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A laboratory experiment exploring the effect of chronic- and background noise on cognitive performance and motivation

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ABSTRACT

Exposure to uncontrollable and unpredictable environmental stressors like noise can induce cognitive deficits. When exposed with unpredictable (changing state) background noise, children perform significantly worse on short-term memory tasks. Additionally, motivation to persist at a difficult task decreases when exposed to noise before or during a task. The latter is associated with learned helplessness. It is assumed that vulnerability to the development of learned helplessness and its motivation-altering effects are increased by chronic noise exposure, although the findings are inconsistent. Some studies have argued that the effects are due to cognitive fatigue and not necessarily learned helplessness. Age and coping mechanisms may play a role as well. This study aims to further investigate the relationships between chronic noise exposure, cognitive performance, cognitive fatigue and motivation between children in different age groups. A laboratory experiment is designed where participants perform a serial recall task and the Stroop color word test either with background noise, to increase cognitive load, or in silence as a control, followed by a motivation task in silence. Chronic noise exposure is taken into account by letting the participants indicate their current and past places of residence and education. Using noise maps, a comprehensive estimation can be made of the chronic noise exposure over their lifetime, as past exposure may affect current cognitive functioning as well. In this paper, the design and first pilot results of the study are presented.

Keywords: Children, Development, Chronic noise exposure, Serial recall, Stroop task, Motivation

INTRODUCTION

Every day we process incoming stressors from both our physical and social environment, whether we experience them consciously or not. We cope with our environment as it impacts our health, wellbeing and cognitive functioning. One of the stressors in the physical environment is noise. Many healthy life years are lost due to the negative effect of noise, including increased stress levels, sleep disturbance and the effects on cognitive functioning[1]. The latter is of vital importance to children and the focus of this paper. The mechanisms behind the effects of noise on cognitive function are well established and include the changing state

hypothesis, interference by semantic processing or a combination of interference by similar processes and distraction (duplex theory) [2–5]. But also chronic noise exposure has been accounted for as an important factor in cognitive functioning in children[3,6–8]. Theories on what may contribute to these longer term effects include the environmental stress model [9,10] and learned helplessness[11].

The environmental stress model states that cognitive resources are needed to appraise and cope with incoming stressors, such as noise, which can lead to fatigue and stress when coping is continuously unsuccessful. Coping mechanisms are benefitted by a sense of perceived control[12]. However, when we experience many situations where coping is unsuccessful this can reduce the perception of control, affecting the motivation to persist at cognitive tasks. The perception of control and motivation are related to learned helplessness, which is a broad psychological concept centered around the perception of control. Learned helplessness is defined as the state that occurs when "an organism learns that its behavior and outcomes are independent…this learning produces the motivational, cognitive, and emotional effects of uncontrollability" [11].

It is assumed that vulnerability to the development of learned helplessness and its motivation-altering effects are increased by chronic noise exposure, although the findings are inconsistent[13]. Additionally, the effect of noise on cognition and on motivation are rarely studied together as came to light in a systematic review performed in 2022[13]. In the reviewed studies, which included both a cognitive and motivation test in their experiments, the focus was on the effect of chronic noise exposure at home or at school[13]. Where some studies found that chronic noise exposure caused less persistence on the puzzle tasks, one found only effects for girls and others found none. It was found that only the studies that conducted the cognitive and motivation tests in a fixed order, with the motivation test last, found effects[13]. Therefore, the motivational effects may be due to cognitive fatigue as well. The studies in the review considered a limited age group, while coping mechanisms develop with age[14] and therefore the effects may differ with age as well.

The direct effects of background noise on motivation are not addressed in the studies included in the review. While in fundamental research into learned helplessness by Glass and Singer noise was used to induce a helpless state in experiments[15]. This was done by exposure to loud unpredictable noise during or even before the task, indicating that short term, background noise, exposure as an effect as well.

This study aims to further explore the mechanisms discussed above and to investigate the relationships between background noise, chronic noise, cognitive performance, cognitive fatigue and learned helplessness while comparing children and young adults. Learned helplessness is measured as task persistence, which encompasses the motivational component of the construct. Motivation is the most common measure of learned helplessness[16] and is presumed to be related to both chronic noise exposure and short-term noise exposure[15,17]. A laboratory study is designed to answer the questions, can noise exposure influence motivation of children and young adults to persist at a difficult task and is this moderated by cognitive fatigue?

MATERIALS AND METHODS

Study design

The aim of the experiment is to measure task persistence of children and young adults at different levels of cognitive fatigue. Cognitive fatigue is moderated by the presence or absence of background noise during a cognitive task. Therefore, this study adopts a between subject 2x2 factorial design with two age groups (8-10 and 18-21 year old) and two in-situ noise conditions as the factors. The chronic noise exposure of participants is estimated through a

survey but not manipulated and therefore not included as a factor. A between subject design is chosen to minimize the participant load, especially for the younger age group. The younger age group is limited to a minimum of 8 years old because to omit the possible effects of reading abilities in the tasks.
Participants are recruited through posters in universities, colleges and primary schools as well as through personal networks. The participants receive financial compensation for their participation. The aspired sample size of this study is 60 participants, of which 30 in age group and 15 for each noise condition within the age group. The experiment is conducted in a soundproof booth in the acoustics lab of Eindhoven University of Technology. The experimental procedure is summarized in Figure 1.

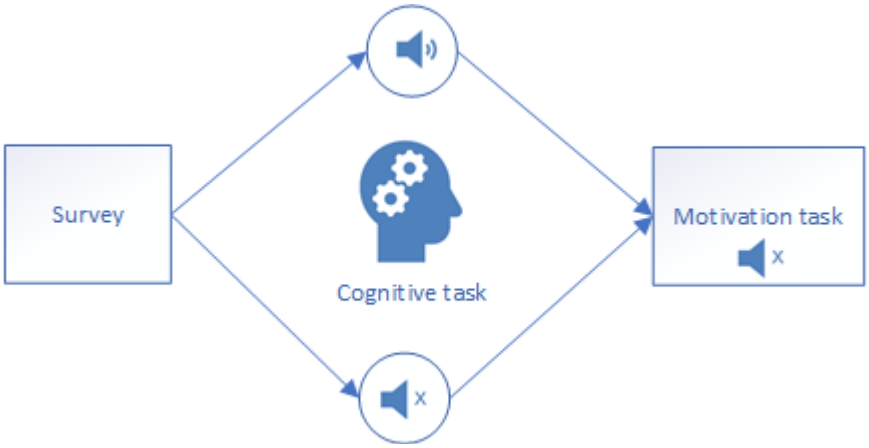

Figure 1 summary of laboratory design

Procedure and components

Survey
The first component of the experiment is a survey which collects socio-demographic information of the participant, chronic noise exposure and their overall wellbeing. The survey is filled in by a parent for the 8-10 year old group.
The chronic noise exposure is estimated through making an inventory of residential locations and school locations in the past 10 years by the use of a map. A noise exposure map is connected to the locations to provide a life-time estimation (exposome approach) to chronic noise. Although the school and home locations do not fully represent an individual's exposure, they cover the largest part and are the most stable because they are used every day for extended periods of time. Questions on overall wellbeing are added and are aimed to get insight in the participants vulnerability to learned helplessness and includes the Strengths and Difficulties Questionnaire[18] (SDQ) and a measure of locus of control.

As stated in the introduction, learned helplessness is a broad psychological factor which is influenced by social stressors as well. Due to social stress and personal factors perception of control over once life can vary. This can be measured through the individual's locus of control. The locus of control can be external or internal. An external locus of control indicates a tendency to believe that outcomes are caused by luck, chance or fate and are not caused by the individuals actions[16]. Therefore, there is a tendency for a lack of perceived control. An internal locus of control focusses on ability and intelligence and generally these individuals belief they can influence their environment[16], i.e. have more control. Someone with an external locus of control is more vunerabele[17] to the onset of learned helplessness, however both types can be affected depending on their attribution of failure when a task in not successful. Failure attributed to lack of skill or intelligence is more likely to cause helplessness symptoms [15,16]. The Rotter scale and the Nowicki-Strickland scale are two of the most frequently used Locus of Control measures[19]. In this study the latter is adopted as it has versions for both children and adults [20,21]. The SDQ is included to provide context on the individuals mental health.

Learned helplessness may lead to emotional problems in the long run, but mental health also influences vulnerability to learned helplessness making it a vicious circle.

Cognitive tasks

Participants are assigned randomly to a background noise or quiet group and will conduct two cognitive tests with or without background noise. The cognitive tests serve both to test the effect of chronic noise exposure on cognitive performance and to induce cognitive fatigue as a pre-treatment for the motivation task. The addition of background noise must increase the task difficulty and therefore also the resulting cognitive fatigue. Therefore a relatively standard test in cognitive noise studies[22] has been chosen, the visual serial recall task, where unrelated items with verbal representation (numbers) are presented one after the other and are to be reproduced afterwards in the presented order. This test has been proven to be disrupted by background noise [22].

Klatte et al argued that in future research care should be taken to add an additional task next to serial recall which requires attention but does not involve short-term memory as a control task for attentional capture[23], the Stroop task is such a task. To test for attention control the Stroop task is incorporated as a second cognitive test. In the Stroop task a word is given spelling a color. This word is printed in the color it spells (congruent) or in another color (incongruent). For example, the word “blue” is shown in a blue color (congruent) or a red color (incongruent). For each trial the participant is asked to name the color of the word on the screen by pressing a button on the keyboard marked with the matching color. The reaction time of the correct responses in incongruent and congruent conditions Is used to calculate the Stroop interference (the difference between the two times). A higher difference indicates a higher interference.

The cognitive tasks are performed on the computer using the PsychoPy-2022.2.5[24]. For the children all instructions to the tasks are narrated and the experience is gamified by adding a story line about scientist that needs their help. The tasks are presented in a random order. In the serial recall task a series length of 5 and 7 random numbers between 1-9 is chosen for children and young adults, respectively. The numbers appear one-by-one for 1500ms with 500ms intervals. After the series is presented, there is a 5 second retention interval after which the recall starts. Children conduct 3 sets of 10 trials with breaks in between sets, the young adults conduct 3 sets of 20 trials.

The Stroop task was identical for both the child and young adult group. The task consists of 100 trials, with 30% incongruent and 70% congruent, that are presented on the screen for 1750ms. Within that time participants are asked to indicate the color of the word by using the keyboard. Due to the high proportion of congruent trials the maintenance of inhibitory control is more difficult than when the proportion of congruent trials would be lower[25], increasing the cognitive load. The presentation of the Stroop stimuli is randomized.

Background noise

A changing state sound is required for the most effective interference of noise with a task. However, semantic interferences need to be avoided as this influences the performance on the task in a different way. To create an ecologically valid background noise a sound recording was made during a university network event using a Tascam D40 recorder and an ISEMcon microphone on a tripod. The recording included babble, people walking past and laughter. The recording was reviewed and audited to make sure there was no intelligible speech. The background noise is presented over headphones (Bose QuietComfort 700) at a moderate comfortable level of 60dB(A). The equivalent sound level was verified by playing the recording over the headphones placed on a head and torso simulator (HATS).

Motivation task

The motivation task is conducted in quiet for all groups to test the influence of pre-treatment

and the effect of chronic noise exposure. After completion of the motivation task, participants will be asked how well they think they did to get insight into their attribution of failure and its relation to their locus of control. Motivation is measured by task persistence. Presenting participants with both possible and impossible tasks and counting the number of tries for the impossible one. An example of this is the Glass and Singer line diagram puzzles[15], where line drawings need to be traced without lifting the pen or retracing lines. The puzzles are presented in a fixed order: insolvable – solvable – insolvable – solvable. The test has a fixed length of ten minutes. The diagrams should be visibly unsolvable and complex enough to take more tries if they are solvable. For the young adults the original drawings from the Glass and Singer experiments are used, see Figure 2. The children's versions are simplified and can be seen in Figure 3.

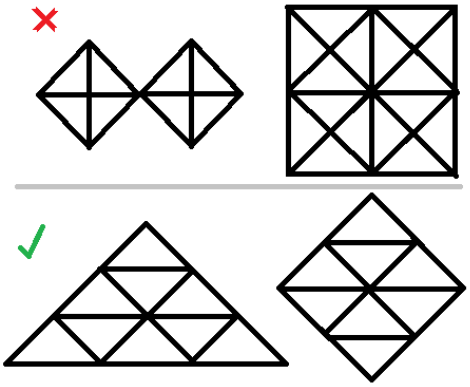

Figure 2 line diagrams adapted from Glass & Singer[15] unsolvable diagrams presented in the top row, solvable in the bottom row

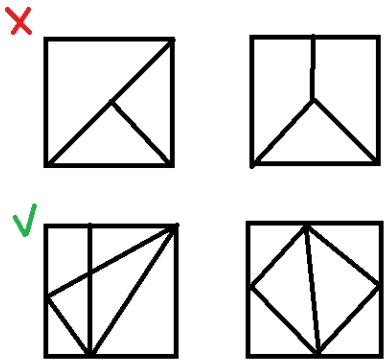

Figure 3 line diagrams adapted from Head[26] unsolvable diagrams presented in the top row, solvable in the bottom row

The participant is presented with four stacks of papers on which one line diagram is presented face down. They are instructed to start on the left and work towards the right and that they have ten minutes. One sheet can be taken from the pile at once. Once they turn around the first sheet the time starts. When they fail to solve the diagram, they have to take a new sheet for each trial and put the old one on a discard pile. They may continue to the next pile at any point when they feel they solved the puzzle or give up trying, but they cannot return to a previous pile. They are informed that some diagrams are more difficult than others, but they should try their best to solve them. When ten minutes have passed this is indicated, with the instruction that they may continue if they wish to do so.

RESULTS

At the time of writing the experiment is still ongoing and two young adults and three children have performed the experiment thus far, one in both groups with background noise and the others in silence. The performance on serial recall and Stroop tasks can be seen in Table 1. The performance on the serial recall task is given in percentages of sequences correctly recalled and it is varying between and within the age groups. The outcome of the Stroop task is presented as the delay in milliseconds in reaction time comparing congruent and incongruent trials, with a greater delay indicating a greater Stroop effect. In the children's group the participant that conducted the test with background noise had a higher reaction time than the two children who conducted it in silence. In the young adult group this was the other way around.

Table 1. First results of performance on the recall and Stroop task.

Participant	Sound condition	Total sequence recalled [% of trials]	Delay in reaction time [ms]
Child 1	Silence	43%	86
Child 2	Background noise	97%	237
Child 3	Silence	100%	85
Young adult 1	Background noise	68%	60
Young adult 2	Silence	15%	209

The motivation task showed clear differences between the two age groups as well. The children persisted more than the young adults. The results for the motivation test van be seen in Table 2.

Table 2. First results of the motivation task, number of trials on each puzzle.

Participant	Number of trials			
	Puzzle 1 (unsolvable)	Puzzle 2 (solvable)	Puzzle 3 (unsolvable)	Puzzle 4 (solvable)
Child 1	14	10	3	-
Child 2	13	1	6	6
Child 3	24	4	22	1
Young adult 1	7	2	9	1
Young adult 2	7	1	4	4

DISCUSSION

The duration of the experiment is lengthy with a duration of 60 to 90 minutes including breaks. The balance between breaks and tasks is delicate. The creation of cognitive fatigue is needed for the experiment, but breaks are required for participant comfort. Especially for the children the duration may be challenging. Participants in the young adult group indicated that especially the serial recall task was taxing, but the duration was doable. The children found the experiment enjoyable and not too long.

The first results show varying performance on the serial recall task. In the Stroop task background noise affects performance in opposite ways between age groups. The young adults have a smaller delay when the task is conducted with background noise and the children a higher one. This can be a matter of coincidence due to the small number of people, but it is an interesting result to look further into in the future.

Finally, in the motivation task, the participants believed they could trace the line drawings even if this was not possible and tried a number of times before moving on to the next one. The children persisted much longer and continued past the ten minute mark, whilst the young adults were finished before the time was up. At this time it is not possible to assess the effect of background noise and the success of fatigue manipulation nor the effects of chronic noise exposure. However if the first results are representative a clear differences in persistence is to be expected between age groups in the final results.
Overall, the experiment seems promising. The final results will give more insight in the concept of learned helplessness in relation to noise exposure. With multiple-exposure research becoming more prominent in studying health effects the concept of learned helplessness may be helpful to bridge between physical and social stressors. The perception of control is dependent on the social environment as well. This study will give way for new hypothesis to test in future studies, possible with more social indicators to explore the discussed concepts in a broader exposure perspective.

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