Exploring the Impact of Room Acoustics on Auditory Selective Attention

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Introduction

In recent years, there has been a growing effort to create experiments that mimic real-life situations, aiming to improve the ecological validity of research. From an acoustic point of view, one step in this direction is using an anechoic binaural reproduction to create a lifelike acoustic environment for participants. A next step is the consideration of room acoustic effects such as reverberation time. Research regarding the effects of room acoustics, specifically reverberation, on auditory perception have found, among others, increased speech reception thresholds [10], decreased ability to differentiate interaural time differences [4] and increased listening effort in children [16]. These phenomena all contribute to the ability to selectively focus ones auditory attention on a specific sound source while filtering distracting sound sources. This mechanism is well-known as the cocktail party effect first introduced by Cherry in 1953 [3]. In a study investigating the impact of low and high reverberation ($T_{60,low} = 0.8s$ and $T_{60,high} = 1.75s$) on the voluntary switching of auditory selective attention (ASA), Oberem et. al [14] found evidence for decreased task accuracy under reverberation as opposed an anechoic baseline condition. In line with the impairment of spatial hearing by reverberation, they also saw an effect on the voluntary switching of attention as well as the differentiation of the spatial position of target and distractor stimuli. Building on these findings, the current study uses a child appropriate version of the paradigm employed by Oberem et. al [14, 2] to replicate the findings and validate the new paradigm.

Despite investigating adult participants, the current study is framed in an elementary school environment to lay a foundation for research on developmental changes in children, since school children face cocktail party - like situations during teaching everyday. Literature suggests that ASA reaches an adult-like level around the age of 8 – 11 years [7, 9] and that children are more affected by noise than adults [11]. However, current research often neglects the effects introduced by room acoustics [11, 18]. While international recommendations for reverberation times in unoccupied classrooms range from 0.3 s for good to 0.9 s for bad rooms [13], real measurements show higher values in unoccupied classroom ranging from $T_{20} = 0.6s$ to $T_{20} = 1.7s$ in a measurement series conducted in Italy [1] and from $T_{30} = 0.35s$ to $T_{30} = 0.97s$ in a measurement series conducted in Germany [12]. Based on these references, the current study investigates the impact of an acoustically favorable and rather unfavorable room on ASA in a listening experiment.

Method

To get more insights on the impact of room acoustics on the voluntary attention switch, a validated child-appropriate paradigm to investigate auditory selective attention in VR [2] was extended by two room acoustic scenarios and their influence was tested using a listening experiment.

Figure 1: Image of the virtual classroom. The participants were placed in the center of the circle of chairs facing the blackboard, where all instructions and the visual stimulus were displayed.

Participants

To get first insights on the validity of the paradigm and create a baseline before testing the actual subject group of children, sixteen adults (age = 21-37 years, M = 26.13 years, SD = 4.34 years, 8 female) participated in the listening experiment. All participants were required to have good German language skills, normal hearing (25 dB[HL] - pure tone audiometry), (corrected to) normal sharpness and color vision. Informed consent was given by all participants.

Reproduction

The acoustic reproduction was realized with a dynamic binaural synthesis including a live rendering of the simulated acoustic room and a generic head-related transfer function using the software Virtual Acoustics

[8] and RAVEN [17]. For each participant, an individual headphone equalization was measured using the ITA-toolbox for Matlab [5]. The visual reproduction was implemented using the Unity game engine and an HTC Vive Pro Eye head-mounted display. The participants were seated in a virtual classroom environment (see Figure 1). During the experiment, they faced a virtual blackboard on which all instructions were displayed. Two HTC Vive controllers with representations of a wing and a paw respectively were displayed in the virtual world for the input.

Experimental Task

During the experiment, the participants were asked to focus their attention on a previously cued position (front, back, left, right, see Figure 2). In each trial, the target stimulus was played from the cued position, while a distracting stimulus was played simultaneously from a different position. Both stimuli played animal names which could belong to flying or non-flying animals. The participants' task was to determine whether the target stimulus played a flying or a non-flying animal name. To match the stimulus length to the reverberation time, the animal names were played in the middle of a matrix sentence, e.g., "Three small bees have flowers." / "Drei kleine Bienen haben Blumen.". The total duration of each sentence was approximately 2 s .

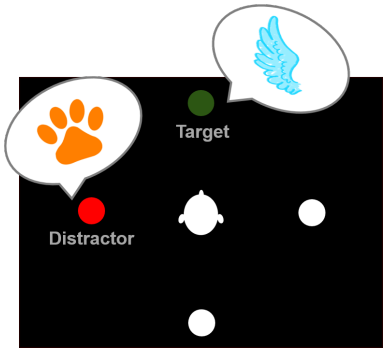

Figure 2: Example of one trial. The target stimulus plays a flying animal name from the frontal position. Simultaneously, the distractor stimulus plays a non-flying animal name from the left position. In the displayed example, the correct answer would be "flying".

Experimental Design

The focus of this study was to investigate the impact of room acoustics on the auditory selective attention. Therefore, two classroom scenarios were created using the RAVEN plugin for SketchUp [17, 15] based on the virtual classroom model introduced in a previous study by Breuer et al. [2] (see Fig. 1). Based on the recommendations of the German DIN 18041:2016 standard [6], two acoustic treatments were proposed. One scenario was designed to have rather favorable room acoustic properties ($T_{30} = 0.48s$), while the other one was expected to be more challenging ($T_{30} = 1.52s$).

Results

To evaluate the performance, error rates (ERs) and reaction times (RTs) were measured for all participants. Analyses of variances (ANOVAs) were conducted for the reaction times and error rates separately. For brevity reasons, only the main effect of reverberation is reported.

The ANOVA revealed a significant main effect of reverberation in error rates ($F(2, 28) = 8.985, p < 0.001, \eta_p^2 = 0.391$). Bonferroni-adjusted post-hoc tests revealed significantly higher error rates in the highly reverberant condition as opposed to the low reverberant and anechoic conditions. This effect was not found for reaction times.

No interactions between the room acoustic modifications and any other experimental factor were found.

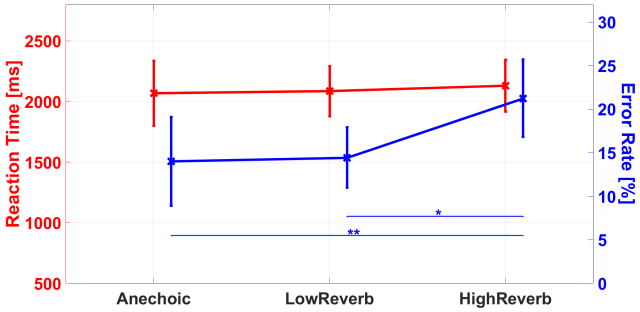

Figure 3: Results for the main effect of reverberation. Reaction times in ms are displayed in red and error rates in % in blue. Mean values are accompanied by the 95 % confidence intervals.

Conclusion

This study aimed at investigating the influence of room acoustics, specifically reverberation, on auditory selective attention. To this extent, two classroom scenarios were created using RAVEN [17]. One scenario was designed to have rather favorable room acoustic properties ($T_{30} = 0.48s$), while the other one was expected to be more challenging ($T_{30} = 1.52s$). In a listening test on the auditory selective attention switch using 16 adult participants, both scenarios were live rendered using the RAVEN integration for Virtual Acoustics in Unity.

While reaction times remained unaffected, participants made significantly more errors in the poor room acoustic scenario compared to the favorable room or no room acoustic simulation. These findings are in line with previous research on adults [14]. Contrary to previous studies, the results do not reflect any interaction of reverberation and spatial separation of target and distracting sound sources. However, questionnaires conducted after the experiment suggest a lower perceived speech intelligibility and higher perceived listening effort under high reverberation and should be considered as an influencing factor on ASA in further studies.

Overall, the results support that considering room acoustic properties in psychoacoustic research is essential to draw conclusions on real-world listening situations. It further underlines the importance of optimizing room

acoustic properties in schools is essential to support learning, especially since the detrimental effects are expected to be worse in children. Finally, the presented study validated the extended ASA paradigm using adult participants and serves as a baseline for further studies including the actual target group of school children.

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