

Tasks

Different tasks need different acoustic conditions for optimal performance and comfort. Especially the performance in complex cognitive tasks is influenced by noise. The characteristics of a task determine the sensitivity of the task to noise [75,76]. The abilities required for a maximum performance of a task can characterize a task, for example memorization, information ordering, mathematic reasoning [77]. Laboratory experiments on the influence of noise on cognitive performance are mostly performed on so called 'pure' cognitive tasks [75] or sub-component cognitive abilities [76]. The studies in [78,79] show for instance that the performance of tasks with semantic characteristics, like reading and writing, is affected by intelligible speech. Most open-plan office tasks have semantic characteristics, this could be an explanation of the severe disturbance by intelligible background speech in open-plan offices.

Hongisto [64] predicts in his model how much the performance decreases due to speech of varying intelligibility. In this model all types of tasks were included, not only semantic tasks. The highest task performance is predicted when the speech intelligibility is minimum, and the lowest performance is predicted if the intelligibility of the background speech is maximum.

Room Acoustics

An influence of the room acoustic parameters can be expected. If the intelligibility of background speech has an influence on performance and disturbance of people working in an open-plan office, then room acoustic parameters are of great importance, because reverberation time and background noise level determine the intelligibility of speech in a room [49].

However, field studies on noise disturbance and performance in open-plan offices seldomly include data from room acoustic measurements. In a study on 21 open-plan offices [80] questionnaire surveys and room acoustic measurements were performed. In this study it was shown that distracting intelligible background speech was perceived as the most important noise source. This research [80] supports the role of room acoustic design, as the intelligibility of speech in an environment will be determined by the acoustics of a room. To measure the acoustic quality of open-plan offices a measurement standard was developed (ISO 3382-3 standard [81]) which describes single number quantities based on the *STI*, describing speech intelligibility and speech privacy.

To determine relations between tasks, sound sources and room acoustics field studies are not sufficient. Unfortunately, in most of the laboratory studies on the influence of noise on task performance, realistic room acoustic parameters are lacking [32]. Therefore, more ecologically valid laboratory studies are needed measuring the effect of room acoustics on performance for open-plan offices and typical office jobs.

Personal factors

How people react to background noise differs per individual and will be influenced by personal factors. One of the most important personal factors is noise sensitivity. Different researchers developed standard questionnaires to measure the individual noise sensitivity [82] [83,84]. Research on the relation between noise sensitivity and cognitive performance and disturbance showed weak or no correlations [85,86,87]. Other personal factors that can influence how people react on noise while performing a task are for instance hearing ability and working memory capacity [88].

1.2.3 Standards and recommendations

The ISO 3382-3 (2012) standard [81] describes single number quantities indicating the acoustical performance of open-plan offices. The ISO specifies methods for measuring these single number properties and the results can be used to evaluate the room acoustic properties. The most important single number quantities are:

- the spatial decay rate of A-weighted sound pressure level of speech per distance doubling($D_{2,S}$);
- the A-weighted sound pressure level of speech at a distance of 4 m from the sound source ($L_{p,A,S,4\,m}$);
- the average A-weighted sound pressure level in the open-plan office ($L_{p,A,B}$);
- the distraction distance from a speaker at which the speech transmission index falls below 0.5 (r_D). Beyond the distraction distance, concentration and privacy improves.

In the standard an example of target values for an open-plan office with good acoustic conditions is indicated: $D_{2,S} \geq 7$ dB, $L_{p,A,S,4\,m} \leq 48$ dB, and $r_D \leq 5$ m. In practice these values are rarely encountered. An acoustic classification with target values for open plan offices was proposed in 2008 by Virjonen *et al*. [89,90], four acoustical classifications were suggested. In a more recent version of this acoustic classification of open-plan offices an extra category was added, probably since most offices were found in the lowest category of the first classification. Table 1.2 shows the five acoustical (Finnish) categories, in which class A represents the highest acoustic quality while E represents the lowest.

In most countries there are no regulations for the acoustics of open-plan offices, only recommendations have been formulated. In Table 1.1 the acoustic requirements for open-plan offices in Nordic countries are described.

Table 1.1 Recommended acoustic parameters in open-plan offices in Nordic countries [91,92].

	Reverberance	Speech intelligibility	Background Noise	Extra recommendations	Status
Denmark	$A_{minimum} \geq 1.1$ x floor area		$L_{Aeq,\,30s} \leq 35$dB		recommended
Finland	T<0.6 s	STI<0.5		Class A and B Table 1.2	regulation
Iceland	T<0.5 s		$L_{p,Aeq,\,T} \leq 35$dB $L_{p,Ceq,\,30s} \leq 55$dB	$D_{2,S} \geq 7$ dB STI limit ≤ 0.2	regulation
Norway	$T \leq 0.16$ s x room height		$L_{p,Aeq,\,T} \leq 35$dB $L_{p,Ceq,\,30s} \leq 55$dB		regulation
Sweden	$T \leq 0.5$ s		$L_{p,Aeq,\,T} \leq 35$dB $L_{p,Ceq,\,30s} \leq 55$dB		regulation

In Germany a new standard on the acoustics of offices took effect on 10-2019, also open-plan offices were discussed in a separate section [93]. In Table 1.2 the numbers from the German draft standard are mentioned based on the parameters described in ISO 3382-3 (2012). French standards differentiate between activities in different spaces (type 1 is telephone work, type 2 is collaborative work and type 3 is low level collaborative work). In Table 1.2 an overview of acoustic parameters in French, Germany and Finnish standards have been compared [94].

Table 1.2 Comparison of acoustic parameters between different standards for open-plan offices [94]

	French - NFS31 199:2016			*German - VDI 2569:2019 Class*			*Finnish - RIL 243-3: 2018 Class*				
	Type 1	*Type 2*	*Type 3*	*A*	*B*	*C*	*A*	*B*	*C*	*D*	*E*
$D_{2,S}$ [dB]	>7	>9	>7	≥8	≥6	≥4	>11	9-11	7-9	5-7	<5
D_n [dB]	≥6	≥4	≥6								
RT [s]	<0.6	<0.6	<0.6	≤0.6	≤0.7	≤0.9					
RT_{125Hz} [s]	<0.8	<0.8	<0.8	≤0.8	≤0.9	≤1.1					
L_{Aeq} [dB(A)]	48-52	45-50	40-45								
L_{bkg} [dB(A)]				≤35	≤40	≤40					
$L_{p,A,S,4m}$[dB(A)]				≤47	≤49	≤51	<48	48-51	51-54	>54	
r_d [m]							<5	5-8	8-11	11-15	>15

We can conclude there exists a lot of research on acoustics in open-plan offices and that recently new acoustic standards for open-plan offices have been published. Therefore, standards on OPSEs or recommendations could be a logical next step.

1.3 Aims and Objectives

The aim of this research is to gain more insight into the influence of the sound environment on students' performance and well-being in open-plan study environments (OPSEs). The ultimate goal is to make a first step towards acoustic recommendations for OPSEs.
This larger aim is split into several smaller objectives:

1. Investigate how students in higher education assess noise in OPSE's in relation to the noise sources they perceive, the tasks they perform and the room acoustic parameters of the corresponding OPSE.
2. Evaluate the relation between the characteristics of the sound environment of an OPSE and the performance and perceived disturbance of students while they perform a specific task.
3. Evaluate the influence of the noise sensitivity of students on their performance and perceived disturbance in OPSEs.

We hypothesize that a realistic sound environment in an OPSE (with background speech of other students) will have a negative effect on performance and disturbance of students working on typical student tasks in comparison to students working in a quiet environment without background speech. Furthermore, we expect that more intelligible background speech will decrease performance and will increase disturbance of students. We also hypothesize that the noise sensitivity of students will have an effect on how they perceive the background speech of other students in an OPSE. We expect noise sensitive students to be more disturbed by the background speech and to perform less due to the background sound in comparison to less noise sensitive students.

1.4 Approach

To get a better understanding of how the sound environment in OPSEs will influence students and how to optimize the room acoustic design, a combination of literature-, field- and experimental studies was used (Figure 1.1).

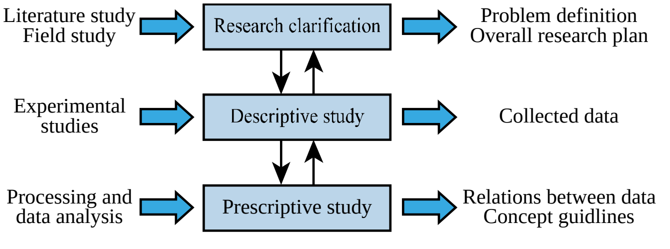


Figure 1.1 Research method.

A literature study was carried out, which focused on how people are disturbed by indoor noise while performing different tasks. Furthermore, the literature study concentrated on the role of room acoustics on performance and perceived disturbance in open work environments [32]. In addition, a field study was conducted in order to acquire lacking knowledge on auditory distraction in open-plan study environments (Chapter 2).

The results of the literature- and field study were used to design the laboratory experiments to collect more detailed data on the relation between sound sources, room acoustics, student tasks and performance and disturbance of students in an OPSE.

Most laboratory experiments that study the influence of the sound environment on performance of subjects are conducted with short term memory tasks and seldom with more realistic tasks. Therefore, the tasks for this laboratory studies were selected from the field research on OPSEs. More realistic student tasks were needed to make a transition from the laboratory experimental results to recommendations for OPSEs. Hence, the most common student tasks, as well as tasks that suffer the most from noise in the environment were selected from the field study to integrate in the laboratory experiments.

Most laboratory studies on sound and task performance make use of unrealistic sound environments, e.g. they use one voice in combination with white noise or in combination with silence without any influence of room acoustics. A realistic sound environment was needed to translate the laboratory experimental results to acoustic recommendations for OPSEs. To create a realistic sound environment for the laboratory experiments, OPSE sound scenarios were developed based on an existing OPSE at the Eindhoven University of Technology. An acoustic computational model was developed for all experiments. This model was tested by comparing calculated parameters with measured parameters. Two variants were developed from the basic model, an absorbing and a reverberant model. For every experiment, depending on the task and specific research question, sound scenarios were composed by convolving recorded speech signals with the calculated impulse responses between talker positions and the receiver position, for each variant. Through a headphone the binaural sound scenario was offered to the students while they performed the selected student tasks.

Three tasks were selected from the field study to explore in an experimental setting; a collaboration task (Chapter 3), a writing task (Chapter 4) and a studying task (Chapter 5). The collaboration task is the most frequently performed task in an OPSE, the writing task was also frequently performed and was one of the most disturbed tasks, and the studying task (preparing an exam) was the task that suffered most from noise disturbance in an OPSE.

In Table 1.3 an overview of the variables in each study is presented.

Table 1.3 Independent and dependent variables.

	Type of Experiment		
Independent variables - sound scenario's	Collaboration (Chapter 3)	Writing (Chapter 4)	Studying (Chapter 5)
Reverberation time	X	X	X
Occupancy rate		X	X
Intelligibility - language	X		
Intelligibillity - *STI*	X	X	X
Intelligibility - *FDCC*		X	
Dependent variables - measures			
Objective variables - Performance:			
- collaboration	X		
- writing		X	
- studying for an exam			X
- logical reasoning			X
- mental arithmetic			X
Subjective variables:			
- self-estimated performance	X	X	X
- perceived disturbance	X	X	X
Moderating variables			
- ability to ignore background noise	X		
- eagerness to continue with the task	X		
- noise sensitivity	X	X	X

1.5 Thesis outline

This thesis describes a research into auditory distraction of students in open-plan study environments in higher education.

In Chapter 2 a field research on five open-plan study environments in higher education is reported. The aim of this study was to investigate how students assess the noise in this environment. Therefore, 498 students filled in a questionnaire and the acoustic parameters of all five OPSEs were measured. From this data we looked for correlations between noise disturbance experienced by students and the noise sources they perceive, the tasks they perform and the acoustic parameters of the open-plan study environment they work in.

In Chapters 3 to 5 three laboratory experiments are reported. The aim of these studies was to find a relation between the parameters of representative sound scenarios and perceived disturbance and performance of students while working on a realistic student task, taking into account personal factors.

In Chapter 3 the performance and perceived disturbance of a collaboration task was measured in a laboratory facility in Gävle, Sweden. Dutch and Swedish students had to work on solving spot-the-difference puzzles, by using the 'DiapixUK' collaboration task [95]. They worked in couples on the task while being exposed to background noise varying in language and reverberation time.

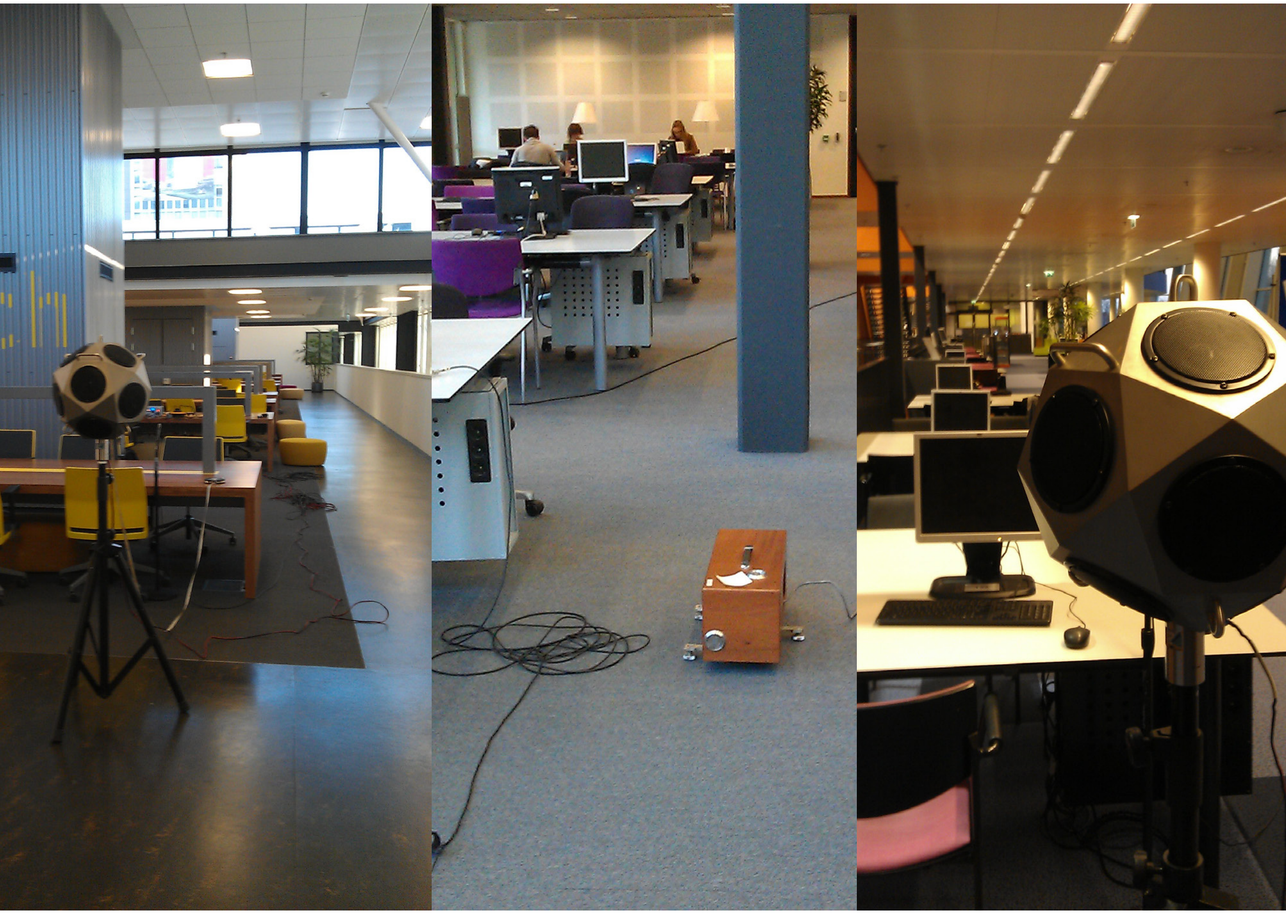
In Chapter 4 the performance and disturbance of a writing task was measured in an individual experimental setting. Students had to write stories while being exposed to different sound scenarios, varying in reverberation time and number of background talkers.

In Chapter 5 the performance and disturbance of a typical student task, 'preparing an exam', was measured in an individual experimental setting. Students had to read and study a text, subsequently had to perform a mental arithmetic task and logic reasoning task and had to answer questions about the text they had read and studied before. During the tasks the students were exposed to four different sound scenarios varying in reverberation time and number of background talkers.

In Chapter 6 an overall discussion and short conclusions are presented, and a first step is made towards acoustic recommendations for OPSEs.

Finally, Appendix A describes the computational modelling of the OPSEs and the development of the sound scenarios used in the experiments. Appendix B presents the questionnaires used in this study. And in Appendix C, pictures of OPSEs are collected to give an impression of OPSEs in higher education in the Netherlands.

CHAPTER 2



FIELD STUDY

2 | Noise disturbance in open-plan study environments: A field study on noise sources, student tasks and room acoustic parameters.

The aim of this study is to gain more insight in the assessment of noise in open-plan study environments and to reveal correlations between noise disturbance experienced by students and the noise sources they perceive, the tasks they perform and the acoustic parameters of the open-plan study environment they work in. Data were collected in five open-plan study environments at universities in the Netherlands. A questionnaire was used to investigate student tasks, perceived sound sources and their perceived disturbance, and sound measurements were performed to determine the room acoustic parameters. This study shows that 38% of the surveyed students are disturbed by background noise in an open-plan study environment. Students are mostly disturbed by speech when performing complex cognitive tasks like studying for an exam, reading and writing. Significant but weak correlations were found between the room acoustic parameters and noise disturbance of students.

This chapter is based on: Braat-Eggen, P.E., van Heijst, A.W.M., Hornikx, M.C.J., Kohlrausch, A.G.(2017). Noise disturbance in open-plan study environments: a field study on noise sources, student tasks and room acoustic parameters. Ergonomics 60, 9, 1297-1314. DOI: 10.1080/00140139.2017.1306631.

2.1 Introduction

An increasing number of students spend a large part of the day in open-plan study environments (OPSEs). These environments are designed to work on individual and group assignments and to encourage communication and interaction between students.

Almost all research on noise in open-plan environments focuses on open-plan offices. Despite the fact that many students work in OPSEs, there is hardly any research on the influence of noise on performance of students in OPSEs. Although being similar in terms of room acoustics and some tasks, open-plan offices and OPSEs have different use and users. For instance, students are younger and not obligated to work for a certain time in a specific OPSE. Due to the differences between open-plan offices and OPSEs, the present study focusses on the effect of noise on students in OPSEs and especially in higher education (post-secondary school institutions).

Research has shown that learning can be influenced by the physical environment where students perform their task [4,96]. However, the majority of research on sound, room acoustics and learning has been conducted in classrooms and in lecture halls, not in OPSEs, and has not been focused on students in higher education [31]. A recent study on spatial implications due to new ways of learning in higher education in the Netherlands [19] showed the growing importance of a diversity of learning settings. In general, two broad categories of learning spaces are distinguished in higher education: formal and informal learning spaces [3]. Formal learning spaces are classrooms and lecture halls where a prescribed course or class dictate the learning activity. In contrast, informal learning spaces are all other environments where students can work on their individual or group assignments and prepare for exams. Informal learning places are diverse: libraries, individual and collaborative study areas, lobbies, atria, corridors, lounges, coffee shops, canteens, restaurants and outdoor places such as meadows. This research focusses on specific informal learning spaces, only intended and designed for students to accommodate individual study activities as well as small group activities, such as individual and collaborative study areas, further named: open-plan study environments (OPSEs).

Historically, libraries have always been important places for studying by offering the opportunity to consult printed books and journals to supplement classroom learning. With the growth of the digital collection of books and journals and access to information via the internet, the role of the physical library space has changed throughout the years. Libraries in higher education have not disappeared but instead have been transformed into places where students can access information in many ways and make use of a wide range of learning environments [97]. New and renovated libraries in higher education are becoming more and more large, open spaces to enhance individual learning and encourage social learning [3], thus they have become OPSEs.

The importance of acoustics in OPSEs is shown in a study by Cha and Kim [98] on the factors that influence the students' choice of study space in an academic library. The noise level was found to be one of the important space attributes for students to choose a study place. Also, the research by Scannell *et al.* [31] on informal learning spaces in higher education showed the importance of acoustics in OPSEs. The participants in this research judged the background noise unsuitable for their learning activities.

Research on open-plan offices established that open-plan environments can be considered to be distractive due to indoor environmental aspects, in particular noise disturbance and the loss of privacy [57,99,100]. Although the use and age patterns of OPSEs are different from open-plan offices, we claim that the acoustical environment and tasks of the users show many similarities with open-plan offices. Therefore, it can be expected that noise has a similar effect on performance of students in OPSEs.

The influence of noise on human performance has been studied by Szalma and Hancock [73]. This meta-analytical synthesis showed that:

- In particular cognitive and communication tasks are influenced by noise;
- Intermittent noise is more disruptive than continuous noise;
- Speech-like noise is the most disruptive sound for cognitive tasks.

These important findings are all applicable to open-plan offices and as we expect also to OPSEs. Indeed, speech-like noise and intermittent noise sources, such as ringing phones and pass-by noise, were found to be the most disruptive sound sources in open-plan offices [58] [62]. Therefore, in this study, background noise of OPSEs is measured during use to gain more insight into the characteristics of noise in OPSEs. Further, different perceived noise sources and their disturbance by students in OPSEs are assessed in this study. Also, according to Szalma and Hancock [73],a decrease of performance for specific office tasks due to speech has been shown, for example for comprehensive reading [101,102] and writing [71] . Due to the importance of the task type in relation to noise disturbance, the correlation between student activities and the noise disturbance is studied in the OPSEs.

The influence of the acoustic design of open-plan offices has been studied mostly in relation to speech intelligibility [65,85,103]. Hongisto [64] presented a model that describes the relation between the speech transmission index (STI) and the performance of users in an office. STI is a physical measure and a predictor of speech intelligibility [104]. The international standard for measuring room acoustic parameters in open-plan offices [81] adopted Hongisto's model [64] and defined new room acoustic parameters related to the STI. Due to the room acoustic resemblance between open-plan offices and OPSEs and the lack of acoustic standards in OPSEs, we decided to measure these room acoustic parameters of open-plan offices also in the OPSEs under study and to examine correlations between noise disturbance and room acoustics.

The aim of the present study is to gain more insight into how students in higher education assess noise in OPSEs and to study the correlation between the noise disturbance of students and the following three aspects: the noise sources they perceive, the tasks they perform and the room acoustic parameters of the corresponding OPSE. In this field study, questionnaires were used as well as sound measurements to gather data of five different OPSEs. These research methods are described in Section 2.2. The results obtained by the questionnaires and by the acoustic measurements and the correlations between noise disturbance and the different parameters are described in Section 2.3. In Section 2.4 the results and correlations in the OPSEs are discussed, and in Section 2.5 the conclusions are formulated.

2.2 Methods

2.2.1 Research design

Data were collected in five OPSEs at universities in the Netherlands. In each OPSE, students filled in a questionnaire on noise disturbance, perceived sound sources and the tasks they performed in the OPSE. In addition, room acoustic parameters were measured in the unoccupied OPSEs and the background sound levels were measured in the occupied OPSEs. Subsequently, data from the questionnaires and measurements were statistically analyzed to gain insight in the level of noise disturbance in OPSEs and to reveal correlations between the different parameters.

2.2.2 Assessment of acoustic comfort

Research site

Five OPSEs in the Netherlands were selected on basis of availability. Three OPSEs are situated in different buildings of the Avans University of Applied Sciences (OPSE A, B and C) and two OPSEs are located in different buildings at the Eindhoven University of Technology (OPSE D and E). OPSE A, B and C are all situated in libraries where students work individually as well as in small groups. No special silent sections and no group or individual zones are defined. The furniture is simple: upholstered office chairs and large desks. OPSE A has a very open structure, two floors are connected with an open space, which is also an OPSE. OPSE B has a less open character, three floors are only connected by a stairwell. OPSE C has large open floors which are connected by open stairs and an open strip near the facade. OPSE D is situated in the central academic library and comprises three floors, openly connected with each other by an atrium in the centre of the space. The furniture is divers, e.g. soft chairs, lounges and office chairs. The lowest floor is reserved as a silent zone and also serves as library space, providing handbooks and newspapers. OPSE E is not a library, the open-plan environment is only in use by students of one department. They work individually and in groups on design projects and coaching by staff members also takes place in the same area.

Pictures of the OPSEs are included in the appendix C. Table 2.1 presents data and surface materials of the five OPSEs. Also, the number of participants in this research is presented in Table 2.1. The students volunteered to complete a questionnaire while working in the OPSE. The students at the University of Applied Sciences followed various Bachelor programs such as economics, management, applied physics, law, education, art, health and engineering. The University of Technology students followed Bachelor and Master Programs. Of the 496 students who completed the questionnaire, 65% were male and 35% were female. The mean age of the respondents was 21.2 years (SD=2.3).

Table 2.1 Data related to the studied open-plan study environments.

		University of Applied Sciences:		*University of Technology:*	
	OPSE A	*OPSE B*	*OPSE C*	*OPSE D*	*OPSE E*
Participants [-]	107	89	101	111	88
Floor area [m^2]	860	4200	4800	8000	500
Floor levels [-]	2	3	3	3	1
Seats [-]	221	883	850	950	160
Floor area per seat [m^2]	3.89	4.75	5.65	8.42	3.13
Material Ceiling	Open suspended ceiling, partially sound absorbing elements.	Sound absorbing suspended ceiling.	Sound absorbing suspended ceiling.	Sound absorbing suspended ceiling.	Sound absorbing suspended ceiling.
Material Floor	Carpet on concrete floor. Large central open connections between floors.	Carpet on a raised computer floor, small cavity.	Carpet on a raised computer floor, big cavity. Open connection between floors near the façade.	Carpet on concrete floor and parquet passages. Large central open connection between floors.	Vinyl on concrete floor.
Material Walls	Plastered walls, glass façade and absorbing perforated gypsum panels.	Plastered walls and glass facade.	Plastered walls and glass facade.	Plastered walls and glass facade.	Plastered walls, glass facade and sound absorbing perforated panels.

Survey measures

Each location was visited on one or two days. The students were asked to participate in the study after being informed about the time it would take to fill in the questionnaire, the data confidentiality and the aim of the research. The questionnaires were filled in during the day and collected on location.

The used questionnaire (available in the appendix B) is a modified version of the assessment questionnaire developed by Pierrette *et al.* [62], which aims to evaluate the employees' comfort in open-plan offices. Because an open-plan study environment differs from an open-plan office, some questions were left out or changed, and new questions were added. The revised questionnaire assesses the noise disturbance by noise sources and performed tasks. A Dutch version of the developed questionnaire was used at the University of Applied Sciences and an English version at the University of Technology. The questionnaire makes use of different types of questions like multiple choice, open and scale questions. The questionnaire was composed of the following components:

- Student characteristics. General information about the student is collected such as: gender, age, domestic situation, study program and study phase.
- Student activities in the open-plan study environment. In this section information is obtained about the behaviour of students in the OPSE such as: the amount of time spent working individually and in groups, the time of the day the OPSE is used, and

the kind of activities carried out in the OPSE. This part of the questionnaire is not based on the questionnaire of Pierrette *et al.* [62].

- Student satisfaction in their physical open-plan study environment. The scale measures satisfaction (5-point scale) regarding the workspace according to two dimensions: control-privacy (7 items) and comfort-functionality (7 items). This part of the questionnaire is based on the questionnaire of Pierrette *et al.* [62].
- Noise sources and noise disturbance in the students' study environment. Students were asked if they heard different types of noise and the disturbance of the different noise sources was assessed (5-point scale). The noise sources asked for were building devices (ventilation, computers, printers), telephones, intelligible and unintelligible conversations of fellow students, and people walking. Students were also asked if they use earbuds or headphones and why. This part of the questionnaire is an adapted version of the questionnaire of Pierrette *et al.* [62].
- The sound sensitivity of the student. This is measured via twelve statements indicating their level of agreement with the statement proposed (4-point scale). This part of the questionnaire was based on the reduced version of the NoiseQ sound sensitivity questionnaire developed by Griefahn [82]. Pierrette *et al.* [62] also used this sound sensitivity assessment in their questionnaire.
- Noise in relation to the students' activities in the open-plan study environment. Students were asked if they were bothered by noise while carrying out different activities (5-point scale). This part of the questionnaire is not based on the questionnaire of Pierrette *et al* [62].

The data were analyzed with the statistical program SPSS 22.0. Descriptive analyses were used to analyze the general information. Cronbach's alpha was used to measure the internal consistency of related items within the questionnaire. The significance of the differences between the variables measured by the questionnaires (ordinal measure) was verified with the Friedman test followed by paired comparisons with the Wilcoxon signed-rank test to examine where the differences actually occur. The significance of the differences of the variables measured by the questionnaires between the five OPSEs (ordinal measure) was analyzed with the Kruskal Wallis test. The significance of the acoustic measurements (ratio measure) between the five OPSEs was analyzed with an ANOVA. Spearman's rank correlation was used to analyze correlations between variables measured in the questionnaires (ordinal measure) and Pearson's correlation was used to analyze correlations between normally distributed data (ratio and ordinal measures).

2.2.3 Measurement of acoustic parameters

While students were filling in the questionnaires, the background sound pressure level was measured in all five open-plan study environments. The measurements were performed in an occupied situation, during typical working hours.

The background noise was measured at one or two positions at each location using an omnidirectional microphone. The microphones were positioned on a central point in the OPSE, not within reach of students, hanging from the ceiling or mounted on a tripod. In OPSEs A, B and C the signal was recorded with a ½-inch microphone in samples of 350 s, ca. 90 samples for one day, for off-line processing with DIRAC 6.0 measurement software (B&K type 7841). Afterwards the equivalent A-weighted sound pressure level ($L_{A,eq}$) was determined over each sample of 350 s. In OPSEs D and E the measurements were carried out with a Rion NL-32 data logger. This data logger determined the equivalent A-weighted sound pressure level ($L_{A,eq}$) over a time period of 30 min and repeated this over the day.

The measurements of the acoustic parameters in the OPSEs were done at all locations as described in ISO 3382-3: 2012. This part of ISO 3382 specifies a measurement method, which results in single number quantities indicating the general acoustical performance of open plan offices. The measurements took place in furnished unoccupied OPSEs, only the three persons involved in the measurements were present in the OPSE. The heating and ventilation devices operated at the same power as during typical working hours. On all five locations, the following single number quantities were determined:

- Distraction distance, r_D [m]
- Spatial decay rate of A-weighted sound pressure level of speech, $D_{2,S}$ [dB(A)]
- A-weighted sound pressure level of speech at 4 meters, $L_{p,A,S,4m}$ [dB(A)]
- Time averaged A-weighted background noise, $L_{p,A,B}$ [dB(A)]
- Reverberation time, averaged from 250 Hz to 2000 Hz, T_{60} [s]

A dodecahedron sound source (B&K Omni Power sound source type 4292-L) was used, positioned at the height of 1.2 m, to generate a maximum-length sequence (MLS) signal. The impulse response at each receiver position was measured using a ½-inch microphone. The signal was recorded for off-line processing with DIRAC 6.0.

Furthermore, to determine the impact sound of different floors, the equivalent sound pressure level at 1 and 4 meters from an impact sound generator tapping machine (B&K type 3204) was measured on 2 locations (A and C). A tapping machine generates impact sound by five hammers dropping on the floor at a constant rate. The signal was recorded with a ½-inch microphone for off-line processing with DIRAC 6.0.

2.3 Results

2.3.1 Questionnaire results

Use and overall assessment of OPSEs by students

Figure 2.1 shows the percentage of students working for a, self-estimated, number of hours individually and in groups in an OPSE during a week. This figure shows that the distribution of study hours is widely spread. The median time of individual work in an open-plan learning environment is 5-8 h weekly and the median time for working in a group is 9-12 h weekly. Students of the University of Applied Sciences (OPSE A, B and C) spent more time working in groups (median 9-12 h vs 5-8 h for students of the University of Technology) and students of the University of Technology spent more time working individually (median 9-12 h vs 5-8 h for University of Applied Sciences) in OPSEs. Students use the study environment mainly in the morning (76.1%) and in the afternoon (83.8%) though rarely in the evening (2.8%).

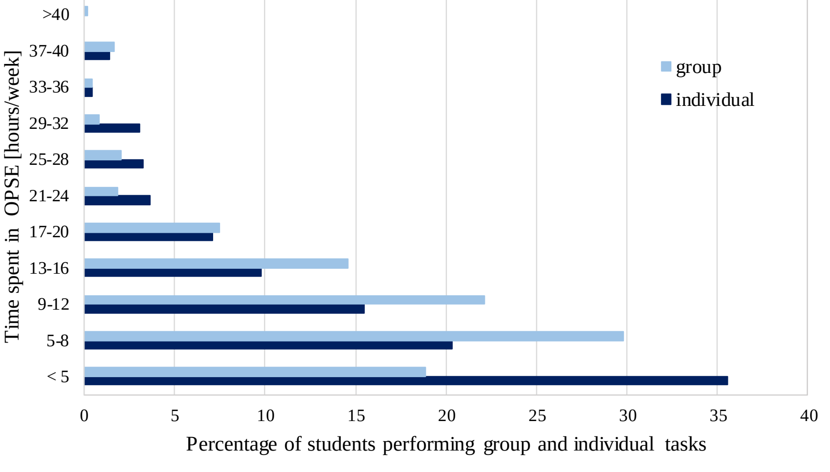


Figure 2.1 Percentage of students working for a self-reported time interval per week in an open-plan study environment for individual work and for working in groups.

The score for global noise sensitivity (4 points scale: 0= ‘completely disagree’, 3= ‘completely agree’) is on average 1.64 (SD=0.44). The reliability analysis shows that the noise sensitivity scale has a good internal consistency (Cronbach alpha=0.81, similar to the Cronbach’s alpha observed by Pierrette *et al.* 2015, which was 0.84). The students seem to be less sensitive to noise than the office workers investigated by Pierrette *et al.* (mean=2.2, SD=0.50).

Figure 2.2 shows the results of the assessment of different indoor environmental qualities. Overall, the values of the 14 environmental qualities differ significantly ($\chi^2(485)=1712.42$, $p<0.001$). Indoor environmental qualities that score the lowest are the possibility to cancel out noise (mean=2.22) and the possibility to work in private (mean=2.36). Post-hoc pairwise comparisons including the Bonferroni correction ($p<0.0018$), reveal significant differences between all indoor qualities except the difference between the possibility to look outside and the position of the workplace (*Z*=-0.320, *p*=0.749) and between the possibility to cancel out noise and to work in private (*Z*=-2.382, *p*=0.017).

If we compare the values across all OPSEs we see a significant influence of the open environment on the questionnaire results (indicated by *$p<0.05$; **$p<0.01$, Figure 2.2). Only the quality of lighting ($\chi^2(4)=4.982$, $p=0.289$), the position of the workplace ($\chi^2(4)=6.844$, $p=0.144$) and the possibility to personalize the workplace ($\chi^2(4)=7.159$, $p=0.128$) do not differ significantly between the OPSEs.

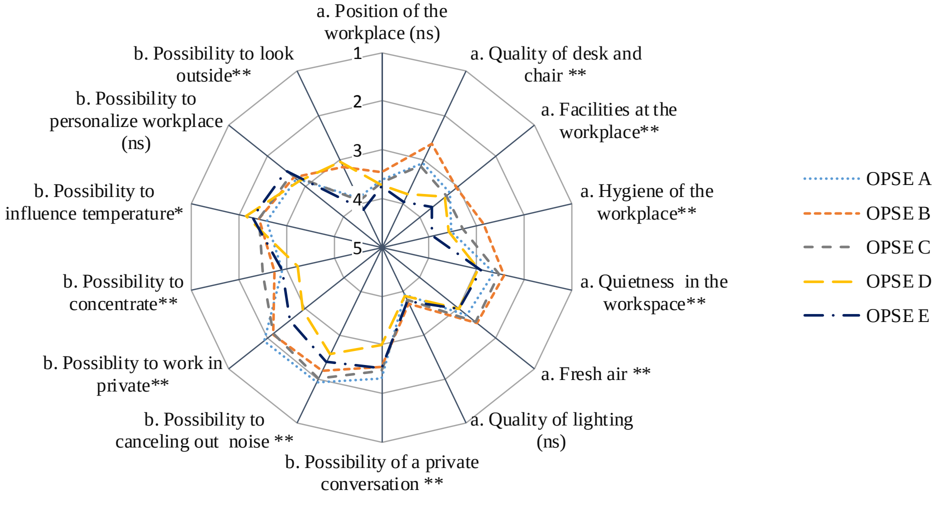


Figure 2.2 A comparison of different indoor environmental qualities, assessed with questionnaires. Significant differences between buildings according to the Kruskal Wallis test: *$p<0.05$; **$p<0.01$; ns=not significant. a. refers to comfort/functionality items; b. refers to quality privacy/control items.

Table 2.2 shows that overall students are reasonably satisfied with their physical study environment (mean=2.98; SD=0.52). At all locations students are less satisfied with control-privacy aspects (mean=2.67; SD=0.55) in comparison with comfort-functionality aspects (mean=3.29; SD=0.60) of their study environment, there is a significant difference between the two scores (Z(491)=22.36, $p<0.001$). The Cronbach's α of the overall satisfaction (α=0.79) shows good internal consistency. However, the comfort-functionality (α=0.70) and the control-privacy (α=0.63) question sets are less consistent than found by Pierrette *et al.* (2015).

If we compare the values between the five OPSEs we see statistically significant differences considering the overall satisfaction ($\chi^2(4)=49.751$, $p=0.001$), the comfort-functionality ($\chi^2(4)=67.738$, $p=0.001$) and the control-privacy ($\chi^2(4)=16.553$, $p=0.002$).

Table 2.2 Satisfaction regarding the study environment on a scale from 1= 'dissatisfied' to 5='satisfied'. SD is the standard deviation of the mean and α is the Cronbach's alpha of the item questions.

		All OPSEs	*OPSE A*	*OPSE B*	*OPSE C*	*OPSE D*	*OPSE E*
overall satisfaction	mean	2.98	2.93	2.75	2.89	3.15	3.17
	SD	0.52	0.46	0.48	0.58	0.52	0.45
	α	0.79	0.73	0.75	0.85	0.78	0.76
comfort-functionality	mean	3.29	3.26	2.95	3.19	3.47	3.58
	SD	0.60	0.55	0.55	0.64	0.56	0.51
	α	0.70	0.64	0.62	0.76	0.66	0.69
control-privacy	mean	2.82	2.80	2.69	2.76	2.92	2.94
	SD	0.55	0.50	0.52	0.61	0.60	0.47
	α	0.63	0.58	0.62	0.75	0.65	0.54

Noise disturbance and sound sources

Figure 2.3 shows the overall background noise perception and background noise disturbance in the OPSEs. On average 38% of the students consider the background noise disruptive (Figure 2.3b). In the following, background noise is divided in 5 categories: building devices, telephones, intelligible and unintelligible conversations of fellow students, and people walking. Figure 2.4 shows that students in OPSEs perceive different types of noise sources. The five different noise sources lead to significantly different levels of disturbance ($\chi^2(492)=347.64$; $p<0.001$). The most disturbing sound source is intelligible speech (mean=3.74) followed by unintelligible speech (mean=3.28) and walking sound (mean=3.01). Post-hoc pairwise comparisons including the Bonferroni correction ($p<0.005$), reveal significant differences between all sound sources except the difference between disturbance by walking sound and telephone ringing ($Z=-2.198$, $p=0.028$).

If we compare the values across all OPSEs, we see a statistically significant difference considering disturbance of sound sources between the five open environments for walking ($\chi^2(4)=42.141$, $p=0.001$), telephone ringing ($\chi^2(4)=14.384$, $p=0.006$) and building devices ($\chi^2(4)=11.574$, $p=0.021$).

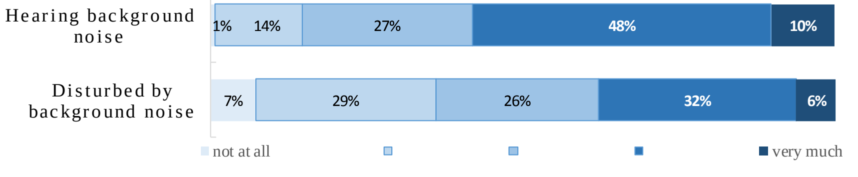


Figure 2.3 Background noise perception and disturbance in open-plan study environments (n=496).

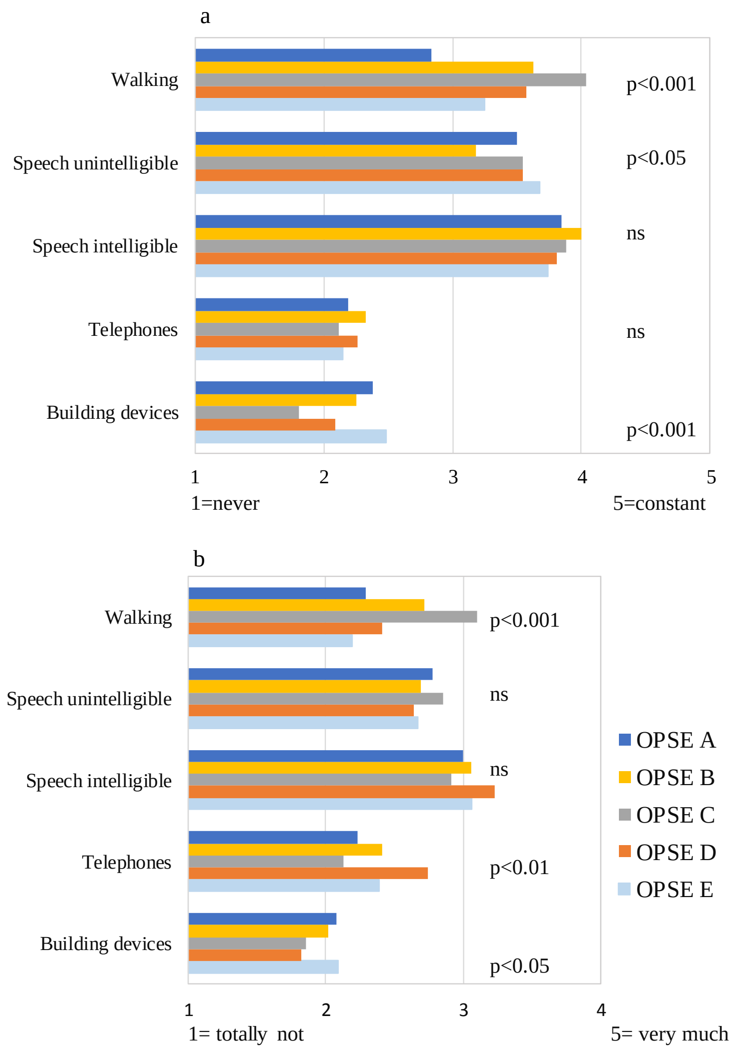


Figure 2.4 Perception (panel a) and disturbance (panel b) of sound sources in open-plan study environments (significant differences between buildings by Kruskal Wallis test; *p*=significant, ns=not significant).

Table 2.3 presents the correlation between noise disturbance of background noise on the one hand, and perception and disturbance of different sound sources, noise sensitivity and satisfaction of the OPSE on the other hand. Most of the Spearman rank correlation coefficients are low (<|0.40|) which indicates a weak correlation. Only the correlation between noise disturbance and noise sensitivity, perception of background noise and the disturbance by speech can be called moderate ($|0.4| < r_s < |0.6|$; $p<0.001$)). The disturbance of speech, intelligible and unintelligible, shows a moderate correlation with disturbance of background noise which indicates the importance of speech as a disturbing noise source.

Table 2.3 Correlations with disturbance of the background noise. (Spearman's rank correlations, r_s).

Correlation between disturbance background noise and:	*All OPSEs* r_s
Perception background noise	**0.54**
Perception sound source:	
- Devices (office machinery)	0.13
- Telephone ringing	0.20
- Intelligible conversation	0.21
- Unintelligible conversation	0.13
- Passing by (walking) people	0.15
Disturbance Sound Source:	
- Devices (office machinery)	0.21
- Telephone ringing	0.27
- Intelligible conversation	**0.54**
- Unintelligible conversation	**0.52**
- Passing by (walking) people	0.39
Noise Sensitivity	**0.51**
Satisfaction physical workspace	-0.32
- Control-privacy aspects	-0.37
- Comfort-functionality aspects	-0.22

Note: All correlations are significant at the 0.01 level (2-tailed).

Noise disturbance and student tasks

Noise disturbance not only depends on the type of noise (Figure 2.4) but also on the tasks people perform in an environment [105,106]. Figure 2.5 shows the activities students perform in OPSEs. Students work in groups on consulting and brainstorming tasks and they work individually on writing, reading and searching tasks. The values for the performed activities in OPSEs (Figure 2.5, dark blue bars) differ significantly ($\chi2(492)=1137.09$, $p<0.001$) and also the activities bothered by sound (Figure 2.5, light blue bars) differ significantly ($\chi2(492)=1124.87$, $p<0.001$). This survey shows that students are mostly bothered by noise when studying for an exam (mean=4.06) followed by reading (mean=3.66) and writing tasks (mean=3.29). Post-hoc pairwise comparisons including the Bonferroni correction ($p<0.001$) reveal significant differences between most of the activities bothered by sound except by pairs including 2 of the following activities: creative, brainstorming, consulting and searching ($0.04 \leq p \leq 0.867$). Also, mathematics and writing (Z=-0.737, p=0.461) do not differ significantly. There are alternative perspectives on how to judge the overall impact of noise on student activities. Although studying is highly disturbed by noise one has to consider that studying for an exam is a less frequently conducted task in an OPSE in comparison with reading and writing. On the other hand it is presumable that the observed frequency of tasks in the OPSEs is partly a reflection of the experienced and expected noise disturbance, as seen in the lower frequency of the activity studying for an exam.

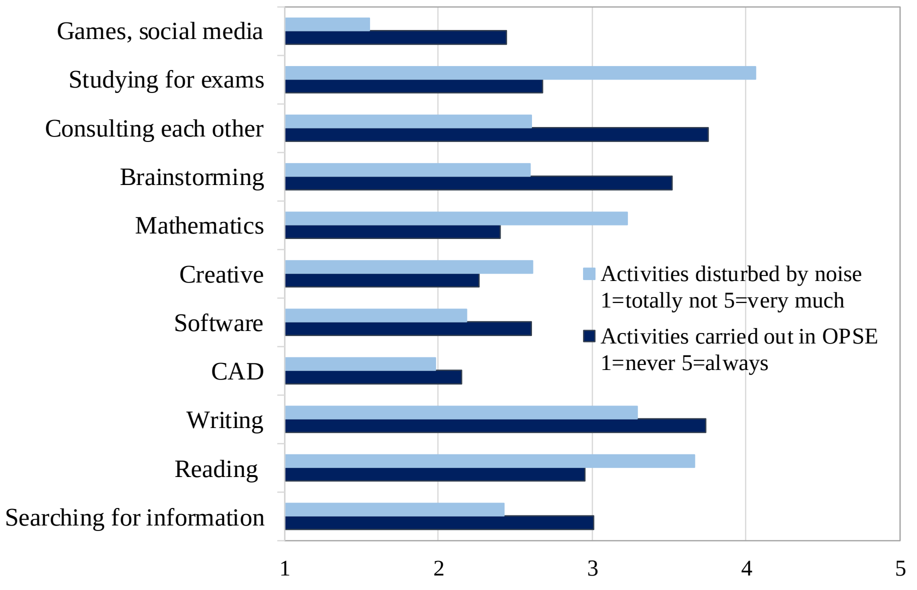


Figure 2.5 Activities carried out and bothered by noise in an open-plan study environment (n=496).

Analyzing the Spearman rank correlation between the sound sources students are disturbed by and the tasks which are bothered by noise, significant though rather small correlations are found. The highest significant correlations, but still weak, were between the disturbance by intelligible speech and the disturbance while reading (r_s=0.350), writing (r_s =0.301) and studying for an exam (r_s =0.300) and between the disturbance by the overall background sound and reading (r_s=0.373), writing (r_s=0.405) and studying for an exam (r_s=0.330).

2.3.2 Acoustic parameters

Acoustic quality of OPSEs

The mean equivalent sound pressure levels in the OPSEs were measured during the time of the day the survey was conducted. In OPSE A, B and C the equivalent A-weighted sound pressure level ($L_{A,eq}$) was determined for 350 s time intervals and subsequently integrated for the time the questionnaires were taken. In OPSE D and E the equivalent A-weighted sound pressure level ($L_{A,eq}$) was determined for time intervals of 30 minutes and then integrated for the time the questionnaires were taken. The mean background level of all OPSEs (in use) during the survey was 52.5 dB(A) and varied between 48.9 dB(A) (OPSE E) and 57.9 dB(A) (OPSE C).

Figure 2.6 shows the unweighted equivalent sound pressure levels during the survey in octave bands. The maximum sound levels occur in the range of 250-500 Hz and roll off in the high frequencies with an approximate slope of 6 dB per octave. This frequency spectrum shape of the background noise is similar to the spectrum of human speech (see Figure 2.6).

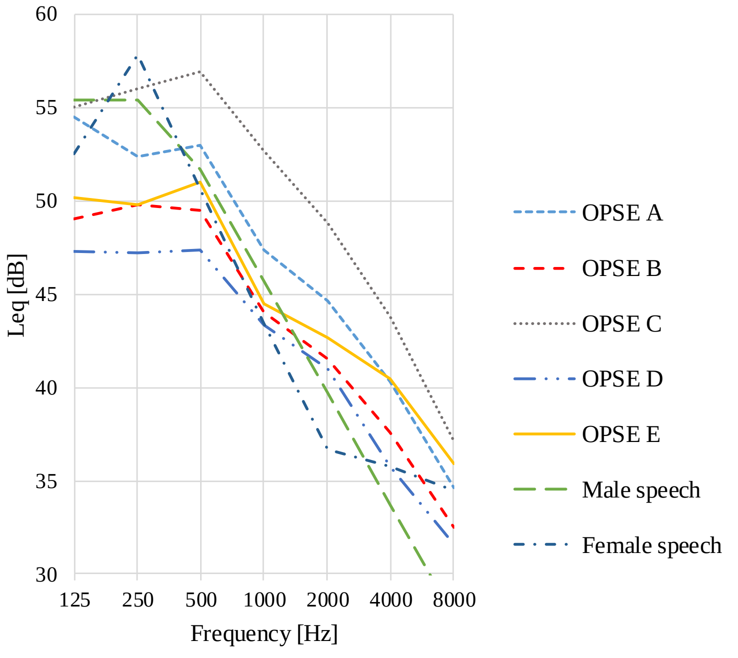


Figure 2.6 Equivalent sound pressure levels per octave band in open-plan study environment during use and survey execution. For comparison, the spectral distribution of male and female speech (IEC 60268-16:2011), at the mean sound pressure level of OPSEs (52.5 dB(A)), is added.

Table 2.4 shows the room acoustic parameters measured in the unoccupied OPSEs. The distraction distance indicates the distance at which the speech transmission index (*STI*) drops below 0.5. Considering the importance of a low *STI* in open-plan offices to improve the work performance [64], the distraction distance r_D is also interesting to analyze in OPSEs. In the five OPSEs the distraction distances (10.2 m to 16.3 m) are significantly higher than the example target value described in ISO 3382-3, 2012) of 5 meters, which indicates that individual speakers in these environments affect a great number of students, leading to a decrease of privacy and concentration. Both $D_{2,S}$ and $L_{p,A,S,4m}$ show the decrease of the speech level over a distance in the OPSE. The measured values of both parameters are not in the range of the example target values described in the ISO 3382-3 standard for open-plan offices, which points towards a decrease of privacy and concentration. All single-number qualities from ISO 3382-3 show little variation between the five environments, except for the r_{D} values (Table 2.4), and all three values do not reach the example target values described in the ISO 3382-3. There are no target values for open plan offices or OPSEs in the Netherlands and also the values mentioned in ISO 3382-3 are example target values for open plan offices with good acoustic conditions. Virjonen *et al.* [89] presented an acoustic classification with target values for open plan offices, in which class A represents the highest acoustic quality while D represents the lowest. All measured values in the OPSEs are in class C and D.

The background levels in the unoccupied OPSEs meet the target values of the Dutch recommendations for open-plan offices (<40dB(A)). On the other hand, the background sound levels are too low (<35dB(A)) to mask speech in an OPSE, which makes speech more disturbing. The reverberation time averaged over the frequency bands from 250 Hz to 2000 Hz on all locations is above the target value for open-plan offices in the Dutch recommendations of 0.5 s. An ANOVA analyses showed that the acoustic parameters distraction distance ($F(4,10)=11.875$, $p=0.001$), reverberation time ($F(4,10)=7.605$, $p=0.004$) and background noise in the unoccupied rooms($F(4,10)=4.558$, $p=0.024$) differ significantly between the five OPSEs (Table 2.4).

Table 2.4 Mean measurement results of the acoustic parameters in the five OPSEs in unoccupied state. l= number of measurement lines; n= number of measurement points; *p*= significance of differences between OPSEs.

Mean value of the measured ISO 3382-3 values (range):	*OPSE A* l=3	*OPSE B* l=3	*OPSE C* l=4	*OPSE D* l=3	*OPSE E* l=2	*p*	*Example Target Values*
Distraction distance r_D [m]	11.1 (9.6-13.0)	12.7 (12.1-13.4)	10.3 (10.0-10.8)	16.3 (15.1-18.2)	13.9 (12.7-15.0)	0.001	≤5 [a]
Spatial decay rate of A-weighted *SPL* of speech $D_{2,S}$ [dB(A)]	5.5 (4.2-7.0)	6.1 (5.8-6.5)	6.3 (5.9-6.6)	5.8 (5.4-6,2)	5.2 (5.0-5.3)	ns	≥7 [a]
A-weighted *SPL* of speech at 4 meters, $L_{p,A,S,4m}$ [dB(A)]	52.9 (52.3-53.8)	53.3 (52.6-54.7)	52.0 (51.3-53.0)	53.5 (52.0-55.7)	53.7 (53.6-53.7)	ns	≤48 [a]
Mean value of measured room acoustic values (SD):	n=21	n=25	n=35	n=49	n=26		*Target Values*
Reverberation Time [s] (T_{30} frequencies 250 to 2000 Hz)	0.65 (0.06)	0.52 (0.05)	0.57 (0.07)	0.58 (0.09)	0.92 (0.08)	0.004	≤0.5 [b]
A-weighted background noise *SPL*; $L_{p,A}$ [dB(A)]	34.6 (1.01)	35.5 (1.06)	38.0 (1.59)	33.5 (1.54)	33.4 (1.72)	0.024	35-40 [b]

note: [a]=ISO 3382-3; [b]=Handbook Offices NVBV (Dutch-Flemish)

Figure 2.7 shows the equivalent sound pressure level at 1 and 4 meter from the impact sound generator tapping machine in the OPSEs. The sound level in the OPSE C is significantly higher than the sound level in OPSE A, due to the lightweight raised computer floor, the values differ by 11 dB(A) at 1 meter and by 12.5 dB(A) at 4 meters.

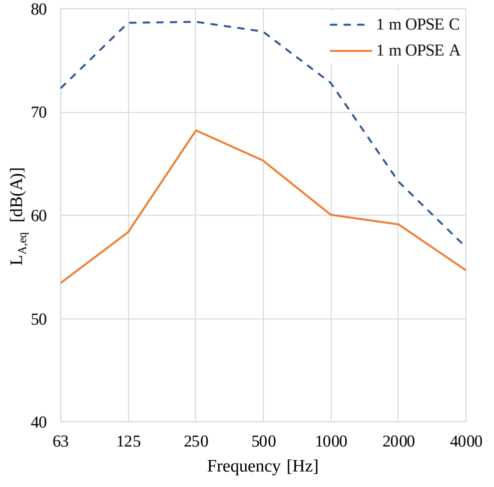


Figure 2.7 Equivalent sound pressure levels per octave band in open-plan study environment on 1 and 4 m from a tapping machine.

Noise disturbance and acoustic parameters

Table 2.5 presents the correlation between disturbance of different sound sources and task disturbance on the one hand, and acoustic parameters on the other hand. Nearly all of the Pearson's correlation coefficients are very low (<|0.20|) and not significant, which indicates a very weak correlation. Only the correlation between reverberation time and reading, writing and studying for an exam are significant and weak instead of very weak. These correlation coeficients show a weak correlation (0.2) between ‘to be bothered by noise’ and an increase of the reverberation time. Walking is the only sound with a significant correlation with the acoustic parameters, although this correlation is weak (0.2-0.3), and the direction of the correlations is partly unexpected. It is not expected that the disturbance by walking sound increases if the demping of sound over distance ($D_{2,S}$) increases. The correlations also show the disturbance by walking sound to increase due to an increase of the background sound (L_{pA}).

Table 2.5 Correlation coefficients between the acoustic parameters and the noise disturbance by sound sources and disturbance of tasks in the five OPSEs. (Pearson's correlation)

	r_D [m]	$D_{2,S}$ [dB(A)]	$L_{p,A,S,4m}$ [dB(A)]	*RT(250-2000Hz)* [s]	$L_{p,A}$ [dB(A)] *unoccu-pied*	$L_{p,A}$ [dB(A)] *occupied*
Disturbance by Sound Source:						
- Overall background noise	-0.064	0.047	-0.019	-0.014	0.077	0.048
- Devices (office machinery)	-0.066	-0.092*	0.100*	0.068	-0.056	-0.053
- Telephone ringing	0.182**	0.004	0.011	-0.038	-0.105*	-0.112*
- Intelligible conversation	0.098*	-0.008	0.012	-0.016	-0.067	-0.065
- Unintelligible conversation	-0.058	0.022	-0.036	-0.008	0.054	0.066
- Walking people	-0.103*	**0.257****	-0.187**	0.155**	**0.278****	**0.212****
Bothered by noise while doing a task:						
- Gaming, social media	-0.013	0.055	-0.031	-0.103*	-0.008	0.030
- Studying for exams	0.067	-0.131**	0.096*	***0.212****	-0.033	-0.115*
- Consulting each other	-0.175*	0.173**	-0.119**	-0.158**	-0.180**	-0.193*
- Brainstorming	-0.239*	0.134**	-0.047	-0.117*	-0.173**	-0.159**
- Mathematics	0.047	-0.184**	0.142**	0.141**	-0.165**	-0.146**
- Creative	-0.016	-0.119*	0.089	0.070	-0.108*	-0.065
- Software	0.102*	-0.017	0.053	-0.001	-0.080	-0.108*
- CAD	-0.037	-0.103*	0.083	0.044	-0.105*	-0.055
- Writing	-0.004	-0.143**	0.149**	***0.198****	-0.045	-0.130**
- Reading	0.145*	-0.191**	0.093*	***0.221****	-0.130**	-0.148**
- Searching for information	0.062	-0.152**	0.182**	0.123**	-0.161**	**-0.200****

Note: * Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

2.4 Discussion

In this study, five OPSEs in higher education were investigated. The study revealed specific user characteristics of OPSEs related to noise disturbance:

- The noise sensitivity test indicates that students (mean age=21.2, SD=2.2) are less sensitive to noise in comparison with the office employees in the research by Pierrette *et al.* [62]. Due to the fact that the data in this research is gathered in OPSEs, it could be possible that the sample is biased by self-selection. Such a bias could occur, because students who are most sensitive to noise and therefore most disturbed by noise probably did not choose to study in an OPSE. As a result, it is plausible that the noise sensitivity of the student population in the OPSE is lower than that of the noise sensitivity of the general student population. Furthermore, analyses show a significant correlation between noise sensitivity and disturbance (Table 2.3). Students that score relatively high on noise sensitivity, above the mean score (>1.64), are more disturbed by background noise (54%), than students with a relatively low noise sensitivity score (<1.64) (22%). Therefore, it is plausible to conclude that the disturbance of students by background noise in an OPSE for the total student population is larger than the value of 38% found in our questionnaire.

- Students work for short periods in an OPSE, they mostly work before and after classes (80%) and between classes (62%). This high number of moving students makes walking sounds a prominent sound category. The results of the survey showed significant differences among the OPSEs in noise disturbance due to walking sounds. Therefore, the architectural design and the floor construction of an OPSE can be highly influential in the resulting noise disturbance. The higher rate of disturbance due to walking sounds in OPSE C can be explained by the floor type of the location (Table 2.1). OPSE C has a lightweight raised computer floor that results in more impact sound from walking than the concrete floors at the other locations. A comparison between the sound radiation of the lightweight raised computer floor in OPSE C and the concrete floor in OPSE A due to excitation of the floors shows a significantly higher sound level in OPSE C than the sound level in OPSE A (Figure 2.7). The disturbance can be explained by the 'changing state' effect [107]. The spectro-temporal variability and segmental structure of walking sound makes this sound more disruptive than a less variable, continuous background sound. The architectural design can also influence the sound level due to walking. Workstations positioned near a through path are exposed to a higher sound level due to the number of people passing.

- The survey shows that students in an OPSE work a great part of the time on group assignments, during which they brainstorm and discuss with each other. These activities induce speech-based noise in open-plan study environments. Background noise measurements during use confirm this by speech-like spectra in the OPSEs (Figure 2.6). As shown by this research (Figure 2.4), speech is the most disturbing sound source; therefore, the simultaneous combination of group work and individual cognitive tasks in OPSEs causes an acoustic dilemma. Background speech is especially disturbing for language-based tasks such as reading and writing (Figure 2.5) as can be explained by the 'interference-by-process' theory [105].

- The only current solution for this acoustic dilemma appears to be the use of earbuds or headphones. The survey shows that many of the students use earbuds or headphones. More than half (57%) of the students indicate they use earbuds or headphones due to the noisy environment and only few students (14%) never use earbuds or headphones in the OPSE. In contrast, in the research by Scannell *et al.* [31] on informal learning spaces only 16% of the students used headphones. More research on the use of headphones in OPSEs is desirable.

In this paper, results found in OPSEs are compared with literature on noise disturbance in open-plan offices and acoustic standards for open-plan offices, while Scannell *et al.* [31] compare their data on informal learning spaces with classroom standards. The activity analysis in the present study shows no-classroom like teacher-student activities which would require a good speech transmission in the OPSE. Although the building characteristics of the OPSEs (Table 2.1) and some of the activities of the students (Figure 2.5) show resemblance with open-plan offices, further analyses show specific features of OPSEs. Compared to open-plan offices, the users are younger, are free to choose their own workplace, work for shorter periods and frequently move in and out the OPSEs causing walking sound to become more important; students use OPSEs as individuals and frequently in groups, are especially disturbed by noise while executing typical learning tasks such as studying for an exam. The implications of this distinctive use of OPSEs for the acoustic requirements and thus for the design of those environments make it necessary to treat open-plan study environments as a separate research category.

Analyses between the room acoustic parameters and noise disturbance showed only weak correlations. The Pearson’s correlation analyses is conducted with relatively few data, the number of questionnaire results is more than enough (496) but the number of values for the room acoustic parameters is very low (5) and confounded while all the values are measured in only five environments. The weak correlations are probably the result of the comparatively equal quality of the five OPSEs, class C and D in the classification for open-plan offices [89]. Furthermore, it is very difficult to find such correlations in a field study due to the many unpredictable and unknown parameters of the different locations that could influence noise disturbance. The weak correlation found showed a relation between the reverberation time and disturbance of complex tasks like reading, writing and studying for an exam. An increase of the reverberation time leads to more disturbance while performing those tasks. A short reverberation time is conform the standards for both open-plan offices (Table 2.4) and classrooms [31]. Overall, studying for an exam is the most disturbed task, but writing is the most frequently conducted individual task in OPSEs.

2.5 Conclusions

The aim of this study is to gain more insight into the assessment of noise in open-plan study environments and to reveal the correlation between, on the one hand, noise disturbance of students and, on the other hand, the noise sources they perceive, the tasks they perform, and the acoustic parameters of an open-plan study environment.

This study showed that more than one third of the surveyed students are disturbed by the background noise in OPSEs. Probably even more students are disturbed by the noise but as a result of the noise they may choose a different working place. Therefore it is presumable that the sample is biased by self-selection.

Students are mostly disturbed by speech, and at one location walking sound is an important disruptive sound source. This survey showed that students are mostly disturbed by noise when performing individual complex cognitive tasks such as studying for an examination, reading and writing. The measured single-number quantities from ISO 3382-3 do not reach the example target values described in the standard of open-plan offices, and there are no target values for open-plan study environments. Only weak significant correlations were found between the room acoustic parameters and noise disturbance of students, probably due to the acoustical comparability of the OPSEs and the limitations of a field study.

Results showed that simultaneous use of the same environment for communication in group work and concentration on individual work creates an acoustic dilemma, in which language-based concentration tasks are the ‘victims’ and for which currently the only way out is the use of earbuds or headphones.

Considering the specific use and needs of students in open-plan study environments, the percentage of students disturbed by noise, the growing number of OPSEs due to changing needs in higher education, and the development of libraries to OPSEs, it is necessary to conduct more research on this topic based on which acoustic target values can be compiled and design tools can be developed to optimize the acoustic environment for students in OPSEs. Not only classrooms and lecture halls but also OPSEs in education buildings need an optimal acoustic environment.

CHAPTER 3

COLLABORATION

3 | Auditory distraction in open-plan study environments: Effects of background speech and reverberation time on a collaboration task.

Previous research has shown that semantic-based tasks are negatively influenced by semantic aspects in background speech. Collaboration is an important task in open-plan study environments and is a semantic task which might be disrupted by background speech. Therefore, the aim of this study was to analyze the influence of irrelevant background speech on student-collaboration.
Participants worked in pairs to solve spot-the-difference puzzles, by using the 'DiapixUK' collaboration task, while they were exposed to different background sound scenarios. The composed sound scenarios varied in semantic content (mother tongue and foreign language background speech) and reverberation time (short vs long), the latter affecting speech intelligibility.
Although a longer reverberation time decreases the intelligibility of background speech and a foreign language decreases meaningfulness of speech, no significant changes in performance were found. On the other hand, the data show an increased perceived disturbance for a longer reverberation time, which we interpret as an increased difficulty of interpersonal communication in the collaboration task due to the increased level of the background speech. The quiet reference condition was the most preferred sound condition which is in line with both the effect of a low background sound level and the absence of semantic interference.

This chapter is based on: Braat-Eggen, P.E., Keus v.d. Poll, M., Hornikx, M.C.J., Kohlrausch, A.G.(2019). Auditory distraction in open-plan study environments: Effects of background speech and reverberation time on a collaboration task. Applied Acoustics 154, 148-160. DOI: 10.1016/j.apacoust.2019.04.038.

3.1 Introduction

An acoustic environment should support people doing their tasks without being disturbed and causing loss of performance. Unfortunately, it is known that auditory distraction is a major problem in all kinds of open-plan work environments [31,57,62]. For instance, many studies show the detrimental effect of background speech on performance of semantic tasks such as comprehensive reading [108,109], proof reading [54,74,101,110] and writing [71,72]. Unfortunately, background speech is common in an open-plan work environment due to telephone calls and interactions between workers [31,62]. These interactions might, in the best case, lead to communication and collaboration. On the other hand, collaboration is also a semantic task which might be disrupted by background speech.

The importance of collaboration tasks in open workspaces is significant for open-plan study environments (see Chapter 2). Due to new ways of learning, informal learning places (e.g. libraries, study areas, lobbies, atria etc.) become more and more important [3,19]. Not only classrooms and lecture halls suitable for teacher-centered instructions but also work environments for participatory learning, group work and individual work are needed [19,111]. Especially spaces intended and designed to accommodate individual as well as small group activities of students, so called open-plan study environments (Chapter 2), have to support a diversity of tasks in the same environment. A situation of several groups working on their group assignment in the same open-plan study environment is a very common situation.

This so called collaborative learning can be defined as: 'working in a group of two or more to achieve a common goal, while respecting each individual's contribution to the whole' [112]. Collaboration therefore implies interaction among students to produce a common product and involves negotiations, discussions, and integrating others' perspectives [113]. Verbal communication is a crucial element of all those activities and will imply speech production. Therefore, background speech, due to speech production of other working groups in the same environment, is unavoidable and all students working in an open-plan study environment will more or less be influenced by background speech while doing their tasks. Therefore, the focus in the present study was on the influence of background speech on a collaboration task in an open-plan study environment.

3.1.1 Why is background speech disruptive for cognitive performance?

The characteristics of a sound in combination with the characteristics of a cognitive task can predict whether the sound will impair cognitive performance in the task [79,105,114]. The "Duplex-Mechanism Account of Auditory Distraction" (DMAAD) [115,116] describes two mechanisms through which sound can disrupt cognitive performance: attention distraction and specific interferences.

The first mechanism, attention distraction, gives an explanation of why an unexpected signal can disrupt performance (attentional capture). Sudden or abrupt changes in the signal capture attention and draw it away from the focal task towards the background sound signal [117]. For instance, a signal like ‘B B B B B B’ is not distracting, while the ‘K’ in the series ‘B B B K B B B’ is distracting and decreases performance because of the violation of the expectation for another ‘B’ (i.e. the deviation effect) [115,117,118]. Besides an unexpected change in the sound signal, also other aspects in the sound can capture attention and thereby disrupt performance, like hearing one's own name in a background conversation [119], or hearing other interesting or relevant information [116,117,120-123].

The second mechanism mentioned in the DMAAD to explain why background sound can disrupt cognitive performance is the occurrence of interference between similar cognitive processes (interference-by-process). A classical way of studying this is measuring serial recall performance. In serial recall, a person has to recall a series of visually presented items (e.g. numbers, words or letters) in the correct serial order. Task-irrelevant sound that is played during the presentation of the visual stimuli impairs task performance. The magnitude of the impairment depends on the acoustical variability of the sound [124,125]. A background sound consisting of almost no acoustical variability, like 'B B B B B B' (a steady state signal) is almost not disruptive for the serial recall performance. Performance in a background with a steady state signal is similar to performance in quiet. On the other side, a signal with acoustical variability, like 'B X K C M L' (a changing state signal) impairs serial recall performance [107,126-128]. This changing state effect [107] can be explained as an interference between voluntary processes required to recall the serial order of the visually presented items and similar automatic processes required to analyze the serial order of the items in the automatically incoming auditory signal, i.e. interference-by-process [117,129]. For instance music and speech can disrupt cognitive performance as long as there is acoustical variability in the sound signal [107,130].

A property that distinguishes speech from other sounds is that speech not only has acoustic characteristics, like changes in frequency and amplitude of the signal, but also has semantic characteristics, like the words and sentences that contain meaning [131]. In line with the interference-by-process account, an interference also occurs between semantic cognitive processes used to automatically analyze the meaning in the background speech signal and similar semantic cognitive processes involved in the execution of a semantic based task, like reading and writing [79]. This should mean that speech intelligibility and meaningfulness of the background speech signal predict distraction on semantic tasks like reading and writing. As highly intelligible background speech contains more semantic information compared to a less intelligible signal, a highly intelligible signal should be more disruptive. Further, a highly intelligible speech signal will reasonably contain more relevant or interesting information that can capture attention and, as explained by the framework of attentional capture, disrupt performance more than a less intelligible signal. Research indeed shows that an increase of intelligibility [71,74,106,132] and meaningfulness [72,79,108-110] of the background speech is related to an increase of disturbance and a decrease of performance on a semantic task.

As mentioned earlier, a serial recall task is also disrupted by background speech, although not due to its semantic properties but due to its auditory-perceptive characteristics [133]. Therefore, a serial recall task is as much disturbed by background speech in an unknown foreign language as by background speech in the mother language [79]. Nevertheless, for tasks with semantic characteristics, the semantics of a speech signal are decisive [133]. Since collaboration has semantic characteristics, in the current study, we expected a highly intelligible and meaningful background speech to be more disruptive compared to less intelligible and less meaningful background speech.

3.1.2 Individual differences

Another factor – in addition to the characteristics of the sound and the cognitive task – that can influence how an individual reacts to noise, is individual differences, like noise sensitivity. Individual differences are important to take into account when organizing workplaces, as those individual differences might require different work environments. It is reasonable to argue that individuals that are sensitive to noise will be more distracted by noise when undertaking a cognitive task, and as a consequence perform worse compared to their less sensitive colleagues. However, studies that investigated the relationship between subjective noise sensitivity (i.e. noise sensitivity measured by self-rating) and cognitive performance have only found small correlations or no correlations at all [86,87,134,135]. In those studies, though, background sound consisted of different kinds of noise, or unintelligible speech. None of the studies used intelligible background speech. Neither has the correlation between noise sensitivity and performance on a verbal collaboration task been investigated. In Chapter 2, a field study in open-plan study environments, noise sensitivity of students showed to be related to the disturbance by noise. Therefore, in the current study we investigated whether individual differences in subjective noise sensitivity predict individual differences in susceptibility to the effects of background speech on collaboration.

3.1.3 How to influence speech intelligibility and meaningfulness?

Room acoustics will influence the intelligibility of speech. A widely used parameter to measure or describe speech intelligibility between a speaker and listener is the speech transmission index (*STI*), where a value of 1 indicates an excellent speech intelligibility and an *STI* value below 0.3 indicates nearly unintelligible speech. The most important aspects that will influence speech intelligibility in an environment are the speech level relative to the background noise level at the listeners' position and the reverberation time [34].

A long reverberation time will decrease speech intelligibility due to the effect of smoothening the temporal profile of the waveform [34,136]. On the other hand, the level of speech at the listeners' position is of great importance, a high speech-to-noise ratio will result in more intelligible speech. The speech level in a room will decrease over distance between talker and listener due to sound absorbing materials in an environment. If more sound absorbing materials are applied to walls, ceiling and floor, not only the intelligibility will increase due to a shorter reverberation time but also the speech level will be reduced at the listeners' position resulting in a decrease of the intelligibility. Speech related room acoustic parameters as described in ISO 3382-3 [81], like spatial decay rate of speech ($D_{2,S}$) and sound pressure level of speech at 4 meter ($L_{p,A,S,4m}$) are correlated with intelligibility. A decrease of the speech level over distance, expressed in a higher $D_{2,S}$ or lower $L_{p,A,S,4m}$ value, will result in a decrease of the speech-to-noise ratio and will therefore lower speech intelligibility. Reducing the speech level over distance can not only be accomplished by applying more acoustic absorbing materials but also by installing high sound screens in an open environment [137,138].

The background noise level will also influence the intelligibility of a speech signal because it reduces the signal-to-noise ratio, therefore, if the background noise increases, speech intelligibility decreases. In a multi-speaker background situation, the noise consists of speech and the loudest background voice is most intelligible for a person doing a task. Also in this situation an increase of the background speech will lead to a reduction of the intelligibility of the speech of the loudest speaker.

A special situation occurs if the task of a worker requires verbal communication, as in a collaboration task. An increase of the background noise level will lead to a louder speech level of the communicating participants in order to compensate the decrease of the signal-to-noise ratio between them. This increase of the speech level will implicate a higher background noise level for other workers in the environment. The latter effect is called the Lombard effect [139], a well-known phenomenon that people in a room speak at a higher sound level due to the background speech, which again leads to a higher background speech level. The Lombard effect was found to start at an ambient noise level around 45 dB and a speech level of 55 dB [140].

A poorly intelligible speech signal can also be less meaningful for the listener, after all, unintelligible speech is also meaningless. It should be noted that meaningless speech is not the same as irrelevant speech, because irrelevant speech can still have a meaning. In an experimental setting meaningfulness of speech can be influenced by for instance spectrally-rotating the speech [72], by playing sentences in reverse [109,110] or by the language of the speech [110]. Research has shown that background speech in an unknown foreign language will decrease the disturbance and increase the performance of a semantic task compared to background speech in the mother tongue [106,110].

3.1.4 The aim of the study

To the author's best knowledge, the influence of background speech on the perceived disturbance and performance of a collaboration task has not been previously investigated. Because of the importance of this task in an open-plan study environment, the aim of this study is to analyze the influence of background speech on the perceived disturbance and performance on a collaboration task considering intelligibility and meaningfulness of the background speech.

The hypothesis is that an increase of intelligibility and meaningfulness of the irrelevant background speech will lead to an increase of disturbance and a decrease of performance in the collaboration task. Furthermore, noise sensitivity will be taken into account in this study. The hypothesis is that highly sensitive individuals will be more disturbed by the background speech and will show a decrease of performance in the collaboration task compared to less sensitive individuals.

3.2 Materials and methods

3.2.1 Design

A within-participants design was used with five different sound scenarios with varying intelligibility and meaningfulness of the background speech. As dependent variables, the performance and self-estimated parameters such as disturbance, ability to ignore the background speech, eagerness to go on and quality of collaboration of the participants accomplishing a collaborative task were used. Also, the noise sensitivity and strategy of the participants was measured.

3.2.2 Participants

A total of 76 participants (37 male and 39 females, mean age=24.5 years, SD=4.9 years) took part in the experiment. The participants were Swedish, Belgian and Dutch students. In total 46 Swedish students from the University of Gävle, 24 Dutch students from Avans University of Applied Sciences and 6 Belgian visiting students at the University of Gävle in Sweden participated in this experiment. The Belgian students had the same native Dutch language as the Dutch students. The students worked in couples which resulted in 23 Swedish couples and 15 Dutch speaking couples. One Swedish couple was left out of the analysis because of technical errors. The Swedish and Belgian students received two cinema tickets and the Dutch students received a financial contribution to their study trip to Stockholm and Gävle as a reward for their participation.

3.2.3 Acoustic Conditions

Five sound scenarios were composed, four comprising different background sounds and one quiet condition. In this study intelligibility of background speech was influenced by manipulating the reverberation time by changing the materials of the walls, floor and ceiling of the room. Although absorption of sound is not the only way to influence the intelligibility, it is the most common way to influence the acoustics of an environment. Adding masking sounds or screens to influence the speech intelligibility of an open environment is another possibility to influence the acoustics, however, it takes architectural or electro-acoustical attributes to add to the environment, while choosing materials for walls, floor and ceiling is a standard procedure of an architect designing an open-plan study environment. To study the influence of intelligibility by changing the reverberation time, two extreme sound absorbing conditions were chosen: one condition with only sound absorbing materials on all walls, ceiling and floor and one condition with no sound absorbing materials, resulting in a very short (T=0.6 s) and very long (T=2.3 s) reverberation time. To study the influence of meaningfulness of the background speech, the semantic content was manipulated by the language of the background speech. In this experiment Dutch and Swedish language was used due to the possibilities created by the cooperation between the University of Gävle (Sweden) and Avans University of Applied Sciences (The Netherlands).

Acoustic models of two virtual open-plan study environments

To create realistic sound scenarios, the acoustics of an open-plan study environment was modelled with a software package based on geometrical acoustics (Odeon version 12.12 [141]).

For this purpose, the open-plan study environment of the 3rd floor of the Vertigo building at the Eindhoven University of Technology was modelled. This study environment has a height of 5.3 meter and a shoe box shape with a volume of 2750 m^3 (Figure 3.1). A picture of the open-plan study environment can be found in the Appendix C.5. A comparison between the acoustic parameters calculated using the room acoustics software and acoustic parameters measured in the study environment showed good agreement. The differences between the calculated and measured reverberation times (*EDT* and T_{30}) were smaller than just noticeable differences indicated in literature of 5-8.5% for $T_{500Hz\text{-}1000Hz}$ [142,143]. For the purpose of the auralizations, two new virtual environments were created by changing the materials of the walls, ceiling and floor. One model of the open-plan study environment was calculated with sound absorbing walls, ceiling and floor resulting in a very absorbing environment (reverberation time T_{30}=0.6 s) and a second model was calculated with reflecting walls, ceiling and floor resulting in a very reverberant environment (T_{30}=2.3 s). In this study the first is called the absorbing model and the latter the reverberant model. The most important materials and absorption coefficients used in the models are presented in Table 4.1 (Chapter 4). Three human talkers were modelled as sound sources and one point as a human receiver. For creating auralizations based on predictions using Odeon, impulse responses were computed for all source-receiver combinations in the two virtual environments.

Sound scenarios

In the scenarios, three talkers were implemented producing Dutch or Swedish background speech. As a result, four sound scenarios were created:

- Absorbing open-plan study environment (T_{30}=0.6s) with 3 Swedish talkers
- Absorbing open-plan study environment (T_{30}=0.6s) with 3 Dutch talkers
- Reverberant open-plan study environment (T_{30}=2.3s) with 3 Swedish talkers
- Reverberant open-plan study environment (T_{30}=2.3s) with 3 Dutch talkers

The position and speech direction of the three talkers and the listening direction of the listener can be seen in the floor plan of the open-plan study environment (Figure 3.1). The talkers were positioned at table groups close to the listener. This listener-talker configuration was chosen as an example of a realistic situation for group work in an open-plan study environment.

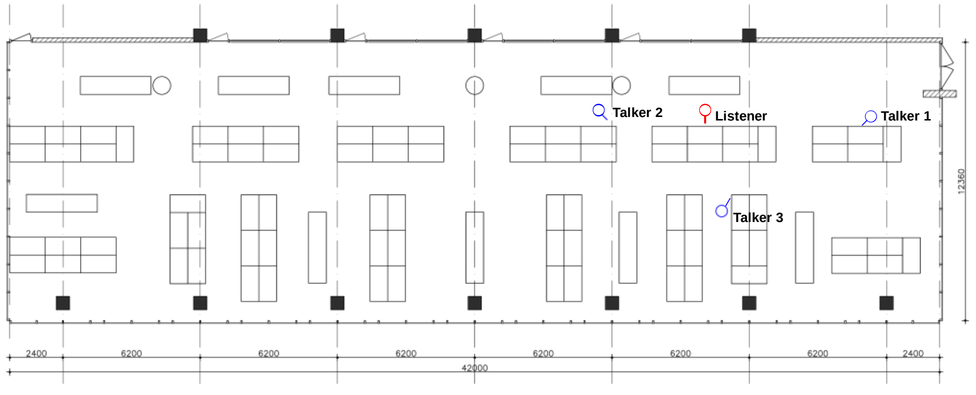


Figure 3.1 Floor plan of the modelled open-plan study environment. Positions of receiver (Listener) and three sound sources (Talker 1-3), with the lines indicating the listening and talking direction. Dimensions in mm.

The background speech consisted of Hagerman sentences (Swedish) [144] and a Dutch version called Matrix sentences [145]. These sentences have been developed for audiological tests measuring speech intelligibility in noise. Each sentence is composed with the same structure of five words (name, verb, number, adjective, object) and each word category can be filled by 10 different words. In this way numerous sentences can be randomly composed. The sentences were recorded in a highly sound absorbing setting and sampled at 44.1 kHz. Ten Dutch and six Swedish students and employees from the Universities of Eindhoven and Gävle have read different Hagerman or Matrix sentences aloud for at least 5 min. From the recordings, three Dutch and three Swedish talkers were selected based on the intelligibility and normal prosody of the spoken sentences. By convolving these recorded speech signals with the calculated impulse responses between the three talker positions and the receiver position (Figure 3.1), four sound scenarios were created: Two absorbing Swedish and Dutch sound scenarios and two reverberant Swedish and Dutch sound scenarios. The sound signal in the quiet control scenario was a pink noise signal at the same background noise level as measured in the real study environment without people, 30 dB(A). The sound levels of the separate sources (talkers) at the receiver position as well as the total sound levels for the different scenarios calculated by Odeon are described in Table 3.1. For the experiment with the collaboration task, the five scenarios were played back through five loudspeakers in a highly absorbing room (T_{30}= 0.4 s, Figure 3.3) creating a realistic sound environment. Odeon software was used to create a 2D surround sound based on a specified speaker rig, therefore no HRTF was included in the auralization. Due to the 2D surround sound and the freedom of the subjects to move their heads, there will be some spread in loudness of the background speech perceived by the subjects and therefore some uncertainty in the calculated STI values.

Table 3.1 Description of the sound sources (talkers) in the absorbing and reverberant model of the open-plan study environment Vertigo floor 3.

Talker	Gender		Sound level at Listener position calculated by Odeon (dB(A))	
	Dutch	Swedish	Absorbing model	Reverberant model
1	female	male	46.1	54.7
2	female	male	47.9	54.8
3	male	female	52.2	56.3
3 talkers			54.3	60.1

The reverberation time of a room will affect the intelligibility of background speech and therefore can influence the disturbance and performance of a semantic task [71,74,106,132]. A comparison of the level of intelligibility of the background speech for the different sound scenarios will be based on a calculation of the speech transmission index (*STI*) of the background speech. A calculation of the *STI* was done with talker 3, the nearest and loudest background voice, in accordance with the international standards IEC 60268-16 [104,146,147]. However, the *STI* is originally developed to measure speech intelligibility in stationary noise, therefore a calculation of the *STI* with background speech will be an estimation of the real intelligibility [148]. The background noise level due to the irrelevant background speech was computed as the L_{Aeq} and L_{A95} level of the two other voices. L_{A95} is the sound level that is exceeded 95% of the time, which is a method to quantify background noise levels of fluctuating signals, i.e. it characterizes the general background sound pressure level that excludes the particular local noise events. L_{A95} was also used in [149] to estimate the background sound level in an open-plan office to calculate the *STI* value. Table 3.2 also shows the calculation of the *STI* value based on the usual procedure, which does not include the background voices only the stationairy 30 dB(A) pink background noise. Due to the low number of talkers and the differences in space angles and distances between listener and talkers (see Figure 3.1) it is very difficult to estimate the stationary noise level, therefore a range of estimations is reported in Table 3.2.

Table 3.2 Estimated *STI* values for different conditions between talker 3 and the listener.

		Absorbing model	*Reverberant model*
STI	L_{Aeq} background speech level	0.55 (fair)	0.37 (poor)
	L_{A95} background speech level	0.83 (excellent)	0.56 (fair)
	Without background speech	0.87 (excellent)	0.62 (good)

3.2.4 Collaboration task

The participating students worked in Swedish and Dutch/Belgian couples on a collaboration task. For this purpose, the 'spot the differences' task, based on the 'DiapixUK' pictures developed by Baker and Hazan [95] was used. Two participants had to discover differences between two pictures without seeing each other's pictures and only using verbal communication. A time limit was set to 3 min, and a maximum of twelve differences could be found in each picture pair. This collaboration task was chosen due to the important vocal communication component (e.g., listening and discussing) in the task in accordance with a collaboration task in an open-plan study environment. Furthermore, this task was suitable for repeated measurements due to the proven equal difficulty of the picture pairs, no learning effect of completing more than one picture and a balanced contribution of both participants [95].

Figure 3.2 Example 'DiapixUK' pictures for the 'spot the differences' collaboration task.

3.2.5 Experimental setup

The participants carried out the test in pairs, seated at a round table in a silent room (60 m^2, Figure 3.3) in a laboratory facility at the University of Gävle. Indoor environmental conditions were kept constant throughout the experiments. The reverberation time of the room was rather short ($T_{30;}$ = 0.4). A realistic sound environment was created by a sound set-up consisting of a laptop (Hp Zbook) generating the sound signal via an external sound card (USB Sound Box ST Lab) connected to a sound amplifier (Sherwood RD-7500) lined to five loudspeakers (*Cambridge Audio minX*). The loudspeakers were set at a height of 1.6 m in a circle surrounding the participants at a distance of 1.4 m (Figure 3.3). A screen was placed between the participants (h=0.3 m above table hight) in order to avoid them seeing each other's pictures. The sound levels of the sound scenarios were calibrated conform the calculated levels by recording the sound signal at both participant positions using a microphone (B&K 4189) and pre-amplifier (B&K type 2671) and subsequently processed off-line with DIRAC 6.0 room acoustics software.

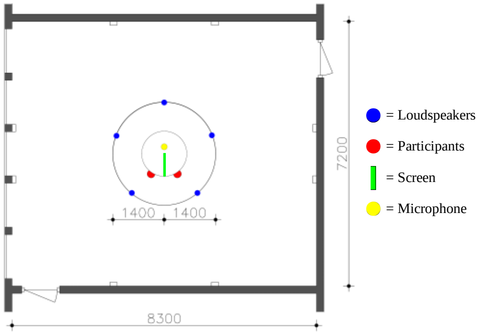


Figure 3.3 Experimental setup. Dimensions in mm.

3.2.6 Dependent Variables

Performance measurements

As an objective variable of performance, the number of found differences for each puzzle was used.

Questionnaire scores

As subjective variables the self-rating scores on questions about their experiences during the collaboration task were used. Besides the questions concerning the noise disturbance, other subjective variables were chosen after a pilot study. A difference in eagerness and motivation during the test was observable, sometimes participants didn't want to stop after the stop signal. Because motivation can influence how subjects react on background speech this question has been added [101]. A difference in collaboration style was also observed during the pilot, therefore a question has been added that maps the self-assessed quality of the collaboration. A seven-points Likert scale, 1 until 7, was used for each question. The questions were:

- the disturbance by the background noise during the task: 'To what extent did you find the background noise disturbing during the execution of the assignment?' where 1 represented ‘totally not disturbing’ and 7 ‘very disturbing’
- the ability to ignore the background noise during the task: 'To what extent could you ignore the background noise?' where 1 represented 'it was very difficult to ignore' and 7 'it was very easy to ignore'. There was also a possibility to choose 0: 'there was no background noise'
- the unwillingness to stop with the puzzle after a time limit set to 3 min: 'How much did you want to continue with the task despite the time was up?' where 1 represented ‘not at all’ and 7 ‘very much’
- the quality of the collaboration during the task: 'How did the collaboration go?' where 1 represented 'very bad' and 7 represented 'very good'

Also, the self-rated noise sensitivity of the participants was measured by a questionnaire developed by Weinstein [83,84]. The noise sensitivity was measured on the basis of eleven statements in which the participants had to indicate to what extent they agreed with these statements (6-point scale). Furthermore, some couples showed changes in their strategy to find the differences during the pilot. Therefore, the participants were asked if they used the same strategy for each picture to find the twelve differences.

Sound measurements

During the execution of the collaboration task, the speech levels of the participants in combination with the background sound scenarios were measured. The sound was recorded at the middle of the round table at a distance of about 0.8 meters from the participants (Figure 3.3) using a microphone (B&K 4189) and pre-amplifier (B&K type 2671) and subsequently processed off-line with DIRAC 6.0 room acoustics software. These sound measurements are lacking for the first seven Swedish participant couples.

3.2.7 Procedure

The participants worked on the collaboration task in couples. These couples were participants with the same native language, Swedish or Dutch. The participants had to solve 'spot-the-difference' puzzles [95] within a time limit of 3 min. Each student was given one picture and was asked to identify the differences through communication with his/her partner. The participants were instructed to use the strategy to start in the left upper corner of the picture and to find the differences by a clockwise description of the pictures. The couples were allowed to change their strategy during the experiment. After a short oral introduction, a training phase of 3 min started to solve the first puzzle to get used to the procedure. The next ten puzzles were presented in the same order to all participants. The sequence of the sound scenarios was different for each couple, they were offered in a counterbalanced sequence using a Latin Square design. The sound scenarios were presented two times after each other for each couple. Each difference on which both participants in a couple agreed on, was marked with a circle at their pictures. 3 min after starting the puzzle a voice announced to stop searching for differences and to fill in individually a short questionnaire about their experiences during the collaboration task. After finishing the questionnaire an instruction on the computer screen indicated to press a button when they wanted to start the next puzzle. At the same time when pressing the button, a new sound environment started playing in the room. When finishing the last puzzle and the corresponding questionnaire the couples were asked to fill in individually the noise sensitivity questionnaire. The experiment lasted about 50 min for each participating couple.

3.2.8 Statistical method

The data were analyzed with the statistical program SPSS 23.0. All questionnaire variables were analyzed taking into account individual participants (n=74). The variables: performance and produced sound level, were measured and analyzed for participant couples (n=37 for performance, n=30 for produced sound level).

To study the impact of the background sound scenarios on the collaboration task, for each dependent variable a single-factor repeated measures ANOVA was used to analyze the significance of the differences between the means of the dependent variable due to the five sound scenarios. Furthermore, a follow-up pair-wise comparison to examine where the differences occur was performed by using post-hoc t-tests with Bonferroni correction.

To study the impact of language and reverberation time on the collaboration task, for each variable a factorial 2(reverberation: absorbing vs. reverberant) × 2(language of background speech: native vs. foreign) repeated measures ANOVA was used.

To verify the influence of the noise sensitivity a mean split was done to divide the subjects in two groups and a factorial 2(reverberation: absorbing vs. reverberant) × 2(language of background speech: native vs. foreign) x 2(noise sensitivity: low vs. high) repeated measures ANOVA was used to analyze the influence of the noise sensitivity on the dependent variables.

To verify the influence of using the same or different strategies a factorial 2(reverberation: absorbing vs. reverberant) × 2(language of background speech: native vs. foreign) x 2(strategy: same vs. different) repeated measures ANOVA was used to analyze the influence of the strategy on the dependent variables.

3.3 Results

3.3.1 Impact of background sound scenarios on a collaboration task

The figures in this section show the impact of the different sound scenarios on different dependent variables.

Performance

Figure 3.4 shows the performance of participants working on the 'DiapixUK' collaboration task while being exposed to different sound scenarios. The different sound scenarios have no significant effect on the performance of the participants ($F(4,144) = 0.42$, $p = .791$).

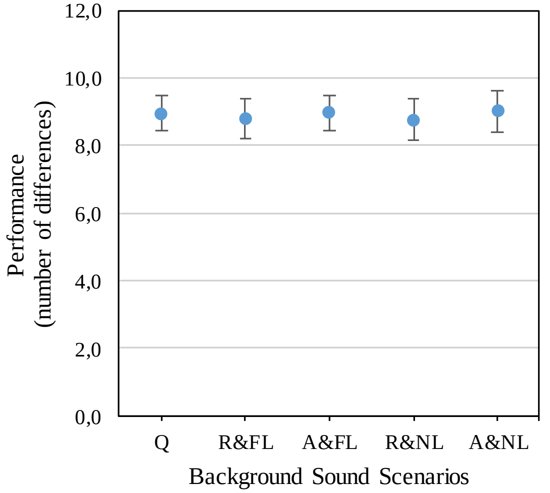


Figure 3.4 Mean values and confidence intervals (95%) of the performance of participant couples (n=37) accomplishing the 'DiapixUK' collaboration task with different background sound scenarios: Quiet (Q), Reverberant & Foreign Language (R&FL), Absorbing & Foreign Language (A&FL), Reverberant & Native Language (R&NL), Absorbing & Native Language (A&NL).

Questionnaire results

Figure 3.5 shows the perceived disturbance of participants working on the 'DiapixUK' collaboration task while being exposed to different sound scenarios. The different sound scenarios have a significant effect on the perceived disturbance of the participants ($F(4,292) = 63.64$, $p < .001$, $\eta_p^2 = .466$). The reverberant sound scenarios were reported as being the most disturbing. The quiet condition was reported as being the most comfortable situation. Follow-up t-tests with Bonferroni adjustment showed significant differences between the quiet condition and the four other conditions and between the reverberant native and absorbing (native and foreign) background speech conditions. The differences between all other conditions were not significant.

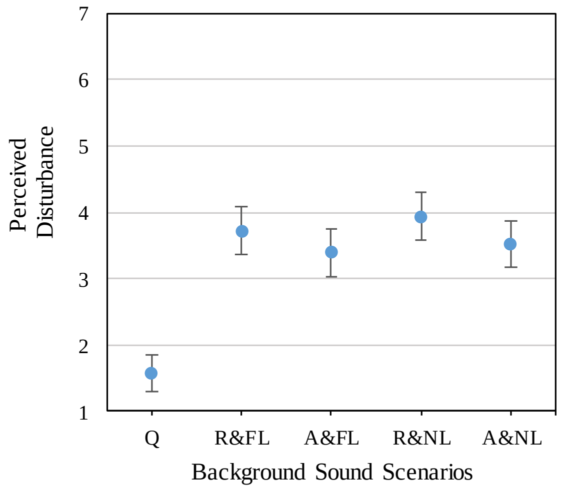


Figure 3.5 Mean values and confidence intervals (95%) of the perceived disturbance of participants (n=74) accomplishing the 'DiapixUK' collaboration task with different background sound scenarios: Quiet (Q), Reverberant & Foreign Language (R&FL), Absorbing & Foreign Language (A&FL), Reverberant & Native Language (R&NL), Absorbing & Native Language (A&NL).

Figure 3.6 shows the self-estimated ability of participants to ignore the background noise while working on the 'DiapixUK' collaboration task and being exposed to different sound scenarios. The different sound scenarios have a significant effect on the ability of the participants to ignore the background noise ($F(4,292) = 45.39$, $p < .001$, $\eta_p^2 = .383$). Post-hoc t-tests with Bonferroni adjustment showed significant differences between the quiet condition and the four other background speech conditions. The differences between all the other conditions were not significant.

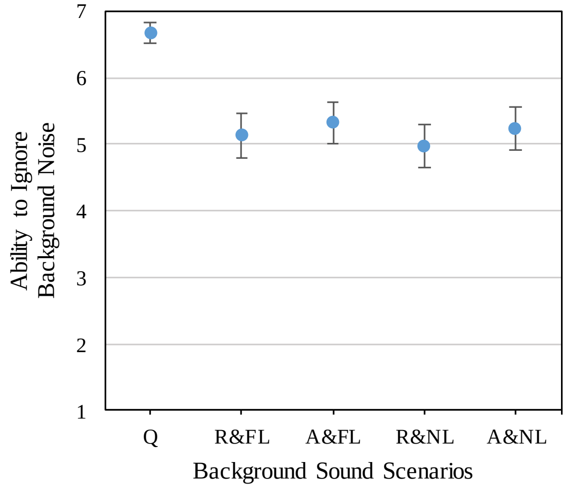


Figure 3.6 Mean values and confidence intervals (95%) of the ability of participants (n=74) to ignore the background noise while accomplishing the 'DiapixUK' collaboration task with different background sound scenarios: Quiet (Q), Reverberant & Foreign Language (R&FL), Absorbing & Foreign Language (A&FL), Reverberant & Native Language (R&NL), Absorbing & Native Language (A&NL).

Figure 3.7 shows the eagerness of participants to continue with the 'DiapixUK' collaboration task while being exposed to different sound scenarios. The different sound scenarios have no significant effect on the eagerness of the participants ($F(4,292) = 1.74$, $p = .141$).

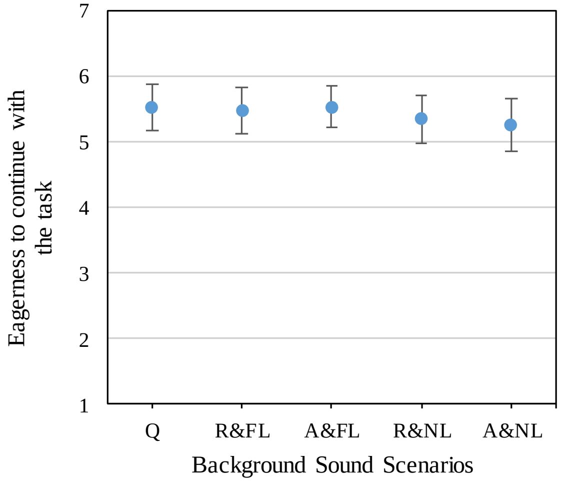


Figure 3.7 Mean values and confidence intervals (95%) of eagerness of participants (n=74) to accomplish the 'DiapixUK' collaboration task with different background sound scenarios: Quiet (Q), Reverberant & Foreign Language (R&FL), Absorbing & Foreign Language (A&FL), Reverberant & Native Language (R&NL), Absorbing & Native Language (A&NL).

Figure 3.8 shows the self-estimated quality of the collaboration of the participants while working on the 'DiapixUK' collaboration task and being exposed to different sound scenarios. The different sound scenarios have a significant effect on the self-estimated quality of the collaboration of the participants ($F(4,292) = 3.11$, $p = .016$, $\eta_p^2 = .041$). The results show that the quiet scenario was reported to have the highest quality. The sound scenarios with background speech in the native language were reported to have the lowest quality. Post-hoc t-tests with Bonferroni adjustment showed significant differences between the means of the quiet condition and the native background speech conditions. Although some of the results are significant, the effect size is very small as can be seen in Figure 3.8.

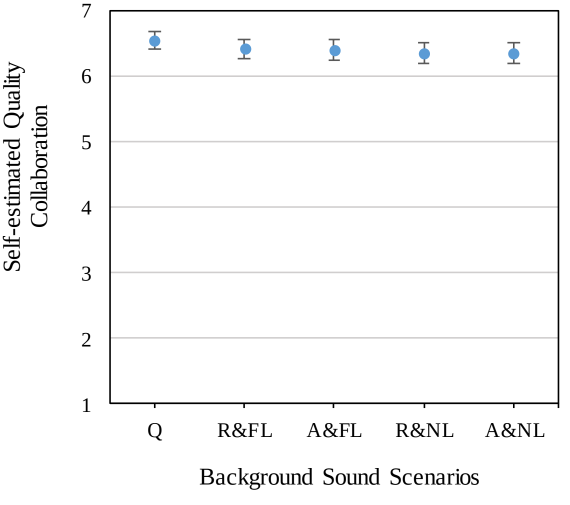


Figure 3.8 Mean values and confidence intervals (95%) of the self-estimated quality of the collaboration of the participants (n=74) while accomplishing the 'DiapixUK' collaboration task with different background sound scenarios: Quiet (Q), Reverberant & Foreign Language (R&FL), Absorbing & Foreign Language (A&FL), Reverberant & Native Language (R&NL), Absorbing & Native Language (A&NL).

Produced sound pressure levels

Figure 3.9 shows the sound pressure levels produced by speech of the participants working on the 'DiapixUK' collaboration task while being exposed to different sound scenarios. The different sound scenarios have a significant effect on the produced sound pressure levels of the participants ($F(4,116) = 109.58$, $p < .001$, $\eta_p^2 = .791$). The highest sound pressure levels are produced while being exposed to the reverberant sound environments. The absorbing sound environments and quiet condition result in significantly lower sound pressure levels as can be seen in Figure 3.9. Post-hoc t-tests with Bonferroni adjustment showed significant differences between the means of the quiet condition and all other conditions and between the reverberant and absorbing background speech conditions. No significant difference were found between the other sound conditions.

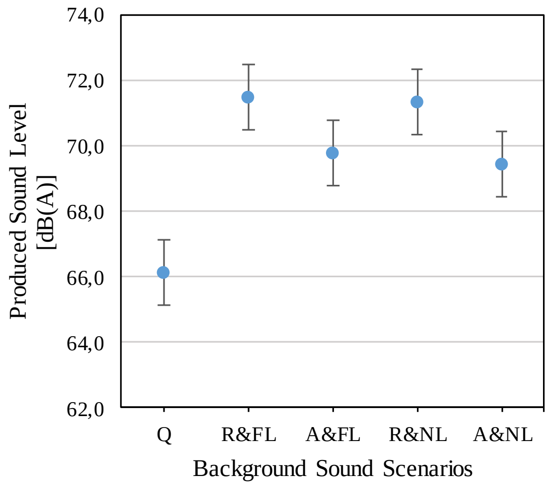


Figure 3.9 Mean values and confidence intervals (95%) of produced sound levels by speech of participants couples (n=30) accomplishing the 'DiapixUK' collaboration task with different background sound scenarios: Quiet (Q), Reverberant & Foreign Language (R&FL), Absorbing & Foreign Language (A&FL), Reverberant & Native Language (R&NL), Absorbing & Native Language (A&NL).

3.3.2 Impact of the language of the background speech and reverberation of the study environment on a collaboration task.

Performance

A factorial 2(reverberation: absorbing vs. reverberant) × 2(language: native vs. foreign) repeated measures ANOVA with performance as dependent variable revealed no significant main effect of the language of the background speech ($F(1,36) = 0.01$, $p = .945$) and no significant main effect of reverberation of the study environment ($F(1,36) = 1.57$, $p = .219$). Also, no interaction effect of the reverberance of the study environment and the language of the background speech on performance was found ($F(1,36) = 0.07$, $p = .788$).

Questionnaire results

Figure 3.10 shows the impact of different languages of background speech and the reverberance of the study environment on perceived disturbance of the 'DiapixUK' collaboration task. A factorial 2(reverberation: absorbing vs. reverberant) × 2(language: native vs. foreign) repeated measures ANOVA with perceived disturbance as dependent variable revealed a significant main effect of the language of the background speech ($F(1,73) = 4.45$, $p = .038$, $\eta_p^2 = .058$) and a significant main effect of reverberation of the study environment ($F(1,73) = 11.23$, $p = .001$, $\eta_p^2 = .133$). Figure 3.10a shows that native background speech was reported as being more disturbing than foreign background speech and Figure 3.10b shows that a reverberant environment perceived more disturbance than an absorbing. No interaction effect of reverberance of the study environment and the language of the background speech on perceived disturbance was found (F(1,73) = 0.35, p = .559).

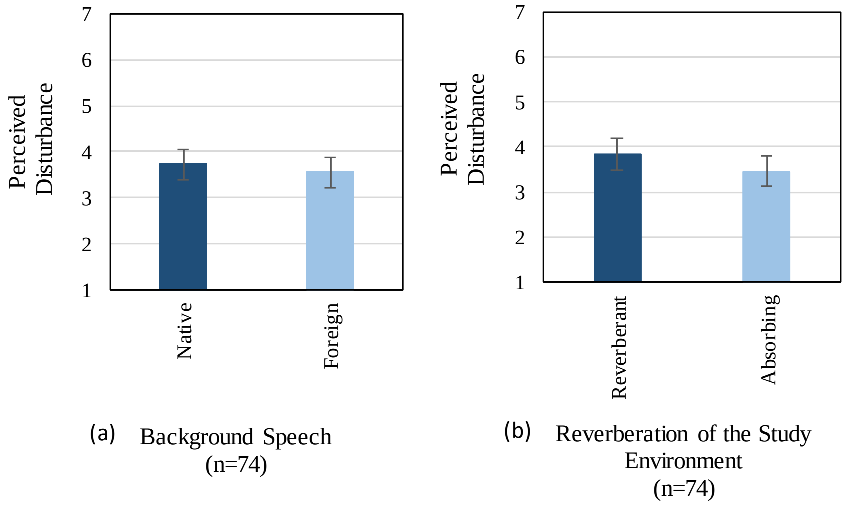


Figure 3.10 Mean values and confidence intervals of perceived disturbance of participants on the 'DiapixUK' collaboration task in relation to language of background speech (a) and reverberance of the study environment (b).

A factorial 2(reverberation: absorbing vs. reverberant) × 2(language: native vs. foreign) repeated measures ANOVA with the ability to ignore the background speech as dependent variable revealed no significant main effect of language of the background speech (F(1,73) = 2.20, p = .143). On the other hand, a significant main effect of the reverberance of the room on the ability to ignore the background noise was shown (F(1,73) = 5.70, p = .002, η_p^2= .072) (Figure 3.11). No interaction effect of the reverberance of the study environment and the language of the background speech on the ability to ignore the background noise was found (F(1,73) = 0.14, p = .788).

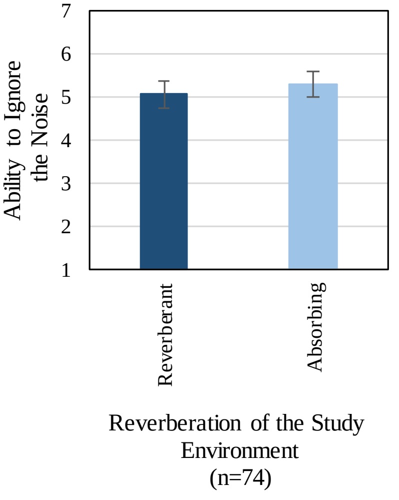


Figure 3.11 Mean values and confidence intervals of the self-estimated ability to ignore the background sound of participants on the 'DiapixUK' collaboration task in relation to the reverberance of the study environment.

A factorial 2(reverberation: absorbing vs. reverberant) × 2(language: native vs. foreign) repeated measures ANOVA with eagerness to go on as dependent variable revealed a significant main effect of the language of the background speech *(F(1,73) = 5.98, p = .017,* η_p^2*= .076)* (see Figure 3.12). On the other hand, no significant main effect of the reverberance of the room on the eagerness to go on with the task was showed (F(1,73) = 0.03, *p* = .868). Also no interaction effect of the reverberance of the study environment and the language of the background speech on the eagerness to go on with the task was found (F(1,73) = 0.64, *p* = .427).

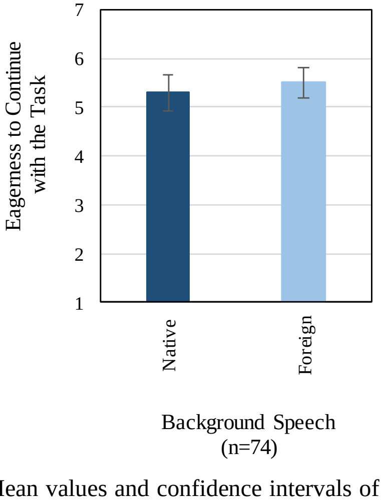


Figure 3.12 Mean values and confidence intervals of the self-estimated eagerness to go on with the 'DiapixUK' collaboration task in relation to the language of the background speech.

A factorial 2(reverberation: absorbing vs. reverberant) × 2(language: native vs. foreign) repeated measures ANOVA on the self-estimated quality of the collaboration as dependent variable revealed no significant main effect of the language of the background speech (F(1,73) = 1.86, p = .177) and no significant main effect of the reverberance of the room (F(1,73) = 0.02, p = .885). No interaction effect of the reverberance of the study environment and the language of the background speech on self-estimated quality of collaboration was found (F(1,73) = 0.10, p = .757).

Produced sound pressure levels

A factorial 2(reverberation: absorbing vs. reverberant) × 2(language: native vs. foreign) repeated measures ANOVA with produced sound pressure level as dependent variable revealed no significant main effect of the language of the background speech (F(1,29) = 2.03, p = .164). On the other hand, a significant main effect of reverberation of the study environment was revealed (F(1,29) = 93.09, p = .001, η_p^2= .762). Figure 3.13 shows the impact of the reverberation of the study environment (reverberant, absorbing) for the different background noise scenarios on the produced sound pressure level during the 'DiapixUK' communication task. The produced sound level by the participants during the reverberant sound scenarios was higher than the produced sound level during the absorbing sound scenarios. No interaction effect of the reverberance of the study environment and the language of the background speech on the produced speech level was found (F(1,29) = 0.76, p = .523).

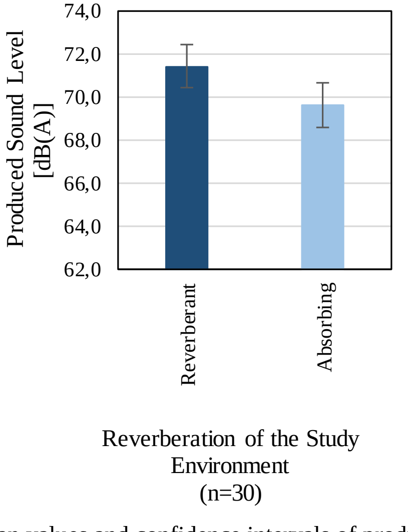


Figure 3.13 Mean values and confidence intervals of produced sound pressure levels during the 'DiapixUK' collaboration task in relation to the reverberation of the environment.

3.3.3 Impact of the noise sensitivity and strategy of participants on the dependent variables

To verify the influence of the noise sensitivity, a mean split was done to divide the participants in two groups. The mean noise sensitivity of all participants was 3.53 (SD=0.56) on a 6-point scale. The mean noise sensitivity of the group most sensitive participants (noise sensitivity > 3.53) was 3.91 (SD=0.34) and the mean noise sensitive of the group participants with the lowest sensitivity (noise sensitivity < 3.53) was 3.03 (SD=0.37). A factorial 2(reverberation: absorbing vs. reverberant) × 2(language of background speech: native vs. foreign) x 2(noise sensitivity: low vs. high) repeated measures ANOVA revealed no significant interactions of the noise sensitivity with one of the other independent variables on the dependent variables (performance, perceived disturbance, ability to ignore the background noise, eagerness to go on with the task, self-estimated quality of the collaboration). Because noise sensitivity is an individual characteristic of each participant, the impact of the noise sensitivity on performance and produced sound level, which both are variables of couples, could not be checked.

To verify the influence of changing the strategy of the couples to find the differences in the pictures, a factorial 2(reverberation: absorbing vs. reverberant) × 2(language of background speech: native vs. foreign) x 2(strategy: no change vs. changing strategy) repeated measures ANOVA was executed for all dependent variables. The results revealed no significant interactions of the change of strategy with one of the other independent variables on the dependent variables.

3.4 Discussion

The aim of this study was to analyze the influence of background speech on performance of a student-collaboration task. Therefore, participants had to carry out a collaboration task while being exposed to four different background sound scenarios and a quiet sound environment in an open-plan study environment. Speech in the background sound environment was varying in semantic content by changing the language in the background speech, and in intelligibility by changing the reverberation time and, in consequence the sound level in the room (Table 3.1).

The results show no significant influence of the background sound scenarios on the performance of the participants of the 'DiapixUK' collaboration task. However, the influence of the background sound scenarios on perceived disturbance, the ability to ignore the background speech and the quality of the collaboration of the participants was significant. Also, the produced speech sound levels of the participants were significantly influenced by the background sound scenarios. For all the self-estimated variables the quiet background sound scenario was most appreciated.

3.4.1 Impact of reverberation time of the open-study environment on the dependent variables

The reverberation time of a room will affect the intelligibility of background speech and therefore could influence the disturbance and performance of a semantic task [71,74,106, 132]. Although a longer reverberation time decreases the intelligibility of speech (Table 3.2), no significant influence of the reverberation time on performance was found. These findings do not fit within a semantic 'interference-by-process' account, as, in line with this account, the performance of a semantic task, such as a collaboration task, should increase due to less intelligible background speech compared to a more intelligible signal [106,132]. After all, less intelligible background speech contains less semantic information compared to a more intelligible signal, therefore, a less intelligible signal should be less disruptive [79]. Furthermore, a less intelligible speech signal will reasonably contain less relevant or interesting information that can capture attention and, as explained by the framework of attentional capture, will disrupt performance less than a more intelligible signal [117].

Table 3.2 shows a decrease of the *STI* value due to the longer reverberation time, qualified from 'fair' to 'poor', from 'excellent' to 'fair' or from 'excellent' to 'good'. According to a model of Hongisto, predicting the effect of speech of varying intelligibility on work performance of different tasks [64], performance starts to decrease when *STI* exceeds 0.2 and the highest performance decrease is reached when the *STI* is 0.6. Estimated *STI* values based on L_{Aeq} are lower than 0.6 (Table 3.2) and therefore a change in performance can be expected. Estimated *STI* values based on L_{A95} and the regular *STI* values vary above 0.6 and despite of a change of intelligibility no change of performance is expected based on Hongisto's model. Some studies have shown that for some complex tasks, like writing [71], word memory and mathematics [67], the largest drop of performance occurs for even lower values of the *STI* than the original model of Hongisto [66] predicted. In Jahncke *et al.* [67] and Keus van de Poll *et al.* [71], the largest drop of performance occurred between *STI* values of .23 and .34. This could be an explanation of the absence of an improvement of performance in this experiment although in any case a significant improvement between the quiet and all other sound scenarios can be expected. Nevertheless, these effects were not found.

An explanation for the increase of disturbance due to a higher reverberation time could be found in the importance of different task components in this complex collaboration task. Although it is impossible to determine the influence of noise on a complex composed task based on the effects of noise on sub-components [76], the analysis of sub-components can give possible explanations of unexpected results found by testing realistic (composed) tasks. Communication by a speech dialog will be very important because negotiating and discussing are important components of a student-collaboration task [113]. The 'DiapixUK' task is an example of a problem-solving collaboration task and contains therefore also an important role for speech communication [95]. Due to less acoustic absorption materials in the reverberant model of the study environment, not only the reverberation time but also the sound pressure level due to noise in a room will increase (Table 3.1) which will lead to more demanding communication circumstances. As for communication it is well known that with increasing background noise, speakers will raise their speech level to guarantee a sufficient signal-to-noise ratio for their communication partner [139]. The raised speech levels of the participants can be seen in Figure 3.13. So, in this collaboration task, not only semantic cognitive processes but also speech communication is important and both sub-components of the complex collaboration task will respond different to room acoustic parameters such as reverberation time and background sound level.

Semantic cognitive processes are less affected by background speech with low intelligibility, a result of a long reverberation time in a room, however, speech communication is made easier by a good signal-to-noise ratio, a result of a short reverberation time. It seems that the higher sound level of background noise, an additional acoustic result of a longer reverberation time in a room, has a dominant influence on disturbance due to the importance of the vocal communication component in the collaboration task.

3.4.2 Impact of language of the background speech on the dependent variables

No significant impact of the meaningfulness of background speech on performance was found. On the other hand, the language of the background speech showed to be significantly important for the self-estimated disturbance of participants while performing a collaboration task (Figure 3.10a). Participants were significantly more disturbed by background speech in the mother tongue than by background speech in a foreign language. This is in accordance with the 'interference-by-process' account and the framework of attentional capture. The cognitive processes used to automatically analyze the unintended meaningful background speech in the mother tongue will interfere with the similar semantic cognitive processes involved in the execution of a semantic based collaboration task. The background speech in the mother tongue will also capture more attention than the meaningless background speech in the foreign language. These findings correspond with research on reading comprehension [108, 109] and proofreading [72,110] which also show an increasing disturbance by increasing meaningful speech.

The language of the background speech can only have an influence on performance and disturbance if the speech intelligibility is sufficient. Although the estimated *STI* values (Table 3.2) give no unambiguous assessment of the level of intelligibility of the background speech, the observed impact of the language of background speech on disturbance indicates intelligible background speech.

3.4.3 Impact of background sound scenarios on a collaboration task

No significant performance differences were found between the sound scenarios (Figure 3.4). Besides the earlier mentioned restricted *STI* diversity between the sound scenarios and the relatively high *STI* values (>0.6), these outcomes may also be the result of a limited number of participant couples (n=37), the limited semantic complexity of the collaboration task or the consequence of a ceiling effect the 'DiapixUK' task due the limit of 12 differences that could be found in a puzzle. The latter would imply a non-discriminatory performance measure. However, the statistical results do not provide convincing evidence for this. The median value of the found differences was rather high (median=9) but the mean number of participant couples with a maximum score of 12 was only 3 (8%).

Although, no significant differences in performance were found during different sound scenarios, disturbance and ignorance of noise were found to be significantly influenced by the sound scenarios. Self-estimated disturbance differentiates to a greater extent and therefore provides interesting additional data to performance data. An explanation of a more differentiated self-estimated disturbance and less differentiated performance might be an extra effort investment of participants in solving a task due to feeling disrupted in an adverse sound environment. Schlittmeier *et al.* [65] call this the 'reactive effort enhancement', and this effect can lead to reduced performance differences [65,150].

The eagerness to work on the task was not significantly influenced by the sound scenarios (Figure 3.7), for all other self-estimated parameters the quiet scenario was significantly the most preferred sound environment. Unfortunately, a quiet sound scenario is seldom the case in open-plan study environments. Workspaces for one group would be the best environment to work on a collaboration task. Acoustic separated sections within an open-plan study environment would also be a better solution, for instance by using high sound screens. Using acoustic absorbing materials is not enough to create an optimal acoustic environment for a collaboration task in an open-plan study environment.

3.4.4 Impact of the noise sensitivity and strategy of participants on the dependent variables

Although in previous research the influence of noise sensitivity of students on disturbance by noise in open-plan study environments was established [62], no influence of the noise sensitivity score on disturbance or performance was found in this study.

The influence of whether or not using different strategies to find the differences in the ten pictures on the dependent variables was not significant. This confirms the robustness of the 'DiapixUK' test. No difference was found between the two groups, which means no learning effect was identified for the group that changed the strategy during the experiment.

3.5 Conclusion and outlook

The hypothesis 'an increase of intelligibility and meaningfulness of the irrelevant background speech will lead to an increase of disturbance and a decrease of performance of a collaboration task' is not supported by the results of this study. The sound scenarios with background speech with a combined language and reverberation time intervention showed that an increase of intelligibility and meaningfulness did not lead to an increase of disturbance and a decrease of performance of the collaboration task.

Although sound scenarios with a longer reverberation time result in less intelligible background speech, these background sound environments were the most disturbing. We argue that the sound level, an additional acoustic result of a longer reverberation time in a room, has a dominant influence on disturbance due to the importance of the signal-to-noise ratio for the vocal communication sub-component in the collaboration task.

The results showed the quiet sound scenario to lead to the lowest level of disturbance, a result in line with the sound level effect, but also in line with the absence of semantic interference. Therefore, it is doubtful if an open-plan study environment is suitable for student collaboration tasks. To create good learning environments applying absorbing materials will not be enough, environments where students can choose to work in quiet zones or a quiet room, as in activity-based offices, might be a possible solution.

The 'DiapixUK' task is limited in difficulty and performance scale which might have had some influence on the research outcomes. Furthermore, this research also shows that a real and complex sound environment must be taken into account. For instance, an increasing reverberation time in an environment implies also an increasing sound level of the background noise and this combination can have consequences for disturbance and performance of people in work environments. In our setting with three spatially separated background speakers located at nearby table groups we observed a strong effect on vocal communication aspects. It is well possible that this effect was smaller if we had chosen a larger distance between speakers and listener which would have resulted in a lower level of background speech.

Therefore, more research is needed on the influence of the effect of background speech on the performance and disturbance of a collaboration task in open plan study environments. Moreover, this study indicates it is worth to perform more linked research on realistic complex tasks, in real acoustic sound environments to bridge the gap which exists between laboratory findings and applications or practical relevance.

CHAPTER 4

WRITING

4 | The influence of background speech on a writing task in an open-plan study environment.

Writing is an important activity in open-plan study environments in higher education. Writing is also a task during which students have indicated to be very disturbed by background speech. The aim of this study was to analyze the influence of realistic sound scenarios in an open-plan study environment on the performance and disturbance of participants working on a writing task, taking into account noise sensitivity as a personal factor. In an experimental setting, participants had to perform a writing task while being exposed to different simulated sound scenarios. These sound scenarios were composed of background speech produced by three or fourteen talkers in a very absorbing (0.6 s) or very reverberant (2.4 s) open-plan study environment. A quiet sound scenario was added as a reference. Results show that the writing performance of participants decreased significantly in the absorbing environment with only three talkers. Although the quiet reference environment was rated as the least disturbing, the performance in the quiet reference condition was not significantly better compared to the other acoustic conditions.

This chapter is based on: Braat-Eggen, P.E., Reinten, J., Hornikx, M.C.J., Kohlrausch, A.G.(2020). The influence of background speech on a writing task in an open-plan study environment. Building & Environment 169, 106586. DOI: 10.1016/j.buildenv.2019.106586

4.1 Introduction

The impact of the physical environment, including noise and room-acoustics, on the quality of learning at schools has been shown [4,96]. While most studies on school acoustics focus on the impact of room acoustics in classrooms and lecture halls, the acoustics of open-plan study environments certainly require attention as well [19,31]. An open-plan study environment (OPSE) is an informal learning space intended for students to work on their individual and group assignments (Chapter 2). As shown in Chapter 2, a field study on OPSEs in higher education, noise disturbance and lack of sound privacy proved to be the most annoying factors in those environments. Furthermore, this research on OPSEs showed ‘writing’ to be both one of the most frequently performed tasks and one of the tasks where students indicated to be very disturbed by noise (Chapter 2). Therefore 'writing' is an important task to involve in further research on the acoustics of OPSEs.

To design OPSEs with a high acoustic comfort it will be necessary to get more information about the relation between realistic sound environments, sound disturbance and task performance. In a literature review on human task performance and the indoor sound environment [32], a lack of suitable research, that adds to the knowledge about the influence of a realistic sound environment on people has been brought to our attention. In this research, a conceptual framework is suggested (Figure 4.1) that shows the interaction between room acoustics, sound environment and task performance considering other influencing factors. The model implies that the sound environment influences task performance and disturbance. The sound environment is not only determined by the sound sources but also by room acoustic characteristics. Also, important aspects like: personal factors, task type and sound-task interaction can be influencing the relation between sound environment and task performance and disturbance (Figure 4.1).

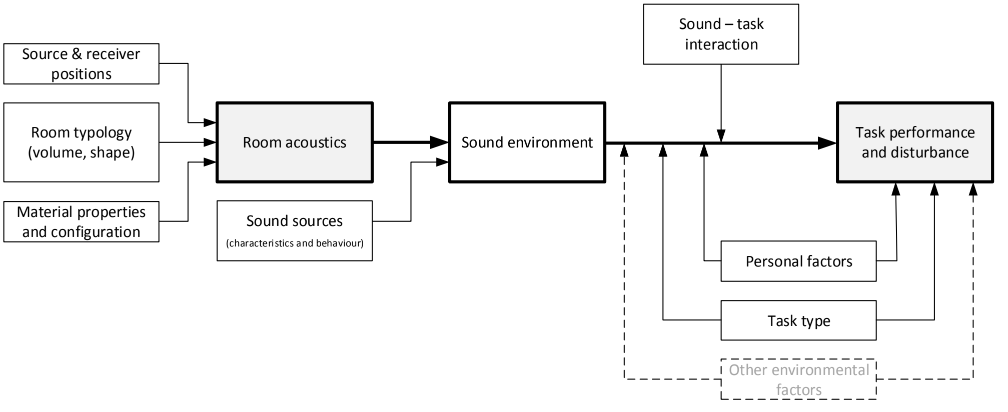


Figure 4.1 Conceptual model adapted from Reinten *et al.* [32] on the effect of room acoustics on task performance and disturbance.

4.1.1 A realistic sound environment in an OPSE

Most research on the influence of background noise on the performance of cognitive tasks, such as background speech on writing, is performed from a psychological point of view and focusses on understanding cognitive processes by studying how people respond to specific sounds, not how people respond to realistic acoustic environments. The results of most of these laboratory studies are not suitable for translation to realistic settings, specifically OPSEs. For instance, most research on the disturbing effect of background speech on writing tasks is performed for sound signals that do not typically occur in OPSEs, such as one background voice combined with white noise [71], rotated speech [72] or pink noise, water waves and multiple voices all with the same sound level [68]. The speech in these studies was recorded in an anechoic environment, and directly offered to both ears of the participants of the experiments by headphones. None of these studies took into account room acoustic parameters such as reverberation time or the implications of spatial aspects such as the position of talkers in relation to the listener in the room. In Keus van de Poll [69], realistic sounds were used in a study on the effect of multiple voices coming from 2 directions on writing performance. Nevertheless, this study did not take room acoustic parameters such as the reverberation time and sound reflections into account. Room acoustic characteristics will impact background speech; speech in a reverberant room will be louder and less intelligible than in an acoustically absorbing room. Furthermore, the position of talkers in a room will affect the speech levels at the listener position.

In an OPSE, where students work individually as well as in groups in the same room, multiple background voices are coming from various directions and distances. Furthermore, in a realistic OPSE the reverberation time will influence the speech levels and the modulations of the speech envelope [136,151], which will result in different degrees of speech intelligibility and varying values of auditory characteristics of the irrelevant background speech. Therefore, it is useful to model a realistic sound environment, with room acoustic characteristics and multiple background speakers at various places in a room, to study the influence of background noise on a cognitive task such as writing in an OPSE.

4.1.2 The influence of background speech on a writing task

The type of task determines the influence of the sound environment on performance and disturbance. Writing is a complex task that involves combining new information with information already stored in memory [152]. For example, writing a story requires organizing old and new information into ideas and turn them into a new concept. To create the final story, the concept needs to be reviewed and rewritten [153]. The complex, cognitive processes involved in the writing task are semantic processes, i.e., processes where the meaning of information is of great importance [72].

Research on the influence of background noise on writing tasks showed that especially background speech is very disturbing and influences writing performance [71,72]. In these studies, it is suggested that the disturbance of a writing task by irrelevant background speech is a result of the obligatory (passive) processing of the background speech. This automatic analysis of irrelevant background speech is a semantic process, just like the processes involved in writing. The interference of these simultaneous semantic processes, the processing of the writing task and the unintended processing of the background speech, explains the disturbing effect of background speech on writing [79]. This so called 'interference-by-process' view is a part of the 'Duplex Mechanism Account of Auditory Distraction' (DMAAD) [115,116]. This account describes two mechanisms through which sound can disturb cognitive performance. First by 'interference-by-process', and secondly by 'attentional capture'. Disruption of a task due to attentional capture occurs when unexpected changes or aspects in the sound signal capture attention and draw it away from the current task to be executed and thus disrupt performance. Attentional capture mainly depends on the distracting elements in the background noise, and so far, no evidence has been found for the dependence on the type of cognitive task [154].

4.1.3 Personal factors

Personal factors have been shown to have an effect on the relation between sound environment and task performance and disturbance (Figure 4.1) [32,85,88]. An important personal factor is the noise sensitivity of people. In Chapter 2, a field study in open-plan study environments, disturbance of students by the background noise appeared to be related to the noise sensitivity of the students. Other studies on the relation between noise sensitivity and cognitive performance and disturbance found weak or no correlations at all [85-87]. To create more clarity on the correlation between noise sensitivity and cognitive performance and disturbance, sound sensitivity is included as a personal factor in this study.

4.1.4 The aim of the study

The aim of this study is to evaluate the relation between the characteristics of a realistic sound environment of an OPSE, writing task performance and sound disturbance, considering noise sensitivity as a personal factor. This experimental research adds to the existing knowledge on writing performance through creating a more realistic sound environment considering room acoustics (reverberation time) and occupation (number of talkers) of the indoor environment. This study also enhances the knowledge on acoustics of OPSEs, a very important learning environment in higher education. Furthermore, the findings of this research will contribute to filling the gap between more theoretical, psychological research and more realistic sound field research, which is needed to develop design tools that help to make better decisions in the process of building and refurbishing schools.

The hypothesis in this study is that an increase of intelligibility of the background speech, due to varying a realistic sound environment, will lead to a decrease of writing performance and an increase of disturbance. We expect that noise sensitive students will show more disturbance and a larger decrease of writing performance due to the background speech.

4.2 Materials and methods

4.2.1 Participants

Forty-seven Dutch students (29 male and 18 female) aged 16 to 27 years (mean age=20.4, SD= 2.8) participated in this laboratory experiment. These students were recruited by a general call to participate in a writing experiment on the university communication platform. Two students were left out of the analysis (1 male and 1 female) because of technical errors. Two students indicated a light hearing impairment (no use of hearing devices). The data from these students did not differ significantly from the others and therefore were included in the analysis. All students signed an informed consent form before starting the experiment and received a credit voucher for an internet store or free study credits as compensation for participation.

4.2.2 The sound environment

Modelling sound scenarios

For this writing experiment, realistic background sound scenarios were created by auralizations based on a digital acoustic model of an existing OPSE. In this way five sound scenarios were developed, one quiet (silent) scenario and four sound scenarios with a varying number of talkers in the background and different room acoustic characteristics of the OPSE. The five sound scenarios were offered to the participating students through headphones (Sennheiser 280 Silver) in an experimental setting.

The acoustic model was created by a software package using geometrical acoustics (Odeon version 12.12) [141] and was based on an OPSE intended for engineering students at the Eindhoven University of Technology. The floor plan of this study environment has a rectangular shape and a volume of 2750 m^3 (see Figure 4.2 and 4.3). The model in this experiment was used and described in Chapter 3, a research on the influence of background speech on a collaboration task.

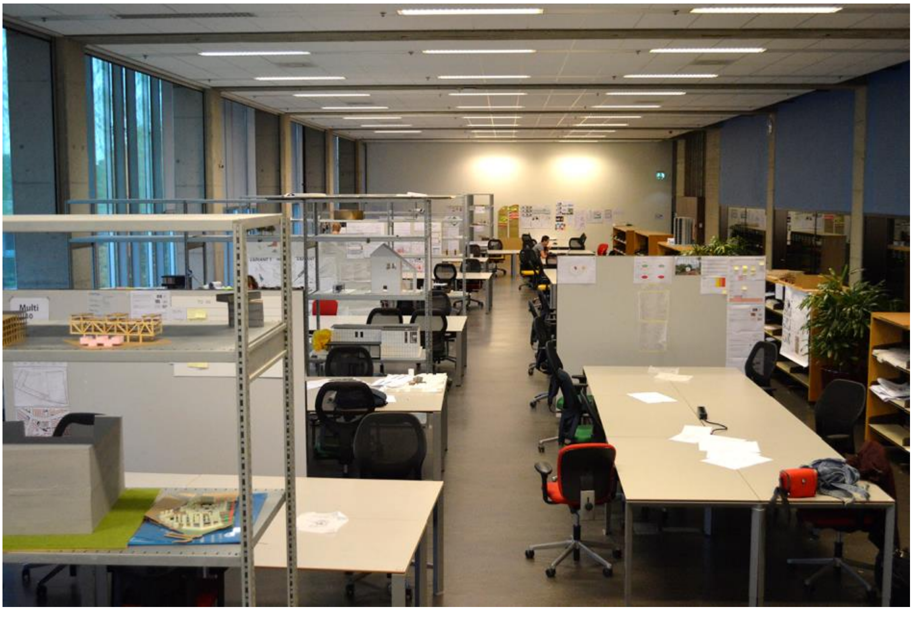


Figure 4.2 OPSE Eindhoven University of Technology, floor 3 Vertigo building.

To create various sound environments, the materials of the ceiling, floor and walls were modified in the digital model of the OPSE. In this way an acoustically absorbing and an acoustically reverberant model were developed. The virtual absorbing environment consists of acoustically absorbing materials such as sound absorbing ceiling tiles, carpet and perforated wall panels and resulted in a reverberation time of T_{30}=0.6 s. The virtual reverberant environment consists of acoustically hard materials such as a concrete ceiling, linoleum on the floor and unperforated wall panels and resulted in a reverberation time of T_{30}=2.3 s (Table 4.1).

Table 4.1 Materials and absorption coefficients for random incidence used in the Odeon models.

Materials	Absorption coefficient					
	125 Hz	*250 Hz*	*500 Hz*	*1000 Hz*	*2000 Hz*	*4000 Hz*
1. Sound absorbing model:						
Sound absorbing ceiling	0.40	0.85	0.99	0.90	0.99	0.99
Fabric floor covering	0.05	0.10	0.30	0.70	0.90	0.75
Perforated wall panels	0.39	0.94	0.92	0.68	0.69	0.58
2. Reverberant model:						
Concrete ceiling	0.02	0.03	0.03	0.03	0.04	0.07
Linoleum floor covering	0.02	0.02	0.03	0.04	0.04	0.05
Unperforated wall panels	0.08	0.11	0.05	0.03	0.02	0.03

Furthermore, alternative auralizations were constructed by varying the number of sound sources. One condition was modelled with fourteen human talkers in the OPSE and a second condition was modelled with three human talkers. Every human talker was given its own place in the study environment and its own speech direction. A human receiver was placed in a fixed position and with a fixed listening direction (listener is red in Figure 4.3) The fourteen talkers were equally divided over the study environment, and in the least occupied setting three distant talkers were chosen (T4, T8, T12 are blue in Figure 4.3). The positions of the listener and the listening direction, and the fourteen talkers and their speech direction, are illustrated in Figure 4.3.

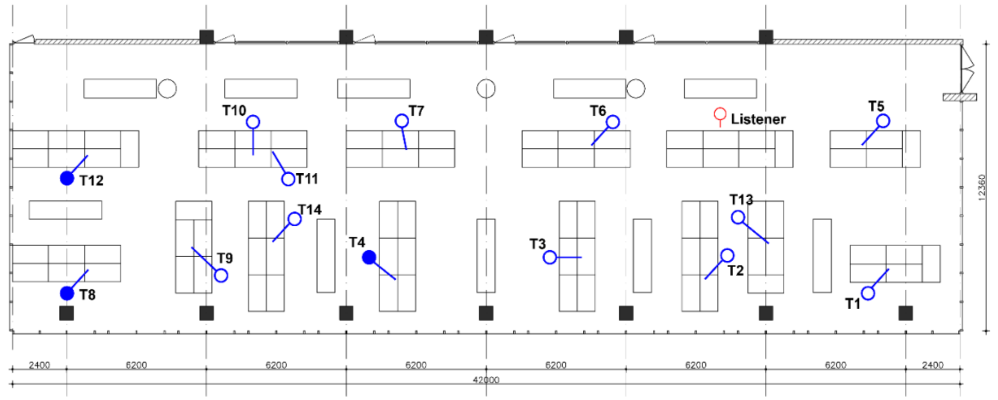


Figure 4.3 Positions of the listener and fourteen talkers (T1-T14), with lines indicating the listening and talking direction.

The recorded speech used for auralization consisted of students telling stories about their study, hobbies, work, future and holidays. Twenty students were individually recorded in a small sound-absorbing booth and the recordings were sampled at 44.1 kHz. Fourteen different student recordings, from five male and nine female speakers, were selected based on intelligibility, pronunciation and normal prosody of the spoken stories. Accordingly, four stereo sound scenarios were constructed suitable for playback through headphones. This was obtained by convolving, the recorded speech signals with the binaural impulse responses. In both virtual models, three and fourteen talkers were implemented producing background speech resulting in four sound scenarios:

- absorbing OPSE (T_{30}=0.6s) with 3 talkers
- absorbing OPSE (T_{30}=0.6s) with 14 talkers
- reverberant OPSE (T_{30}=2.3s) with 3 talkers
- reverberant OPSE (T_{30}=2.3s) with 14 talkers

The quiet control scenario consisted of pink noise at a level of 30 dB(A), which was the same level as measured in an unoccupied situation of the real OPSE. The sound levels of the background speech signals from all talkers were modeled at a level of 59.5 dB(A) at a distance of 1 m from the mouth, and the sound power spectrum was in accordance with normal speech [148]. As a result of varying absorption and reflections of the speech signal from talker to receiver, different sound pressure levels occurred for the five sound scenarios. The identical sound power levels at the talker position resulted in the sound pressure levels presented in Table 4.2. To calibrate the sound pressure levels of the signals offered by headphones to the subjects in accordance with the calculated sound pressure levels, a Head and Torso simulator (B&K 4128-C) was used.

Table 4.2 Description of the sound sources (talkers) in the absorbing and reverberant model of the OPSE in the Vertigo building at floor 3 of Eindhoven University of Technology.

Talker	Number of talkers in the model		Gender	Sound level at listener position [dB(A)]	
	3 talkers	14 talkers		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
pink noise				30.0	
14 talkers				53.8	63.7
3 talkers				41.1	54.4

Indicators to predict the influence of the sound environment on a writing task

In the case of interference of semantic processes, as for a writing task in combination with irrelevant background speech, research has shown that more intelligible [71] but also more meaningful [72] background speech, appears to be more disturbing. Therefore, if we want to predict the influence of background noise that contains speech, on the performance and disturbance of a semantic cognitive task such as writing, it is of great importance to use a parameter that can measure the speech intelligibility.

A frequently used metric to measure the intelligibility of speech is the Speech Transmission Index (*STI*) [34]. This metric measures the effect of a transmission channel, the path between source and receiver, by the change in the modulation depth of a speech-like signal. An *STI* value of 1 indicates an excellent intelligibility of speech, and an *STI* value below 0.3 indicates that the speech is almost unintelligible. Noise and reverberation will influence the intelligibility of a speech signal by reducing the modulation depths of a speech signal and thus reduce its intelligibility and *STI* value. While in numerous experiments the *STI* is used as a metric to predict performance of a cognitive task [64,68,71], in experiments with realistic sound environments containing background speech, the use of the *STI* is problematic. This is because the *STI* is developed for measuring the speech intelligibility of a specific transmission path between one talker and one listener which makes it difficult, if not impossible to determine the *STI* in a situation with multiple background talkers. To consider talkers in the background environment as (stationary) noise would not be correct either, as speech is a dynamic sound and the *STI* can only be calculated with continuous noise [34]. Therefore, since irrelevant background speech is the most important background sound source in an OPSE (Chapter 2), the *STI* is not very suitable. However, since most literature is related to the *STI* [64,68,71], also this study will include an estimation of the *STI* values used in the experiment.

Another metric is the Frequency Domain Correlation Coefficient (*FDCC*), which originated in the field of psychoacoustics to measure the spectro-temporal characteristics of an irrelevant background sound [151,155]. This relatively new metric is designed to predict the effect that different types of background noise will have on short-term memory performance based on the spectral dynamic character of the noise. Speech is such a sound with a dynamic character and different spectra in successive segments. To establish an *FDCC* value for the background sound, at first the sound must be divided into sequential tokens by localizing high intensities in the sound signal. The window that is subsequently used to select sequential segments is positioned around the local maxima of the envelope and therefore does not have a fixed duration [156]. For normal speech, this token selection process results usually in one token per syllable. For each token, the signal is filtered using 19 one-third octave filters from 125 Hz to 8 kHz. Then the power P is calculated for each band for each token. For a pair of successive tokens, the *FDCC* is defined by:

$$FDCC_i = \frac{\sum_{j=1}^{19} P_{i,j} P_{i+1,j}}{\sqrt{\left(\sum_{j=1}^{19} P_{i,j}^2\right)\left(\sum_{j=1}^{19} P_{i+1,j}^2\right)}}$$

In this formula $P_{i,j}$ stands for the power spectrum for token *i* and frequency band *j*. The *FDCC* value for a speech stimulus is based on the average of these individual correlation values. The *FDCC* value is approaching 1 if changes in the frequency domain between tokens are minimal, and the tokens are less distinctive and more similar. The lower the *FDCC* value, the stronger the spectral variation between successive tokens. A decrease of the *FDCC* value, indicating more variability, is likely to result in a decrease of short-term memory performance [151,156]. Although, this metric has been specifically developed for short-term memory studies, the properties of the *FDCC* measures (the spectral dynamics of a signal) are strongly related to the intelligibility of speech and therefore also interesting for other cognitive studies.

Both metrics, *FDCC* and *STI*, are physical measures, derived from the acoustic properties of the (speech) sounds. Therefore, if we use these metrics to predict the influence of background speech on a writing task, we only estimate the influence of irrelevant background speech based on the physical characteristics of the sound. Both metrics do not take into account semanticity aspects such as language, meaning of speech and sentence structure.

STI and FDCC values of the sound scenarios

The intelligibility of the background speech for the listener will be influenced by the reverberation time and by the background noise level in the OPSE [34]. Because speech intelligibility was expected to be of great importance for the writing performance and disturbance, a calculation of the intelligibility of the different background sound scenarios was made. *STI* values were calculated for the different sound scenarios between the loudest background voice and the listener in each model: talker 13 for the scenarios with fourteen talkers and talker 4 for the sound scenarios with three background talkers (Table 4.3, Figure 4.3). To calculate the *STI* values, an estimation of the background noise was necessary. Normally, the background noise to determine the *STI* is a stationary sound, however, in this experiment, and in all OPSEs, the main background noise is irrelevant background speech which is not a stationary sound. To estimate the background noise level due to the irrelevant speech the L_{Aeq} and L_{95} were calculated for the talkers in the different background sound scenarios. The L_{95} is the sound level that is exceeded 95% of the time and is often used to quantify background noise levels of varying and dynamic signals. The approximations of the *STI* values due to the different reverberation times and estimated background noise levels were calculated by Odeon software in accordance with IEC 60268-16 [34,104]. Furthermore, the *STI* values without background speech, with 30 dB(A) pink background noise, were calculated for both talkers (13 and 4) as a reference (Table 4.3).

Also, the frequency domain correlation coefficient (*FDCC*) for the different sound scenarios was calculated (Table 4.3) as a measure of spectral variability and as an indicator of the speech intelligibility of the background speech signal [156].

Table 4.3 Estimated *STI* values in four different sound conditions between the nearest talker and the listener (see Figure 4.3) and the measured *FDCC* values of all five sound scenarios.

Sound Scenario	Estimated *STI* value between nearest talker and listener			*FDCC* value
	L_{A95}	L_{Aeq}	Without background speech (30 dB(A) pink noise)	
Pink Noise	-	-	-	0.86
Reverberant - 14 talkers	0.18	0.12	0.48	0.68
Reverberant - 3 talkers	0.38	0.29	0.43	0.61
Absorbing -14 talkers	0.38	0.26	0.72	0.59
Absorbing - 3 talkers	0.62	0.52	0.62	0.53

4.2.3 Writing task

The participating students had to write five stories associated with five different landscapes: mountains, forest, beach, desert and sea. The participants were not allowed to describe the landscapes, they had to create a story connected to the themes. The topics were chosen in accordance with writing experiments of Keus van de Poll [68,69,71].

4.2.4 Dependent Variables

Performance

The performance of writing can be measured by many different quantitative aspects of the produced text but also qualitative aspects like creativity and coherence of the final edited text are possibilities to measure the performance of writing [72]. Earlier research has shown that qualitative aspects of writing were not suitable for measuring the influence of different background sounds on writing performance. A method at which independent judges scores were used to measure the degree of creativity and coherence of the final edited text in different sound conditions turned out to be unsuccessful [72]. The inter-rater agreement on creativity and coherence between the assessors turned out to be low and no difference was measured between the sound conditions [72]. Therefore, in this study the performance of writing is based on the quantitative aspects of the produced text.

The objective indicators to measure writing performance were extracted from the writing process of the participants by using InputLog [157], a key logger that records and observes the writing process. The measured quantitative aspects were the number of typed characters (with and without spaces) and the number of characters (with and without spaces) and words in the final edited text. In order to allow easier comparison with other studies, the values are expressed as values per minute. The number of characters in the final text are all typed characters minus characters that had been deleted using delete and backspace keystrokes. Also, the number of pauses longer than 1, 3 and 5 s during the writing session were measured as a performance measure. More characters and words per minute and fewer pauses can be interpreted as a higher performance [68,69,71,72].

Self-estimated performance and disturbance

The self-estimated influence of the background sound scenarios on writing performance and disturbance was measured after each writing assignment and different background sound scenario. These measurements were done by presenting four statements to the participants that were to be assessed on a 6-point scale response format. Three statements addressed the influence of the background noise during the writing task ("The background noise during the writing task has influenced:"): the writing speed ("my writing speed and therefore the length of my story"), the quality of the story ("the quality of the content of my story"), the number of writing errors ("the number of writing errors in my story"), and one statement on the disturbance of the participants by the background noise ("The background noise was disturbing"). The 6-point scale was verbally indicated with "disagree completely - disagree - slightly disagree - slightly agree - agree - agree completely". This questionnaire was offered to the participants in the Dutch language.

After the last writing assignment, the noise sensitivity of the participants was measured. The reduced version of the NoiSeQ noise sensitivity questionnaire developed by Griefahn [82] was used. The noise sensitivity was measured via twelve statements in which the participants had to indicate their level of agreement with each statement on a 4-point scale. The 4-point scale was verbally indicated with " disagree completely - slightly disagree - slightly agree - agree completely". This questionnaire was offered to the participants in the Dutch language.

4.2.5 Design and Procedure

A repeated measures, within-participants design was used with five different sound scenarios with varying intelligibility of the background speech by changing the occupancy and reverberation time of the environment. As dependent variables, the writing performance and subjective parameters such as disturbance and self-assessed writing performance of the participants were used. Also, the noise sensitivity of the participants was measured.

The participants were asked to write a qualitatively good story related to a topic. They had to write as quickly as they could and without writing errors. The participants had to use a word processor (msword) to write the story. After a short oral introduction by the experimental researcher a training session started. The participants had to write a story for a period of 2 min to get accustomed to the procedure. The topic was displayed on a computer screen at the start of each writing assignment and for each following assignment the writing period was set to 5 min. The topics were presented in the same sequence to all participants. The five sound scenarios were offered to the participants by headphones in a counter balanced sequence using a Latin Square design. After each writing assignment the participants filled in a short questionnaire about their experiences during the writing task. After the last assignment the participants had to fill in the noise sensitivity questionnaire according to Griefahn [82].

The experiments were performed at Avans University of Applied Sciences. Participants accomplished the experiment alone in a quiet room (28-32 dB(A)), wearing a headphone, sitting behind a laptop at a desk. The room had one window, facing a street and other buildings.

Headphones were used throughout the experiment. The session duration per participant was about 55 min.

4.2.6 Statistical analysis

For analyzing the data, the statistical program SPSS 23.0 was used. The impact of the background sound scenarios on the writing task was studied by a single-factor repeated measures ANOVA. This was done for each dependent variable in order to analyze the significance of the differences between the means due to the five sound scenarios. Furthermore, to examine where the differences occur a follow-up pairwise comparison was performed by using post-hoc t-tests.

The impact of reverberation time and occupancy on the writing task was analyzed by a two-way repeated measures ANOVA. This was done for each dependent variable by a factorial 2(reverberation: absorbing vs. reverberant) x 2(occupancy: 3 vs. 14 talkers) analysis. In this analysis the quiet sound scenario was not taken into account because for the quiet scenario the reverberation time as well as the occupancy was of no relevance.

The impact of the noise sensitivity of the participants on the quantitative and self-estimated qualitative performance of writing was analyzed by a factorial 2(reverberation: absorbing vs. reverberant) x 2(occupancy: 3 vs 14 talkers) x 2(noise sensitivity: low vs high) repeated measures ANOVA. In this analysis the quiet sound scenario was not taken into account. Also, a factorial 5(sound scenarios) x 2(noise sensitivity: low vs. high) repeated measures ANOVA was performed. For all noise sensitivity analyses the participants were split into two groups, participants with a noise sensitivity higher than the median (median noise sensitivity = 2.67) and participants with a noise sensitivity lower than the median.
For all analyses a significance level of 5% was used.

4.3 Results

4.3.1 Impact of background sound scenarios on a writing task

The tables and figures in this section show the impact of the different sound scenarios on different dependent variables.

Performance

The performance of writing is measured by the number of typed characters and words and the number of pauses, while participants were writing the stories and being exposed to the five sound scenarios. In Table 4.4 the mean number of characters is shown for the five different background sound scenarios. The ANOVA only shows a significant effect of the five background sound scenarios for the number of characters in the final text without spaces. Further, pairwise comparisons show that only the performance in the '3 talkers-absorbing' sound scenario is significantly lower than the performance in all other background sound scenarios (including the quiet sound scenario) (*p*<.034).

The performance of writing is also measured by the number of words per minute in the final text. In Table 4.4, the mean number of words is shown for the five different background sound scenarios. The ANOVA shows a significant effect of the five background sound scenarios for the number of words in the final text. Further, pairwise comparisons show that only the performance in the '3 talkers-absorbing' sound scenario is significantly lower than the performance in all other background sound scenarios (*p*<.033) except for the performance in the '3 talkers-reverberant' sound scenario (*p*=.079).

The number of pauses is also a performance measure, fewer pauses indicate a higher performance. The number of pauses is measured for pauses longer than 1, 3 and 5 s. In Table 4.4, the mean number of pauses is shown for all three time conditions for the five different background sound scenarios. The ANOVA only shows a significant effect of the five background sound scenarios for the number of pauses longer than 3 s. Further pairwise comparisons show that only the number of pauses in the '3 talkers-absorbing' sound scenario is significantly higher, implicating a lower performance, compared to all other background sound scenarios (p<.030) except for the '14 talkers-reverberant' sound scenario (*p*=.095).

The percentage gap of the significant performance differences between the '3 talkers-absorbing' sound scenario and the other sound scenarios ranged from 8.2 to 10.6 characters per minute, or 41 to 53 characters for the story written in 5 min. This results in a maximum decrease of performance of 7.5% in the intelligible '3 talkers-absorbing' sound scenario in comparison to the other sound scenarios. The performance decrease in words was 11 to 15 words for the story written in 5 min, with a maximum decrease of 8.8%. Finally, the maximum increase of the number of pauses larger than 3 s was 7.7%.

Table 4.4 Means for quantitative performance measures of stories written while exposed to five different sound scenarios.

Quantitive performance measures	*Background sound scenarios*					*F(4,176)*	η_p^2
	quiet condition	*14 talkers reverberant*	*14 talkers absorbing*	*3 talkers reverberant*	*3 talkers absorbing*		
Characters							
Typed characters per min incl. spaces	234.75	229.32	231.96	232.25	222.68	1.57	0.03
Typed characters per min excl. spaces	195.36	190.14	189.00	193.53	185.21	1.08	0.02
Characters per min in the final text incl. spaces	186.41	184.48	184.14	183.10	173.50	2.30	0.05
Characters per min in the final text excl. spaces	152.25	150.21	150.54	149.81	141.60	2.39*	0.05
Words							
Words per min in the final text	34.35	34.25	33.66	33.74	31.37	2.67*	0.06
Pauses							
Number of pauses > 1 s	29.60	31.04	29.64	28.69	30.98	1.63	0.04
Number of pauses > 3 s	6.11	6.56	5.84	6.24	7.49	2.97*	0.06
Number of pauses > 5 s	2.44	2.60	2.29	2.60	3.16	1.57	0.03

* *p<0.05*

Self-estimated performance and disturbance

The self-estimated influence of the sound scenarios on the quality of the writing task was measured by a questionnaire after each writing assignment. In Table 4.5 the mean scores (on a 6-point scale) are shown for the five different background sound scenarios. The ANOVA shows a significant effect of the five background sound scenarios on all quality items: the quality of the story, the writing speed and the number of errors. All self-estimated variables show significant differences between the means. The participants estimated the number of writing errors to be the least influenced by the background speech and the writing speed to be the most influenced by the background sound scenarios. Pairwise comparisons show that the influence of the 'quiet' background sound scenario on the quality variables is significantly lower in comparison to all other background sound scenarios (p<.001). Also, the '14 talkers-absorbing' sound scenario has a significantly lower influence on the self-estimated correctness of spelling in comparison to the '14 talkers-reverberant' sound scenario (p=0.050).

The perceived disturbance due to the sound scenarios during the writing task was also measured by the questionnaire after each writing assignment. In Table 4.5 the mean values of the disturbance scores on a 6-point scale for the five different background sound scenarios are presented. The ANOVA shows a significant effect of the five background sound scenarios on disturbance. Further pairwise comparisons show that the perceived disturbance during the 'quiet' background sound scenario is significantly lower in comparison to all other background sound scenarios (p<.001). Also, the disturbance due to the '14 talkers-absorbing' sound scenario is significantly lower in comparison to the '3 talkers-absorbing' sound scenario (p=0.034).

Table 4.5 Means for self-estimated influence of background noise on different quality aspects of a writing task.

Qualitative performance measures	*Background scenarios*					*F(4,156)*	η_p^2
	quiet condition	*14 talkers reverberant*	*14 talkers absorbing*	*3 talkers reverberant*	*3 talkers absorbing*		
Self-estimated quality measure							
Quality of the story	2.40	4.10	3.70	4.02	4.10	20.02*	0.34
Writing speed	2.60	4.33	3.95	4.10	4.25	17.61*	0.31
Number of writing errors	2.40	3.80	3.63	3.50	3.45	13.57*	0.26
Self-estimated disturbance							
Perceived disturbance	2.10	4.70	4.43	4.48	4.83	60.31*	0.61

* *p<0.01*

4.3.2 Impact of reverberation time and occupancy of the study environment on a writing task.

The impact of both the reverberation time and occupancy of the study environment was tested by a two-way ANOVA for all dependent variables. As can be seen in Table 4.6, the reverberation time of the study environment has no significant main effect on the measured quantitative or self-estimated qualitative performance parameters. Also, the occupancy has no significant main effect on the self-estimated qualitative performance parameters. However, there is a significant main effect of occupancy on the produced number of words in the final text. An interaction effect for reverberation and occupancy has been shown for the number of pauses longer than 3 s and for perceived disturbance (Table 4.6). Simple main effects analyses showed that in an absorbing environment a low occupancy rate (3P) was resulting in significantly more pauses (less writing performance) than a high uccupancy rate (14P) (p=0.002), but in an reverberant environment there were no significant differences between the number of pauses due to the occupancy rate (p=0.64). Analyses also showed that in an absorbing environment a low occupancy rate (3P) was resulting in more disturbance than a higher occupancy rate (14P) (p=0.034), but in an reverberant environment there were no significant differences between disturbance due to the occupancy rate (p=0.163).

Table 4.6 Results (means) of a factorial 2 by 2 analysis on reverberation and occupancy by a repeated measures ANOVA for different dependent variables.

Quantitative performance measures	Effect of:	*Absorbing*	*Reverberant*	*14 talkers*	*3 talkers*	*grand mean*	*F(1,44)*	η_p^2
Characters per min in the final text excl. spaces	Reverberation	146.07	150.01				1.95	0.04
	Occupancy			150.37	145.71		3.64	0.08
	Reverb*Occup					148.04	2.11	0.05
Words per min in the final text	Reverberation	32.51	33.99				2.74	0.06
	Occupancy			33.95	32.55		4.37*	0.09
	Reverb*Occup					33.25	1.33	0.03
Number of pauses > 3 s	Reverberation	6.67	6.40				0.56	0.01
	Occupancy			6.20	6.87		2.63	0.06
	Reverb*Occup					6.53	6.61**	0.13
Self-estimated performance measures	Effect of:	*Absorbing*	*Reverberant*	*14 talkers*	*3 talkers*	*grand mean*	*F(1,39)*	η_p^2
Self-estimated quality of story	Reverberation	3.90	4.06					
	Occupancy			3.90	4.06		1.12	0.03
	Reverb*Occup					3.98	1.98	0.05
Self-estimated writing speed	Reverberation	4.10	4.21				0.68	0.02
	Occupancy			4.14	4.18		0.04	0.01
	Reverb*Occup					4.16	3.58	0.08
Self-estimated number of writing errors	Reverberation	3.54	3.65				0.59	0.02
	Occupancy			3.71	3.48		3.83	0.09
	Reverb*Occup					3.59	0.26	0.01
Perceived disturbance	Reverberation	4.63	4.59				0.08	0.01
	Occupancy			4.56	4.65		0.61	0.02
	Reverb*Occup					4.61	5.90*	0.13

** p<0.05, ** p<0.01*

4.3.3 Impact of the noise sensitivity of participants on a writing task.

Analyses showed that only the quantitative performance measures were significantly influenced by the noise sensitivity of the participants. A significant interaction effect between reverberation, occupancy and noise sensitivity was found for the number of characters in the final text without spaces (F(1,43) = 4.67, η_p^2=0.10, *p*=.036), for the number of words in the final text (F(1,43) = 5.03, η_p^2=0.11, *p*=.029), and for the number of pauses larger than 3 s (F(1,43) = 5.46, η_p^2=0.11, *p*=.024). This interaction effect can be seen in figure 4.4. No significant interaction effect of the noise sensitivity of the participants was found for the self-estimated parameters. Figure 4.4 shows the influence of the sound scenarios on the performance of writing for the participants with the lowest and highest noise sensitivity. The results show that the participants with the lowest noise sensitivity performed significantly ($p \leq .006$) lower in the '3 talkers-absorbing' sound scenario, the most intelligible speech sound scenario, in comparison to the other sound scenarios. This effect was not shown for the group of participants with the highest noise sensitivity. Furthermore, this high noise sensitive group showed a significantly lower performance score than the lower noise sensitivity participants of the experiment (Figure 4.4).

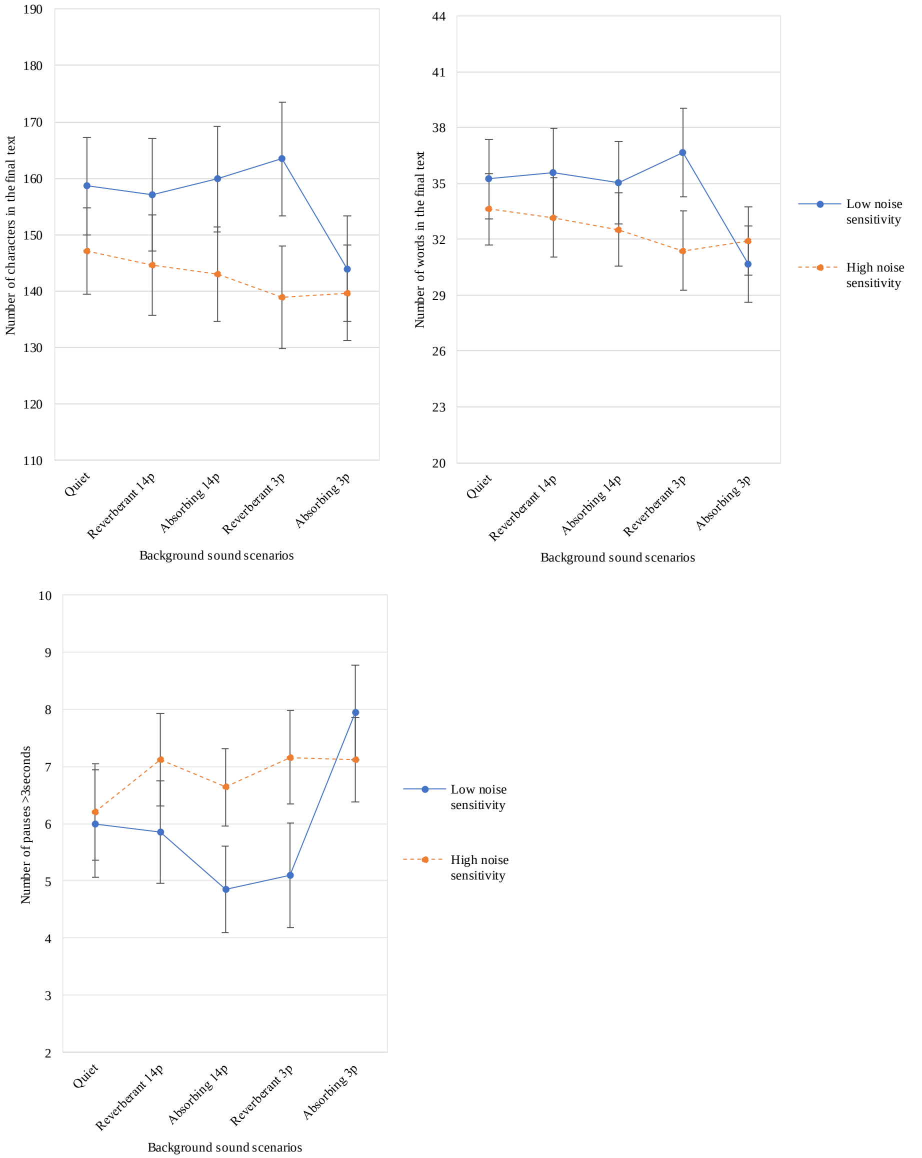


Figure 4.4 Mean values and confidence intervals (95%) of quantitative performance writing parameters (number of characters and words in the final text and number of pauses > 3s) during different background sound scenarios for the group of participants with the lowest and highest noise sensitivity.

4.4 Discussion

4.4.1 Impact of the sound scenarios on a writing task

Performance

The impact of a realistic sound scenario on writing performance, measured by the number of characters (without spaces), words and pauses above 3 s, is significant. It is shown that the '3 talkers-absorbing' sound scenario, the sound scenario with the highest speech intelligibility and lowest *FDCC* value, has a significantly lower writing performance score for all three performance indicators. The calculated *STI* value of 0.62/0.52 (Table 4.3) for the '3 talkers-absorbing' sound scenario, is the highest *STI* value and led to the lowest writing performance score. In this sound scenario the writing performance decreased 6-7% for characters and 8-9% for words compared to the sound scenario with the lowest *STI* value (*STI*=0.18/0.12), the '14 talkers-reverberant' sound scenario, and the 'quiet' sound scenario. The *STI*-performance model of Hongisto [64] and writing experiment results of Keus van de Poll [71] showed also a decrease of approximately 7% in writing performance due to more intelligible background speech with a higher *STI* value. A performance increase was expected in this experiment; however, it was not clear what percentage to expect in more realistic sound scenarios. A further validation of the performance model of Hongisto for all *STI* values is difficult to establish due to the limited number of *STI* values in this research (only four) and due to the difficulty of translating realistic dynamic sound scenarios into *STI* values.

The lowest performance score during the sound scenario with the lowest occupancy (3 talkers) and lowest reverberation time (0.6 s) of the study environment can be explained by the 'interference-by-process' view [79]. This sound scenario has the highest speech intelligibility (highest *STI* and lowest *FDCC* value) of the background speech on the listener's position, and therefore will lead to an increase in the interference of two semantic processes: the unintended interpretation of the background speech and the writing process [79]. Consequently, this will result in a performance reduction of writing.

Self-estimated performance and disturbance

The impact of a realistic sound scenario on the self-estimated writing performance of the participants is significant. Results show that the participants estimated the 'quiet' sound scenario to significantly have the least influence on their writing performance. On the other hand, the participants did not identify the sound scenario with significantly lowest writing performance, the most intelligible '3 talkers-absorbing' sound scenario, as the most disturbing sound scenario.

The impact of the sound scenarios on perceived disturbance was significant. However, we must consider that pairwise comparisons showed no significant differences between the disturbance means of the different sound scenarios except for the means in comparison to the 'quiet' condition.

Therefore, we can conclude that there is a difference between the influence of a realistic sound scenario on the quantitative writing performance in comparison with the influence of the same realistic sound scenarios on the self-estimated writing performance. Background speech with the highest estimated *STI* value and lowest *FDCC* value (3 talkers-absorbing) decreased the writing performance the most, while this intelligible background sound scenario was not rated as the most disturbing background sound scenario. Also, whereas the 'quiet' sound scenario was rated as least disturbing, this scenario is not the sound scenario with the significantly highest performance.
Moreover, we can conclude that background speech is disturbing, the students rated the background speech as slightly disturbing or disturbing while they rated the quiet condition (30 dB(A) background noise) as not disturbing (Table 4.5).

4.4.2 Impact of the reverberation time and occupancy of the study environment on a writing task

No significant main effect was found for the reverberation time of the study environment. A significant main effect of occupancy was only found for the number of words as a performance indicator. Also, an interaction effect for reverberation time and occupancy was found for the number of pauses > 3 s and for perceived disturbance (Table 4.6).

The level of speech intelligibility in the sound scenarios is determined by the reverberation time in combination with the number of background talkers (Table 4.3). Therefore, based on the presumed importance of the speech intelligibility [71,72,79], a main effect of the reverberation time and occupancy on the output measures was expected. However, the effects shown in this analysis are not consistent, a few dependent variables show significant effects in line with the expectation, but most variables show no effect of the reverberation time or occupancy.

4.4.3 Impact of the noise sensitivity on a writing task

A significant influence of the noise sensitivity of the participants was found on the quantitative writing performance indicators. Results show that people with high noise sensitivity have significantly lower peformance scores (Figure 4.4). Also, a significant interaction effect between reverberation, occupancy and noise sensitivity was found for writing performance.

As shown in Figure 4.4, the worst-case scenario with regards to performance of the participants with the lowest noise sensitivity scores is the '3 talkers-absorbing' sound scenario, the scenario with the highest *STI* and the lowest *FDCC* value. The participants with the highest noise sensitivity scores do not have a preferred or adverse sound scenario were performance significantly improves or detoriates. In general, the noise sensitive participants perform significantly lower than less noise sensitive participants. This applies to all sound scenarios, with exception of the '3 talkers-absorbing' sound scenario, this intelligible sound scenario also reduces the performance of the participants with the lowest scores for noise sensitivity. It shows that noise sensitive people are disturbed by all sound environments and people less sensitive to noise are mainly disturbed by intelligible speech.

4.4.4 STI and FDCC as a predictor of performance and disturbance of a writing task

Although the intelligibillity of the background speech is a good predictor of the performance and disturbance of a writing task, the speech transmission index (*STI*) is not such a suitable predictor in a realistic sound environment. The background noise in an OPSE is mostly irrelevant speech from students consulting each other and working on a group assignment. A usual way to calculate the *STI* value does not include background speech, only stationary background noise signals. Therefore, it is difficult to calculate and use the *STI* value in such a realistic sound environment as a predictor of intelligibility, in a realistic sound field *STI* is merely an estimation. The *FDCC* value, on the other hand, is not developed to measure the intelligibility of speech, this psychoacoustic metric is developed to predict how sound influences specific cognitive processes. It measures the spectral variation and segmentation of background noise. Intelligible speech will show spectral variation and will result in a lower *FDCC* value. The results of this experiment show that the sound environment leading to the lowest performance and the most disturbance, is the sound scenario with the lowest *FDCC* value, and the least disturbing quiet sound scenario shows the highest *FDCC* value. The advantage of the *FDCC* value in comparison with the *STI* value is the possibility to measure (calculate) the *FDCC* value of all sound scenarios, also the 'quiet' and the dynamic background speech scenarios, while the *STI* can only estimate the dynamic sound scenarios and not the 'quiet' sound scenario. Furthermore, the *FDCC* metric measures the dynamic characteristic of the sound scenarios in a multi-talker scenario at the listener's position, while the *STI* can only measure one talker-listener position at the same time.

Despite all the advantages of the *FDCC* value, it is not a metric developed to measure the speech intelligibility. A negative correlation can be found between the estimated *STI* values compared to the calculated *FDCC* values (Table 4.3), with the highest correlation for the *STI* values based on the L_{A95} background noise. However, based on this experiment it is not clear whether the *FDCC* value or one of the estimated *STI* values are the best predictors of writing performance.

4.4.5 Towards acoustic recommandations for OPSEs

Current recommendations on open-plan work environments focus on realizing a reduction of the sound level of irrelevant speech over distance to reduce the speech intelligibility of the irrelevant background speech [47,81,158]. In order to be able to realize such a rapid decrease of sound level over distance, acoustic consultancies will advise the application of sound absorbing materials and the use of acoustic screens [47,158]. Although such measures will reduce the sound level of the irrelevant speech, the speech intelligibility will still be high compared to the same irrelevant speech in a more reverberant environment. It is important to find the right balance between absorption and reverberation in an environment. An increase in absorption results in a decrease of the sound level from irrelevant background speech and will increase the intelligibility of the background speech [81]. In contrast, reverberation will reduce the modulation depths of a speech signal and thus reduce its intelligibility [34,104, 156], but will increase the overall background sound level. The optimal balance will be influenced by the kind of tasks being performed in the environment and their sensibility to intelligible speech and high background noise levels.

Especially in an OPSE, reducing the intelligibility of background speech through room acoustic design is very important (Chapter 2). After all, the combination of different tasks in an OPSE, group assignments producing speech and individual (semantic) tasks, is an important cause of the disturbance of students by intelligible background speech.
This research shows that the least disturbance and the least decrease of self-estimated performance occur in a quiet environment. Therefore, we plead for activity based OPSEs, with plenty of individual silent workplaces that are acoustically separated from group work places.

4.5 Conclusions

The results of this study, that distinguishes itself by using realistic sound scenarios, show that the intelligibility of background speech significantly influences the performance and disturbance of students working on a writing task in an OPSE. The lowest performance on a writing task was measured in an absorbing environment with a low occupancy rate, a situation with intelligible background speech. This is in line with earlier studies, mainly conducted from a psychological perspective [71,72,79], and also in line with our hypothesis.

Given the practical point of view of this study, our results are an important contribution to the evidence that an increase in intelligibility of background speech will lead to a decrease in performance. We see the relevance of this result in the fact that current recommendations on open work environments often lead to very sound absorbing environments [47,81,158], which in itself will lead to an acoustic scenario that increases speech intelligibility if no additional measures are taken.

The second part of our hypothesis was not confirmed by the data in this study. We expected noise sensitive students to be more disturbed and to show a larger decrease of writing performance due to the intelligible background speech compared to the less noise sensitive students, this effect was not established. However, this study did show noise sensitive people to be disturbed by all sound environments, while less sensitive people were mainly disturbed by intelligible speech. Nonetheless, all people consider a very quiet OPSE without irrelevant background speech to be the least disturbing.

The findings of this research are the beginning of gathering data that will contribute to the development of design tools that help to make better decisions in the process of developing acoustic comfortable open-plan study environments. In the future, more realistic student tasks must be tested in environments with different acoustic parameters, for instance by changing the reverberation time in a room, changing the decrease of sound level over distance using screens or changing the background sound level and spectrum.

CHAPTER 5

STUDYING

5 | The effect of background noise on a 'studying for an exam' task in an open-plan study environment.

Students can be disturbed by background noise while working in an open-plan study environment. They indicated to be very disturbed by background speech while preparing for an exam. Therefore, in this study, the influence of different sound scenarios on students working on this typical student task, 'studying for an exam', has been investigated. Three sound scenarios and a quiet reference sound scenario were developed, based on the sound environment of a real open-plan study environment, with a varying number of talkers in the background and different reverberation times of the study environment. Seventy students worked on a set of tasks simulating a 'studying for an exam' task. They performed a studying task and additionally a mental arithmetic task, and a logical reasoning task, while being exposed to the sound scenarios. Performance, self-estimated performance and disturbance of students were measured. No significant effect of the sound scenarios was shown on performance of students working on a studying and mental arithmetic task. However, a significant effect of sound was shown on performance of students working on the logical reasoning task. Furthermore, a significant effect of the sound scenarios was shown on self-estimated performance and perceived disturbance for all tasks from which the studying task was the most disturbed task. It is argued that the absence of a detrimental sound effect on performance of students working on the studying task, is a result of focusing due to task engagement and task difficulty, both aspects working as a 'shield against distraction'.

This chapter is based on: Braat-Eggen, P.E., Reinten, J., Hornikx, M.C.J., Kohlrausch, A.G. (2020). The effect of background noise on a ‘studying for an exam’ task in an open-plan study environment. In preparation for submission to the Journal of Environmental Psychology

5.1 Introduction

Open-plan study environments (OPSEs) are becoming increasingly important in higher education. Not only the importance of their function but also the number of square meters is increasing [3,19]. The need for OPSEs is a result of changed visions on education, and enable new ways of learning. In addition to the well-known knowledge-based education also competence-based education is becoming increasingly important [19,159]. This new type of education, in which skills and attitude of students are of great importance in addition to knowledge, have led to different work forms with corresponding assessment procedures [159]. Besides the well-known individual written and oral exams, the assessment of competences is often based on the outcome of individual or group assignments or projects [159, 160]. As a result of these educational changes, there is a need for workspaces where students can work on their assignments and projects, individually but also in groups. Accordingly, not only classrooms and lecture halls, but also OPSEs become part of buildings for higher education.

A survey amongst 496 students in five OPSEs (Chapter 2) showed that the tasks students perform in OPSEs are diverse, ranging from preparing for an individual exam to brainstorming for a group assignment (see Figure 2.5). This variety of activities implicates different demands on the acoustic environment, but also induces noise production, which in combination can lead to disturbance.

Although the sound environment in OPSEs can be very disturbing, no recommendations or guidelines have so far been developed for the design of acoustically comfortable OPSEs. To do so, more knowledge is needed on tasks and the sound environment in an OPSE in relation to task performance and disturbance.

5.1.1 Studying for an exam

The most disturbed task students perform in an OPSE, 'studying for exams' (Figure 2.5), will be further investigated in this study. As far as we know, earlier research into the influence of different sound environments on a studying task has not yet been carried out in the context of performance and disturbance. Most studies on the influence of noise on cognitive performance are executed to find specific mechanisms responsible for distraction of a cognitive task. Therefore, these experiments are mostly performed on so-called 'pure' cognitive tasks [75] or sub-component cognitive abilities [76], such as for instance short-term memory tasks [117,161,162] or tasks using retrieval from semantic memory [66,163]. The use of experimental 'sub-component ability' results may be complementary but not enough for understanding the effects of noise on a realistic complex cognitive task [76]. Therefore, in this research on OPSEs we will study the influence of noise on complex student tasks. It will be instrumental for developing recommendations for acoustically comfortable OPSEs.

Preparing for an examination is a typical student task and it is a very complex task. When students are learning for an exam, they have to analyze and understand the material to be studied. Moreover, they also have to make strategic choices and decide what to learn and to store in memory. Studies on participants performing self-regulated learning tasks are mostly performed in a quiet laboratory setting [164,165]. In these studies, not only memorizing but also learning strategies are the subject of the research questions. In a recent study on self-regulated learning, the influence of noise as an environmental factor has been studied in relation to the strategic and metacognitive aspects of learning [166]. The duration of the study time was related to the auditory distraction in the environment. The strategic choices of the participants were measured by how much time the participants had spent on various study items. It appeared that the duration of study time was not extended when the participants were disturbed by the noise during the study process, while it was expected that the participants would invest more study time when they were disturbed by the noise. Due to the lack of compensatory strategies, such as extending the study time, a decrease of performance was found. The researchers explained this as a distortion of time perception by auditory distraction [166].

Assessments in higher education are an essential part of a curriculum and evaluate the educational level of graduate students [167]. There is a wide variety in ways to organize an exam, however, there are some basic characteristics of an exam in higher education. Exams at this educational level must include higher-order thinking skills and encourage conceptual understanding [168]. A model to describe different levels of cognitive skills has been developed by Bloom [169,170]. His model describes six cognitive categories with increasing complexity: knowledge, comprehension, application, analysis, synthesis and evaluation. A revised version of his taxonomy changed the categories into more skill-based levels: remember, understand, apply, analyze, evaluate and create [171] (Figure 5.1). In practice, it means that when students in higher education prepare for an exam they do not only have to remember and understand knowledge but also have to be able to apply, analyze, and evaluate that knowledge. ‘Creating’, the top of Bloom's pyramid, is the most complex cognitive skill and is often tested in (multidisciplinary) projects.

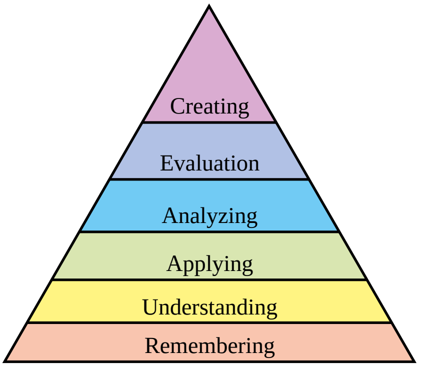


Figure 5.1 Revised Taxonomy of Bloom, a classification system for levels of cognitive skills and learning behavior [172]

5.1.2 The sound environment

The most disturbing sound in an OPSE is intelligible background speech (see Chapter 2). Background noise and especially background speech has been proven to have a detrimental effect on cognitive performance [23,32,73]. These results have been described by the duplex-mechanism account [117]. In this account, two ways of disruption have been distinguished; interference-by-process and attentional capture. The first mechanism, interference-by-process, arises if the processes needed to perform an intended task are similar to those needed to process background sound. For instance, the processes needed for a semantic task like reading a text will interfere with the unintended processing of background speech, which is a semantic task as well. The second mechanism of distraction is attentional capture, whereby sound causes disruption of cognitive performance when it removes the focus from the intended task. Specific attentional capture occurs when the content of the sound distracts you from the core task, like for instance hearing your own name [173]. Another way of attentional capture is that a specific sound capture attention, due to the context in which it occurs [117]. For instance, the B within the sequence AAAAABAA will capture attention due to the deviation from the expected A [115,118]. Auditory distraction can be overruled by cognitive control [22]. For instance, an increased task demand, a more difficult task or a greater engagement into the task can shield against distracting effects of noise on tasks [78,101,117, 174,175].

Translation of the results of experimental studies on the influence of noise on task performance and disturbance into room acoustic requirements is difficult. A translation is only possible if the experimental sound environments are comparable with the real sound environment in which the task is expected to be performed. In a literature review on the influence of the indoor sound environment on human task performance [32] it was found that only a limited number of studies made use of realistic variations of the room acoustic parameters in combination with realistic sound sources. The influence of room acoustic parameters is seldom taken into account in experiments, and in many cases background speech consists of only one or two talkers. With regard to the importance of developing recommendations, this study will work with a variation in acoustical properties and different realistic sound sources in an OPSE. In this research, background sound scenarios will contain different speech sources and the OPSE will have different reverberation times.

5.1.3 Personal factors

Different personal factors can influence the effect of noise on cognitive performance [32]. An important personal factor that can influence task performance and disturbance of people in noisy open environments is noise sensitivity [85]. In earlier studies on the influence of the sound environment of OPSEs on cognitive performance and disturbance, noise sensitivity was taken into account. In a field study on OPSEs (Chapter 2) it was shown that noise sensitive students were more disturbed by noise than students being less sensitive to noise. In the experimental study on a collaboration task in an OPSE (Chapter 3) no influence of noise sensitivity was found, while in the experimental study on a writing task (Chapter 4) noise sensitive students showed a significantly lower writing performance in comparison to students less sensitive to noise. As some of the studies show an important influence of noise sensitivity of students on performance and disturbance in an OPSE, we will include noise sensitivity of students as a personal factor also in this study.

5.1.4 The aim of the study

In this experiment, the influence of background speech on the performance and disturbance on a typical student task, 'studying for an exam' in higher education, will be investigated by using a set of assignments. Based on the duplex-mechanism account, we hypothesize that a realistic sound environment with background speech will have a negative effect on performance and perceived disturbance of this student tasks in an OPSE in comparison to a quiet environment. Furthermore, we expect that more intelligible background speech will decrease performance and will increase disturbance of students. Also, the noise sensitivity of students is expected to affect how they perceive the disturbance of the background speech. We expect noise sensitive students to be more disturbed by the background speech and to perform less due to the background sound in comparison to less noise sensitive students.

5.2 Method

5.2.1 Design

To verify the hypotheses posed in Section 5.1.4 a within-participants experimental design with repeated measurements was developed. The experiment included three tasks: a studying task, a logical resoning task, and a arithmetic task, together representing a 'studying for an exam' task. Four different sound scenarios with background speech were used in the experiment. Students had to perform each task four times, each time a different sound scenarios was presented.

5.2.2 Participants

Seventy bachelor students from Avans University of Applied Sciences took part in the experiment. The results of four students were not included in the analysis. One of these student had severe hearing loss, the results of two other students were excluded due to computer problems during the test and the experiment of yet one student was interrupted by his mobile phone. All participating students were native Dutch speakers. The sixty-six students (24 female and 42 male) included in the analysis were between 17 and 30 years old (mean age=20.2, SD=2.7). As a reward for their participation, the students received an internet voucher or educational credits.

5.2.3 Research settings

The experiments were conducted at Avans University of Applied Sciences in a small two-person office (2.60 m x 2.25 m) with no windows, originally intended for audio processing. The walls were covered with acoustic absorbing material and the room was acoustically well insulated. During the experiment the participant was sitting at one desk while the researcher was sitting at the other desk, next to each other. The participant was working on a laptop with external sound card (ST Lab USB sound box) and was wearing a headphone (Sennheiser HD 380 PRO) throughout the experiment.

5.2.4 Sound Conditions

Background sound scenarios

To create realistic OPSE background sound scenarios, auralizations based on computed impulse responses were used. Therefore, a digital model of an existing OPSE at the Eindhoven University of Technology was constructed. The computational modelling and auralization was performed using the room acoustic modelling software Odeon (version 12.12). From this basic model two new models were developed, an absorbing variant applying sound absorbing materials instead of the materials used in the real OPSE, and a reverberant variant applying sound reflecting materials. These two models had also been used in the previous studies on the influence of background sound on student tasks Chapter 3 and 4).

Four sound scenarios were created for this experiment, one quiet reference scenario and three scenarios with background speech. Not only the material properties of the OPSE but also the number of talkers in the OPSE were varied. The number of talkers in combination with the reverberation time in the modelled OPSEs resulted in sound scenarios with different levels of intelligibility of the background speech. In Table 5.1 the four sound scenarios are described by the reverberation time, background sound level due to speech and the intelligibility of the background speech (see Chapter 4). The intelligibility is here based on the nearest speaker and is described by the estimated Speech Transmission Index (*STI*). *STI* is a dimensionless number between zero and one, where an excellent intelligibility results in an *STI* value of 1, and an *STI* value below 0.3 indicates almost unintelligible speech [34]. The position of the talkers and their speech directions are described in Figure 4.3. More information about the modelling, materials, sound levels, and estimated *STI* values have been described in previous Chapters on the influence of background speech on a collaboration and a writing task (Chapters 3 and 4).

Table 5.1 Characteristics of the background sound scenarios.

Sound Scenario	Reverberation (time)	Background Speech	Sound Level L_{Aeq} Background Speech	Estimated *STI* values
A&3T	Absorbing (T_{30}=0.6s)	3 Talkers	41 dB(A)	0.62
A&14T	Absorbing (T_{30}=0.6s)	14 Talkers	54 dB(A)	0.38
R&14T	Reverberant (T_{30}=2.3s)	14 Talkers	64 dB(A)	0.18
Quiet		pink noise	30 dB(A)	-

To create a realistic sound environment, recordings were made of students telling about their study, hobbies and work. Subsequently, the speech recordings were convolved with the binaural impulse responses of the absorbing and reverberant model as calculated by Odeon. The quiet control sound condition consisted of a pink noise signal at 30 dB(A), which is equal to the background noise level in the existing, unoccupied OPSE (Chapter 4).

5.2.5 Measures

5.2.5.1 Task performance

The typical student task 'studying for an exam' was simulated by a series of assignments. The examination format chosen for this experiment was an individual written examination, a common format for examining knowledge in higher education [160]. One of the characteristics of this format is the time gap between the studying activity, that could take place in an OPSE, and the testing of the knowledge. To simulate the time gap in the experiment, after the study activity and before testing, two other assignments were introduced to the participants, a logical reasoning task and a mental arithmetic task. Performing these tasks not only simulates a time gap, but also what happens in real life: within the time span between studying for an exam and performing an exam, students are busy performing all kinds of tasks that take their focus away from the exam topic. The tasks which where chosen to fill in the time gap rely on cognitive skills that complement the study task in order to cover the cognitive skills described in Bloom’s model. The combination of the three assignments used in the experiment represents five out of six levels of cognitive skills as described in Bloom's revised taxonomy [171]:

- remembering: reading comprehension, mental arithmetic
- understanding: reading comprehension syllogism, mental arithmetic
- applying: mental arithmetic
- analyzing: reading comprehension syllogism, mental arithmetic
- evaluating: reading comprehension syllogism

The highest level of cognitive tasks in Bloom's taxonomy, ‘creating’, was not included in the assignments, to reduce the duration and complexity of the experiment. Each assignment was designed to represent the level of a beginning bachelor student. In this experiment the performance and disturbance of all three tasks, the studying task and the tasks to simulate the time gap (the reading comprehension and mental arithmetic task) were analyzed.

Studying for an exam

The 'studying for an exam' task shows resemblance to a comprehensive reading test. At the start of the task, students were instructed to study an informative text, as if they were preparing for an exam about the content of that text, that would be conducted later in the experiment. Four texts with the same length (mean=645 words) and a similar level of complexity were selected. To this end, texts from 'The State Exams Dutch as a second Language (NT2)' were chosen. These texts are normally used for the national language proficiency exams for non-native adult speakers, who want to start a study at a Dutch University or want to work in the Netherlands. To study the influence of different background sound scenarios on a task in a repeated measurement design, it is very important to select four texts of the same difficulty level. Therefore, a pilot study was performed (n=8) and from the analysis of the results the final four texts were selected.

The performance of the 'studying for an exam task' was measured by the number of correct answers to the questions about the text, the exam. In total 10 multiple choice questions were formulated for each text. The students answered the questions after a time interval of 8 min. In these 8 min the students worked on two assignments, a logical reasoning task and a mental arithmetic task. These 'in-between' tasks were intended to simulate the time gap between studying and doing an exam.

Logical reasoning

The logical reasoning task consisted of a set of so-called syllogisms. Students had to read two statements, subsequently they had to judge conclusions drawn from these two statements on validity. For example:

Statements:

- All mountains have rocks
- All countries have mountains

Conclusions:

1. All rocks have countries
2. All countries have rocks
3. Not all rocks have countries
4. No conclusion possible

A well-tested set of 40 (4x10) syllogisms, developed by Making Moves B.V. (2019) [176], was used. The performance of the logical reasoning test was measured by the number of correct answers.

Mental arithmetic

In the mental arithmetic test the students had to solve 18 calculations without the use of paper and pen or calculator. The calculations were examinations at a first-year bachelor educational level, in the Netherlands defined as level 3F [177]. The performance of the mental arithmetic test was measured by the number of correct answers.

5.2.5.2 Self-estimated performance and perceived disturbance

The self-estimated performance and perceived disturbance of tasks were measured by a questionnaire, on a 5-point scale, after each sound scenario (Figure 5.2). The questions were based on ISO/TS 15666 "Acoustics - Assessment of noise annoyance by means of social and social-acoustic surveys" and formulated in the Dutch language [178].

- Thinking about the last experiment, how much did noise bother, disturb or annoy you while studying the text: not at all - slightly - moderately - very - extremely?
- Thinking about the last experiment, how much did the noise influence the number of correct answers on the questions about the text: not at all - slightly - moderately - very - extremely?
- Thinking about the last experiment, how much did noise bother, disturb or annoy you while working on the logical reasoning statements: not at all - slightly - moderately - very - extremely?
- Thinking about the last experiment, how much did the noise influence the number of correct answers on the logical reasoning statements: not at all - slightly - moderately - very - extremely?
- Thinking about the last experiment, how much did noise bother, disturb or annoy you while working on the calculations: not at all - slightly - moderately - very - extremely?
- Thinking about the last experiment, how much did the noise influence the number of correct answers on the calculations: not at all - slightly - moderately - very - extremely?

5.2.5.3 Noise sensitivity

The noise sensitivity of the students was measured with the reduced version of the Noise Sensitivity Questionnaire (NoiSeQ-R), developed by Griefahn [82]. The questionnaire was translated and offered in the Dutch language to the students. They had to indicate their agreement on twelve statements related to their sensitivity to noise. For each statement the level of agreement could be chosen on a 4-points scale: "disagree completely - slightly disagree - slightly agree - agree completely".

5.2.6 Procedure

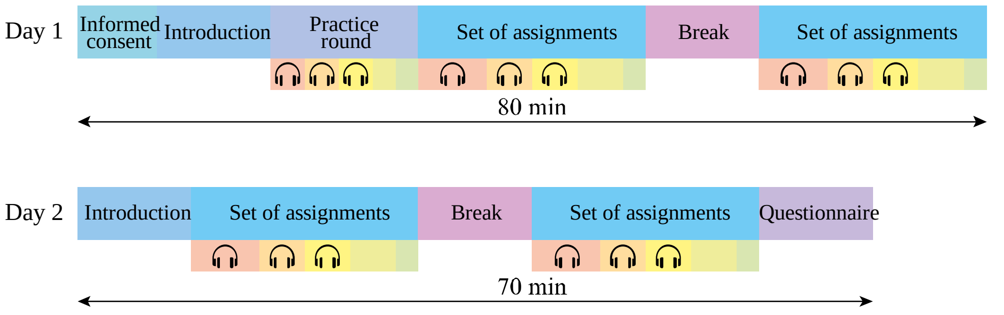
The whole experiment took about two 2 h and 30 min spread over two sessions (Figure 5.2). The first session started with an instruction by the experimental researcher, followed by a set of assignments to practice the type of questions and to get familiar with the procedure (Figure 5.2). After practicing, the first set of assignments was presented to the student while being exposed to one of the sound scenarios. After finishing the first set, a short break of 10 min was programmed before starting the second set of assignments. This set was presented to the student with another background sound scenario. This first session took about 80 min.

The second session took place on another day, where the student worked on two new sets of assignments while being exposed to two different sound scenarios. Between the sets of assignments, a short break of 10 min was prescribed. At the end of the session the student had to fill in a questionnaire about noise sensitivity and personal factors like age, gender, and hearing. The second session took about 70 min.

Students worked individually on the experiment. All instructions about the assignments were displayed on the laptop and 'start' and 'stop' instructions were given orally through the headphone. The background sound conditions were offered through the headphones during both the study task and the assignments but not during answering the questions about the text.

The set of assignments simulating the 'studying for an exam' task started with reading and studying a text. The participating students were informed that they had to answer some questions about the text later in the experiment. The text was printed on paper and the use of pen and marker was allowed during their study activity. After 6 min, participants had to put the text, including all their notes, in a closed box. This task was followed by the logical reasoning task, assignments (syllogisms) were presented at the laptop screen. After 4 min the last task started, the mental arithmetic task. While working on the calculation exercises, making notes and using a calculator were forbidden. After 4 min this task was closed and the questions about the initial text were presented. Finally, a questionnaire was presented about the perception of the background sound and the self-estimated influence of the sound scenario on performance. An overview of order and duration of the assignments can be seen in Figure 5.2.
All tasks were announced on the laptop screen and after pushing the start button the time clock and assignments were started on the laptop. The elapsed time was shown on the screen, so the students knew how much time there was left to perform their task. The assignments

were presented in the same sequence to all participants. The four sound scenarios were offered to the participants in a counter-balanced sequence.



Assignment	practice [min]	test [min]
Studying text	3	6
Logical reasoning	3	4
Mental arithmetic	3	4
Questions text	2	4
Perception questionnaire	2	2

Figure 5.2 The order and duration of a set of assignments in the experiment.

5.2.7 Statistical analysis

All statistical analyses were performed using SPSS 23.0. The influence of the background sound scenarios on the performance, self-estimated performance and perceived disturbance was analyzed by a single-factor repeated measures ANOVA. The significance of the differences between the means of the dependent variables due to the four sound scenarios was tested and a follow-up pairwise comparison to examine where the differences occur was performed by using post-hoc t-tests with Bonferroni correction.

The influence of noise sensitivity was studied after a median split was done to divide the subjects in two groups. By using a factorial 4(four sound scenarios) x 2(low versus high noise sensitivity) repeated measures ANOVA, the influence of the noise sensitivity on performance, self-estimated performance and perceived disturbance was studied.

5.3. Results

5.3.1 Impact of the background sound scenario on performance

Table 5.2 shows the influence of the different background sound scenarios on performance of students accomplishing a studying task, a logical reasoning task and a mental arithmetic task. The performance has been determined by the number of correctly answered questions for the assignments.

The analyses show that different sound scenarios do not have a significant effect on performance of a 'studying for an exam' task (p =.142). The analyses also show that different sound scenarios have a significant effect on performance of a logical reasoning task (p = .013). The background sound scenarios with speech lead to a decrease of performance. Follow-up t-tests with Bonferroni correction showed significant differences between the performance means of the quiet situation and the reverberant sound scenario with 14 talkers (p =.008). A 11% decrease in performance of the logical reasoning task is measured between the 'reverberant 14 talkers' sound scenario and the 'quiet' sound scenario. A performance reduction of an average of 7% is measured if all three sound scenarios are compared with the 'quiet' sound scenario. The analyses show that the sound scenarios have no significant effect on performance of a mental arithmetic task (p = .934).

Table 5.2 Mean number of correct answers as a performance measure of different tasks while exposed to different sound scenarios.

Task	Background sound scenario				F(3,192)	η_p^2
	quiet condition	3 talkers absorbing	14 talkers absorbing	14 talkers reverberant		
studying for an exam	7.02	6.63	6.40	6.77	1.837	0.027
logical reasoning	7.51	7.31	6.97	6.66	3.713*	0.055
mental arithmetic	7.47	7.29	7.39	7.44	0.143	0.002

*p<0.05

5.3.2 Impact of the background sound scenario on self-estimated performance

Figure 5.3 shows the influence of the different background sound scenarios on the self-estimated performance of students accomplishing the three tasks. The self-estimated performance has been measured on a 5-point scale.

The analyses show the different sound scenarios to have a significant effect on the self-estimated performance of the students working on a studying task (F(3,195) = 34.129, p < .0001, η_p^2 = .344), a logical reasoning task (F(3,189) = 38.468, p < .0001, η_p^2 = .379), and a mental arithmetic task (F(3,189) =26.953, p < .0001, η_p^2 = .300). The quiet condition was reported as least influenced condition. Follow-up t-tests for all tasks with Bonferroni adjustment showed significant differences between the self-estimated performance means of the quiet condition and the three other sound scenarios (p<.0001).

Self-estimated performance of the mental arithmetic task seems the least influenced by the background sounds (Figure 5.3). However, a one-way repeated measures ANOVA shows that for each sound scenario the kind of task has no significant effect on self-estimated performance (p>.05).

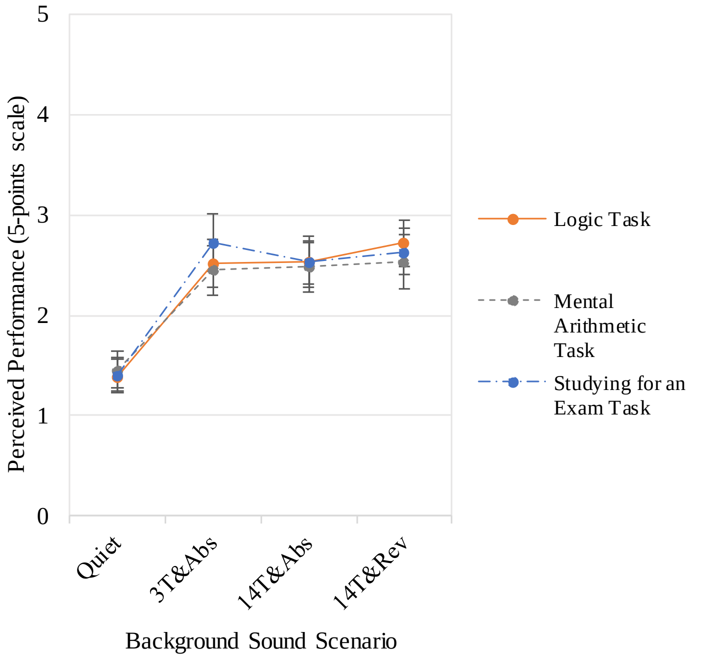


Figure 5.3 Mean values and confidence intervals (95%) of the perceived performance of participants (n=66) accomplishing three tasks with four different sound scenarios: Quiet, 3 Talkers & Absorbing (3T&Abs), 14 Talkers & Absorbing (14T&Abs), 14 Talkers & Reverberant (14T&Rev).

5.3.3 Impact of the background sound scenario on perceived disturbance

Figure 5.4 shows the influence of the different background sound scenarios on perceived disturbance of students working on the three tasks. The perceived disturbance has been measured on a 5-point scale.

The analyses show different sound scenarios to have a significant effect on perceived disturbance of a study task (F(3,195) = 94.280, p < .0001, η_p^2 = .592), a logical reasoning task (F(3,195) = 59.285, p < .0001, η_p^2 = .477) and a mental arithmetic task (F(3,192) = 44.976, p < .0001, η_p^2 = .413). The quiet condition was reported as the least disturbed sound condition. Follow-up t-tests for all tasks with Bonferroni adjustment showed significant differences between the perceived disturbance means of the quiet situation and all other sound scenarios (p<.0001).

Students rated studying for an exam as the most disturbed task due to the background noise (Figure 2.5 and 5.4). A one-way repeated measures ANOVA for all sound scenarios with speech (not the quiet scenario) shows that students are significantly more disturbed when performing a study task then in the other tasks (3 Talkers Absorbing: F(2,130) = 13.389, p < .0001, η_p^2 = .171); 14 Talkers Absorbing: F(2,130) = 12.772, p < .0001, η_p^2 = .164); 14 Talkers Reverberant: F(2,130) = 11.353, p < .0001, η_p^2 = .151).

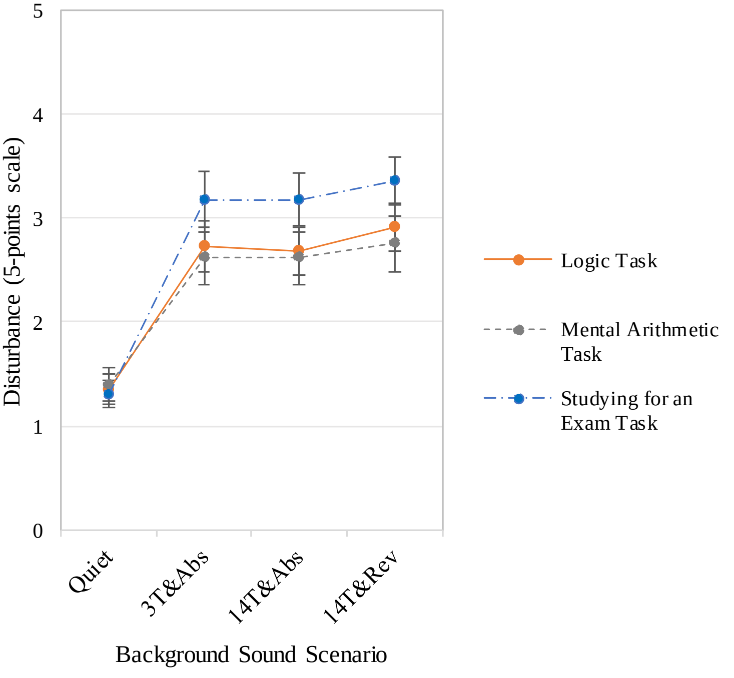


Figure 5.4 Mean values and confidence intervals (95%) of the perceived disturbance of participants (n=66) accomplishing three tasks with four different sound scenarios: Quiet, 3 Talkers & Absorbing (3T&Abs), 14 Talkers & Absorbing (14T&Abs), 14 Talkers & Reverberant (14T&Rev).

5.3.4 Impact of noise sensitivity of participants on task performance and disturbance

To verify the influence of noise sensitivity of participants on the three output measures, a general linear model with repeated measurements was used with sound scenarios as within-subject factor and noise sensitivity as between-subject factor. The participants were divided in two groups by a median noise sensitivity split. A low sound sensitivity group (mean=2.51) was formed by participants with a noise sensitivity lower than the median (median=2.83, scale1-4), and a high noise sensitivity group (mean=3.21) was formed by participants with a noise sensitivity higher than the median.

No significant interaction effect was found for any of the independent variables (performance, self-estimated performance and perceived disturbance) for any of the tasks (studying, logical reasoning, mental arithmetic).

5.4 Discussion

5.4.1 Impact of the background sound scenarios on performance

The analysis of the results (Table 5.2) showed no significant effect of the sound scenarios on the performance of students for the 'studying for an exam' or 'mental arithmetic' task. Only the performance of students working on the 'logical reasoning' task was significantly impaired by the background sound scenarios with speech. Although for all tasks the quiet condition showed the highest student performance, only the 'logical reasoning' task showed a significantly performance effect. The highest detrimental effect on student performance of the cognitive tasks was expected during the sound scenario with the most intelligible background speech, the scenario with only three talkers in an absorbing environment (Table 5.1). This should be the result of the interference of semantic processes in the task, and the automatic semantic processing of the background speech [117]. However, no significantly higher decrease of student performance has been shown for any task while being exposed to the 3 talkers-absorbing sound scenarios.

'Studying for an exam' tasks in higher education have, for as far as we know, not been studied in an experimental setting until now. For comparison with previously conducted studies, experimental research into reading comprehension with delayed answers would be the best approach. A reading comprehension test with delayed answers by Martin *et al.* [108] indeed showed a similar procedure as the present study. The findings of this research showed a detrimental effect of unattended speech on comprehensive reading and the importance of semantic characteristics of speech. Also, a study of Oswald *et al.* [109] on comprehensive reading showed that meaningful as well as meaningless speech decreased performance, although the procedure of this study was less comparable with the current study. Results of both studies are not in line with our results, as we could not establish significant effects of noise on performance. An essential difference between the previous studies and this study can be found in the characteristics of the sound environments. In the compared studies [108,109], one voice with perfect intelligible speech was used as background noise, in contrast to the sound scenarios in the current study were a realistic OPSE sound environment was simulated with at least three voices influenced by room acoustic parameters like the reverberation time. This might be an explanation for the differences between the results of the studies. Another important difference is the design of the experiments. In the current study, the comprehensive reading test with delayed answes has been presented as an exam, combined with several other tests. The importance and the difficulty of an exam might have affected the performance of the test.

Research on the influence of noise on a one-digit 'mental arithmetic' task showed a decrease of performance for noise with and without background speech [179]. Also, a study of Jancke [66] on a three-digit 'mental arithmetic' task showed a decrease of performance, although relatively low in comparison to other office tasks (less than 3%). Both studies showed that the performance in a mental arithmetic task was not determined by the intelligibility of the background speech. In the present study no significant effect of the sound scenarios on performance of the mental arithmetic task was found, and certainly no influence of the intelligibility of the background speech. The realistic three-digit calculation task of Jahnke showed a good similarity with the test and results of the present study. The small effects on performance are in line with the research of Jahncke [66] and in combination with the realistic sound scenarios used in this experiment, the effect size of the current study was probably too small to measure.

5.4.2 Impact of the background sound scenario on self-estimated performance and perceived disturbance

The subjective parameters, self-estimated performance and perceived disturbance (Figures 5.3 and 5.4) showed for all tasks to be significantly impaired by background speech. Students expected the quiet sound scenario to have significantly the least detrimental effect on their performance. We expected the most intelligible background sound scenario (3 talkers-absorbing) to be estimated as the most detrimental for self-estimated performance, but this was not established by the results. The results of the self-estimated performance of the students was not in line with our hypothesis based on the 'interference of processes' theory of the DMAAD account [117].

The analysis of the perceived disturbance of the participants during the different tasks showed major similarities with the self-estimated performance results. The least disturbance was experienced during the quiet sound environment, and the most intelligible sound scenario (3 talkers-absorbing) was not identified as the most disturbing. However, it is remarkable that when comparing the tasks among themselves, the participants were significantly more disturbed by the background noise when performing the task 'studying for an exam' compared to the performance of the other tasks (Figure 5.4). This is even more remarkable when one takes into account that the decrease in performance of the task 'studying for an exam' certainly did not the show the greatest decrease compared to the other tasks. A mean decrease of performance of students due to the background noise in comparison to the quiet environment was 5.9% for the 'studying for an exam' task, 1.3% for the 'mental arithmetic' task and 7.1% for the 'logical reasoning' task. The major disturbance of the 'studying for an exam' task is in accordance with the findings in a field study on five OPSEs (Chapter 2). In this research 'studying for an exam' was identified by students as the most disturbed task by noise they perform in an OPSE (see Figure 2.5).

'Studying for an exam' is a very important task for a student, as the odds for passing an examination depends on the quality of the studying phase. Therefore, it could be expected that the task engagement for 'studying for an exam' is very high. Furthermore, an exam in higher education is a complex task that requires higher order thinking skills [168], and therefore it is a very difficult task. Both aspects, engagement and difficulty of a task, have shown to determine for amount of focusing on a task and will shield against distraction and a decrease of performance by the background noise [174,175]. In contrast, this shielding is not seen if we measure perceived disturbance. The perceived disturbance during the studying task by background noise was significantly higher than the perceived disturbance for both other tasks

(Figure 5.4). This might also be the result of the difficulty and engagement of the task while an extra effort investment was needed of participants to perform the task which could lead to a feeling of disturbance. Schlittmeier *et al.* [65] call this the 'reactive effort enhancement', and this effect can lead to reduced performance differences and increased perceived disturbance differences [65,150].

5.4.3 Impact of the noise sensitivity on the dependent variables

In this study no significant influence of the sound sensitivity of students was found on their performance and disturbance. This is in line with the findings in the experimental research on a collaboration task in Chapter 3. On the other hand, in the field study in Chapter 2 and the experimental study on writing performance in Chapter 4, noise sensitive students showed to be more disturbed by background sound than less noise sensitive students.

An explanation for the absence of a significant influence of noise sensitivity of students on performance and disturbance for a 'studying for an exam' task could be the same as for the absence of significant sound effects on performance of students: decrease of importance of background noise due to task engagement and task difficulty. These aspects overrule the noise effect whereby noise sensitivity becomes less important.

5.4.4 Limitations of the method

To study the influence of noise on a 'studying for an exam' task, a repeated measurement design with four sound scenarios was used. This implicates that the 'studying for an exam' task had to be tested four times. To simulate the studying task, a set of assignments was used that led to an extensive experiment with a long duration. In total, inclusive short breaks between sets of assignments and a practice set of tests, the experiment took 2 h and 30 min. Performing five times the set of tests could implicate fatigue, boredom and loss of concentration effects. The bias caused by these effects could only partly be removed by counterbalancing the sound conditions [180,181]. Therefore, it was decided to split the experiments in two parts. The students had to perform a practice set of tests and two sets of assignments at the first day (approximately 80 min) and two sets of assignments on the second day (approximately 70 min). Splitting an experiment in two parts introduces possible sources of variation as well. After all, the condition of a subject on two different instances within a week can be different, which can influence the results. For instance, a student could perform the first part of the test on a day where he is fit and has slept well and the second part of the test on a day where he is tired and did not have much sleep. However, a statistical comparison of the results of day 1 and day 2 did not show significant differences between the two days.

Repeated measurements can also implicate learning effects as a confounding factor. In this experiment we started with a practice set of tests to let the students get familiar with the assignments and the procedure, after all, significant learning effects occur mostly in the first tests [182]. A learning effect was not expected for the 'studying for an exam' test; the texts and questions were very different. Syllogisms were used from a well-tested set of assignments and the mental algorithmic tests were diverse. A similar level of complexity of the tests is discussed in the method section.

5.4.5 Towards acoustic recommendations for OPSEs

All performance measures of all tasks show the quiet situation to be preferred. Speech intelligibility of the background speech did not show to be of any importance for performance, disturbance or self-estimated performance. Therefore, no optimal acoustic parameters for an OPSE can be distill from this experiment. A quiet OPSE can only be accomplished by separating different activities by creating activity zones. Strict behavioural rules are required in some of these zones, as no talking is allowed in silence zones.

5.5 Conclusions

In this study the complex task 'studying for an exam' has been analyzed by a set of assignments. This typical student task was simulated by a comprehensive reading task with delayed answering (studying task), a mental arithmetic task, and a logical reasoning task, while being exposed to three sound scenarios and a quiet reference sound scenario. In our first hypothesis we expected that a sound environment with background speech would decrease performance and self-estimated performance and increase perceived disturbance of students working on a set of tasks simulating a 'studying for an exam' task in an OPSE. This was not shown for the 'studying for an exam' and 'mental arithmetic' task performance. However, it was demonstrated for the 'logic reasoning' task performance and also for self-estimated performance and perceived disturbance for all tasks.

Our second hypothesis claimed more intelligible background speech to have a negative influence on task performance of students and to find an increase of perceived disturbance of students. This hypothesis was not confirmed by the results. Also, no the influence of noise sensitivity of students on performance and disturbance of students working on the study tasks was seen in this study.

The 'studying for an exam' task showed the highest perceived disturbance in comparison with the other tasks, however, no significant decrease of performance was found due to the background sound scenarios. This might be the result of the difficulty and importance of the studying task. Both aspects, difficulty and importance, will lead to very high concentration levels for students, resulting in less influence of the background sound scenarios.

A minimal effect of the realistic simulated background sound scenarios on student performance for these complex tasks was shown. However, we observe significant effects of the sound scenarios on the subjective variables like self-estimated performance and perceived disturbance. This subjective negative perception of background noise will influence student's well-being. The consequences of acoustically uncomfortable OPSEs on the long term is not clear.

The translation of the experimental results to requirements for OPSEs is very difficult, while the quiet background sound scenario is mostly preferred for all studied tasks. Therefore, quiet zones in an OPSE are recommended, with only individual activities and strict behavioural conditions for students.

CHAPTER 6

DISCUSSION

6 | Discussion and conclusions

The aim of this research was to gain more insight into the influence of the sound environment on students' performance and well-being in open-plan study environments (OPSEs). The ultimate goal was to make a first step towards acoustic recommendations for OPSEs.

This larger aim was split into several smaller objectives: (1) to investigate how students in higher education assess noise in OPSEs in relation to the noise sources they perceive, the tasks they perform and the room acoustic parameters of the OPSE; (2) to evaluate the relation between the characteristics of the sound environment of an OPSE and the performance and perceived disturbance of students while they perform a specific task; (3) to evaluate the influence of the noise sensitivity of students on their performance and perceived disturbance in OPSEs.

To achieve the first objective, a field study was conducted in five study environments (Chapter 2). The results of this study have been used to set up three laboratory experiments (Chapters 3, 4 and 5). Each laboratory experiment focussed on a specific task while students were being exposed to different sound scenarios. These laboratory experiments were used to reach objectives two and three.

This chapter summarizes the main findings of the studies in Section 6.1, discusses de relations between the conclusions of the different studies in Section 6.2, and finally discusses the overall conclusion and ideas for future studies in Section 6.3.
In the last, more practical part of this thesis (Section 6.4), a first step towards acoustic recommendations for OPSEs is made.

6.1 The key findings

6.1.1 The assessment of the acoustic quality of OPSEs

A field study was conducted to investigate how students assess noise in an OPSE and to reveal correlations between noise disturbance and the sound environment and tasks students perform (Chapter 2). Therefore, in five OPSEs in higher education questionnaires were used to investigate student tasks, perceived sound sources and their perceived disturbance. Also, measurements were performed to determine the room acoustic parameters. The key findings of this research are:

- **More than 38% of the students is disturbed by background noise in an OPSE.**
  The research showed 38% of the students working in an OPSE to be 'much' to 'very much' disturbed by the background noise (Figure 2.3). However, it is plausible that the disturbance of students by background noise in an OPSE for the total student population is larger than the value found in our questionnaire. It could be possible that the sample is biased by self-selection, because students who are most sensitive to noise and therefore most disturbed by noise, probably did not choose to study in an OPSE and were therefore left

out of the questioning. This assumption is supported by the significant correlation found in this study between noise sensitivity and disturbance. Students who are more sensitive to noise are more disturbed by background noise in an OPSE. Furthermore, the mean noise sensitivity of students in this study is lower than the one found for office workers in a comparable study by Pierrette *et al* [62], which could implicate that noise sensitive students avoid noisy OPSEs.

- **Students in an OPSE work on individual and group tasks, where students are mainly disturbed by noise while performing individual cognitive tasks.**
  The study showed that students are mostly disturbed by noise when performing individual cognitive tasks. Studying for an exam is the most disturbed task in an OPSE, although less frequently conducted than other tasks. Reading and writing are frequently performed tasks and students indicated that they are bothered by noise while performing these tasks.

- **Students are most disturbed by intelligible background speech.**
  From all sound sources in an OPSE, speech is the most disturbing sound source (Figure 2.4), and in particular intelligible speech. On the other hand, students produce a lot of speech by working a great part of the time on group assignments during which they brainstorm and discuss with each other. This combination of individual cognitive tasks and group work in an OPSE causes an acoustic dilemma. In particular semantic cognitive tasks showed to be very much disturbed by intelligible background speech, which can be explained by the Duplex-Mechanism Account of Auditory Distraction (DMAAD) [117].

- **Walking sounds are of great importance in an OPSE.**
  Student mostly work for short periods in an OPSE, they work before, after and between classes. As a result, walking sounds are a major component of the sound environment in an OPSE. They can have large effects on the sound environment, depending on the architectural design (routing) and the floor construction. The field study revealed significant differences among the five OPSEs in perceived noise disturbance due to walking sounds. One of the OPSEs showed that the highest disturbance was generated by walking sounds (Figure 2.4); the construction of the floor of this OPSE was a lightweight raised computer floor, which resulted in more impact sound from walking in comparison to concrete floors.

- **Only weak correlations were found between the room acoustic parameters and noise disturbance of students in OPSEs.**
  The correlations found between the room acoustic parameters and noise disturbance of students were weak and not for all acoustic parameters and all tasks correlations were found. A weak correlation was found between the reverberation time and disturbance of students performing an individual cognitive task like reading, writing and studying for an exam. An increase of the reverberation time led to more disturbance while performing those tasks.

- **More than half of the students (57%) working in an OPSE use earplugs or headphones due to a noisy environment.**

  86% of the students make use of earplugs or headphones while working in an OPSE, while 57% of all students indicate to use earplugs or headphones as sound protection. In contrast, in a research on informal learning spaces by Scannell *et al*. [31], only 16% of the students used headphones. This shows the importance of the need for a suitable sound environment in this special informal open learning space.

- **OPSEs are distinctive from other educational environments and open-plan offices, and OPSEs need acoustic recommendations**.

  The activity analysis shows no resemblance with specific teacher-student interactions in classrooms which would require good speech transmission in an OPSE. Although the building characteristics and the activity analysis show resemblance with open-plan offices, a lot of characteristics of OPSEs are different. The users of OPSEs are much younger in comparison to office-workers, they are free to choose their own workplace, they work for shorter periods and move in and out the OPSE causing walking sounds. The students use OPSEs individually as well as in groups and are especially disturbed by noise while working on typical individual student tasks like studying for an exam.

  The importance of OPSEs in the context of new learning systems is clear, which is why more and more space is reserved for OPSEs in new educational buildings in higher education and more and more libraries are being converted into OPSEs. However, something will have to be done about the high percentage of students in OPSEs being disturbed by noise. Therefore, more research will have to be done to develop acoustic recommendations to optimize the sound environment of OPSEs, since we cannot treat these environments as standard educational spaces but also not as open-plan offices.

6.1.2 The influence of the sound environment on different tasks

Three laboratory experiments were conducted to evaluate correlations between the characteristics of the sound environment of an OPSE and the performance and perceived disturbance of students when working on various student tasks. In addition, the influence of the noise sensitivity of students on their performance and perceived disturbance in OPSEs was studied. In the experiments, parameters of representative sound scenarios were correlated with the disturbance and performance of participants working on student tasks that were qualified as important (writing and collaboration) and student tasks that were particularly sensitive to disturbance (studying for an exam, writing). The tasks for the experiments were selected from the field study. Realistic sound scenarios were created by auralization of binaural room impulse responses, calculated by computational modelling of an existing OPSE. The key findings of these studies are described for each task.

Collaboration task

In this experiment participants worked in pairs to solve spot-the-difference puzzles by using the 'DiapixUK' collaboration task. One quiet and four sound scenarios with background speech were used. The sound scenarios varied in semantic content (mother tongue and foreign language background speech) and reverberation time (short vs long), the latter affecting speech intelligibility.

Key findings:

- **The sound scenario had no significant effect on the performance of participants working on a collaboration task.**

  The sound scenario, the reverberation time, the speech transmission index and the meaningfulness (language) of the background speech did not show any significant influence on the performance of the collaboration task. Although we expected that more intelligible and meaningful speech would lead to a decrease of performance, the limited range of *STI* values between the sound scenarios and the relatively high *STI* values (>0.6) might be the cause of the absence of a significant effect of the soundscenarios on peformance. The performance model of Hongisto shows only significant performance changes when *STI* values vary between 0.2 and 0.6. These outcome may also be the result of a limited number of participant couples (n=37) or the limited semantic complexity of the collaboration task.

- **The sound scenarios had a significant effect on the perceived disturbance, the ability to ignore the background speech and the self-estimated quality of the collaboration task by the participants**

  All subjective variables showed to be significantly influenced by the sound scenarios. Especially perceived disturbance of participants varied to a great extent due to exposure to the sound scenarios.

  The disturbance of the participants performing a collaboration task increased when exposed to a sound scenario with a longer reverberation time. This is probably the result of a sub-component of this problem-solving collaboration task: speech communication. In a reverberant environment the sound levels of the background speech will be higher due to the lack of absorbing materials and this will lead to a decrease of the signal-to-noise level between communicating participants. This results in more demanding communication circumstances. As a result, the speakers will raise their voices, which again will lead to an increased sound level, an example of the 'Lombard effect' [139]. In a real situation this effect would be much larger, as the background talkers would also raise their voices due to the difficult communication circumstances. So, although semantic cognitive processes are less disturbed by background speech with low intelligibility (i.e., longer reverberation time), speech communication on the other hand requires a good signal-to-noise ratio and therefore a lower background noise level (i.e., shorter reverberation time).

The disturbance of the participants performing a collaboration task increased with meaningfulness (language) of speech: Participants were significantly more disturbed by background speech in their own mother tongue. This is in line with the 'interference-by-process' account and the framework of attentional capture [117].

For all subjective variables the quiet sound scenarios was the most preferred by the participants while working on a collaboration task. The preferred 'quiet' sound scenario is not a very realistic sound environment in an OPSE. It is included in the experiment as a reference.

- **The noise sensitivity of the participants had no significant effect on the performance or disturbance of the participants working on a collaboration task.**

  No explanation could be found for the missing influence of the noise sensitivity of participants on performance or disturbance.

Writing task

In this experiment participants had to write five stories associated with five different landscapes. One quiet and four sound scenarios with background speech were used. The sound scenarios varied in occupancy (number of talkers in the OPSE: 3 vs 14) and reverberation time (short vs long), both affecting the speech intelligibility of the background speech.

Key findings:

- **The sound scenario had a significant effect on the performance of students working on a writing task.**

  All objective performance variables (characters, words and sentences) showed to be significantly influenced by the sound scenarios.

  The '3 talker-absorbing' sound scenario, the sound scenario with the highest speech intelligibility and lowest *FDCC* value, showed a significantly lower writing performance score. A 6-7% decrease of writing performance was found in the experiment, comparable with the performance model of Hongisto [64] and the writing experiments of Keus vd Poll [71]. In the present experiment a more realistic sound scenario was used with multiple talkers at different positions in the room and room acoustics was taken into account. This result was in line with the hypothesis, the scenario with the most intelligible speech was expected to have the most detrimental effect on writing performance. This was in accordance with the Duplex-Mechanism Account of Auditory Distraction (DMAAD) [117].

- **The sound scenario had a significant effect on the perceived disturbance of students when performing a writing task**

  All the subjective variables showed to be significantly influenced by the sound scenarios. Furthermore, for all subjective variables the quiet sound scenario was the most preferred by the participants while working on the writing task. On the other hand, the participants did not identify the sound scenario with significantly the lowest performance, the '3 talkers-absorbing' sound scenario, as the most disturbing sound scenario.

- **The noise sensitivity of the participants had a significant effect on performance of participants working on a writing task.**

  Participants with a relatively high noise sensitivity (higher than the median score) showed a significantly lower writing performance than participants with a relatively low noise sensitivity. Furthermore, it was shown that participants with a high noise sensitivity did not have a preferred or adverse sound scenario were writing performance significantly improves or deteriorates. For participants with a relatively low noise sensitivity, the most intelligible sound scenario (3 talkers-absorbing) had a significantly detrimental effect on writing performance.

Studying for an exam task

In this experiment participants performed a studying task, a mental arithmetic task and a logical reasoning task. One quiet and three sound scenarios with background speech were used. The sound scenarios varied in occupancy (number of talkers in the OPSE: 3 vs 14) and reverberation time (short vs long), both affecting the speech intelligibility of the background speech.

- **The sound scenarios had no significant effect on the performance of participants working on a studying for an exam task and a mental arithmetic task. There was a significant effect of the sound scenarios on the performance of participants on a logical reasoning task.**

  Although for all tasks the quiet sound scenario showed the highest student performance, only the 'logic reasoning' task showed a significant performance effect.

- **The sound scenarios had a significant effect on the perceived disturbance and self-estimated performance of students when performing a studying for an exam task, a mental arithmetic task and a logical reasoning task.**

  Students were the least disturbed by the quiet sound scenario and expected the quiet sound scenario to have significantly the least detrimental effect on performance. It is remarkable that the participants were significantly more disturbed by the background noise while performing the 'studying for an exam' task in comparison to the performance of the other tasks (Figure 5.4). On the other hand, the major disturbance of the 'studying for an exam' task is in accordance with the findings in a field study on five OPSEs (Chapter 2). Studying for an exam is a very important but also very difficult task for students. Both aspects, engagement and difficulty of a task, have been shown to be determinative for focusing on a task and protection against distraction by the background noise [174,175]. The performance results of this studying task showed no significant effects of noise, probably as a result of focusing which is a 'shield against distraction' [101,175].

- **The noise sensitivity of the participants had no significant effect on performance of participants working on a studying for an exam task, a mental arithmetic task and a logical reasoning task.**
  An explanation for the absence of a significant influence of noise sensitivity of students on performance and disturbance for a 'studying for an exam' task could be the same as for the absence of significant sound effects on performance of students: decrease of importance of background noise due to task engagement and task difficulty. These aspects overrule the noise effect whereby noise sensitivity becomes less important.

6.2 The impact of the sound environment and noise sensitivity on task performance and disturbance

6.2.1 The impact of the sound environment

In the field research (Chapter 2) only the impact of the sound environment on disturbance of students working in an OPSE has been tested. The field study showed that 64% of the students in an OPSE was slightly to very much disturbed by the background noise, while 38% of all students were much to very much disturbed by the background noise (Figure 2.3). The effect of the sound scenarios on the objective performance variable (Table 6.1) was only significant for the writing and logical reasoning task, for all other tasks no significant sound effects were found. On the other hand, the effect of the sound scenarios on the subjective variables showed to be significant for all tasks.

Table 6.1 Significance of the effects of the sound scenarios on task performance, self-estimated performance and perceived disturbance, the effect size (η^2) and the percent gap between the performance in the quiet (reference) situation and the lowest performance.

Task	Performance		Self-Estimated Performance	Perceived Disturbance
	significance		significance	significance
	partial η^2	percent gap*	partial η^2	partial η^2
collaborating (n=36/74)	*not significant*		*significant*	*significant*
	0.01	2.1%	0.04	0.47
writing	*significant*		*significant*	*significant*
• characters (n=47)	0.05	8.8%	0.34	0.34
• words (n=47)	0.06	7.1 %		
studying (n=66)	*not significant*		*significant*	*significant*
	0.03	8.8%	0.34	0.59
logical reasoning (n=66)	*significant*		*significant*	*significant*
	0.06	11.3%	0.38	0.48
mental arithmetic (n=66)	*not significant*		*significant*	*significant*
	0.002	2.4%	0.30	0.41

*Percent gap = ((Reference performance - Lowest performance)/Reference performance) *100%

The impact of the sound environment on performance, self-estimated performance and perceived disturbance has been tested in three experiments (Chapters 3,4,5). In Table 6.1 an overview of the significance of the effects of different sound scenarios on task performance, self-estimated performance and perceived disturbance of students is indicated for the different tasks based on a confidence interval of 95% ($\alpha \leq 0.05$). Also, the statistical effect size by partial eta squared (η^2) and the percent gap between the lowest performance and the performance in the quiet (reference) situation are indicated in Table 6.1.

An explanation for a more differentiated perceived disturbance in comparison to performance might be the extra effort participants invest in solving a task when feeling disrupted by an adverse sound environment. This effect is called 'reactive effort enhancement' [65]. This effect makes it valuable to combine objective performance variables with subjective disturbance variables when evaluating the effects of the sound environment on students' performance and well-being in OPSEs.

Another effect that results in a decrease in the influence of the sound environment on the performance of tasks is extra concentration as a shield against distraction [101,174,175]. In particular, people working on demanding, difficult or very important tasks show this effect. Students feel very much disturbed by the sound environment, but no significant performance effects can be demonstrated. However, it is unknown what the long-term consequence will be of making extra effort to perform well in an adverse sound environment.

The percent gap in Table 6.1 has been described in percentage of decrease between the performance during the quiet reference sound scenario and lowest performance during the sound scenarios with background speech. For the collaboration task and the mental arithmetic task, the percent gap (2.1-2.4%) and partial etha square values (0.002-0.01) for the influence of background noise on performance are very low and no significant sound effect was found. A power calculation (G*Power 3.1.9.4) based on the measured effect size (η^2) and $\alpha \leq 0.05$, showed a very low power of 0.08 for the collaboration task and 0.15 for the mental arithmetic task. Furthermore, the calculated minimum number of participants needed for this experiment were very high: 390 for the collaboration task and 2864 for the arithmetic task. The power value as well as the number of needed subjects imply no sound effect on both tasks. The writing and logical reasoning tasks showed a significant decrease of performance due to the sound scenarios with speech in comparison to the quiet sound environment without background speech (Table 6.1). Even though no statistically significant effect of the sound scenarios on the studying task was found, a percent gap of 8.8% was shown, which is an effect in the same order of magnitude as for writing and logic reasoning. This may imply an effect of noise on studying. A power calculation showed a power of 0.47 and a minimal number of 192 subjects needed to show a significant effect of sound on studying performance.

Among statisticians there is currently a discussion about the value of only looking at significance by drawing conclusions about data, the statistical effect size, related to the percent gap in table 6.1, is mentioned as another very important factor that should be included in the analysis of data [183].

The sound environment

Different sound scenarios have been used in the laboratory experiments. The sound scenarios were composed by the sound sources and the room acoustic parameters (Figure 4.1). The most important sound source in an OPSE showed to be speech from other students (Figure 2.4). Therefore, the number of talkers and the language of the talkers in the sound scenarios were varied. In combination with two different reverberation times, all sound scenarios varied in speech intelligibility.

The sound scenarios used in the experiments were realistic sound scenarios, with multiple talkers, positioned at different tables in a simulated OPSE (Figure 4.3). The positions of the talkers in the OPSEs varied in the experiments. In the collaboration experiment only three talkers were placed in the OPSE at a relatively short distance from the receiver (Figure 3.1). In this experiment the language of speech (Swedish and Dutch) was implemented as a parameter in the sound scenarios. The relatively short distances between talkers and receiver were chosen to measure the influence of the language as an intelligibility measure. In all other experiments three and fourteen talkers were implemented, spatially distributed over the OPSE (Figure 4.3).

In our hypotheses we expected more intelligible and meaningful background speech to be more disturbing and to result in a decrease of performance of students working on their cognitive tasks. The writing task showed a decrease of performance for the most intelligible sound scenario, the scenario with three talkers in an acoustically absorbing environment. This was in line with the Duplex-Mechanism Account of Auditory Distraction (DMAAD) [117]. Looking at all other performance and disturbance results, the most intelligible or meaningful sound scenarios did not lead to the significantly most disturbing or worst performing sound environment for students. Other important aspects of task performance, such as concentration level due to the difficulty level and engagement in the task and putting extra effort in performance as a result of perceived disturbance, probably reduced the influence of the sound environment.

To indicate the level of speech intelligibility the Speech Transmission Index (*STI*) and the Frequency Domain Correlation Coefficient (*FDCC*) were used. Both quantities are not developed to measure the speech intelligibility in an environment with background speech, so the calculated *STI* and *FDCC* values could only be used as an estimation of the speech intelligibility of the background speech in an OPSE.

The use of *STI* and *FDCC* as quantifiers for the speech intelligibility in an environment with speech as background noise, was tested in one of the laboratory experiments (Chapter 4). It turned out that it was difficult to estimate the *STI* in such an environment. The first problem is that the *STI* is defined for speech in continuous background noise while background speech has a dynamic character. Secondly, the *STI* is defined for only one source-receiver path and does not characterize the intelligibility of a sound environment with multiple background talkers. To test the suitability of the *STI* as a quantifier for the intelligibility of background speech in an OPSE more research is needed to verify the best approach to estimate the *STI*.

The advantage of the *FDCC* was the suitability of this value for dynamic sound environments and the independence of the source-receiver channel, because the *FDCC* can be calculated for the sound field at the receiver position. However, the *FDCC* is not developed as a speech intelligibility measure, it determines the dynamical characteristics of a sound signal. To find a suitable measure for indicating the intelligibility of speech in an acoustically dynamic environment with background speech, which is needed to predict disturbance and loss of performance in an OPSE, more research is needed.

The use of sound scenarios based on realistic acoustic parameters in an OPSE showed the complexity of sound environments. For instance, a sound environment with a longer reverberation time also implicates that the sound level of the background speech will increase. The collaboration experiment showed the increased speech level to be more important than the decreased intelligibility of the speech. Due to the importance of communication, the signal-to-noise level was normative and therefore the sound level of the background speech. On the other hand, the writing experiments showed that a longer reverberation time decreased the speech intelligibility and therefore increased performance. The increased sound level was not important for this task. Therefore, to be able to use experimental results for practical recommendations, it is favourable to use realistic sound environments.

Tasks

The student tasks tested in the experiments were chosen from the field research and showed different characteristics. The collaboration task was a problem-solving task with an important oral communication component. The communication between two students required good intelligibility. The writing and studying tasks were semantic tasks that required unintelligible background speech. As a result, we found task dependent room acoustic requirements; for communication a sound scenario with a shorter reverberation time and only three talkers were preferred by the participants, while this sound scenario with the most intelligible background speech showed a significant detrimental effect on writing performance. For the studying task no significant preference of rejection for a sound scenario with speech was found, only the quiet sound scenario was indicated as the least disturbing.

The implication of different tasks in an OPSE with different sub-components can lead to acoustic dilemmas and can lead to an impossibility to design a comfortable acoustic environment for all students performing different tasks. However, for all students and all tasks the quiet sound scenario was perceived as significantly the least disturbing sound environment.

6.2.2 The impact of the noise sensitivity

The influence of the noise sensitivity of students in the field research on perceived disturbance showed to be significant. Students more sensitive to noise showed to be more disturbed by the background noise in the OPSE.

The influence of the noise sensitivity of students on performance, self-estimated performance and disturbance was also measured in the laboratory experiments. Table 6.2 summarizes the results of the measurements on noise sensitivity. It is remarkable that the influence of noise sensitivity was not consistently demonstrated in all experiments.

Table 6.2 Influence of the noise sensitivity of students on performance, self-estimated performance and performance.

Task	Performance	Self-Estimated Performance	Perceived Disturbance
collaboration	not significant	not significant	not significant
writing (words & pauses>3s)	significant	not significant	significant
studying	not significant	not significant	not significant
logical reasoning	not significant	not significant	not significant
mental arithmetic's	not significant	not significant	not significant

6.3 Conclusion and future research

6.3.1 Conclusion

The aim of this research was to gain more insight into the influence of the sound environment on students' performance and well-being in open-plan study environments (OPSEs).

We hypothesized that a realistic sound environment in an OPSE (with background speech of other students) would have a negative effect on performance and disturbance of students working on typical student tasks in comparison to students working in a quiet environment without background speech.

Furthermore, we expected that more intelligible background speech would decrease performance and would increase disturbance of students. Also, the noise sensitivity of students would be expected to have an effect on how they perceive the background speech of other students in an OPSE. We expected noise sensitive students to be more disturbed by the background speech and to perform less due to the background sound in comparison to less noise sensitive students.

This study has partially confirmed the hypotheses. Results showed that the sound environment in an OPSE will have a negative effect on disturbance of students if the sound environment comprises background speech and if students are performing cognitive complex tasks. The results of the experiments did show a decrease of performance due to the sound scenarios, but not for all tasks. Students performing a writing task and a logical reasoning task showed a significant decrease of performance due to more intelligible background speech. Also studying showed a considerable decrease of performance (8.8%) although these results could not be proven statistically significant. The lack of significant influence of intelligible background speech on performance of students is probably related to the difficulty and importance of a task, the importance of sub-tasks and extra effort of students when performing a task, which they perceive as disturbed by the sound. In addition, the noise sensitivity of students only influenced perceived disturbance in the field research and in the laboratory experiment on a writing task.

6.3.2 Future research

In this thesis it was shown that there is not an optimum sound environment for all tasks in an OPSE. The task performance and disturbance of students is dependent on the task type in combination with the sound environment. In this research only a limited number of tasks and a limited number of sound environments have been tested. Experimental research on realistic complex tasks in combination with realistic sound environments provide research data suitable for formulating room acoustic recommendations. Therefore, more research on finding relations between the influence of realistic sound environments on task performance and perceived disturbance will be necessary to formulate target values for room acoustic recommendations for more acoustically comfortable OPSEs.

In this study, only the short-term effects of the sound environment on performance and disturbance were investigated. The results indicate that probably extra effort and extra concentration was used by students to compensate for the disturbance of the sound environment. It would be interesting to study the long-term effects of these extra efforts and the feeling of disturbance.

In this research perceived disturbance of noise was measured by using questionnaires. Although these measurements presented significant data, more objective methods to measure disturbance might be interesting for future research. Methods of interest could be eye-tracking methods or physiological measurement techniques.

In all laboratory experiments the lighting, thermal and ventilation conditions were constant. In an OPSE physical parameters will interact and affect performance and disturbance. A next step in research could be a more integral approach on the influence of the physical environment on performance and well-being of students in an OPSE.

Finally, in this research we found out that there was no suitable quantitative measure on speech intelligibility in a sound environment with background speech. As in OPSEs intelligible speech is obvious the most disturbing sound source, an index to calculate (predict) the speech intelligibility of environmental speech would be of great importance.

6.4 Acoustic recommendations for OPSEs

Finally, in this last section an attempt is made to translate the results of this study into practical recommendations to optimize the acoustical environment of an OPSE. Although the field study showed only weak correlations between the acoustic parameters of the OPSEs and disturbance of students, the experiments showed a significant influence of room acoustic parameters on disturbance and performance. Therefore, it can be argued that recommendations can be formulated to diminish the disturbance of students and enhance their performance in cognitive tasks. In a literature study of Reinten *et al.* it was claimed that the evidence regarding the effectiveness of using the acoustic design as a strategy to control the sound environment with respect to task performance is lacking. A combination of task type, sound source characteristics and personal factors determine the effect of room acoustics on performance [32].

In an OPSE the characteristics of the sound sources are related to speech. Therefore, the noise characteristics at a listener position in an OPSE will depend on the number of talkers and the position of talkers in an OPSE in combination with the room acoustics. Room acoustic recommendations for OPSEs should be aimed at minimizing disturbance due to speech. It is important to reduce intelligible speech in an OPSE, because the writing experiment, the field research and literature show the detrimental effect of intelligible speech on cognitive tasks. However, this is not the best solution for student tasks where communication and collaboration play an important role. In that situation, it is shown that good speech intelligibility within a collaboration group is the normative acoustic condition. When an acoustic comfortable situation is achieved by creating an environment with high STI values between the group members, the talkers within a group will not feel the urge to raise their voices [139]. This will result in a normal speech level which is very important for the sound level in the rest of the OPSE. To achieve a high STI value the reverberation time and the background noise level must be low. These conflicting demands on speech intelligibility between individual cognitive tasks and collaboration tasks are difficult to achieve in the same OPSE. Furthermore, a collaboration task always will produce unwanted background speech. Therefore, our first recommendation is to divide OPSEs in task-zones. Acoustic recommendations for each task-zone have to be developed separately. The zones and a first attempt to formulate recommended room acoustic parameters will be described in the next sections.

6.4.1 Collaboration zone

When students work in a group on an assignment, a high speech intelligibility is required within the student group. The sound level in a group will be determined by their own speech level and the sound level of the speech produced by the surrounding groups. The produced speech level by the group, as a result of communication within a group, must be decreased in such a way that the nearest neighbour group is not bothered by it. The speech signal-to-noise ratio within the working group must be large enough to communicate without raising one's voice. When the background noise level is above 50 dB(A) people will raise their voice when they have to communicate orally with each other [139].

By studying different floor plans of existing OPSEs we can conclude that table groups of OPSEs are often placed within a distance of 2 meters. A decrease of the speech sound level by 10 dB(A) (normal speech 60 dB(A) at 1 meter [148]) must be accomplished to derive a background speech level of maximum 50 dB(A) due to the nearest background talker. Since it can be assumed that there are more talkers in the environment, a decrease of 10 dB(A) is a minimum value. A decrease of the sound level could be accomplished by sound absorption or adding screens between groups. Hence, the reverberation time of the collaboration section in an OPSE must be short. A target value for the reverberation time could be derived from Table 1.1 and Section 1.1.3, and could be 0.5 s or less. Background noise due to equipment or ventilation must be limited (i.e. < 40 dB(A)), otherwise the total background level inclusive background speech would rise above 50 dB(A). In many OPSEs adding only sound absorption will not be enough to decrease the background speech to an acceptable level, and more measures will be needed.

6.4.2 Zones for individual demanding cognitive tasks

How students perform individual cognitive tasks in an OPSE is depending on the type of task. Students working on a semantic task, such as writing an assignment or studying for an exam, showed to be disturbed by background speech. Students working on a writing task also showed a significant decrease in performance when the background speech was intelligible. Therefore, a quiet environment without speech is recommended for such tasks. If there nevertheless are speech sources, the room acoustic characteristics should be chosen to reduce speech intelligibility. This can for example be achieved by a longer reverberation time and by a higher background sound level which could be caused by installation devices.

Recommendations on room acoustic parameters in an OPSE suitable for complex, semantic individual tasks should result in low speech intelligibility. Because there is no suitable quantity for speech intelligibility in a dynamic sound environment, a recommendation for the reverberation time in combination with a recommendation for the background noise level due to equipment and ventilation (not speech), would be a good alternative. The target value for the reverberation time in the demanding cognitive task zone must be longer than the value for the collaboration zone (> 0.5 s), and the target value for the background noise due to equipment and ventilation must be higher than the value for the collaboration zone (i.e. > 40 dB(A)) to induce a lower intelligibility of speech. However, these choices need to be balanced against the negative influence that too high background levels will have, particularly for noise-sensitive students. So, the right balance between the different parameters will depend on the environment and must be determined in new studies. The exact target values cannot be derived from this study.

Besides of zones for demanding cognitive tasks it is important to create zones where students can work on less demanding individual tasks in a more informal, relaxed setting. It is important to create an environment with a comfortable homely ambience. Target values cannot be derived from this study.

6.4.3 Recommendations to optimize the acoustic environment in an OPSE

Besides target values for acoustic parameters also architectural recommendations are important to design an acoustically comfortable OPSE. To decrease sound disturbance by impact sound due to walking, the routing of the students in the design should be optimized to avoid long walking paths from OPSEs to classrooms and lecture halls. Furthermore, a correct choice must be made with regard to the floor finish and the construction of the floor. The floor finishing should be soft, for example carpet. Light weighted constructions like wooden floors or computer floors are not suitable for an OPSE due to the impact noise when walking on those floors.

Calm and quiet behaviour of students will contribute to an acoustically comfortable environment. By placing silence signs and giving instructions to new students, calm behaviour can be encouraged. Furthermore, hearing protection, like earbuds can be offered to the students in the case the sound environment is not quite enough for noise sensitive students working on important tasks. It is advisable for universities to provide some silent single study rooms. For severely noise sensitive students with special needs and in special circumstances, this is the only solution to work comfortably and effectively.

All these considerations led up to the following bullet list of architectural and acoustic recommendations:

- Divide OPSEs in task-zones, for instance:
  - a zone for collaboration tasks
  - a zone for demanding cognitive tasks
  - a zone for less demanding tasks

  The sound isolation between the zones must be sufficient.
- The routing of students through the OPSE should be optimized to avoid long and disruptive walking paths from OPSEs to classrooms and lecture halls.
- The floor finish must be soft and light weighted floor constructions such as wooden floors or computer floors should be avoid.
- Stimulate calm behaviour of students in the cognitive tasks zones by placing silence signs and giving instructions to new students.
- Offer earbuds and noise-cancelling headphones for noise sensitive students.
- Provide silent single rooms for exceptional situations or exceptional noise sensitive students.

Further research into target values for different task- zones is necessary to formulate reliable and practical recommendations.

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Sound scenarios: the making off

Steps of modelling:

Acoustic measurements case study OPSE

Vertigo floor 3 TU/e
Lp, EDT, T30, C80
(help: M.Kalee)

Computational Modelling case study OPSE

Vertigo floor 3 TU/e
Odeon and Catt Acoustics
(help: M.Kalee)

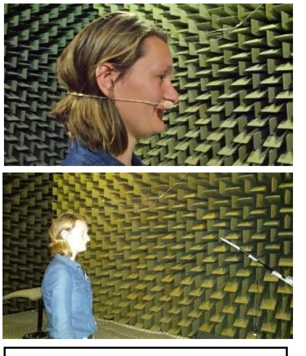
Compare and analyze, optimize models

Odeon
(help: M.Kalee)

Design model variants

Absorbent - Reverberent OPSE
EDT, T30

Calibrating headset



Binaural Impulse Response
&
Calculated acoustic parameters
Absorbed and Reverberent OPSE

Lp, EDT, T30, C80, D50, Ts

Mobiel recording studio

Determine filter headset

Anechoic Room
(Help: Philips, C.Hak)

Recording speech signals

Dutch stories (10 min)
Dutch & Swedisch Hagerman sentences

Modelled BRIR

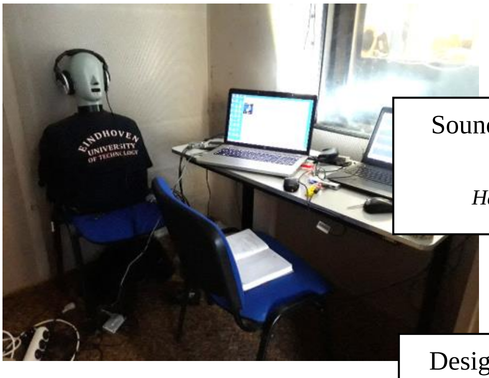
Recorded Speech

Auralization variants

HRTF, headphone

Analyze Binaural Impulse Response

COMPARING parameters:
measuring auralisaton: DIRAC
calculating via modelling: Odeon
EDT, T30, C80, D50, Ts
JND (<10% 1000Hz)



Sound levels calibrating on headphone

Hats, DIRAC, Odeon Lp

Design Soundscape by Mixing of sources, level test

Hats, DIRAC, Odeon Lp

4 SOUNDSCAPES

Reverberant - Absorbent
combined with
High occupency - Low occupancy rate

4 SOUNDSCAPES

Reverberant - Absorbent
combined with
Dutch - Swedish language

Appendix B | Questionnaires used in this study

B 1 Questionnaires Chapter 2: Field study

Dutch version:

Locatie: *Datum:*

Enquête Open-Werkomgevingen binnen Hoger Onderwijs

Activiteitenanalyse en de Invloed van Geluid op Beleving en Productiviteit

Het doel van deze enquête is om inzicht te verkrijgen in jouw activiteiten en de beleving van deze open werkomgeving.

Alle antwoorden worden anoniem en in vertrouwen verwerkt.

Er is geen verkeerd antwoord. Geef alsjeblieft een eerlijk antwoord.

Algemene informatie over jou.

1. Geslacht: *O man* *O vrouw*
2. Leeftijd: …….. jaar
3. Je bent: *O uitwonend* *O thuiswonend*
4. Aan welke onderwijsinstelling studeer je? *O AVANS* *O anders,……….*
5. Welke opleiding volg je?…………………………………….
6. In welke studiefase bevind jij je momenteel?

   O Propedeuse *O 2e of 3e jaar* *O Minor* *O Afstuderen*

Jouw activiteiten in een open werkomgeving (Xplora, werkplekken open ruimten, etc.).

7. Hoeveel uur per week werk je individueel in een open werkomgeving?

   O <5 uur O 5-8 uur O 9-12 uur O 13-16 uur O 17-20 uur
   O 21-24 uur O 25-28 uur O 29-32 uur O 33-36 uur O 37-40 uur
   O > 40 uur

8. Hoeveel uur per week werk je in groepsverband in een open werkomgeving?

   O <5 uur O 5-8 uur O 9-12 uur O 13-16 uur O 17-20 uur
   O 21-24 uur O 25-28 uur O 29-32 uur O 33-36 uur O 37-40 uur
   O > 40 uur

9. Op welk dagdeel maak je vooral gebruik van een open werkomgeving? (meerdere antwoorden mogelijk)

   O 's ochtends (8-13 uur) *O 's middags (13-18 uur)* *O 's avonds (>18 uur)*

10. Wanneer maak je gebruik van een open werkomgeving? (meerdere antwoorden mogelijk)

    O tussen de lessen door *O voor of na de lessen* *O op dagen zonder lessen*

11. Wat doe je in een open werkomgeving? Kruis aan wat het meest van toepassing is.

	Nooit	Bijna nooit	Soms	Vaak	Altijd
a. Opzoeken informatie (literatuuronderzoek)	O	O	O	O	O
b. Het lezen van stukken (beeldscherm, boeken, etc.)	O	O	O	O	O
c. Werkstukken of opdrachten schrijven	O	O	O	O	O
d. Werken met tekenpakketten (Autocad, Revit, etc.)	O	O	O	O	O
e. Werken met Avans software-pakketten	O	O	O	O	O
f. Ontwerpen, creatieve activiteiten (creatief denken)	O	O	O	O	O
g. Studeren aan rekenvakken (wiskunde, constructie, etc.)	O	O	O	O	O
h. Samen brainstormen voor groepsopdrachten: project of cursus	O	O	O	O	O
i. Samen overleggen voor groepsopdrachten: project of cursus	O	O	O	O	O
j. Studeren voor tentamen (lezen, onthouden, etc.)	O	O	O	O	O
k. Spelletjes, Social Media, surfen op internet	O	O	O	O	O
Anders: …………….……	O	O	O	O	O

12. Zou je meer van een open werkruimte gebruik maken als er: (meer antwoorden mogelijk)

O meer plek is *O minder stoorgeluid is* *O een betere sfeer is* *O betere faciliteiten zijn*

anders………………………………………………………………………………

Privacy, functionaliteit en beheersbaarheid van deze open werkruimte.

13. Hoe tevreden ben jij over de verschillende omstandigheden en mogelijkheden van deze open werkruimte?

	ontevreden		*neutraal*		*tevreden*
a. Stoorgeluid in de werkruimte	O	O	O	O	O
b. Mogelijkheid tot concentreren	O	O	O	O	O
c. Kwaliteit van de verlichting	O	O	O	O	O
d. De positie (plaats) van je werkplek	O	O	O	O	O
e. Mogelijkheid voor een privé gesprek	O	O	O	O	O
f. Mogelijkheid je af te sluiten van geluid	O	O	O	O	O
g. Kwaliteit van je bureau en stoel	O	O	O	O	O
h. Mogelijkheid om naar buiten te kijken	O	O	O	O	O
i. Hygiëne van de werkruimte	O	O	O	O	O
j. Faciliteiten bij de werkruimte	O	O	O	O	O
k. Mogelijkheid beïnvloeden temperatuur	O	O	O	O	O
l. Verse lucht in de werkruimte	O	O	O	O	O
m. Persoonlijk maken van de werkplek	O	O	O	O	O
n. Privé werken, niet gezien door anderen	O	O	O	O	O

Geluid in deze open werkruimte.

14. Is er over het algemeen veel stoorgeluid (achtergrondgeluid) in deze werkruimte?
helemaal niet *O O O O O* ***heel erg***
15. Is het achtergrondgeluid over het algemeen storend voor jou?
helemaal niet *O O O O O* ***heel erg***
16. Hoor je in deze open werkruimte geluid van installaties (ventilatie, computers, printers, etc..) ***nooit*** *O O O O O* ***constant***
17. Is het installatiegeluid storend voor jou?
helemaal niet *O O O O O* ***heel erg***
18. Hoor je vaak telefoons afgaan als je in deze open werkruimte werkt?
nooit *O O O O O* ***constant***
19. Is het geluid van telefoons storend voor jou?
helemaal niet *O O O O O* ***heel erg***
20. Kan je op deze werkplek in de open werkruimte de gesprekken van medestudenten verstaan? ***nooit*** *O O O O O* ***constant***

21. Zijn de gesprekken van de medestudenten storend voor jou?
helemaal niet *O O O O O* ***heel erg***
22. Kan je op deze werkplek in de open werkruimte gesprekken horen maar niet verstaan? (verder weg)
nooit *O O O O O* ***constant***
23. Zijn deze niet verstaanbare gesprekken storend voor je?
helemaal niet *O O O O O* ***heel erg***
24. Hoor je op deze werkplek in de open werkruimte mensen op en neer lopen?
nooit *O O O O O* ***constant***
25. Is het loopgeluid storend voor jou?
helemaal niet *O O O O O* ***heel erg***
26. Gebruik je oortjes, oordopjes of een koptelefoon als je werkt in een open werkruimte?
nooit *O O O O O* ***constant***

- Als je bij vraag 26 nooit hebt ingevuld ga dan naar vraag 28

27. Waarom gebruik je oortjes, oordopjes of een koptelefoon? (meerdere antwoorden mogelijk)
O omdat ik van muziek houd
O omdat ik graag gesprekken luister op de radio
O omdat de ruimte rumoerig is, ik kan me dan beter concentreren
Anders nl…………………………………………………………………

Hoe geluidgevoelig ben je in het algemeen (thuis, 's nachts, op school)?

28. Geef aan in hoeverre je het eens bent met de volgende stellingen:

	helemaal mee oneens	***beetje mee oneens***	***beetje mee eens***	***helemaal mee eens***
a. Het moet voor mij stil zijn om te kunnen slapen	O	O	O	O
b. Het moet voor mij stil zijn om nieuwe taken uit te kunnen voeren	O	O	O	O
c. In de open werkruimte ben ik snel gewend aan het geluid	O	O	O	O
d. Ik ben geïrriteerd als er iemand praat als ik wil slapen	O	O	O	O
e. Ik ben gevoelig voor geluid van de buren	O	O	O	O
f. Ik vind het moeilijk te werken als mensen om me heen rumoerig zijn	O	O	O	O
g. Ik presteer duidelijk minder in een rumoerige omgeving	O	O	O	O

h.	Ik ben overdag niet echt alert als ik 's nachts gestoord ben door geluid	O	O	O	O
i.	Het zou me niet uitmaken om in een drukke straat te wonen met veel geluid	O	O	O	O
j.	Ik zou best nadelen accepteren om in een stille omgeving te wonen	O	O	O	O
k.	Ik heb rust en stilte nodig om een moeilijke taak uit te voeren	O	O	O	O
l.	Ik kan zelfs slapen als het rumoerig is	O	O	O	O

Geluid en de activiteiten in de open werkruimte

29. In hoeverre wordt je bij het uitvoeren van onderstaande activiteiten in de open werkruimte gehinderd door geluiden in de omgeving (spraak, installaties, loopgeluiden, telefoons, muziek etc..). Indien je de activiteit nooit uitvoert dan niets invullen.

		helemaal niet gehinderd door geluid			***heel erg gehinderd door geluid***	
a.	Opzoeken informatie (literatuuronderzoek)	O	O	O	O	O
b.	Het lezen van stukken (beeldscherm, boeken, etc.)	O	O	O	O	O
c.	Werkstukken of opdrachten schrijven	O	O	O	O	O
d.	Werken met tekenpakketten (Autocad, Revit, etc.)	O	O	O	O	O
e.	Werken met Avans software-pakketten	O	O	O	O	O
f.	Ontwerpen, creatieve activiteiten (creatief denken)	O	O	O	O	O
g.	Studeren aan rekenvakken (wiskunde, constructie, etc.)	O	O	O	O	O
h.	Samen brainstormen voor groeps-opdrachten: project of cursus	O	O	O	O	O
i.	Samen overleggen over groeps-opdrachten: project of cursus	O	O	O	O	O
j.	Studeren voor tentamen (lezen, onthouden, etc.)	O	O	O	O	O
k.	Spelletjes, Social Media, surfen op internet	O	O	O	O	O

30. Als je iets mocht veranderen aan deze open werkruimte, wat zou dat dan zijn?

Hartelijk bedankt voor het invullen van deze enquête.

B 2 Questionnaires Chapter 3: Experiment on collaboration

Swedish questionnaire:

FRÅGELISTA

Vi vill gärna ställa dig några frågor angående hur du upplevde det att utföra uppgiften och hur du upplevde den akustiska miljön. Frågorna handlar bara om senaste bilden.

Svara på följande frågor genom att ringa in det alternativet som motsvarar bäst hur du kände när du utförde uppgiften.

Fråga 1: I vilken utsträckning tyckte du att bakgrundsmiljön (t ex att det var prat eller tyst i bakgrunden) var störande för att kunna utföra uppgiften?

väldigt lite störande			varken lite eller mycket störande			väldigt mycket störande
1	2	3	4	5	6	7

Fråga 2: I vilken utsträckning kunde du ignorera bakgrundsljudet?

Det fanns inget Bakgrundsljud	I väldigt liten utsträckning			i varken liten eller stor utsträckning			i väldigt stor utsträckning
0	1	2	3	4	5	6	7

Fråga 3: I vilken utsträckning ville du fortsätta göra uppgiften trots att tiden var slut?

I väldigt liten utsträckning			i varken liten eller stor utsträckning			i väldigt stor utsträckning
1	2	3	4	5	6	7

Fråga 4: Hur fungerade samarbetet?

Mycket dåligt			varken bra eller dåligt			mycket bra
1	2	3	4	5	6	7

Återvänd nu till datorn och följ instruktionerna.

Frågelista

Till slut vill vi ställa dig några andra frågor också:

Använde ni samma strategi för att hitta skillnaderna för alla bilderna?

- o Ja
- Nej

Om nej, hur ofta bytte ni strategi?____________________

Efter vilken bild (efter vilka bilder) bytte ni strategi?

____

____

Vilken bakgrundssituation tyckte du var bäst att utföra uppgiften i?

- o Svensk bakgrundsprat – kort efterklang
- o Svensk bakgrundsprat – lång efterklang
- o Holländsk bakgrundsprat – kort efterklang
- o Holländsk bakgrundsprat – lång efterklang
- o Tystnad
- o Det spelade ingen roll

Fortsätt med frågelistan på nästa sida

Fp nr: ____________

Kön: ____________

Ålder: ____________

Har du svenska som modersmål?

- ☐ Ja
- ☐ Nej

Har du holländska som modersmål?

- ☐ Ja
- ☐ Nej

holländska- och svenskakunskaper

Nedan ska du ange en siffra som bäst motsvarar dina tal- och skriftkunskaper i respektive språk. Du ska tänka på att jämföra dina kunskaper i svenska och holländska när du anger dina svar.

Svenska

1 2 3 4 5 6 7

Mycket dåliga kunskaper — Mycket bra kunskaper

holländska

1 2 3 4 5 6 7

Mycket dåliga kunskaper — Mycket bra kunskaper

Reaktioner på ljud

Läs varje påstående och markera det alternativ som bäst beskriver hur väl du instämmer beträffande hur du känner/reagerar. **Det är viktigt att du markerar efter alla påståenden.**

1. Jag skulle inte ha något emot att bo på en bullrig gata om lägenheten jag hade var trevlig.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

2. Jag är mer uppmärksam på ljud än vad jag brukade vara tidigare.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

3. På biografer störs jag av att andra viskar och prasslar med papper.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

4. Jag väcks lätt av ljud.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

5. Jag vänjer mig ganska lätt vid de flesta typer av ljud.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

6. Hur mycket skulle du bry dig om att en lägenhet du var intresserad av att hyra varbelägen mitt emot en brandstation?

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

7. På ett bibliotek bryr jag mig inte om ifall folk talar med varandra bara de gör det tyst.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

8. Det finns ofta tillfällen då jag vill ha fullständigt tyst.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

9. Jag har svårt att koppla av på en plats som är bullrig.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

10. Jag har ingenting emot att bo i en lägenhet med tunna väggar.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

11. Jag är känslig för ljud.

☐	☐	☐	☐	☐	☐
Instämmer starkt (absolut)	Instämmer	Instämmer nog	Instämmer nog inte	Instämmer inte	Instämmer absolut inte

Dutch questionnaire:

Vragenlijst

We willen graag een paar vragen stellen over hoe jullie het vonden om de taak uit te voeren en hoe jullie de akoestische omgeving ervaarden.

Beantwoord de volgende vragen door een cirkel te zetten om de uitspraak die het best past bij hoe je je voelde toen je de opdracht uitvoerde.

Vraag 1: In hoeverre vond je het achtergrondgeluid (bijv. dat er gepraat werd of stil was) storend tijdens het uitvoeren van de opdracht?

Helemaal niet storend			noch veel noch weinig storend			erg storend
1	2	3	4	5	6	7

Vraag 2: In hoeverre kon je het achtergrondgeluid negeren?

Er was geen achtergrondgeluid	het was heel moeilijk om het te negeren			het was noch makkelijk noch moeilijk om het te negeren			het was erg makkelijk om het te negeren
0	1	2	3	4	5	6	7

Vraag 3: Hoe graag wilde je doorgaan met de taak ondanks dat de tijd op was?

Helemaal niet graag			neutraal			erg graag
1	2	3	4	5	6	7

Vraag 4: Hoe ging het samenwerken?

Erg slecht			noch goed noch slecht			erg goed
1	2	3	4	5	6	7

Volg nu de instructies op het computerscherm.

Vragenlijst

Tot slot willen we graag ook nog wat andere vragen stellen:

Gebruikte jullie voor elk plaatje dezelfde strategie om de verschillen te vinden?

- o Ja
- o Nee

Zo nee, hoe vaak hebben jullie van strategie gewisseld?____________________

Na welk plaatje (Na welke plaatjes) wisselden jullie van strategie?

____

____

Welke achtergrondsituatie vond je het beste om de opdracht in uit te voeren?

- o Achtergrondgeluid met Zweedse taal en korte nagalmltijd
- o Achtergrondgeluid met Zweedse taal en lange nagalmtijd
- o Achtergrondgeluid met Nederlandse taal en korte nagalmtijd
- o Achtergrondgeluid met Nederlandse taal en lange nagalmtijd
- ● Stilte
- o Het maakte niet uit

Ga verder met de vragenlijsten op de volgende bladzijdes

Pp nr: ______________

geslacht: ______________

leeftijd: ______________

Is Nederlands je moedertaal?

- ☐ Ja
- ☐ Nee

Is Zweeds je moedertaal?

- ☐ Ja
- ☐ Nee

Nederlandse en Zweedse taalkennis

Geef hieronder aan welk cijfer het beste je kennis van de Nederlandse respectievelijk Zweedse taal (zowel mondelinge als schriftelijke kennis) aangeeft.

Nederlands

1	2	3	4	5	6	7
Zeer slechte kennis					Zeer goede kennis	

Zweeds

1	2	3	4	5	6	7
Zeer slechte kennis					Zeer goede kennis	

Reacties op geluid

Lees de hieronder staande beweringen en geef voor elke uitspraak aan in hoeverre je het ermee eens bent. Kies de optie die het beste past bij hoe jij op onderstaande situaties zou reageren of hoe je je zou voelen in de onderstaande situaties.

1. ***Ik zou er niets op tegen hebben om in een straat met lawaai te wonen als mijn appartement gezellig zou zijn.***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

2. ***Ik merk geluiden eerder op vergeleken met vroeger***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

3. ***In de bioscoop stoort het mij dat anderen zitten te fluisteren en met papiertjes zitten te ritselen.***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ Helemaal mee oneens

4. ***Ik word makkelijk gewekt door geluid***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

5. ***Ik kan makkelijk wennen aan de meeste soorten geluid***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

6. ***Het maakt mij niet uit dat een appartement waarin ik geinteresseerd ben om te huren tegenover de brandweerkazerne ligt.***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

7. ***In de bibliotheek maakt het me niet uit als mensen met elkaar praten zolang ze het zacht doen.***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

8. ***Er zijn vaak situaties waarin ik wil dat het volledig stil is.***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

9. ***Ik heb moeite om tot rust te komen op een plaats met lawaai.***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

10. ***Ik ben geluidsgevoelig***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

11. ***Ik heb er niets op tegen om in een appartement met dunne muren te wonen.***

☐ Helemaal mee eens	☐ mee eens	☐ beetje mee eens	☐ Beetje mee oneens	☐ mee oneens	☐ helemaal mee oneens

B 3 Questionnaires Chapter 4: Experiment on writing

Naam proefpersoon:

nr. proefpersoon:

Datum:

ENQUETE 1 t/m 5:

Het achtergrondgeluid in deze test heeft invloed gehad op:

	mee oneens	*beetje* oneens	*beetje* eens	*mee* eens
• De kwaliteit van mijn verhaal	O	O	O	O
• Mijn schrijfsnelheid en dus de lengte van mijn verhaal	O	O	O	O
• Het aantal schrijffouten in mijn verhaal	O	O	O	O
• Het achtergrondgeluid was erg hinderlijk	O	O	O	O

VERVOLG:

ENQUETE 6:

Algemene informatie over jou.

Geslacht:	*O man*	*O vrouw*		
Leeftijd:	…….. jaar			
Vooropleiding:	*O MBO*	*O HAVO*	*O VWO*	*O Anders*................................
Mijn gehoor:	*O is in orde*	*O ik hoor minder goed*		
Dyslexie	*O Ja*	*O Nee*		
Ben je:	*O introvert*	*O extrovert*		

introvert: De introverte persoon is graag alleen, trekt zich in gezelschap terug, gaat liever lezen dan naar een receptie en praat minder dan een extraverte persoon

extrovert: Extraverte mensen krijgen energie uit interactie met anderen. Extraverte mensen praten over wat ze bezighoudt, door te praten ordenen ze hun gedachten.

Hoe geluidgevoelig ben je in het algemeen (thuis, ’s nachts, op school)?

Geef aan in hoeverre je het eens bent met de volgende stellingen:

		mee oneens	*beetje* oneens	*beetje* eens	*mee* eens
a.	Het moet voor mij stil zijn om te kunnen slapen	O	O	O	O
b.	Het moet voor mij stil zijn om nieuwe taken uit te kunnen voeren	O	O	O	O
c.	In de open werkruimte ben ik snel gewend aan het geluid	O	O	O	O
d.	Ik ben geïrriteerd als er iemand praat als ik wil slapen	O	O	O	O
e.	Ik ben gevoelig voor geluid van de buren	O	O	O	O
f.	Ik vind het moeilijk te werken als mensen om me heen rumoerig zijn	O	O	O	O
g.	Ik presteer duidelijk minder in een rumoerige omgeving	O	O	O	O
h.	Ik ben overdag niet echt alert als ik ‘s nachts gestoord ben door geluid	O	O	O	O
i.	Het zou me niet uitmaken om in een drukke straat te wonen met veel geluid	O	O	O	O
j.	Ik zou best nadelen accepteren om in een stille omgeving te wonen	O	O	O	O
k.	Ik heb rust en stilte nodig om een moeilijke taak uit te voeren	O	O	O	O
l.	Ik kan zelfs slapen als het rumoerig is	O	O	O	O

Sommige achtergrondgeluiden tijdens de test hadden invloed op:

•	De kwaliteit van mijn verhalen	O	O	O	O
•	Mijn schrijfsnelheid en dus de lengte van mijn verhalen	O	O	O	O
•	Het aantal schrijffouten in mijn verhalen	O	O	O	O

B 4 Questionnaires Chapter 5: Experiment on studying

B 4.1 Questionnaire on Perception

Voor deze enquete (12 vragen) heb je 2 minuten de tijd, er staat een klokje in de onderbalk.

Vraag 1. Als je denkt aan dit laatste experiment, in welke mate ergerde, stoorde of hinderde het achtergrondgeluid tijdens **het bestuderen van de tekst**?

helemaal niet	*een beetje*	*tamelijk*	*erg veel*	*extreem veel*
O	O	O	O	O

Vraag 2. Als je denkt aan dit laatste experiment, welk getal van nul tot tien geeft het beste aan in welke mate je geergerd, gestoord of gehinderd werd door het achtergrondgeluid tijdens het bestuderen van de tekst?

helemaal niet … *extreem veel*

1	2	3	4	5	6	7	8	9	10
O	O	O	O	O	O	O	O	O	O

Vraag 3. Als je denkt aan dit laatste experiment, in welke mate beinvloedde het achtergrondgeluid het aantal goede antwoorden op de vragen over de tekst, ofwel beinvloedde het achtergrondgeluid je prestatie?

helemaal niet	*een beetje*	*tamelijk*	*erg veel*	*extreem veel*
O	O	O	O	O

Vraag 4. Als je denkt aan dit laatste experiment, welk getal van nul tot tien geeft het beste aan in welke mate het achtergrondgeluid het aantal goede antwoorden op de vragen over de tekst (de prestatie) beinvloedde?

helemaal niet … *extreem veel*

1	2	3	4	5	6	7	8	9	10
O	O	O	O	O	O	O	O	O	O

Vraag 5. Als je denkt aan dit laatste experiment, in welke mate ergerde, stoorde of hinderde het achtergrondgeluid tijdens het maken van de logica vragen?

helemaal niet	*een beetje*	*tamelijk*	*erg veel*	*extreem veel*
O	O	O	O	O

Vraag 6. Als je denkt aan dit laatste experiment, welk getal van nul tot tien geeft het beste aan in welke mate je geergerd, gestoord of gehinderd werd door het achtergrondgeluid tijdens het maken van de logica vagen?

helemaal niet … *extreem veel*

1	2	3	4	5	6	7	8	9	10
O	O	O	O	O	O	O	O	O	O

Vraag 7. Als je denkt aan dit laatste experiment, in welke mate beinvloedde het achtergrondgeluid het aantal goede antwoorden op de logica-vragen, ofwel beinvloedde het achtergrondgeluid dus je prestatie?

helemaal niet	*een beetje*	*tamelijk*	*erg veel*	*extreem veel*
O	O	O	O	O

Vraag 8. Als je denkt aan het laatste experiment, welk getal van nul tot tien geeft het beste aan in welke mate het achtergrondgeluid het aantal goede antwoorden op de logica-vragen (de prestatie) beinvloedde?

helemaal niet									*extreem veel*
1	2	3	4	5	6	7	8	9	10
O	O	O	O	O	O	O	O	O	O

Vraag 9. Als je denkt aan dit laatste experiment, in welke mate ergerde, stoorde of hinderde het achtergrondgeluid tijdens het maken van de reken-vragen?

helemaal niet	*een beetje*	*tamelijk*	*erg veel*	*extreem veel*
O	O	O	O	O

Vraag 10. Als je denkt aan dit laatste experiment, welk getal van nul tot tien geeft het beste aan in welke mate je geergerd, gestoord of gehinderd werd door het achtergrondgeluid tijdens het maken van de reken-vagen?

helemaal niet									*extreem veel*
1	2	3	4	5	6	7	8	9	10
O	O	O	O	O	O	O	O	O	O

Vraag 11. Als je denkt aan dit laatste experiment, in welke mate beinvloedde het achtergrondgeluid het aantal goede antwoorden op de reken-vragen, ofwel beinvloedde het achtergrondgeluid je prestatie?

helemaal niet	*een beetje*	*tamelijk*	*erg veel*	*extreem veel*
O	O	O	O	O

Vraag 12. Als je denkt aan dit laatste experiment, welk getal van nul tot tien geeft het beste aan in welke mate het achtergrondgeluid het aantal goede antwoorden op de reken-vragen (de prestatie) beinvloedde?

helemaal niet									*extreem veel*
1	2	3	4	5	6	7	8	9	10
O	O	O	O	O	O	O	O	O	O

Questionnaire on Noise Sensitivity and personal information as in Appendix B3 page 147

B 4.2 Informed Consent

Instemming onderzoeksdeelname

Dit document geeft je informatie over het onderzoek 'Studeer-experiment'. Voordat het onderzoek begint is het belangrijk dat je kennis neemt van de werkwijze die bij dit onderzoek gevolgd wordt en dat je instemt met vrijwillige deelname. Lees dit document a.u.b. aandachtig door.

Doel en nut van het onderzoek

Het doel van dit onderzoek is om meer te weten te komen over de invloed van de akoestische werkomgeving op studeren (voorbereiden van een tentamen). De verkregen informatie wordt gebruikt om werkomgevingen van studenten te verbeteren.

Het onderzoek wordt uitgevoerd door Ella Braat docent bij Avans en onderzoeker bij de TU Eindhoven.

Procedure

Bij dit experiment word je gevraagd om een 4 maal, verdeeld over twee dagen, een stukje tekst te bestuderen, een korte logica test te doen, een hoofdrekentoets en vervolgens vragen te beantwoorden over de bestudeerde tekst. Probeer de testjes zo goed mogelijk uit te voeren.

De verschillende teksten die je gaat bestuderen krijg je op papier. Na het bestuderen van de tekst krijg je op de laptop een logica test en een hoofdreken test. Vervolgens krijg je vragen over de tekst die je eerder hebt bestudeerd. Let goed op de instructies die in het rode kader verschijnen op het scherm!

Tussen de opdrachten in wordt je steeds gevraagd een korte enquete in te vullen. Ook op het eind van de laatste opdracht wordt je gevraagd een iets langere enquete in te vullen.

Bij de start van het experiment krijg je eerst een korte oefening om vertrouwd te raken met de procedure.

Risico's

Dit onderzoek brengt geen risico's met zich mee, en ook geen nadelige bijwerkingen.

Duur

Het onderzoek duurt ongeveer 150 minten verdeeld over 2 dagen, ieder dagdeel 75 minuten inclusief korte pauze.

Vrijwilligheid

Jouw deelname is geheel vrijwillig. Je kunt zonder opgaaf van redenen weigeren mee te doen aan het onderzoek en je deelname op welk moment dan ook afbreken. Ook kan je nog achteraf (binnen 24 uur) weigeren dat je gegevens voor het onderzoek mogen worden gebruikt. Dit alles blijft te allen tijde zonder nadelige gevolgen.

Vergoeding

De vergoeding bedraagt een financiele vergoeding van 40 euro aan bol.com bonnen.

Vertrouwelijkheid

Wij delen geen persoonlijke informatie over jou met mensen buiten het onderzoeksteam. Er worden geen video- of audio-opnames gemaakt. De informatie die we met dit onderzoek verzamelen wordt gebruikt voor het schrijven van wetenschappelijke publicaties en wordt slechts op groepsniveau gerapporteerd. Alles gebeurt geheel anoniem en niets kan naar jou herleid worden.

Nadere inlichtingen

Als je nog verdere informatie wilt over dit onderzoek, dan kan je je wenden tot Ella Braat (email: pe.braat-eggen@avans.nl).

Voor eventuele klachten over dit onderzoek kan je eveneens terecht bij Ella Braat-Eggen (pe.braat-eggen@avans.nl).

Instemming onderzoeksdeelname:

Bij dezen verklaar ik, (NAAM)…………………..... dat ik dit document heb gelezen en begrepen en dat ik de gelegenheid heb gehad om vragen te stellen. Ik stem ermee in om vrijwillig deel te nemen aan dit onderzoek van Avans en de Technische Universiteit Eindhoven.

Handtekening: Datum:

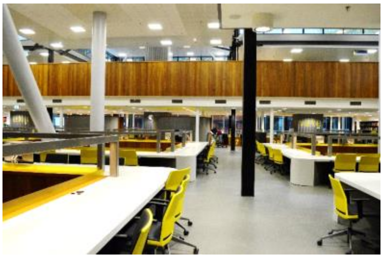
Appendix C | Pictures OPSEs (2016)

C1 Location A: Avans University of Applied Sciences - Tilburg

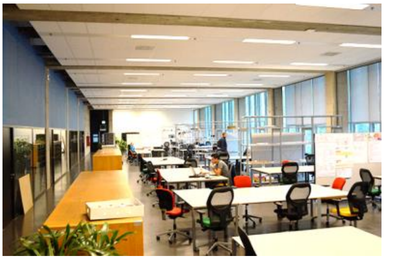
C2 Location B: Avans University of Applied Sciences - 's-Hertogenbosch

C3 Location C: Avans University of Applied Sciences – Breda

C4 Location D: Eindhoven University of Technology - Metaforum



C5 Location E: Eindhoven University of Technology - Vertigo

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Acknowledgements

My first plans to conduct a doctoral research started in 2014. The policy at the time was to encourage HBO teachers to obtain their doctorate. I started my research within the Spark project in 2014 and was awarded with the NWO doctoral grant for teachers in 2015. With the support of Avans and NWO, I was able to work part-time on my research for six years.

I had quite some experience with practical research, but it soon became clear to me that scientific research was really something else. Maarten Hornikx and Armin Kohlrausch became my supervisors and guided me in the process to become a scientific researcher.

Maarten, my first promotor, is a talented young ambitious scientist specialized in acoustics. Thank you Maarten, for giving me the space and trust to conduct a study in a new direction within your research group and supporting me with your scientific knowlegde.

Armin, my second promotor, is a very experienced and prominent physicist specialized in perception and acoustics. His scientific vision, coaching skills and knowledge always took me a step further. Armin knows how to link disciplines, theories and people, which was essential in my research. Also his PhD students Toros, Nemanja and Alejandro helped me a lot. Thank you all for all your support and kindness.

My visit to Sweden and the collaboration with the Environmental Psychology department in Gävle was very important for my personal and scientific development. I would like to thank Patrick Sörqvist and Marijke Keus van de Poll for giving me this opportunity. Marijke, thanks to you my time in Sweden was not only of scientific importance but also inspiring. I will never forget the beautiful gatherings in your church and the pleasant atmosphere in your family.

I would never have been able to do my research without the help of many students at Avans and the TUE. In particular thanks to Marc Kalee, Anne van Heijst, Ben Ludlage, Lieke Dernison, Loretta Ying, Marnick van Veghel, Wies Westerhout, Chris van Loenen, Myla Gonzales Alonso and Kristina Mues. Also, thanks to all students and teachers of the AB&I minor 'Renovation of the Existing Housing Stock' who have come to visit me in Sweden and took part of my collaboration experiment. Thanks to the many Avans students who took part in the field study and experiments. Thanks to all the TUE students and friends of my daughter who helped me recording speech signals for my sound scenarios.

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About the author

Ella Braat-Eggen was born on the 26th of January 1962 in Schiedam, the Netherlands. In 1980, she started her study at the Department of the Built Environment at Eindhoven University of Technology. She specialized in building acoustics and graduated on 'A measurement method for vibration intensities on plate-shaped constructions with two accelerometers' in 1986.

She started working at TNO, (Dutch Organization for Applied Scientific Research) at the department CBO located at the Eindhoven University of Technology. As a researcher, consultant, teacher and project manager she worked on national en international projects until 1995. She published about her research on the acoustic quality of the Dutch housing stock[1] (1990), the acoustic research and design of Music Centre Eindhoven[2,3] (1993, 1994) and the acoustic design of the first Dutch underground station in Rotterdam[4] (1994). In addition, she published together with professor Renz van Luxemburg a book about sound insulation in residential construction, the architectural consequences of the introduction of the new acoustic requirements at the introduction of the first 'Bouwbesluit'[5] (1992).

In the evening, she was lecturer at a post-bachelor education Building Physics ('s-Hertogenbosch 1990-1993) and a post-bachelor education Environmental Science (Heerlen, 1992-1993) teaching Building Acoustics.

From 1996 until now, Ella is a teacher at Avans University of Applied Sciences in Tilburg and 's Hertogenbosch. She teaches building physics, building acoustics, mathematics and research methods. In 2004 she became teacher of the year (as first woman). She was chairman of the curriculum committee AB&I (2009-2014) and member of the management team AB&I (2010-2013).

In 2014 she wrote a research proposal on the acoustics of open-plan study environments and Avans gave her permission to start her research for two days a week at the group of Building Acoustics at the Department of the Built Environment at Eindhoven University of Technology under supervision of prof. dr. ir. Maarten Hornikx and prof. dr. Armin Kohlrausch.

In 2015 Ella obtained a doctoral grant for teachers from NWO for 0.4 FTE for 5 years to continue her research. The results of her PhD research are presented in this dissertation.

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Due to new ways of learning in higher education, not only classrooms and lecture halls but also informal learning spaces are becoming increasingly important. This research focusses on informal open learning spaces, intended and designed for students to accommodate individual study activities, as well as small group activities. These study areas will be referred to as open-plan study environments (OPSEs). Although research shows that learning activities can be negatively influenced by noise, and noise disturbance can be expected in open environments, there is little research into the acoustics of OPSEs and no acoustic recommendations are available for OPSEs. Hence, the objective of this research is to gain more insight into the influence of the sound environment on students' performance and noise disturbance in OPSEs.

To investigate how students are disturbed by background noise in an OPSE, a field study was conducted in five OPSEs in higher education. Subsequently, three experimental studies were conducted to investigate correlations between the parameters of representative sound scenarios and the disturbance and performance of students working on a student task. The field study showed that nearly 40% of the students were much to very much disturbed by background noise. The experiments showed that students performing different tasks in an OPSE require different sound conditions. Therefore, to increase student performance and decrease noise disturbance in OPSEs, it is recommended to develop activity based OPSEs, with sections acoustically optimized for specified student tasks.

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