# THE EFFECTS OF THE SOUNDFIELD SYSTEM ON COGNITIVE PERFORMANCE OF ELEMENTARY SCHOOL CHILDREN

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**ABSTRACT**

The purpose of this study was to analyse the effects of a Sennheiser Soundfield System on cognitive performance of school children within a classroom with average room acoustic conditions. The speech material used for the performance tests was recorded twice in the original classroom, with and without the aid of the soundfield equipment. This material was presented to the children over headphones during a laboratory experiment. This realistic simulation enabled performance data to be investigated under controlled laboratory conditions. The results show noticeable improvements of subjective speech intelligibility and working memory performance with the test material recorded through the Soundfield System. In all three performance tests, significant improvements were shown when the speech material recorded via the Soundfield System was presented. The effect seems to increase with task complexity: Within a phoneme discrimination task, improvements were noted but these were relatively small with regards to the total values obtained. Additionally, the improvement was only found with younger children. However, considerable improvements were found with both age groups for a short-term memory task (identification and storage of heard digits) as well as for a task requiring the execution of complex oral instructions (identification, storage and processing of heard sentences).

## 1 INTRODUCTION

International studies have proven that an increased level of stress occurs for children and teachers when exposed to classroom noise (Schick, Klatte & Meis 1999). Learning in loud, reverberant rooms is made difficult by poor speech intelligibility. If the background noise level is high compared with the speech signal, the speech will be masked, causing information to be incorrectly understood or missed completely. The same holds true for speech signals which arrive at the listener distorted due to poor acoustical room conditions. This is especially the case for listeners positioned in the back of reverberant rooms, relatively far away from the speaker. Under such conditions, listening is very strenuous and children tire quickly. The consequences of this problem become clear when one remembers the importance of listening during instruction. It has been estimated that children spend about 75% of class time listening (Berg & Imhoff 1996).

The detrimental effects of noise on teachers was recently shown in extensive interview studies on stress effects at work for this labour group (Rudow 2000). Noise was named one of the most essential causes of stress. Instructing in classrooms with poor room acoustic quality means that teachers must constantly speak with a raised voice, repeat themselves often and admonish children to be quiet. Working in noisy environments is extremely strenuous over time, and leads to throat, voice, and hearing difficulties**,** not to mention disinclination and annoyance.

The solution to these problems can be offered by different measures. The reverberation time can be improved substantially by means of construction such as the installation of sound absorbing ceilings and/or walls. Speech intelligibility in classrooms can be improved by installing electro-acoustical equipment or systems like the Soundfield System. Systematic and significant verification of the effectiveness of such interventions has been rare up to now. The purpose of this study was to analyse the effects of a Soundfield System on cognitive performance of school children under well defined room-acoustical conditions.

### 1.1 Hypotheses

In this study, the effects of changes in classroom acoustics due to the installation of a Soundfield System on cognitive performance of school children was to be tested. The point of interest was: Is there an effect and if so, how can it be quantified? It is presumed that younger children, whose speech development has not yet been completed, are especially prone to speech intelligibility difficulties in classrooms. Consequently, they should gain most from an improvement of acoustic conditions. Subjects (Ss) chosen were therefore elementary school children in the second and third grades.

## 2 METHODS

The speech material needed for the performance tests was recorded twice in the same classroom, once “untreated” without the Soundfield System (control condition) and then with Soundfield equipment (Soundfield condition). These recordings were done in a classroom at an elementary school in Oldenburg.

After mixing the recorded sounds, the test material was presented to the children in a laboratory experiment via headphones. The recording and replay techniques implemented guaranteed that each sitting position in the laboratory was an exact reconstruction of the impression a pupil sitting in the classroom would have. This realistic simulation of listening conditions enabled performance data to be investigated under controlled laboratory conditions.

### 2.1 Characteristics of the Classroom and Acoustic Parameters

In the elementary school, the frequency dependent reverberation time has been determined for a total of three classrooms. Using this room characteristic, one of the rooms has been chosen for the recordings of the laboratory experiment. With respect to their ground plan, volume, and form, all three rooms were identical. The ground plan is almost square in form (8 m x 8 m). The ceiling has a slight slant and a height of about 2.90 m to 3.60 m.

Besides the reverberation time as a global acoustic quantity (500-2000 Hz: 0,99 s), other non-statistical acoustic parameters according to DIN EN ISO 3382 were determined such as ”Deutlichkeit” $D_{50}$,= 56%, Speech Transmission Index STI and RASTI =0.63, Loss of Articulation for Consonants $Al_{cons}$=48% for the pupil’s seat while playing sound material (without the Soundfield System) from the position of the simulated teacher. Values between good and satisfactory values were determined for speech intelligibility.

## 2.2 Recording of Test Material

The speech material was read aloud by a trained speaker in the sound insulated and highly damped laboratory of the Institute for Research into Man-Environment Relations and was recorded with a DAT-Recorder (Sony DTC-ZE700). This was done so that the original signal did not contain any signs of reverberation or acoustic influences caused by the room. The available CD of the OlKi Test was used for the Phoneme Discrimination Test.

### 2.2.1 Recording the Wanted Signal

The following two recorded materials were played twice successively for the conditions to be compared. Teacher in the classroom without electro-acoustical support (as follows “control condition“) and teacher in the classroom supported by the electro acoustic Soundfield System with four loudspeakers (as follows “Soundfield condition“). For the control condition, the sound signal was amplified with a HiFi amplifier (HK AVR 3000) and played monaurally via one loudspeaker (Yamaha-G30 MKII), which was located at a height of approx. 120 cm (the level at which a sitting teacher’s head would be).

The $L_{AEQ}$ at a distance of 1 m from the speaker was 60 dB. In the case of the “Soundfield condition”, the signal was additionally amplified by the Soundfield System (Sennheiser EMP 2015) and was played via speakers (Type DAS Factor 5) mounted in the corners of the room at a height of approx. 150 cm. The $L_{AEQ}$ at a distance of 1 m from every Loudspeaker was 66 dB. It must be taken into account that not only the four additional speakers contribute to the overall sound level, but also the unchanged teacher played at 60 dB.

With an artificial head (Neumann KO100) at the pupils position, the signals were recorded using DAT tape. These recordings hereby represent the acoustic situation a pupil is exposed to at the examined position if a speaker articulates at a normal voice level and volume in the classroom. No pupils were in the room so that the recordings contain only the characteristic reverberation of the room and no other noise.

Without playing the wanted signal, noise made by eight elementary school girls aged 8-10 in a typical working group situation was recorded (58 dB LAEQ). An approximately 15 s piece was taken from the sound material which had neither pauses nor distinct peaks in volume or obvious spoken speech which could be understood. The chosen part of the noise signal was repeated several times in a loop and was then mixed with the wanted signal. In the Soundfield condition, the levels were left unchanged. In the control condition, the wanted signal level was raised to 6 dB higher before being mixed with the noise signal in order to simulate the usual raising of voice in a teaching situation. In the experiments, this is equivalent to the $L_{AEQ}$ of 66 dB at a distance of 1 m from the speaker. The teacher was granted a bonus of 6 dB, because one can assume that the voice will be raised as high as that in teaching situations with interfering noise. This correction was not made in the Soundfield condition, since the raising of one’s voice is not expected when the Soundfield System is amplifying the voice. Since the same material for wanted and interfering unwanted portions was used in both the control and the Soundfield situations, two identical combinations of wanted and unwanted signals result. They only differ in the acoustic quality of the wanted signal (level, clarity and distinctiveness of the teacher’s voice). In this way, there are no variations of the teacher’s voice or variations of the noise disturbances from the students to be considered between the conditions.

The signal to noise ratio amounts to 3 dB in the control condition and 6 dB in the Soundfield condition. The difference of level between both conditions for the overall sound signal is 2 dB. The mixed signals (series of numbers, OlKi sentences, Knuspel instructions) were converted into separate Wave-Files and integrated into the control software for the experiment (Power Point presentations).

## 2.2 Subjects

Thirty-eight children from an elementary school in Oldenburg participated in the experiment, 20 second-graders and 18 third-graders. They were aged between 7 – 11 years with a median of 8 years and 10 months.

### 2.3 Experimental Tasks

#### 2.3.1 Auditory Discrimination Test

Based on the Oldenburger Kinderreimtest (OlKi), a computer-aided procedure was constructed which measures the discrimination between similar word-trigrams. Subjects were simultaneously presented three illustrations of familiar objects whose German names differ only in one sound (for example “Rose” – “Dose” – “Hose”).

All three objects appeared next to each other on the screen. At the same time, the children heard an instruction like “Please point to (test word)”. Thirteen trials were conducted in each sound condition. The task was to mark the position of the appropriate object with a cross on a prefabricated answer sheet. Transferring the spatial arrangement on the screen onto the answer sheet was intentionally designed to be simple. Even the youngest subjects had no difficulties with this task.

#### 2.3.2 Short-term Memory

In this task, sequences of spoken digits were presented to the subjects. The sequences varied in length from 3 to 6 digits. After presentation of the last digit, the children had to fill in the sequence in the correct order on a prefabricated answer sheet. Each sequence length was presented three times, so there was a total of 12 series presented in each experimental block. The evaluation took place in a very strict manner; only the digits reproduced in the appropriate position were considered correct.

#### 2.3.3 Carrying Out Complex Oral Instructions

This test is based on a German reading test for elementary school children: Knuspels Leseaufgaben, Subtest 1 (Marx 1998). A computer version with two parallel test forms was developed. A speaker gives complex instructions that children must carry out on their answer sheets (for example: “What is your last name? Write just the first three letters of your last name in upper-case letters on the line.”). The evaluation took place with the use of a key provided by the test (summed scores were tallied on the basis of the number of correctly done elements per instruction).

We used this task since it involves a heavy load on verbal working memory, concerning both storage and processing resources. If children need much cognitive capacity to understand sentences, there will be less resources available for storage and processing. Improving speech intelligibility with the Soundfield System should therefore result in an improvement of performance.

### 2.4 Procedure

The children were tested in groups of four in a sound-insulated and highly damped room at the Institute for Research into Man-Environment Relations. By placing furniture (tables, chairs, bookshelves and screen) appropriately, a setting similar to that of a classroom was realised. Visual test material was projected from a personal computer outside the laboratory over a video projector onto the screen. Acoustic material was presented via headphones (SENNHEISER HE 60/HEV 70) from the personal computer. The experimental design was characterised by repeated measurements, i.e. every child completed all test tasks under both sound conditions (Soundfield and control conditions). Therefore, parallel forms A and B were constructed for each test. Half of the subject groups completed test form A under the Soundfield condition and form B under the control condition and vice versa. Every task began with detailed instructions and several trial exercises. Test order and sound conditions were balanced among the groups.

## 3 RESULTS

The data was analysed with ANOVA, the factors being sound condition (within-subjects; sound vs. control) and grade (between-subjects; 2$^{nd}$ vs. 3$^{rd}$). The significance level was set at $\alpha = 5\%$.

### 3.1 Phoneme Discrimination Test

In this test, significant effects were found with regards to sound conditions and age. There was also a significant interaction between these factors ($F(1.36) = 5.1$; $p < 0.05$, respectively $F(1.36) = 5.14$; $p < 0.05$). The children made less mistakes when they were presented the verbal material recorded with the Soundfield System (see Figure 1).

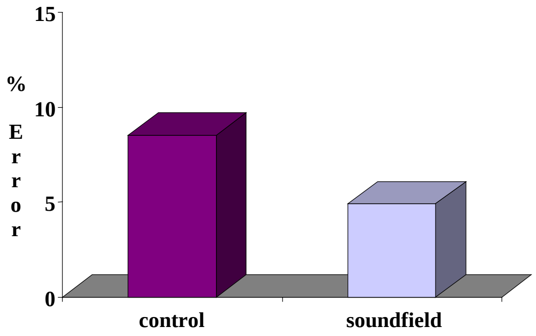


Figure 1: Phoneme Discrimination Task (following OlKi): Mean error Percentages for two Listening Conditions

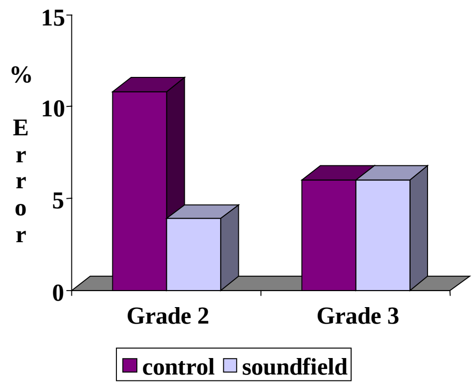


Figure 2: Phoneme Discrimination Task - Error Percentages with Respect to Grade and Listening Condition

This effect is small when considering the number of absolute mistakes. Performance was also good in the control condition**.** This indicates that speech intelligibility in the untreated classroom was not optimal but not extremely bad either. This fits with the desired criteria for the study which was to replicate a situation in a typical classroom. Closer inspection of data reveals that the Soundfield System's positive effect was limited to younger children ($2^{nd}$ grade; see Figure 2). Third-graders did not show any differences in performance depending on the sound conditions. They hardly made any mistakes in both conditions. This result can be explained by the rapid growth of vocabulary during the first school years. Younger children require more clarity than older students in order to decode heard speech flawlessly. Therefore, they particularly benefit from the improvement of speech intelligibility.

### 3.2 Short-Term Memory: Reproduction of Spoken Digits

This task also indicated a significant effect from sound conditions ($F(1.36) = 22.5$; $p < 0.001$). Children made less mistakes when the digits to be remembered were recorded via the Soundfield System (see Figure 3 and 4 [serial position]). This holds for both age groups.

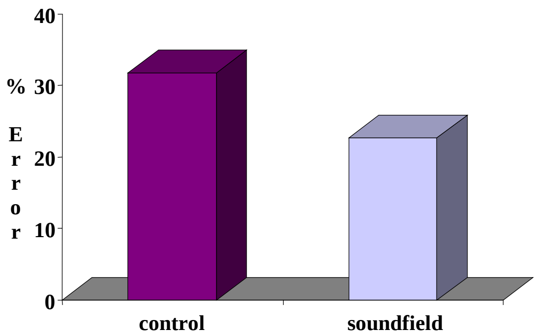


Figure 3: Short-term Memory for Spoken Digits: Error Rates with Reference to Grade

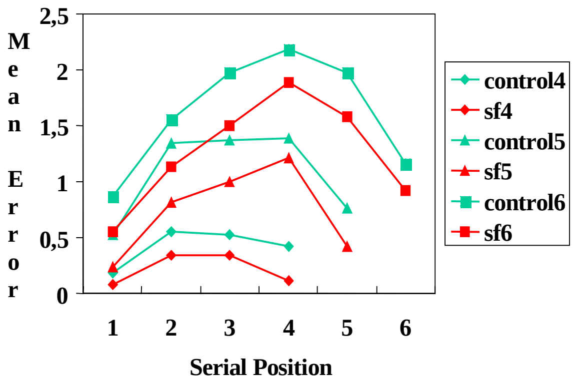


Figure 4: Effects of Listening Condition on Serial Recall of Digits: Error Rates with Reference to Serial Position

### 3.3 Knuspels Leseaufgaben (Knuspel's Reading Exercises)

This task also reveals a highly significant effect from sound conditions ($F(1.36) = 19.1$; $p = 0.001$). Performance was about 8% better when the instructions recorded by the Soundfield System were presented. This holds for both age groups in the same way (see Figure 5); the interaction between the factors "sound condition" and "grade" was not significant ($F(1.36) < 1$).

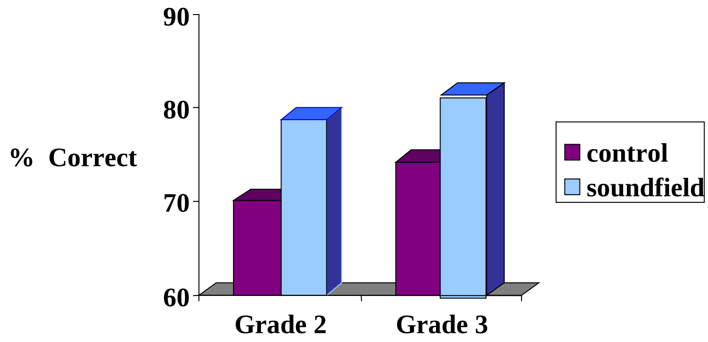


Figure 5: Executing complex instructions: Mean percentages of correct responses with reference to grade and listening condition

## 4 CONCLUSION

In all three performance tests, significant improvements of performance were attained when the Soundfield recordings of the speech material were presented. The effect seems to increase with task complexity: The phoneme discrimination test, only requiring the identification of speech sounds, showed significant but small effects which were confined to the younger children. On the other hand, very distinct effects were noticed in both age groups for the short-term memory task (identification and storage) as well as for the complex instructions task (identification, storage and processing). This confirms the assumption that the improvement of speech intelligibility has positive effects, even if identification of verbal information is already successful under given acoustic conditions in a room (third-grades had no trouble with phoneme discrimination). Therefore, when judging the acoustic quality of a room, it is obviously not enough to simply apply a speech intelligibility test or to ask learners on how well they perceive speech. All in all, these results allow the conclusion that improving acoustic conditions, as the Soundfield System does, reduces hearing effort remarkably, leading to less fatigue and allowing more effective use of the cognitive resources required for central processing of heard information. In addition, the results emphasise the significant meaning of optimal hearing conditions for elementary school children's success at learning. How these optimal hearing conditions are to be reached depends on the individual acoustic circumstances of the classroom and on the type of instruction taking place. By reinforcing the share of direct sound, the Soundfield System is clearly an effective method for improving speech intelligibility. The effectiveness of different measures to improve room acoustics besides the Soundfield System, for example the installation of acoustic wall or ceiling panelling or carpet, should be proven in practice in various teaching situation.

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