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DESIGN OF A CHILD-APPROPRIATE DUAL-TASK PARADIGM EXAMINING THE INFLUENCE OF DIFFERENT NOISE CONDITIONS ON LISTENING EFFORT IN ADULTS

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ABSTRACT

Hearing in noisy situations is known to be more effortful than in quiet environments for adults and especially for children. Listening effort is defined as the cognitive, attentional, and perceptual processing resources necessary to understand and process speech. This study developed a child-appropriate dual-task paradigm considering aurally accurate sound reproduction to assess listening effort in children and adults. The primary task is a word recognition task and the secondary task is a serial recall task. The influence of different noise conditions on listening effort is studied by examining a no-noise situation and multi-talker babble noise in an anechoic and reverberant environment. In addition, different signal-to-noise ratios (SNRs) are applied. This work presents the first part of the study, where listening effort is examined in adults. The aim is to validate the newly developed child-appropriate paradigm. Consequently, it is expected that the results of the experiment indicate that adults require a higher listening effort in noisy conditions than in the noise-free condition. Additionally, it is studied whether differences in listening effort occur between the noise types and SNRs.

Keywords: *listening effort, dual-task paradigm, noise effects, auditory cognition*

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1. INTRODUCTION

Children's activities during school lessons can be quite diverse: there is, e.g., frontal teaching, silent work, or group work. All these activities involve listening to the teacher or peers as an important aspect of communication. However, noise in schools is disturbing communication and a known problem. Recent research has already shown that noise in educational buildings affects children's learning, e.g., during speech perception [1], their health, and development [2]. Thus, the question arises: How effortful is listening for children at school?

Gagné et al. [3] define listening effort as the quantity of processing resources required for a given listening task that is highly demanding when the listener's motivation to perform is high. There are three common ways to assess listening effort: self-report, behavioural, and psychophysiological [3]. This study examined the behavioural approach by using a dual-task paradigm as it has a high ecological validity. The dual-task approach's underlying theory is that the total cognitive processing resources are limited in capacity and speed leading to limitations in performance when two tasks demand the same processing capacities [4]. Until now, there has been intensive research studying listening effort in adults with a dual-task paradigm [3], e.g., research has shown that listening effort increases with increasing noise level in adults [3]. However, only few studies have investigated listening effort with a dual-task paradigm in children. The aim of this research is to investigate and compare listening effort with the developed child-appropriate dual-task paradigm in adults and children in an acoustically realistic listening scenario. The study presented here examines listening effort in adults in an attempt to validate the paradigm and investigate the effect of different noise conditions.

2. LISTENING EXPERIMENT

2.1 Participants

Twenty-five young adults (mean age 25.84, 32% female) participated in the listening experiment. The inclusion criteria were German speaking, normal-hearing (HL < 25 dB), normal or corrected to normal vision and without ADHD or epilepsy diagnosis. No participants needed to be excluded. The participants were compensated with a 10€-voucher from a local bookstore offering online dispatch.

Figure 1. A participant sitting in the hearing booth, conducting the experiment.

2.2 Experiment Task

The experiment task was a dual-task paradigm. Two tasks were conducted concurrently, the primary and the secondary task. The name primary task is derived from the fact that the participants' main focus should be on this task. In this study, a word recognition task with words from the NORAH wordlist was chosen [5]. For every spoken word there are four pictures representing similar words from which one was the correct choice. The secondary task was a serial recall task, in which seven digits from one to seven had to be remembered. The experiment structure was as follows: First, the seven digits to be remembered were shown. They had to be memorized over the duration of four word recognition trials. Afterwards, the memorized digits were to be responded on a shuffled number field.

2.3 Experiment Procedure

The listening experiment was conducted in the mobile hearing laboratory, a caravan with an integrated hearing booth [6]. The experiment procedure was separated into three parts. First, the informed consent was collected and the data collection took place. Data collection included the personal data, the conduction of an audiometry, the measurement of the size of the participants' heads and the measurement of the headphone-related transfer function (HpTF). Second, the introduction of the experiment started. In the three-parted introduction the participants first practiced only the word recognition (primary) task, then the serial recall (secondary) task and finally the experiment task (primary and secondary task combined). After the introduction, the actual experiment started. It was split into five blocks, each testing a different noise condition. Between each block, the participants had the possibility to take a break. The experiment responses were entered by the participants on a tablet, which was controlled by the experimenter from the main computer. Error rates (ERs), unit-free from zero to one, and response times (RTs), in milliseconds, were assessed for both tasks.

2.4 Close-to-real-life Reproduction

The listening experiment aimed to create a scenario that was as close to being realistic as possible. Therefore, sound production was individualized and a classroom-typical speaker setup was chosen. Sounds were played back binaurally using the head-related transfer function (HRTF) of the artificial head of the Institute for Hearing Technology and Acoustics (IHTA) [7]. The generic HRTF was adapted according to the participants' interaural time differences (ITDs) resulting from their head sizes [8]. In addition, the HpTF was measured and taken into account [9]. The virtual spatial speaker positions corresponded to a typical classroom situation meaning that the spoken words to be recognized were always spoken from the front at 0°. In addition, the noise was played back from positions surrounding the listener: front-right (45°), back-right (135°), back-left (225°), and front-left (315°). The source directivity of all sound sources corresponded to one of a human speaker.

2.5 Noise Conditions

The experiment comprised five different noise conditions: a baseline condition, and two different noise types with two different SNRs each. The experiment's baseline condition did not include any noise. The first noise type used was a German multi-talker babble of four girls (aged eight to nine) reading a fairy tale, which was recorded in an anechoic chamber. The second noise type was based on the first, but was a reverberant multi-talker babble, representing the noise scenario of a typical classroom. Therefore, a typical classroom (Cluster 1) from the Edura Database [10] with T_{30} = 0.75sec was chosen. The binaural room impulse responses on the four diagonal noise positions and on the speaker position were simulated with RAVEN [11]. These were adapted according to the participants' ITDs and convolved with the anechoic multi-talker babble. These two noise types were both tested for two typical classroom SNRs, 0 dB and -3 dB which were chosen according to the study by Klatte et al. [1].

3. RESULTS

A one-way Analysis of Variance (ANOVA) was conducted to analyze the experiment's results each for ER and RT for the primary and the secondary task, respectively. The one-way ANOVA for the primary task showed a significant difference between blocks for ER, $F(3.147) = 25.509, p = .000$ (Greenhouse-Geisser corrected), and for RT, $F(2.802) = 3.871, p = .015$. Thus, a Bonferroni-corrected post-hoc test was conducted for ER and RT. For ER, it revealed significant higher error rates in the block without background noise disturbances compared to the block with:

- anechoic multi-talker babble at SNR = 0 dB: $M_{Diff} = 0.053$, $SD = .011, p = .001$
- anechoic multi-talker babble at SNR = -3 dB: $M_{Diff} = 0.093$, $SD = .013, p = .000$
- reverberant multi-talker babble at SNR = 0 dB: $M_{Diff} = 0.084$, $SD = .007, p = .000$
- reverberant multi-talker babble at SNR = -3 dB: $M_{Diff} = 0.124$, $SD = .014, p = .000$

In addition, a significant higher ER was found for a SNR = -3 dB compared to SNR = 0 dB in the case of the anechoic multi-talker babble ($M_{Diff} = 0.040$, $SD = .012, p = .031$). Also, a significant higher ER was found for the comparison of the anechoic multi-talker babble at an SNR of 0 dB to the reverberant multi-talker babble at an SNR of -3 dB ($M_{Diff} = 0.071$, $SD = .015, p = .001$). For RT, the Bonferroni-corrected post-hoc test revealed a significantly higher RT for the reverberant multi-talker babble at SNR = -3 dB compared to the no noise condition ($M_{Diff} = 0.171$, $SD = .053, p = .006$)). The primary task's results for ER and RT are presented in Figure 2.

The ANOVA for the results of the secondary task was neither significant for ER (p = 0.235) nor for RT (p = 0.389). Looking at the mean ER in the serial recall task ($M = .205$, $SD = .021$), on average, five to six digits were memorized correctly. A qualitative trend is visible showing that error rates increase with increasing difficulty of the noise conditions, which can be seen in Figure 3.

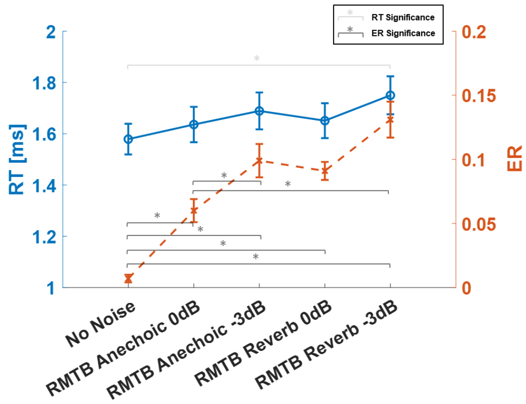

Figure 2. The results for ER and RT for the primary task. Error bars represent standard error.

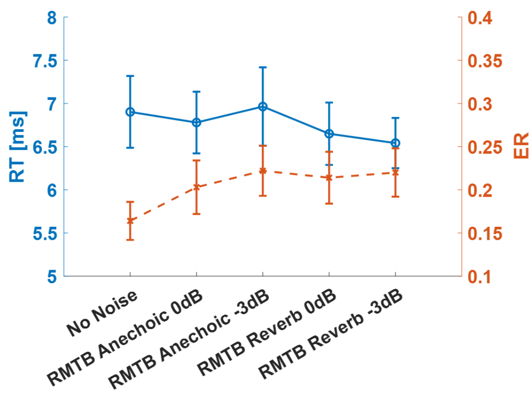

Figure 3. The results for ER and RT for the secondary task. Error bars represent standard error.

4. DISCUSSION

As expected, the performance in the speech recognition task decreases significantly with decreasing SNR. In addition, there is a performance reduction between the anechoic and the reverberant noise scenario. This leads to the conclusion that speech recognition is harder in the reverberant noise condition representing a typical classroom than in an anechoic one. The significantly higher RT for the multi-talker babble noise at an SNR of -3 dB compared to the no noise condition suggests that the word recognition processes were impaired by challenging noise scenarios. These insights show the importance to include reverberant noise conditions in listening experiments to assess listening effort in realistic, classroom-like noise scenarios.

Regarding the validation of the newly developed dual-task paradigm, it was expected that the noise conditions also affect the performance in the serial recall task. Qualitatively, a trend of increasing ER with decreasing SNR and noise type (from anechoic to reverberant) is observable (see Figure 3), but not significant. According to Kahneman's theory [4], the noise load should have resulted in fewer cognitive resources being available for the secondary task, leading to a reduction in performance. This, however, is not observed. There are two explanations for this: either the secondary task was too easy not leading to an exceedance of cognitive resources, or the secondary task was not suited to be used in that dual-task paradigm. The study by Rakerd et al. [12] found effects of listening effort in the serial recall task with speech noise. However, their experiment included relevant speech and nine digits. Here, it was assumed that the serial recall task with nine instead of seven digits would have been too difficult in view of the comparatively low SNR and the dual-task load. Now, considering this study's results for the secondary task and the comparably low ERs, it is advisable to reconduct the experiment using nine instead of seven digits to be remembered in the secondary task. For now, the dual-task paradigm with a seven digit serial recall task could not be validated to measure listening effort in adults as it was done in previous studies [3, 12]. This is because no significant differences were found in the secondary task for the noise conditions. Still, due to significant differences between noise conditions in the primary task, the presence of higher listening effort in the more challenging noise conditions was indicated.

5. CONCLUSION

The results show that word recognition is more challenging in reverberant than in anechoic noise scenarios, which highlights the importance of including reverberant noise conditions in listening experiments. Unfortunately, the newly developed dual-task paradigm could not be validated to measure listening effort in adults. However, the results of the word recognition task showed significant differences between noise conditions indicating a difference in listening effort. Potentially, using a serial recall task with nine instead of seven digits could validate the paradigm which needs to be tested in future studies.

6. ACKNOWLEDGMENTS

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