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The Effect of Background Noise on a "Studying for an Exam" Task in an Open-Plan Study Environment: A Laboratory Study

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Students can be disturbed by background noise while working in an open-plan study environment. To improve the acoustic quality of open-plan study environments a study was done on the influence of different sound scenarios on students working on a typical student task, "studying for an exam". 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 while being exposed to the sound scenarios. This task comprises a reading comprehension task with text memory by delayed answering questions about the text, with additional tasks being performed in the gap between studying the text and retrieving. These additional tasks are a mental arithmetic task and a logical reasoning task. Performance, self-estimated performance and disturbance of students were measured. No significant effect of the sound scenarios was found on performance of students working on the reading comprehension task with text memory and the mental arithmetic task. However, a significant effect of sound was found on performance of students working on the logical reasoning task. Furthermore, a significant effect of the sound scenarios was found on self-estimated performance and perceived disturbance for all tasks from which the reading comprehension task with text memory was the most disturbed task. It is argued that the absence of a detrimental sound effect on the performance of students working on a reading comprehension task with text memory is a result of focusing due to task engagement and task difficulty, both aspects working as a "shield against distraction".

Keywords: open-plan study environment, student task, background speech, task performance, noise disturbance, well-being, acoustic quality

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 (Montgomery, 2014; Beckers et al., 2015). The need for OPSEs is a result of changed visions on education and enables new ways of learning. In addition to education that is primarily aimed at knowledge transfer, education that focuses more on competencies is becoming increasingly important (Beckers et al., 2015; Koenen et al., 2015). 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 (Koenen et al., 2015). 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 (Koenen et al., 2015; Curry and Docherty, 2017). 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 on students tasks, perceived sound sources and noise disturbance among 496 students in five OPSEs showed that the tasks students perform in OPSEs are diverse, ranging from preparing for an individual exam to brainstorming for a group assignment (Braat-Eggen et al., 2017). Furthermore, the survey also showed that students are mostly bothered by noise when performing an individual complex cognitive task like studying for an exam, reading or writing. The variety of activities in the same OPSE implicates different demands on the acoustic environment. Disturbance can also occur because some students perform group tasks that will induce noise, while other students perform individual complex cognitive tasks.

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.

THEORETICAL BACKGROUND

Studying for an Exam in Higher Education

As showed in a study on noise in OPSEs, (Braat-Eggen et al., 2017) the most disturbed task students perform in an OPSE is "studying for exams". This task 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 were executed to find specific mechanisms responsible for distraction of a cognitive task. Therefore, these experiments are mostly performed on so-called "pure" cognitive tasks (Sörqvist, 2014) or sub-component cognitive abilities (Sörqvist, 2015), such as for instance short-term memory tasks (Haapakangas et al., 2011; Schlittmeier et al., 2011; Hughes, 2014) or tasks using retrieval from semantic memory (Jahncke, 2012; Jones et al., 2012). 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 (Sörqvist, 2015). 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 analyse and understand the material. 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 (Dunlosky and Ariel, 2011a; Dunlosky and Ariel, 2011b). 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 (Hanczakowski et al., 2018). 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 (Hanczakowski et al., 2018).

Assessments in higher education are an essential part of a curriculum and evaluate the educational level of graduate students (Flores et al., 2015). 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 (Jensen et al., 2014). A model to describe different levels of cognitive skills has been developed by Bloom (Bloom and Krathwohl, 1956; Adams, 2015). 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 (Anderson and Kratwohl, 2001). 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.

The Sound Environment

A study of five OPSEs (Braat-Eggen et al., 2017) showed various sound sources (e.g., unintelligible speech, walking sounds, noise of devices, telephones ringing) of which intelligible background speech was perceived as the most disturbing. Background noise and especially background speech has been proven to have a detrimental effect on cognitive performance (Szalma and Hancock, 2011; Klatte et al., 2013; Reinten et al., 2017). These results have been described by the duplex-mechanism account (Hughes, 2014). 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 (Conway, 2001). Another way of attentional capture is that a specific sound captures attention, due to the context in which it occurs (Hughes, 2014). For instance, the B within the sequence AAAAABAA will capture attention due to the deviation from the expected A (Hughes et al., 2005; Hughes et al., 2007). Auditory distraction can be overruled by cognitive control (Clark and Sörqvist, 2012). 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, but if the task load is too heavy, it can also lead to abandonment (Engelmann et al., 2009; Halin et al., 2014a; Halin et al., 2014b; Hughes, 2014; Marsh et al., 2015). Furthermore, it should be acknowledged that even if students are able to shield against noise in terms of performance, they might require longer processing time, as has been shown in school aged children (age 6–7; 11–13) (Prodi et al., 2019; Schiller et al., 2020).

Generalization 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 (Reinten et al., 2017) 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 seldomly taken into account in experiments, and in many cases background speech consists of only one or two talkers which is an interesting disturbing sound environment (Keus van de Poll et al., 2014) but not the most representative setting for an OPSE.

Personal Factors

Different personal factors can influence the effect of noise on cognitive performance (Reinten et al., 2017). An important personal factor that can influence task performance and disturbance of people in noisy open environments is noise sensitivity (Haapakangas et al., 2014). 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, it was shown that students with a noise sensitivity score above the median score were more disturbed by noise than students with a noise sensitivity score below the median score (Braat-Eggen et al., 2017). In the experimental study on a collaboration task (together solving a problem) in an OPSE no influence of noise sensitivity was found (Braat-Eggen et al., 2019a), while in the experimental study on a writing task students with a noise sensitivity score above the median score showed to be more influenced by the sound environment resulting in a significantly lower writing performance in comparison to students less sensitive to noise (Braat-Eggen et al., 2019b). 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, measured by a well-tested questionnaire (Griefahn, 2008), as a personal factor also in this study.

The Aim of the Study

In this laboratory 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 reading comprehension, logical reasoning, and mental arithmetic assignment. 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 acoustically simulated OPSE.

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 while performing the "studying for an exam" task in an OPSE in comparison to a quiet environment. "Studying for an exam" has many sub-components as mentioned earlier, but based on the semantic elements within the task we expect that more intelligible background speech will reduce performance and will increase disturbance of students measured by a questionnaire (ISO/TS 15666, 2003). 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.

MATERIALS AND METHODS

Design

To verify the hypotheses posed in Section *The aim of the study* a within-participants experimental design with repeated measurements was developed. The experiment included three tasks: a reading comprehension task, a logical reasoning task, and an 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 scenario was presented.

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 students had severe hearing loss, the results of two other students were excluded due to computer problems during the test and the experiment of 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.

Research Settings

The experiments were conducted in a small two-person office (2.60 m × 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 headphones (Sennheiser HD 380 PRO) throughout the experiment.

Sound Conditions

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 modeling and auralization was performed using the room acoustic modeling software Odeon (version 12.12). From this basic model two new models were developed, an sound absorbing model with a reverberation time of 0.6 s applying sound absorbing materials instead of the materials used in the real OPSE, and a reverberant model with a reverberation time of 2.4 s applying sound reflecting materials. These two models had also been used in the previous studies on the influence of background sound on student tasks (Braat-Eggen et al., 2019a; Braat-Eggen et al., 2019b).

Four sound scenarios were created for this experiment (**Table 1**), 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 modeled OPSEs resulted in sound scenarios with different levels of intelligibility of the background speech. In **Table 1** the four sound scenarios are described by the reverberation time, background sound level due to speech and the intelligibility of the background speech (Braat-Eggen et al., 2019b). 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 (Houtgast et al., 1980). The position of the talkers and their speech directions are described in **Figure 1**. More information about the modeling, materials, sound levels, and estimated *STI* values has been included in earlier research on the influence of background speech on a writing task (Braat-Eggen et al., 2019b) In this study the same OPSE models were used as in the current study. These models were used to research the influence of the sound environment of a (simulated) OPSE, varied by the number of background talkers and reverberation time, on performance and disturbance of students carrying out a writing task.

To create a realistic sound environment, recordings were made of students talking about their study, hobbies and work. Subsequently, the speech recordings were convolved with the binaural impulse responses using HRTFs (stereo effect) 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 (Braat-Eggen et al., 2019b). The sound pressure levels offered to the subjects by headphones were calibrated in accordance with the calculated sound pressure levels in the models (**Table 1**). The calibration was performed with a Head and Torso simulator (B&K 4128-C).

Measures

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 (Curry and Docherty, 2017). 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 were 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 (Anderson and Kratwohl, 2001):

- remembering: reading comprehension with delayed retrieval, mental arithmetic
- understanding: reading comprehension, logical reasoning, mental arithmetic
- applying: mental arithmetic
- analyzing: reading comprehension, logical reasoning, mental arithmetic
- evaluating: reading comprehension, logical reasoning

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 (reading comprehension task) and the tasks to simulate the time gap (the logical reasoning and mental arithmetic task) were analyzed.

Reading Comprehension With Delayed Answering

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

TABLE 1 | Characteristics of the background sound scenarios.

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

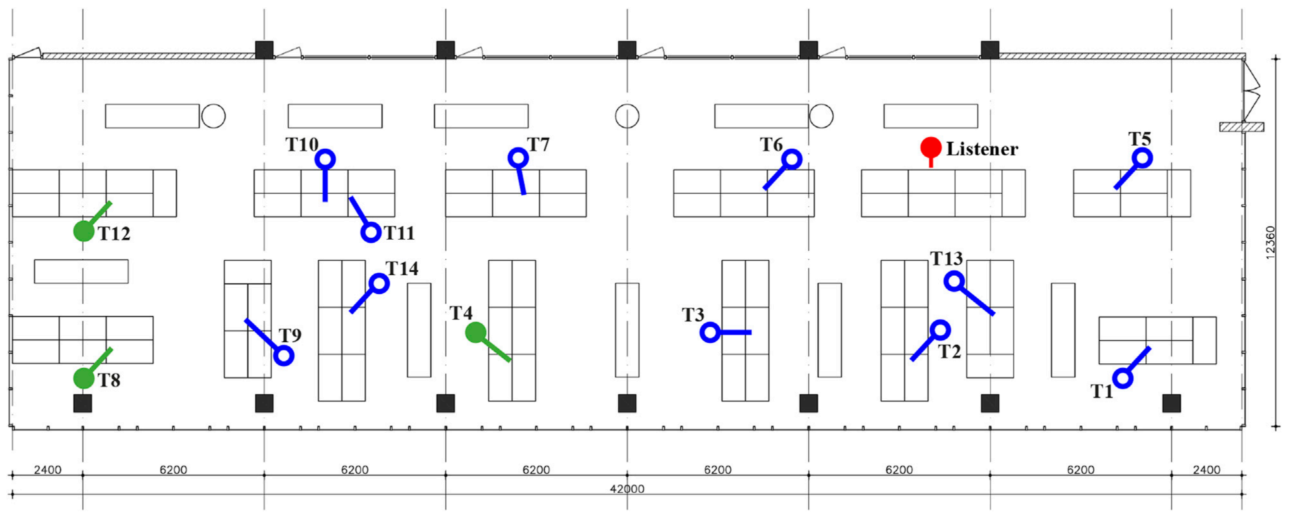


FIGURE 1 | Floor plan of the modeled OPSE with the positions of listener and three talkers (T4, T8, T12), and fourteen talkers (T1-T14), with lines indicating the listening and talking direction. Dimensions in mm (Braat-Eggen et al., 2019b).

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 reading comprehension 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 syllogisms, developed by (Making Moves, 2019), was used. Each student had to solve ten syllogisms in all four different sound environments. 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 (Citrus, 2018). The performance of the mental arithmetic test was measured by the number of correct answers.

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 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 (ISO/TS 15666, 2003). Question 1, 3, and five measured noise disturbance when students were performing the three tests and question 2,4 and six measured the impact of noise on performance estimated by the students after performing the three tests.

1. 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?

2. 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?

3. 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?

4. 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?

5. 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?

6. 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?

Noise Sensitivity

The noise sensitivity of the students was measured with the reduced version of the Noise Sensitivity Questionnaire (NoiSeQ-R), developed by Griefahn (Griefahn, 2008). 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".

Procedure

The whole experiment took about 2 h and 30 min spread over two sessions (**Figure 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 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. The time interval between the two test sessions varied, the average was 7 days. During the second session each 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.

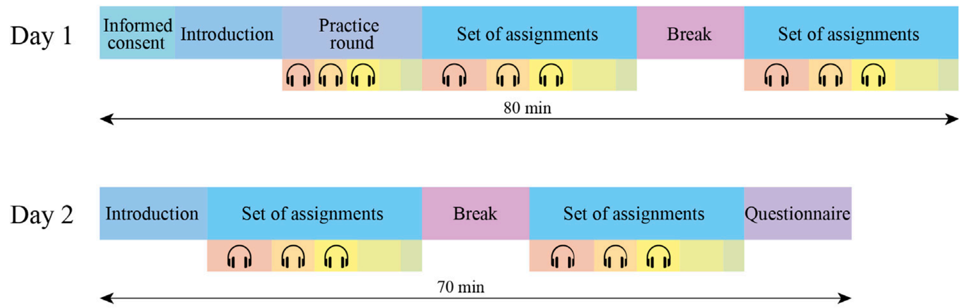
The set of assignments simulating the "studying for an exam" task started with reading and studying a text. The participating students were informed that they had to answer some questions about the text later in the experiment. The text was printed on paper and the use of pen and marker was allowed during 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. Students had 4 min to answer the questions about the initial text. Finally, a questionnaire was presented about the perception of the background sound and the self-estimated influence of the sound scenario on performance. In total a set of tests (including the perception questionnaire) took 20 min (6 + 4 + 4 + 4 + 2 min), the practice set of tests took 13 min (3 + 3 + 3 + 2 + 2 min). An overview of order and duration of the assignments can be seen in **Figure 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.

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 occurred was performed by using post-hoc t-tests with a Bonferroni correction.

The influence of noise sensitivity was studied after a median split was done to divide the subjects in two groups: a low noise sensitive group (below the median score) and a high noise sensitive group (above the median split). By using a factorial 4 (four sound scenarios) x 2 (low vs. high noise sensitivity) repeated



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 2 | The order and duration of a set of assignments in the experiment.

measures ANOVA, the influence of the noise sensitivity on performance, self-estimated performance and perceived disturbance was studied.

RESULTS

Impact of the Background Sound Scenario on Performance

Table 2 shows the influence of the different background sound scenarios on performance of students accomplishing a reading comprehension 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 "reading comprehension" task (p = 0.142), and neither on the performance of a mental arithmetic task (p = 0.934). The analyses also show that different sound scenarios have a significant effect on performance of a logical reasoning task (p = 0.013). 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 for the quiet situation and the reverberant sound scenario with 14 talkers (p = 0.008). 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.

Impact of the Background Sound Scenario on Self-Estimated Performance

Figure 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 was measured on a 5-point scale for each task. Scale value one indicated that students estimated their performance not at all to be influenced by background noise, while scale value five indicated that students estimated their performance to be extremely influenced by the background noise.

The analyses show the different sound scenarios to have a significant effect on the self-estimated performance of the students working on a reading comprehension task (F (3,195) = 34.129, $p < 0.0001$, $\eta_p^2 = 0.344$), a logical reasoning task (F (3,189) = 38.468, $p < 0.0001$, $\eta_p^2 = 0.379$), and a mental arithmetic task (F (3,189) = 26.953, $p < 0.0001$, $\eta_p^2 = 0.300$). The quiet condition was reported as the least influencing condition. Follow-up t-tests with Bonferroni adjustment for all tasks showed significant differences between the self-estimated performance means for the quiet condition and the three other sound scenarios ($p < 0.0001$).

Self-estimated performance of the mental arithmetic task seems the least influenced by the background sounds (**Figure 3**). A one-way repeated measures ANOVA shows that for each sound scenario the kind of task has no significant effect on self-estimated performance ($p > 0.05$).

Impact of the Background Sound Scenario on Perceived Disturbance

Figure 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 for each task. Scale value one indicated that students felt not at all to be disturbed by background noise, while scale five indicated that students felt extremely disturbed by the background noise.

The analyses show different sound scenarios to have a significant effect on perceived disturbance of a study task (F

TABLE 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		
Reading comprehension	7.02	6.63	6.40	6.77	1.837	0.027
Logical reasoning	7.51	7.31	6.97	6.66	3.713[a]	0.055
Mental arithmetic	7.47	7.29	7.39	7.44	0.143	0.002

[a]$p < 0.05$.

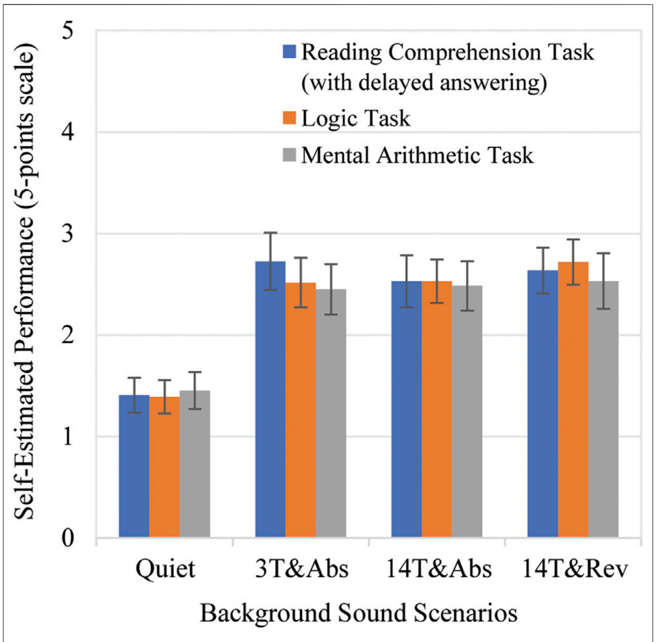


FIGURE 3 | Mean values and confidence intervals (95%) of the self-estimated performance of participants (n = 66) accomplishing three tasks with four different sound scenarios: Quiet, three Talkers and Absorbing (3T&Abs), 14 Talkers and Absorbing (14T&Abs), 14 Talkers and Reverberant (14T&Rev).

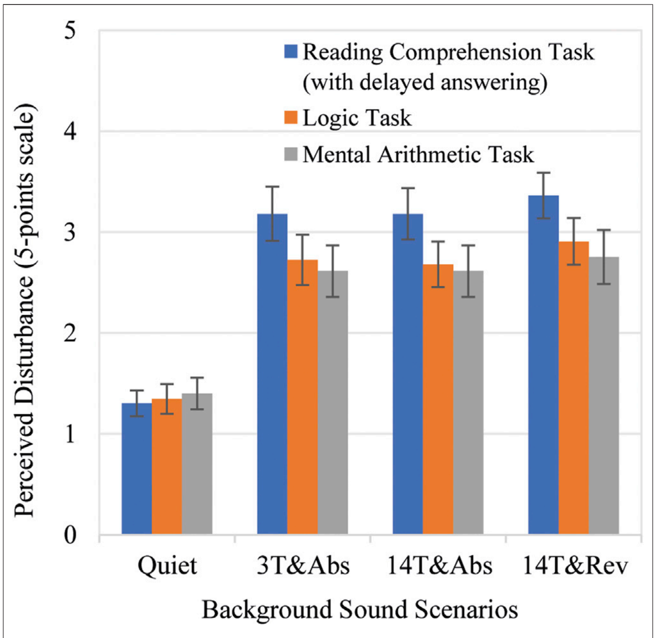


FIGURE 4 | Mean values and confidence intervals (95%) of the perceived disturbance of participants (n = 66) accomplishing three tasks with four different sound scenarios: Quiet, three Talkers and Absorbing (3T&Abs), 14 Talkers and Absorbing (14T&Abs), 14 Talkers and Reverberant (14T&Rev).

(3,195) = 94.280, $p < 0.0001$, $\eta_p^2 = 0.592$), a logical reasoning task (F (3,195) = 59.285, $p < 0.0001$, $\eta_p^2 = 0.477$) and a mental arithmetic task (F (3,192) = 44.976, $p < 0.0001$, $\eta_p^2 = 0.413$). The quiet condition was reported as the least disturbed sound condition. Follow-up t-tests with Bonferroni adjustment for all tasks showed significant differences between the perceived disturbance means for the quiet situation and all other sound scenarios ($p < 0.0001$).

Students rated the reading comprehension task with delayed answering as the most disturbed task due to the background sound scenarios (**Figure 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 in comparison to the other tasks (3 Talkers Absorbing: F (2,130) = 13.389, $p < 0.0001$, $\eta_p^2 = 0.171$); 14 Talkers Absorbing: F (2,130) = 12.772, $p < 0.0001$, $\eta_p^2 = 0.164$); 14 Talkers Reverberant: F (2,130) = 11.353, $p < 0.0001$, $\eta_p^2 = 0.151$).

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, n = 32 participants) 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, n = 38 participants) 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 (reading comprehension, logical reasoning, mental arithmetic).

DISCUSSION

Impact of the Background Sound Scenarios on Performance

The analysis of the results (**Table 2**) showed no significant effect of the sound scenarios on the performance of students for the "reading comprehension" 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 significant reduction in performance due to background speech and reverberation. (**Table 1**).

"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.* (Martin et al., 1998) 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.* (Oswald et al., 2000) 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 (Martin et al., 1998; Oswald et al., 2000), one voice with perfect intelligible speech was used as background noise, in contrast to the sound scenarios in the current study where a realistic OPSE sound environment was simulated with at least three voices. 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 answers 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 (Banbury and Berry, 1998) and on different "mental arithmetic" tasks (Caviola et al., 2021) showed a decrease of performance for noise with and without background speech. Also, a study of Jahncke (Jahncke, 2012) 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 Jahncke 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 (Jahncke, 2012) 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.

Impact of the Background Sound Scenario on Self-Estimated Performance and Perceived Disturbance

The subjective parameters, self-estimated performance and perceived disturbance (**Figures 3**, **4**) showed for all tasks to be significantly affected by background speech. Students expected the quiet sound scenario to have 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 supported 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 (Hughes, 2014).

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 'reading comprehension' compared to the performance of the other tasks (**Figure 4**). This is even more remarkable when one takes into account that the decrease in performance of the task 'reading comprehension' 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 "reading comprehension" task, 1.3% for the "mental arithmetic" task and 7.1% for the "logical reasoning" task. The major disturbance of the "reading comprehension" task with delayed answering is in accordance with the findings in a field study on five OPSEs (Braat-Eggen et al., 2017). In that research "studying for an exam" was identified by students as the most disturbed task by noise they perform in an OPSE.

"Studying for an exam" is a very important task for a student, as the odds for passing an examination depend 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 (Jensen et al., 2014), and therefore is a very difficult task. Both aspects, engagement and difficulty of a task, have shown to determine the amount of focusing on a task and will shield against distraction and a decrease of performance by the background noise (Engelmann et al., 2009; Halin et al., 2014a). In contrast, this shielding is not seen if we measure perceived disturbance. The perceived disturbance during the reading comprehension task by background noise was significantly higher than the perceived disturbance for both other tasks (**Figure 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.* (Schlittmeier et al., 2008) call this the 'reactive effort enhancement', and this effect can lead to reduced performance differences and increased perceived disturbance differences (Kahneman, 1973; Schlittmeier et al., 2008). Also, a prolonged processing time as a result of the sound environment could lead to a feeling of disturbance, even if the performance is unaltered (Prodi et al., 2019; Schiller et al., 2020).

Impact of the Noise Sensitivity Performance and Disturbance

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 OPSE's (Braat-Eggen et al., 2019a). On the other hand, in the field study on OPSEs (Braat-Eggen et al., 2017) and the experimental study on writing performance (Braat-Eggen et al., 2019b), 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.

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 (Pan et al., 1994; Bergh and Vrana, 1998). 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 such as a spread in time-gap between the test days. However, a statistical comparison of the results of day 1 and day 2 did not show significant differences between the 2 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 (Collie et al., 2003). A learning effect was not expected for the reading comprehension' 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.

Using a laboratory setting implies limitations in ecological validity of the sound environment. Although the modeling of the simulated sound environment is based on a real OPSE, which leads to a more realistic sound scenario than used in comparable research on the influence of noise on task performance and disturbance, the spaciousness is limited by the raytracing method used in Odeon, and also the use of headphones is limiting the spaciousness of the perception of the sound signal. Furthermore, not seeing the sources of the background noise (talkers) can contribute to a different perception of the sound field. The advantages of a laboratory study in giving the opportunity to study the influence of different parameters on performance and disturbance is obvious. In our view, this outweighs the disadvantages of a laboratory experiment.

CONCLUSION

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 "reading comprehension" 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 influence of noise sensitivity of students on performance and disturbance of students working on the study tasks was seen in this study.

The "reading comprehension" task with delayed answering 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 reading comprehension with delayed answering task. Both aspects, difficulty and importance, will lead to very high concentration levels for students, resulting in less influence of the background sound scenarios. On the other hand, mental stress and fatigue could be the consequence of prolonged high concentration and high disturbance levels. Therefore, background sound scenarios with background speech are not preferred for important cognitive tasks.

A minimal effect of the realistic simulated background sound scenarios on student performance for all 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 comfort. Therefore, it will be interesting to study the long-term impact of acoustically uncomfortable OPSEs in future work.

The translation of the experimental results to requirements for OPSEs is very difficult. All performance measures and all subjective measures of all tasks show the quiet situation to be preferred. A quiet OPSE is the best, this situation can 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.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

EB-E was responsible for the research design, conducted the experiment and wrote the manuscript. JR, MH, and AK gave feedback on the research design and contributed to the manuscript revision, read and approved the submitted version.

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