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Research Article

An assessment of Effects of noise and reverberation on speech perception and listening in lecture Halls

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Abstract

The effects of lecture hall noise and background speech on speech perception, measured by word-to-picture matching, and listening comprehension, measured by execution of oral instructions, were assessed in a lecture hall setting. Lecture hall noise evoked a reliable disruption in Students' speech perception even under conditions of short reverberation. RT had no effect on speech perception in silence, but evoked a severe increase in the impairments due to background sounds in all age groups. For listening comprehension, impairments due to background sounds were found in the Students, but a stronger effect on listening comprehension, remaining significant when speech perception was controlled. This indicates that background speech affects higher-order cognitive processes involved in Student's comprehension. Student´s ratings of the sound-induced disturbance were low overall and uncorrelated to the actual disruption, indicating that the Students did not consciously realize the detrimental effects.

Keywords: Speech perception, Noise, Lecture Hall

INTRODUCTION

The present study investigates the effects of reverberation and noise on speech perception and listening comprehension in children and adults in an everyday-like setting. In professional educational settings such as schools, preschool facilities and other learning environments, information is predominantly presented orally to the learner. Thus, listening is an important precondition for successful learning, and the acoustic conditions under which instruction takes place play a major role in learning facilitation. This is especially true for younger pupils, as the ability to recognize speech under adverse listening conditions does not reach adult levels until the teenage years. Consequently, the issue of classroom acoustics has gained much interest in recent years(Shield and Dockrell, 2003). The major determinant of room acoustics is reverberation time (RT). RT is the time in seconds required for sound pressure at a specific frequency to decay 60 dB after the sound source has stopped. Long RTs reduce the clarity of the speech and thereby intelligibility. This is because the speech signals reaching a listener are a mixture of direct energy and time-delayed reflections. In addition, when RTs are too long, undesired sounds (such as moving chairs or scraping feet) remain longer in the room and consequently, noise levels increase.

Current standards in the United Kingdom, Germany and the United States, as well as the World Health Organization (WHO) guideline values for schools (Berglund, 2008) explicitly recommend that RTs do not exceed 0.6 seconds for classrooms with a volume of about 250 m3, and that ambient noise levels in the empty rooms do not exceed 35 dB(A)(Crandell and Smaldino, 2000). However, these guidelines are often neglected when schools are built or reconstructed, and teaching and learning often takes place in reverberant and noisy classrooms. (Schick and Klatte, 1999).

Psychoacoustic studies have shown that children are more affected by unfavorable acoustic conditions than adults (Talarico and Abdilla, 2007) Most of these studies were conducted in laboratory settings and focused on effects of noise and reverberation on speech perception, as assessed through identification of single words or syllables. In general, it was found that young children's performance in such tasks does not differ much from that of adults if the signals are presented in silence and without reverberation. In contrast, if the signals are distorted through noise and/or reverberation, performance is worse in children as compared to that of adults.

During school lessons, however, the listening tasks faced by the children are much more complex, as they involve not only identification, but also short-term storage and mental processing of the spoken information. There is evidence that noise and reverberation may affect such higher-order cognitive functions involved in comprehension. Studies with adults have shown that even under conditions of perfect intelligibility of the speech signals, background sounds and reverberation impair memory for spoken items,(Schlittmeier and Hellbrück, 2008) listening comprehension, (Gordon and Daneman, 2009) and memory for spoken lectures. Similar effects were reported for elementary school children. These effects have been attributed to a reduction of the cognitive resources available for storage and processing of the information due to increased listening effort or to the background sounds specific interference with short-term memory representations “Irrelevant Sound Effect” (Schlittmeier and Hellbrück, 2008). Thus, perfect speech intelligibility does not exclude noise-induced impairments in complex listening tasks, such as those faced by children during school lessons. Taking together these issues, it seems obvious that experimental research exploring the effects of noise and reverberation under conditions which closely resemble those given in actual classroom settings is needed to understand the impact of acoustic factors on school learning, and helps to assess the cost-benefit ratio of acoustic improvements in schools.

There is some evidence that children’s performance in complex tasks is more impaired by speech noise when compared to non- speech sounds. This has been shown for listening tasks and for tasks involving storage and processing of visually presented items. In the current study, the effects of background speech (female voice reading a newspaper article) and classroom noise without speech on speech perception and listening comprehension were investigated in two virtual classrooms in first- and third-grade children and adults. The virtual classrooms simulated the RTs of a real elementary school classroom before and after acoustic renovation. Thus, one of the virtual rooms had good and one had poor interior acoustics according to the German Industry Norm DIN 18041 (2004).[5]. It was hypothesized that children are more affected than adults by adverse listening conditions, and that impairments in a complex listening task occur even under conditions of high speech intelligibility.

THEORY AND METHOD

Speech perception was assessed by means of a word-to-picture matching task requiring discrimination between similar sounding words. Twelve lists of three similar-sounding common and concrete German nouns were created (e.g., *Fee* [fe:], *Reh* [re:], *See* [se:]). Each item was represented by a simple and easy-to-name picture. In each trial, three pictures representing the similar-sounding words were presented to the participants. Two seconds after onset of this slide, a spoken word corresponding to one of the three objects was presented. The participants had to mark the appropriate picture on the prepared answer sheets. Two parallel versions of the task were created which differed only in the order of the items. In each sound condition, 24 items were presented. Prior to the task, all pictures were shown to the participants and named by the experimenter.

Listening comprehension was assessed by means of execution of complex oral instructions. This is a task which is used in most of the standardized tests of language comprehension in Germany. For the present experiments, a paper and pencil version of this kind of task was constructed. Complex oral instructions were presented to the participants (e.g., “Put a cross under the book that lies next to the chair”). The task was to carry out the instructions on prepared response sheets on which, for each instruction, a row with an arrangement of small black-and-white drawings, representing the target objects and distractor stimuli, was depicted. The answer sheets were available to the participants throughout the task. Participants were thus free to prepare execution of the instructions concurrent to their presentation. After offset of the instruction, 18 seconds were given to complete the entries on the response sheets.

Scoring was based on the number of elements correctly executed according to the given instruction. This was realized by means of an *a priori* constructed manual providing unequivocal scoring rules for each individual item. For each age group, two parallel versions of this task with different, but formally similar instructions were constructed. Pilot studies ensured equal difficulty of the parallel test versions and equal task difficulty across the age groups. The latter resulted in longer and more complex instructions for adults as compared to children. Since the instructions were accompanied by background sounds, adults were also longer exposed to a higher “dose” of irrelevant sounds. However, as we expected stronger background noise effects for children, this works against our hypothesis.

Disturbance ratings: Noise-induced disturbance during task performance was rated in adults by means of a 5-point category scale. Participants had to complete the sentence “My performance in this task was by the background sound” with one of five response alternatives reaching from “not at all disturbed” to “most disturbed”. For the children, a scale with smileys was constructed which differed in the form of the mouth.

Sounds

Speech signals: The words and instructions were read by a professional male speaker in a sound-attenuated laboratory and recorded with an artificial head system (Cortex MK2) with a sampling rate of 44.100 Hz and 16-Bit-resolution.

Background sounds: Performance was measured during silence and two different sound conditions: background speech, and classroom noise without speech. The background speech consisted of a Danish newspaper article read by a professional female Danish speaker. The record contained no reverberation and no remarkable changes in loudness and intonation. The classroom noise without speech contained typical classroom sounds such as moving chairs, scraping feet, coughing, leafing through papers, rattling with writing utensils and opening and closing school bags. The record was produced in a sound-attenuated laboratory room equipped with school furniture with assistance of 12 children and adults using an artificial head system (Cortex MK2).

For the speech perception task, each word was mixed with a 3-second episode of the background sounds such that word onset was 1 second after onset of the background sound. For the sentence comprehension task, the background sounds started 1 second before onset of the instructions and endured until the end of the 18 seconds execution phase.

RESULTS AND DISCUSSIONS

Speech perception in noise and reverberation as a function of age

One of the first-grade children from the condition classroom noise/favorable room performed at chance level in the silent control condition of the task, indicating a misunderstanding of the instruction. The data from this participant were discarded from the analysis.

In a first step, the effects of Age, Reverberation and Seat row on performance in the silent control condition were analyzed by means of a three-factorial analysis of variance (ANOVA). The analysis yielded a significant main effect of Age [$F(2, 285) = 49.86$, MSE = 24.5, partial $\eta 2 = 0.26$; $P < 0.001$], with mean percent correct M = 92.13 (SD = 6.85), M = 96.04 (SD = 4.57) and M = 99.29 (SD = 1.9) for first graders, third graders and adults, respectively, a significant main effect of Seat row [$F(2, 285) = 3.99$, MSE = 24.5 partial $\eta 2 = 0.03$, $P < 0.05$] (despite only marginal differences in mean percent correct scores: M = 94.8, M = 95.7 and M = 96.6 for the first, second and third seat rows, respectively), but no effect of Reverberation and no interactions ($F < 1$ in all cases). Concerning the age effect, Bonferroni-corrected *post hoc* tests confirmed that the first graders performed worse than the third graders, who in turn scored lower than the adults ($P < 0.001$ in both cases). Thus, with the current signal level and quality, speech perception in silence was relatively high and unaffected by reverberation in each of the age groups.

As a measure of impairment evoked by noise in the two virtual rooms, difference scores were calculated for each participant by subtracting identification performance in noise from performance in the silent control condition. This measure was used as dependent variable. Separate 3-factorial ANOVAs were performed for each sound group (i.e., the group which performed the task with background speech and the group which performed the task with classroom noise) with Age, Reverberation and Seat row as between-subjects factors.

For background speech, the analysis revealed significant main effects on all factors: Reverberation [$F(1, 135) = 65.7$, MSE = 110.13, partial $\eta 2 = 0.33$, $P < 0.001$]; Seat row [$F(2, 135) = 32.33$, MSE = 110.13, partial $\eta 2 = 0.32$; $P < 0.001$] and Age [$F(2, 135) = 6.48$, MSE = 110.13, partial $\eta 2 = 0.09$, $P < 0.01$] and significant interactions between Age × Row and Row × Reverberation [$F(4, 135) = 2.47$, MSE = 110.13, partial $\eta 2 = 0.07$, $P < 0.05$, $F(2,135) = 3.79$, MSE = 110.13, partial $\eta 2 = 0.05$, $P < 0.05$]. Importantly, there was no Age × Reverberation interaction found [$F(2, 135) = 1.83$, $P < 0.16$]. The three-way interaction was also non-significant ($F < 1$). Means and standard errors of the difference scores with respect to age in the favorable and unfavorable room conditions are given in Figure 2 (for each seat row) and Figure 3a (pooled across seat rows).

As is evident from the figures, the magnitude of the disruption due to background speech was much more pronounced in the unfavorable as compared to the favorable room, and more pronounced in the children as compared to adults. The effect of seat row was more pronounced in the children as compared to adults, and more pronounced in the unfavorable as compared to the favorable room. The age differences in the impairment were further explored by separate analyses for each reverberation condition. These proved stronger impairment in the children when compared to adults in the unfavorable room [$F(2, 65) = 5.3$; $P < 0.01$], whereas in the favorable room, the groups did not differ [$F(2, 70) = 1.7$; $P < 0.19$].

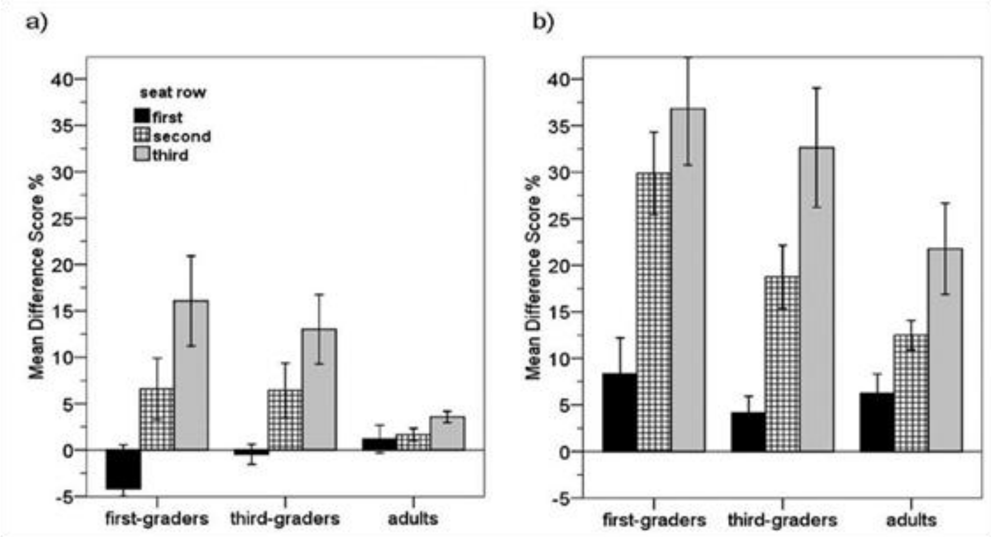

Figure 1. Percentage drop in speech perception performance in the presence of background speech (percent correctly identified words with competing speech subtracted from percent correctly identified words in silence) with respect to seat row and age. Error bars represent standard errors of the mean: (a) favorable room (b) unfavorable room.

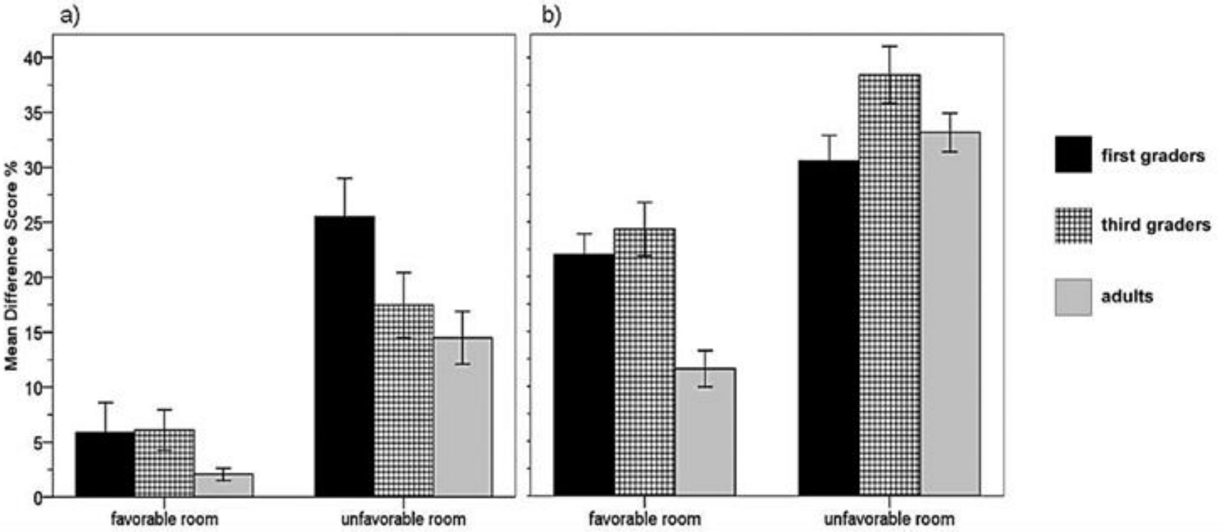

Figure 3. Percentage drop in speech perception performance in the presence of background speech (a) and classroom noise (b) with respect to age and reverberation (pooled across seat rows). Error bars represent standard errors of the mean.

For classroom noise, the analysis revealed significant main effects for all factors, Reverberation [$F(1, 132) = 75.37$, MSE=100.52, partial $\eta2 = 0.36$, $P < 0.001$]; Seat row [$F(2, 132)= 10.07$, MSE = 100.52, partial $\eta2 = 0.13$; $P < 0.001$] and Age [$F(2, 132) = 10.07$, MSE = 110.13, partial $\eta2 = 0.13$, $P < 0.01$], as well as a significant interaction between Age and Reverberation [$F(2, 132) = 4.89$, MSE = 100.52, partial $\eta2 = 0.07$ $P < 0.01$]. No other interactions were found to be significant. Means and standard errors with respect to age and reverberation are given in Figure 3b. *Post hoc* tests confirmed stronger impairments in both groups of children as compared to adults ($P < 0.01$). However, the age effect varied with reverberation. As Figure 3b indicates, the two-way interaction between Age and Reverberation results from the fact that the advantage of the adults in the favorable room is eliminated in the unfavorable room. Separate analysis for both room conditions confirmed that the disruption in both groups of children was more pronounced when compared to adults in the favorable room ($P < 0.001$ in both cases). In the unfavorable room, the magnitude of the disruption in the adults did not differ significantly from that found in the first and third graders.

In order to compare the magnitude of the disruption evoked by the two sounds, a three-way ANOVA was performed with the between-subject factors Age, Type of sound and Reverberation. This analysis yielded effects of Age and

Reverberation in the same direction as in the earlier analyses. For the additional variable, Type of Sound, a main effect was found as well [$F(1, 291) = 117.7$, MSE = 139.47, partial $\eta 2 = 0.29$, $P < 0.001$]. Interactions were found for Type of sound Age [$F(2, 291) = 3.81$, MSE = 139.47, partial $\eta 2 = 0.03$, $P < 0.05$] and between all three factors, [$F(2, 291) = 4.88$, MSE = 139.47, partial $\eta 2 = 0.03$, $P < 0.01$]. No other interactions were found to be significant, including Age × Reverberation ($F < 1$). Thus, performance was more disrupted by classroom noise as opposed to background speech, and the effect of reverberation did not differ with age and type of sound. As Figure 3 indicates, the three-way interaction was due to a reversal of the age effects in the disruption due to classroom noise versus background speech in the two reverberation conditions: In the favorable room, there was a marginal age difference in the background speech condition, but a strong age effect in the classroom noise condition. In the unfavorable room, a clear age effect emerged in background speech condition, whereas no clear developmental trend was evident with classroom noise. The two-way interaction between Type of sound and Age was due to the stronger effect of age in the background speech condition, although this was only evident in the unfavorable room.

The analyses described above proved a considerable increase in the noise-induced impairments with reverberation. As outlined earlier, as a result of reverberation, background sound levels were about 3 dB higher in the unfavorable as compared to the favorable room. In order to explore whether the effect of reverberation is solely caused by the increase in noise levels, the reverberation effect was re-analyzed with background sound level at the participants' seat position included as covariate. For both classroom noise and background speech, the effect of reverberation was eliminated when noise level was controlled ($P < 0.17$ and $P< 0.13$, respectively).

Thus, children's listening comprehension was significantly impaired by background speech and classroom noise, whereas adults were unaffected. The disruption found in the children was further explored by means of a three-factorial ANOVA with the between-subject factors Age (first vs. third graders), Type of sound and Seat row. The analysis revealed significant main effects on all factors [Age: $F(1, 90) = 7.45$, MSE = 206.48, partial $\eta 2 = 0.08$, $P < 0.01$; Type of sound: $F(1, 90) = 6.07$, MSE = 206.48, partial $\eta 2 = 0.06$, $P < 0.05$; Seat row: $F(2, 90) = 10.6$, MSE = 206.48, partial $\eta 2 = 0.19$, $P < 0.001$], but no interactions ($F < 1$ in all cases). First graders were more affected by the background sounds than third graders. Irrespective of age, background speech evoked a stronger disruption in listening comprehension when compared to classroom noise. This finding is important, since, as outlined above, speech perception was more impaired by classroom noise than by background speech. Thus, background speech and classroom noise seem to have differential effects on speech perception and listening comprehension in children. These potential interactions were explored further by including Type of task (speech perception vs. listening comprehension) as independent variable.

In the present study, the effects of classroom noise and background speech on speech perception and listening comprehension were investigated in children and adults in a classroom-like setting. Speech perception was assessed by means of a word-to-picture matching task requiring discrimination between similar-sounding words. Listening comprehension was assessed by means of a paper-and-pencil task requiring the execution of complex oral instructions. For speech perception, the impact of reverberation also was explored. To achieve this aim, testing was done in two virtual classrooms, simulating the RTs of a real elementary school classroom before and after acoustic renovation. Mean RTs were 0.47 second in the favorable and 1.1 second in the unfavorable room condition. As a measure of impairment due to noise or due to the combination of noise and reverberation, difference scores were computed for each participant by subtracting performance in noise from performance in silence. For each of the four task × sound combinations, the difference scores differed significantly with age, confirming stronger impairment in the children when compared to adults.

For speech perception, reverberation had no effect when the task was performed in silence, but led to a severe increase in the disruption evoked by the background sounds. Background speech had a weaker effect on speech perception when compared to classroom noise. The age effect in the noise-induced impairments varied with type of sound and reverberation: in the favorable room, there was a marginal, non-significant age difference in the impairment evoked by background speech (6% drop in both groups of children and 2% in adults), but a strong age difference with classroom noise (22, 24, and 12% drop in first graders, third graders and adults, respectively). In the unfavorable room, a clear age effect was found in the background speech condition (25, 17, and 14% drop in the first graders, third graders and adults, respectively), whereas no clear developmental trend was evident with classroom noise. With the latter, the drop in performance exceeded 30% in each of the age groups. For background speech, the impact of the listeners' distance from the signal source on the sound-induced disruption was stronger in the unfavorable as compared to the favorable room, and stronger in the children when compared to adults.

For listening comprehension (measured in the favorable room), reliable impairments due to background speech and classroom noise were found in children. First graders were more impaired than third graders. Adults were unaffected by both background sounds. Further analyses of the children's data proved differential effects for the two sounds on speech perception and listening comprehension, as revealed by strong crossover interactions between task and type of sound. When compared to classroom noise, background speech had a weaker effect on speech perception, but a stronger effect on listening comprehension. Performance in the listening task deteriorated by 25 and by 17% in the presence of background speech in the first and third graders, respectively.

Before discussing these results in greater detail, we should remind that the noise and reverberation conditions used in the present study do not represent unrealistic listening situations for school children. Mean RTs exceeding 1 second are not rare in elementary school classrooms; average noise levels during the school lessons most often exceed 55 dB(A).[2,6,7,23] Shield and Dockrell [7] performed comprehensive measurements in classrooms of elementary schools in London and found average noise levels between 57 and 77 L_{Aeq} , depending on the specific classroom activity (e.g., silent individual work vs. group work with children moving around the classroom).perception, listening comprehension and disturbance ratings will be addressed in succession, followed by a set of concluding remarks.

Speech perception

For speech perception, the most important results of the current study are the age effect in the disruption evoked by background sounds, and the severe increase in the sound-induced impairments when the task was performed in the unfavorable room. The former finding is in line with psychoacoustic studies demonstrating an increase in the detrimental effects of noise on speech perception with decreasing age (see Introduction). The current study verifies that this holds also for classroom-like settings.

A couple of mechanisms are responsible for young children's susceptibility to sound-induced disruption. Firstly, children are less able to use phonological long-term representations to reconstruct degraded speech signals. This is because their phoneme categories are less precise and thus less robust,[24-26] and their phonological word representations are more holistic and less segmented into phoneme units, which reduces the probability of successfully matching incomplete speech input with stored representations.[27] Secondly, children are less able than adults to focus attention on task-relevant information and resist interference from irrelevant sounds.[28-30] With respect to the auditory domain, there is evidence for poorer selective attention in children, indicated by higher susceptibility to informational masking in auditory signal detection tasks,[31,32] and more intrusions from the distractor message in dichotic listening tasks.[33] In a related account, Werner[34] proposed that children are less flexible in the usage of perceptual strategies for speech perception, resulting in difficulties to take advantage of the available cues in unfavorable listening conditions.

The second finding, the severe increase in noise-induced impairments in the unfavorable room, provides further evidence for the detrimental effects of prolonged reverberation on students speech perception in classroom settings. In prior field studies,[1,35,36] students' word-in-noise identification scores were 10–37% worse in classrooms with long as compared to classrooms with short reverberation. In the current study, the impairment evoked by background sounds (pooled across age groups) increased from 5 to 19% for background speech and from 19 to 34% for classroom noise when the task was performed in the unfavorable room. Further analyses proved that the effect of reverberation was completely eliminated when background sound levels at the participants' seat positions were controlled (remind that noise levels were about 3 dB higher in the unfavorable as compared to the favorable room). No evidence for other mechanisms, such as distortion of the speech signals, was found. In line with this, speech perception in silence was unaffected by reverberation in all age groups. With respect to practical issues, however, this result should be interpreted with caution. The finding might not hold for classrooms with RTs still exceeding 1.1 seconds, or for speakers with a less clear and trained voice than that used in the present study. Furthermore, a certain level of background noise is unavoidable during school lessons, especially in elementary schools.[2] This is particularly true in view of the fact that frontal teaching methods are more and more replaced by contemporary teaching forms including student-centered activities such as group work. Thus, speech perception in silence is a relatively untypical task in actual classrooms. In the following section, we will focus on the effects of reverberation on speech perception under conditions of background noise.

Despite equal sound levels, background speech evoked a weaker disruption of speech perception as compared to classroom noise. In the favorable room, background speech evoked a minor impairment, which did not differ with age. This might be due to the fact that the amplitude variations of a single-talker speech noise create short gaps in the waveform, which help the listener to identify segments of the target voice.[37] Other factors, such as spectral differences between the target and the competing voice, may also play a role. However, when testing was performed in the unfavorable room, the disruption evoked by background speech increased considerably. This was particularly true for the first graders, who showed a 6 and 25% decrement with speech noise in the favorable and unfavorable conditions, respectively. Separate analyses in each age group proved that only for first graders, the difference between classroom noise and speech was eliminated in the unfavorable room, resulting from a disproportionate increase in the disruption evoked by speech noise. The first graders who sat in the second and third rows in the unfavorable room were most impaired by competing speech [Figure 2]. This indicates that young children are less able to take advantage of the temporal gaps inherent in speech when the acoustic conditions are more difficult.[34] Thus, we may conclude that young children who are sitting in the back rows in a reverberating classroom are at great risk of failing to follow the teachers instructions, or a group discussion, under conditions of competing speech. From a practical viewpoint, this means that group work with two or more concurrent discussions in a reverberating classroom is extremely difficult to handle for beginning school learners. The successful realization of such modern teaching forms requires optimal room acoustic conditions.

For classroom noise, a reliable impairment was found even under conditions of short reverberation. Children were more affected than adults. The advantage of the adults in the favorable room was eliminated in the unfavorable room. Thus, not even adults are capable to compensate for the speech perception impairment evoked by the combination of classroom noise and reverberation. Overall, the disruption found with classroom noise seems strong in view of prior findings reported by Jamieson *et al*.[38] In this study, the effects of classroom noise on speech perception, measured by word-to-picture matching, were investigated in children from kindergarten to grade 3, with more strictly controlled laboratory conditions using headphone presentation. In quiet and at 0 dB SNR, all the children performed at a comparable level, reaching more than 90% correct. At 6 dB, first graders' identification scores decreased by 18%, whereas performance in the third graders remained stable. In our study, in contrast, classroom noise evoked about 22% decrement in first and third graders at 3 to 4 dB SNR (i.e., in the favorable room, and more than 30% decrement with 6 to 0 dB SNR (i.e., in the unfavorable room). This confirms Jamieson's notion [38] [p. 516] that strictly controlled laboratory studies even underestimate the noise-induced disruption in children's speech perception in classroom settings.

The present results suggest that reducing reverberation is a necessary, but not a sufficient method to prevent negative effects of classroom noise. In addition, noise reduction can be achieved by adequate classroom furniture, and by arranging rules with the children such as wearing slippers instead of outdoor shoes during the lessons, avoiding metal paper-and-pencil cases, etc. In addition, in view of the significant impact of seat row, i.e., distance from the signal source, on the noise-induced impairments, teachers should assign children with poor learning abilities or specific developmental disorders to working places in front of the room, at the nearest distance from the teacher's place. These children are still more reliant on good acoustic conditions in order to follow the teacher's instructions than normally developing children.

Listening comprehension

As outlined in the Introduction, the listening demands faced by children at school are much more complex than those involved in a word identification task. Therefore, a listening comprehension task was included in the current study. Due to the children's poor speech perception performance in the unfavorable room, the listening task was only conducted in the favorable room. Children's performance was severely impaired by background speech and classroom noise, stronger for first than for third graders, whereas adults were unaffected. Background speech evoked a stronger disruption than classroom noise. This contrasts the effects found for speech perception, which was impaired stronger by classroom noise.

This pattern of results indicates that the effects of classroom noise and background speech on children's listening comprehension result from different mechanisms. We propose that classroom noise affects comprehension through interference during encoding, i.e., energetic or informational masking. The smaller effect of classroom noise on listening comprehension when compared to speech perception may be due to the fact that comprehension of the instructions does not require perfect intelligibility of each syllable. Missing elements can be restored with the help of contextual cues. Obviously, the third graders are better able to solve this task than the first graders. In the former, the effect of classroom noise on listening is much smaller than its effect on perception

In contrast to classroom noise, the effect of background speech on listening may result from interference with higher-order cognitive processes involved in children's listening comprehension. This account leads to the prediction that the difference in the effect of background speech on listening in children and adults should survive when speech perception in background speech is controlled, whereas the differential effect of classroom noise on listening performance in children and adults should be eliminated when speech perception is controlled. This prediction was confirmed in an ANOVA on the difference scores derived from the listening task in the first graders and adults (the third graders were not included, as speech perception and listening comprehension were assessed in different subgroups of children). For classroom noise, the age effect was eliminated when speech perception in classroom noise was included as covariate ($P < 0.11$). For background speech, in contrast, the age effect remained significant when speech perception in speech noise was controlled ($P < 0.01$).

Thus, we may conclude that the effect of background speech on children's listening performance cannot be attributed to poor speech perception. The finding coincides with a prior study demonstrating significant impairments of first graders' listening comprehension, measured by a similar task, due to background speech under conditions of perfect speech intelligibility. How can this effect be explained? We attribute the disruptive effect of background speech on children's listening comprehension to the involvement of verbal short-term memory in this task. It has been shown that in children, listening comprehension is closely related to short-term memory.[39] In adults, in contrast, short-term memory plays a minor role in comprehension. This is presumably because in adults, comprehension usually proceeds on-line, whereas in children, semantic and syntactic analyses often “lag behind” the incoming discourse. In such situations, the temporary representation of the speech input held in short-term memory may significantly contribute to comprehension. In the framework of the “irrelevant sound effect”, numerous studies with adults have shown that verbal short-term memory is highly susceptible to disruption by background speech, and that this effect does not result from impaired encoding.[45] Current studies extended these findings to children. Thus, background speech may impair children’s listening performance through interference with the temporary record of the incoming speech in short-term memory. However, the significant impact of seat row, i.e., distance form the sound source, on the disruption indicates that other mechanisms, such as masking or difficulties in stream segregation, also contribute to the impairment found in the children. Taken together, the current results provide further evidence for negative effects of background speech on children’s listening comprehension. This is an important finding from both a theoretical and a practical viewpoint, which clearly deserves further research.

Disturbance ratings

The children’s ratings of the disturbance evoked by the background sounds in the speech perception task were surprisingly low, with mean ratings between “not at all disturbed” (0) to “a bit disturbed” (1). This is a surprising result in view of the reliable drop in children’s speech perception performance due to classroom noise in both reverberation conditions, and due to background speech in the unfavorable room. Furthermore, the effects of reverberation and type of sound on the disruption of speech perception performance were reflected in the disturbance ratings of the adults, but not in those of the children. For listening comprehension, the children’s ratings of perceived disturbance were unrelated to the actual impairment and did not reflect the differential effects of classroom noise and background speech on performance. Obviously, the children did not consciously realize the degree of disruption evoked by the background sounds. Prior studies have shown that elementary school children give reliable judgments of annoyance due to classroom noise, which correlate with noise levels and reverberation. Nevertheless, the children seem unable to estimate the impact of the noise on their own performance. In view of this discrepancy, it might be argued that our rating method was inadequate for children. However, the smiley scale is widely used in studies with young children and has proven reliable and valid results. We propose that even though children are able to judge overall noise annoyance, they have difficulties to assess the degree of noise-induced disruption evoked in specific tasks. This finding clearly indicates that teachers and researchers cannot rely on the children’s judgments when assessing the acoustic quality of classrooms.

CONCLUSIONS

The current study provides further evidence for the importance of adequate listening conditions in classrooms. In view of the magnitude of the observed impairments, current findings indicating chronic effects of noise and reverberation in classrooms on children’s development are easily comprehensible. Clearly, children who, due to poor interior acoustics, often lose the content of the teachers‘instructions are at risk of poor academic achievement. In line with this, it has been shown that indoor noise levels in classrooms are significantly related to academic attainment with socioeconomic factors controlled A related study demonstrated poorer phonological processing abilities and less positive relationships to peers and teachers in children from reverberating classrooms when compared to children from classrooms with favorable acoustics. It should be kept in mind that noise, in particular classroom noise and speech, is unavoidable during school lessons. The present results demonstrate that the effects of these sounds on children’s speech perception depend heavily on the acoustic quality of the classrooms. Today, the knowledge on how to achieve optimal interior acoustics in classrooms is well established, and the considerable impact of acoustic conditions on children’s learning is by now undisputable. The authorities responsible for the building of schools should now take care that this knowledge is efficiently transferred into practice. However, our results also demonstrate noise-induced impairments under conditions of good interior acoustics. Young children have severe difficulties to listen effectively in the presence of moderate intensity noise, whereas adults are unaffected. Teachers should be aware of such developmental effects and care for silence in learning episodes where listening is required.

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