Effects of irrelevant speech and traffic noise on speech perception and cognitive performance in elementary school children

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ABSTRACT
The effects of background noise of moderate intensity on short-term storage and processing of verbal information were analyzed in 6 to 8 year old children. In line with adult studies on "irrelevant sound effect" (ISE), serial recall of visually presented digits was severely disrupted by background speech that the children did not understand. Train noises of equal intensity however, had no effect. Similar results were demonstrated with tasks requiring storage and processing of heard information. Memory for nonwords, execution of oral instructions and categorizing speech sounds were significantly disrupted by irrelevant speech. The affected functions play a fundamental role in the acquisition of spoken and written language. Implications concerning current models of the ISE and the acoustic conditions in schools and kindergardens are discussed.

Keywords: Children, irrelevant sound effect, noise, phonological awareness, speech perception, working memory

There is a considerable amount of literature documenting the effects of chronic noise exposure on children's cognitive development. Reading skills are especially vulnerable to the negative effects of noise. Field studies have consistently shown that children from aircraft noise areas exhibit deficits in reading development when compared to children from quiet areas. Evans and Maxwell point out that the effects of noise on reading may be partly due to noise-induced impairments in the development of speech perception. In their study, children exposed to aircraft noise scored lower on a reading test and on a speech perception test requiring identification of words in noise. Current research on reading development indicates that deficits in speech perception are a causal factor in reading disorders.

Research on the effects of noise on children's cognition has concentrated on subjects exposed to high levels of aircraft noise. Little is known about the effects of moderate-intensity noise on cognitive development. This is an important question since noise is a problem in many schools and kindergartens. Noise has been identified as one of the most important sources of stress in teachers and caregivers in preschool facilities. Maxwell and Evans provided evidence for chronic effects of noise in a preschool daycare center on language acquisition and prereading skills. They investigated children from a preschool facility in which, as a result of poor interior acoustics, average noise levels reached 76 dB(A).

Testing was done in a separate, quiet room with two groups of children. One group was investigated before the installation of sound-absorbent panels, which led to a noise reduction of 5 dB(A). The second group was tested in the year after this intervention. The children of the second group scored higher on a measure of prereading skills and were rated higher by the teachers on scales concerning expressive and productive language abilities. The authors conclude that chronic exposure to noise in early childhood affects the development of basic language functions which are of special importance in reading acquisition. However, the specific mechanisms linking noise, language acquisition and reading are still unclear.

Chronic effects of noise on cognitive development are a result of enduring impairments of basic cognitive functions due to acute noise. Thus, laboratory studies on the acute effects of specific noises on cognitive performance may help to assess the risk of chronic effects of permanent exposure to such noises. Experimental studies with adults have convincingly shown that phonological short-term memory is especially sensitive to the negative effects of acute noise. Phonological short-term memory is a component of working memory responsible for coding and storage of speech-based representations. In studies on the effects of noise on short-term memory, sequences of verbal items such as digits, syllables or words have to be recalled in the correct serial order in the presence of background sounds that the subjects...
are instructed to ignore. Performance is severely disrupted by background speech which the subjects do not understand and also by certain nonspeech sounds such as tones or instrumental music. The ISE has been shown to depend on the inherent properties of the irrelevant sound. Performance is impaired by irrelevant sounds with a changing-state characteristic, that is, by sounds which consist of distinct auditory-perceptive objects that vary consecutively. For example, irrelevant sounds consisting of different consonants or tones evoke an ISE whereas steady-state sounds such as continuous broadband noise or repetitions of single syllables or tones have a minor effect or none at all.[11-13] However, changes in intensity alone do not evoke an ISE.[14]

It is assumed that changing-state sounds have automatic access to short-term memory where they interfere with the representations of the material to be remembered. Elliott[15] was the first to analyze this so-called “irrelevant sound effect” (ISE) in children. She found that the ISE was more pronounced in younger than in older children who in turn were more affected than adults.

The ISE has gained considerable interest in the area of cognitive psychology as it demonstrates a close link between auditory perception and short-term memory.[11,16] However, these findings are also of interest in the context of noise effects on children as although short-term memory does not play a dominant role in an adult’s everyday cognition, it is of major importance in cognitive development. The ability to hold verbal items in short-term memory is a predictor of children’s vocabulary[17,18] and is significantly associated with expressive language abilities,[19] storage of sentences,[20] listening comprehension,[21] and reading achievement.[22,23]

Concerning language acquisition, it is assumed that short-term memory provides a temporary representation of the phonological structure of incoming speech and that this representation underlies long-term learning of new phonological and syntactical forms. The temporary record may also contribute to reading and listening comprehension in situations where semantic and syntactic processing “lags behind” the incoming discourse. In adults, this is only the case with rather complex materials. In everyday cognition, an adult’s comprehension proceeds on-line, that is, without the help of a temporary back-up store.[24] As children’s language processing is slower and less automatized than adults', it is reasonable to assume that short-term memory plays a greater role in children’s listening comprehension.[17,24] In line with this view, phonological memory was shown to be highly associated with listening comprehension in six to eight year-old children.[24]

Concerning the association between short-term memory and reading acquisition, a common view is that short-term memory is involved in i) the acquisition of letter-sound mapping rules and ii) in the storage of individual sound segments prior to blending during phonological recoding.[23,24]

In a related view, the association between short-term memory and reading is mediated by phonological awareness, that is, the ability to access and manipulate the sound structure of language.[23] Phonological awareness has been identified as the most important precursor in the acquisition of written language.[25,26] Measures of phonological awareness and short-term memory are strongly associated, indicating a common phonological coding substrate.

Taken together, short-term memory is highly sensitive to the negative effects of moderate-intensity noise and is of major importance in the acquisition of oral and written language. Thus, in addition to speech perception, short-term memory might be a mediator between noise, language and reading. The aim of our study was to further explore this hypothesis. In three experiments, we analyzed the effects of moderate-intensity environmental noise on children’s short-term memory and on complex cognitive functions which also involve short-term memory, that is, listening comprehension and phonological awareness.

Background speech and train noise were used as irrelevant sounds. On the basis of literature discussing ISE, we hypothesized that background speech should exhibit stronger effects on short-term memory and sentence comprehension than train sounds as the latter show less changes in state in the sense described above. However, this prediction is based on studies with adults. It is yet unclear whether the characteristics of ISE are the same in children.

In experiments 2 and 3, two train sounds were included which varied with respect to the frequency spectrum. This was done in order to test whether potential negative effects could be decreased or eliminated by means of a reduction of the sound energy in the low-frequency region. The relevance of the low frequencies in the effects of noise was the main question in the research network “Quiet Traffic”, into which this study was incorporated. Thus, the effects of the original sound were compared to the effects of a modified (filtered) version of the same sound.

General Procedure

The speech materials used in the experimental tasks were prerecorded in a sound-attenuated laboratory. The materials were read by a trained male speaker and recorded on DAT-tape via a dummy head (Cortex MK2) with a sampling rate of 44100 Hz and 16-bit-resolution. The recordings were converted to wav-files and processed with standard sound editing software (Cool Edit). Danish speech produced by a female speaker was used as irrelevant background speech. The record contained no reverberation and no remarkable changes in loudness and intonation. The train noises were from a recording of an Intercity Express passing by from a distance of about 200 meters. The recording had a duration of 15 seconds and was characterized by an increase in level.
when approaching, a steady part when passing and a decrease in level when leaving [Figure 1]. In addition to the original train sound, a modified version was used in which the frequencies below 220 Hz were reduced by 12 dB. For the control condition, a low-level continuous noise was generated from the sounds of a highway recorded from a distance of 200 meters. This was done in order to avoid an unnatural silence in the sound cabin and to minimize potential effects of sounds produced by the children themselves (hustling, rustling, scraping one’s feet etc.).

In all experiments, the sound conditions were varied randomly from trial to trial, which is a common procedure in studies on ISE as it allows control for practice and fatigue for individual subjects. One might argue that this procedure impedes potential habituation to irrelevant sounds, thus leading to an overestimation of the sound effects. However, there is convincing evidence that habituation to irrelevant sounds does not occur, even with enduring exposure.\textsuperscript{12,22} Details concerning the presentation of the sounds will be given in the method part of the particular experiment.

The experiments were run in a sound-attenuated laboratory of about 35 m\textsuperscript{2}, equipped with school furniture. Testing was done in groups of two to four children. Each task was introduced in detail by the experimenter and then practised by the children. None of the children could understand Danish.

Experiment 1

Elliott\textsuperscript{13} has used the standard serial recall task in order to investigate the irrelevant sound effect in children. In the area of cognitive development in young children, short-term memory is usually measured in a different way, that is, with nonword repetition. In this task, nonwords increasing in length are presented auditorily and have to be repeated by the children. This ability is a predictor of the development of vocabulary and expressive language in children.\textsuperscript{17} Deficits in nonword repetition often occur along with deficits in the acquisition of oral and written language. In this experiment, we tested whether this basic cognitive ability is sensitive to the negative effects of irrelevant sounds. In order to make the task suitable for tests with groups of children, pairs of nonwords were presented and the children had to decide whether they were “same” or “different”.\textsuperscript{29} Additionally, the effects of background sounds on listening comprehension were examined. Complex oral instructions were presented to the children and had to be carried out on prepared response sheets. This task reflects an everyday requirement at school. Furthermore, a speech perception task requiring discrimination between similar-sounding words was included in order to control for the effects of masking.

Two groups of first-grade children took part in this experiment. One group performed the tasks in the control condition and in the presence of background speech (Experiment 1A). The other group performed the tasks in the control condition and in the presence of the unfiltered train sound (Experiment 1B). The effects of the background speech and train sounds were compared in a combined analysis. Performance in the control condition was included as a covariate in order to control for interindividual differences in the general abilities of the children assigned to the two groups. This design was preferred to a complete repeated measurement design as the requirement to perform each task in each of the three sound conditions would have been too much of an effort for first-graders.

Tasks

Speech perception: In each trial, three pictures representing similar-sounding words were presented to the children (e.g., “Arzt”, “Axt” and “Ast”). Two seconds after the onset of this foil, a spoken word relating to one of the three objects was presented (e.g., “Arzt”). The children had to mark the picture representing the word in prepared response sheets. Ten items were presented in each of the two conditions (control and background speech vs control and the train sound). Prior to the task, all pictures were shown to the children and named by the experimenter.

Phonological short-term memory: In each trial, a pair of nonwords was presented to the children with an interstimulus interval of three seconds. The nonwords consisted of

![Waveform of an instruction from the sentence comprehension task](image-url)
consonant-vowel syllables and varied in length between three and five syllables. In half of the pairs, the same word was repeated, in the other half, the second word of the pair was changed (e.g., "giboda-guboda"). In the dissimilar pairs, the items differed in vowels because vowels are easier to discriminate than consonants. Thus, the nonword task was less sensitive to masking than the speech perception task. In conditions of unaffected speech perception, impairments in the nonword task could therefore be attributed to memory deficiency. The children had to indicate whether the nonwords were "same" or "different". Response sheets were prepared in which each trial was represented by a box with two identical cars ("same") and a box with a car and a bicycle ("different"). Ten nonword pairs were presented in each of the two sound conditions.

Sentence comprehension: In this task, verbal instructions were presented to the children, which had to be carried out on prepared response sheets (e.g., "Put a cross under the book that lies next to the chair."). Scoring was based on the number of elements correctly solved in each sentence. Eight sentences were presented in each of the two sound conditions.

Sounds
The speech materials (words, nonwords and sentences) were mixed with each of the three sounds described above: background speech, unfiltered train sound and control noise. For the word identification task, three-second episodes of each sound were generated and mixed with the words. For the train sound, the three-second episode was taken from the part where the train passed by with a constant level. Each word started one second after the onset of the background sound.

The nonword pairs and the sentences were mixed with 15 second episodes of the control, the background speech and the whole train sounds. The increase and decrease in level while approaching and leaving is a major characteristic of train sounds which might cause attentional distraction. Thus, it seemed unwise to confine to the stationary part of the sound. For each of the three background sounds, the instructions started two seconds after the onset and finished three seconds before offset of the sound. The nonword pairs started two seconds after the onset and finished four seconds before the offset of the sound. Figure 1 shows the waveforms of an instruction in isolation and in combination with the train sound.

The level of the speech signal was set to 62 dB(A). The 15 seconds Leq was 59 dB(A) for the train sound, 57 dB(A) for the background speech and 36 dB(A) for the control sounds. The level of the stationary part of the train sound was 62 dB(A). Thus, the signal-to-noise ratio (SNR) was +5 dB(A) in the background speech condition, 0 dB(A) in the train sound condition (on the basis of the stationary part) and +26 dB(A) in the control condition.

Procedure
The presentation of the pictures and sounds was controlled by means of standard presentation software (Microsoft PowerPoint XP). Sounds were presented via open headphones. Each trial started with a warning signal consisting of two tones ("ding-dong").

In each task, pictures of the children’s response sheets were shown on a 50-inch plasma screen located in front of the room. In each trial, a red arrow pointed to the line in which the children had to put their answer on the sheet.

The effect of sound condition on performance was tested via a repeated-measurement design. Two parallel versions of each task were constructed. For each task, half of the children received version 1 with the control sound and version 2 with the experimental sound (Experiment 1A: background speech, Experiment 1B: train sound), the other half received version 2 in the control condition and version 1 in the experimental condition. The order of the sound conditions was randomized from trial to trial such that no condition was repeated more than twice in succession.

Experiment 1A: Control condition vs background speech

Subjects
Twenty-three first-graders (nine male, 14 female) of an Oldenburg elementary school took part in this experiment. The children were 6-7 years old with a median age of 7 years, 1 month. One child was late at the time of testing and could not participate in the word identification task. Thus, the analysis concerning this task is based on 22 children.

Results

Speech perception: The children reached a high level of word identification performance irrespective of the sound condition. Mean percent correct scores were 95 in the control condition and 92.7 in the presence of irrelevant speech. There was no significant difference between the means (T (21) = 1.16; P < 0.26).

Short-term memory: Performance in the nonword task was severely disrupted by background speech. Mean percent correct scores were 87.4 in the control and 66.5 in the speech condition (notice that 50 percent correct items are to be expected by pure guessing). Statistical analysis proved a highly significant difference between the means (T(22) = 8.07; P < 0.001). The magnitude of this effect was confirmed in an analysis of the individual data. None of the children performed better in the presence of background speech than in the control condition. Three children showed similar
performance in both conditions. The remaining 20 children scored lower in the presence of background speech.

Sentence comprehension: Sound conditions were found to have a significant effect on the execution of oral instructions ($T(22) = 3.74; P < 0.001$). Mean percent correct scores were 73.14 in the control condition and 62.92 in the background speech condition.

Thus, verbal short-term memory and sentence processing were severely disrupted by background speech that the children could not understand. This effect cannot be attributed to masking as the speech perception task was completely unaffected. The effect of the train noise on these tasks was analyzed in experiment 1B.

**Experiment 1B: Control condition vs train sound**

**Subjects**

Twenty-five first-graders (15 male, ten female) from two Oldenburg elementary schools took part in this experiment. The children were 6-8 years old with a mean age of 7 years, 1 month. One child misunderstood the instruction concerning the word identification task. Hence, this analysis is based on 24 children.

**Results**

Speech perception: A significant effect of the train sound was found on word identification ($T(23) = 4.41; P < 0.001$). Mean percent correct scores were 98.3 in the control and 89.2 in the train sound conditions.

Short-term memory: Mean percent correct scores were 87.2 in the control and 82 in the train sound conditions. The difference between the means was not significant ($T(24) = 1.61; P < 0.12$).

Sentence comprehension: There was no effect of the sound condition on the execution of oral instructions ($T(24) < 1$). Mean percent correct scores were 72.0 in the control and 72.12 in the train sound conditions.

Contrary to background speech, the train sound did not affect nonword storage or the execution of oral instructions. The effect of this sound was confined to the identification task. The train sound masked the speech sounds necessary to discriminate between the similar sounding words. Sentence comprehension does not require perfect identification of single speech sounds as missing sounds can be deduced with the aid of contextual information. Obviously, the train sound did not affect cognitive processes involved in storage and comprehension.

**Combined analysis**

Mean percent correct scores of performance in the noise condition with respect to the type of the task and the experimental group are depicted in Figure 2.

The effects of the train and background speech sounds were compared by means of a one-way analysis of variance with
the sound condition as a between-subject factor. Performance in the quiet control condition was included as a covariate.

**Speech perception**: The difference in performance between the train sound and the background speech conditions did not reach significant levels. However, there was a tendency towards poorer performance in the presence of the train sound (F(1.43) = 3.24; P < 0.079).

**Short-term memory**: The sound condition was found to have a highly significant effect (F(1.45) = 18.65; P < 0.001). Performance was significantly worse in the presence of background speech than in the train sound condition.

**Sentence comprehension**: Performance was significantly worse in the presence of background speech than in the train sound condition (F(1.45) = 8.79; P < 0.005).

Thus, background speech and train noise had differential effects on the experimental tasks. Sentence comprehension and short-term memory were significantly worse in the irrelevant speech condition than in the presence of the train sound. Word identification was affected by the train sound but not by background speech.

**Discussion**

The results of experiment 1 are clear-cut. Speech perception was impaired by the train sound, but unaffected by background speech. This finding is in line with prior studies demonstrating better intelligibility with speech noise when compared to continuous noise,[42] and may result from less physical masking due to the sound level fluctuations inherent in speech. Phonological storage and sentence comprehension were significantly impaired by background speech that the children did not understand but unaffected by a train sound of equal intensity. In the nonword task, background speech reduced performance by about 20 percent. The impairment due to background speech cannot be explained by masking-it occurs in short-term memory.

The effect of background speech on the oral instruction task indicates that, as was stated in the introduction, short-term memory is indeed involved in children's listening comprehension. Taken together, background sounds may significantly affect children's storage and comprehension of spoken languages, even under conditions of perfect intelligibility as measured by a word identification task. In the following experiment, we extended these findings to a task closely related to written language acquisition.

**Experiment 2**

One cognitive skill that is closely related to short-term memory and the acquisition of written language is phonological awareness-the ability to access and manipulate the sound units of language. Phonological awareness has been identified as the most important prereading skill. Training for phonological awareness in young children reduces the risk of reading and spelling disorders in later school years.[39] Deficits in phonological awareness are closely associated with developmental dyslexia.

In order to perform a phonological awareness task, the child must encode and maintain phonological representations in short-term memory. Thus, it is reasonable to assume that irrelevant sounds impair performance in phonological awareness tasks. To our knowledge, this hypothesis has not been tested with children yet. Baddeley and Salamé[31] found no effect of background speech on adults' performance in rhyme and homophone judgment tasks and concluded that phonological processing is not susceptible to irrelevant speech. However, their tasks did not involve phonological processing on the basis of individual phonemes and thus, did not reflect the demands faced by young children in the early stage of reading. A task more suitable in this respect was used by Smith et al.[32] In the framework of auditory imagery and without referring to ISE, these authors analyzed the effects of background speech on adults' performance in a task requiring the solution of strings like D2R ("detour") or NME ("enemy"). The subjects scored 72 percent in the control condition, but only 40 percent in the presence of background speech. On the basis of this evidence, we analyzed the effects of speech and train noises on phonological processing in children.

**Subjects**

Twenty-two second-grade children (seven male, 15 female) from two elementary schools served as subjects. The children were 7-8 years old with a mean age of 8 years, 5 months.

**Task**

In this task, the children had to decide which of three words differed from the others with respect to the initial or the final sound. This is a standard task in the assessment of phonological awareness in children called "Odd One Out."[33] In each trial, three monosyllabic words or nonwords were presented auditory to the children with an interstimulus interval of one second. After a five-second retention interval, a picture appeared on the screen showing a snake, partly hidden by a wooden case. The snake served as a cue indicating whether the initial or the final sound of the words had to be analyzed in the particular trial. If the initial sound of the words was crucial, the former part of the snake including the head was visible, whereas the tail of the snake was hidden behind the case. If the final sound was crucial, only the tail of the snake was visible. The position of the "odd" word in the sequence had to be marked on a prepared response sheet. If the first (second, third) of the three words was the odd one, the first (second, third) of three boxes arranged in a row had to be marked. The children had 13 seconds to mark their response. Trials requiring the analysis of initial and final sounds were mixed randomly on the condition.
that no type of task was encountered more than three times in succession. Each block of trials consisted of eight word trials, e.g., "Wein-Satz-Blitz" (final sound crucial, "Wein" is the odd word) followed by eight nonword trials, e.g., "Rack-Wiss-Ropp" (initial sound crucial, "Wiss" is the odd one).

Parents' questionnaire

In order to ensure that the experimental task is closely related to written language acquisition, the parents were asked to rate their children's performance in reading and spelling. The statement "When compared to other children of their class level, learning to read (to spell) is ..., for my child" had to be completed by means of a rating scale with the labels: "much easier", "a little easier", "neither/nor", "a bit more difficult", "much more difficult".

Sounds

The prerecorded word and nonword sequences were mixed with each of the following four sounds: Danish speech, unfiltered train, filtered train and the control sounds. Twenty-one second-episodes of the sounds were generated. The train sounds were achieved by elongating the stationary part where the train is passing by with a constant noise level. The word and nonword sequences occurred during the first few seconds of the train sounds where the train approaches and the sound level is still low, thus ensuring perfect intelligibility.

The level of the speech signals was set to 62 dB(A). The 21 seconds Leq was 57 dB(A) for the background speech and 36 dB(A) for the control sounds. The levels of the stationary part of the train sound were 62 dB(A) for the original sound and 61 dB(A) for the filtered sound (the reduction of low frequencies hardly affects the A-filtered decibel measure as low frequencies are weighted much less than higher ones). The sounds were presented via open headphones (Sennheiser HD 600).

The children showed perfect and effortless identification of the items in all sound conditions. The background sounds were present during presentation and retention of the word and nonword sequences and during ten seconds of the recall period.

Procedure

Testing was done in groups of two children. A 17-inch computer screen was placed in front of each child. Two blocks of 16 trials were solved in each of two experimental sessions separated by about one week. Each child performed the task under each of the four sound conditions: background speech, unfiltered train noise, filtered train noise and control sound. In each of the four experimental blocks, four trials were presented with each of the four sounds. The sound conditions varied in a quasi-random order from trial to trial. No sound was repeated more than twice in succession. Thus, the children completed 16 trials in each of the four sound conditions.

Results

Overall performance in the odd-one-out task (number of trials correctly solved out of 64) was significantly correlated with the parents' ratings of the children's reading and spelling abilities (r = 0.46 and r = 0.6 respectively; P < 0.05 in both cases). This confirms the assumption that the task involves phonological abilities closely related to reading and spelling.

A one-way analysis of variance with repeated measurements on the number of items correctly solved revealed that the sound condition had a highly significant effect (F(3,63) = 14.59, P < 0.001). Bonferroni-corrected posthoc tests proved that performance in the background speech condition differed significantly from all other conditions, which did not differ from each other. Mean percent correct scores (averaged across the type of the task) are depicted in Figure 3.

Discussion

Just as in experiment 1, performance was severely disrupted by background speech but unaffected by the train sounds. Relative to the control condition, children's performance decreased by about 25 percent in the presence of background speech. Since the odd-one-out task required storage of the three words, we cannot exclude the possibility that the background speech affects only storage but not phonological processing per se. However, no such storage component was involved in the letter-number-string task used by Smith et al.,[32] who nevertheless got a strong effect of irrelevant speech. Furthermore, storage of three items is not a heavy demand in eight-year-olds. In the light of the magnitude of the effect, it is reasonable to assume that phonological processing is also affected by irrelevant speech.

In any case, the cognitive processes involved in this task are essential in learning to read. Performance was significantly correlated with the parents' ratings of the children's reading and spelling abilities. Thus, it is reasonable to assume that chronic exposure to moderate-intensity noise affects reading acquisition, at least in the case of background speech. Before interpreting the results in the framework of the irrelevant sound effect, we tried to replicate the main findings with the standard task used in this area, that is, serial recall of verbal items presented visually.

Experiment 3

Subjects

Twenty-one second-grade children (ten male, 11 female) participated in the experiment. The children were between 7 years, 5 months and 8 years, 11 months old with a mean age of 8 years, 4 months. Thirteen subjects also participated in experiment 2 while the remaining eight subjects participated in a pilot study related to experiment 2.
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Figure 3: Mean percent correct scores in the “odd-one-out” task with respect to the sound condition (Exp. 2). Sound conditions were varied within subjects

Task
Each trial started with a visual warning signal in the form of a red square shown in the center of the computer screen for one second. This was followed by a sequence of digits drawn at random from the set of 1 to 9 without repetition. The digits were presented one by one in the center of the screen. The presentation rate was one digit per second with an interstimulus interval of one second. Then, a picture of the children’s answer sheets appeared on the screen. Each trial was represented on the answer sheets as an array of small boxes arranged in a line. The children had to enter the digits into the boxes in the serial order. They were instructed to write down the digits from left to right and to leave empty the boxes related to digits that could not be remembered. Each trial was started by the experimenter when the children had finished recall of the previous trial. Each experimental block consisted of 16 trials, increasing in list lengths from three to six digits. Four trials were presented at each of the four list lengths.

Sounds
Sequences of 15, 17, 19 and 21 seconds were created from each of the four sounds (background speech, unfiltered train, filtered train and control sounds). The sounds were embedded into the software controlling the digit recall task such that, for each list length, the sounds began one second prior to the visual warning signal, endured during the presentation of the digits and stopped six seconds after the beginning of the recall phase. Sound levels were the same as in experiment 2. The sounds were presented via open headphones (Sennheiser HD 600).

Procedure
The experimental procedure was the same as in experiment 2. Each child performed the task under each of the four sound conditions. Two blocks of 16 trials were solved in each of two experimental sessions separated by about one week. In each of the four experimental blocks, four trials were presented with each of the four sounds. The sound conditions varied in a quasi-random order from trial to trial. No sound was repeated more than twice in succession. All in all, 16 trials were completed in each of the four sound conditions (four trials at each list length).

Results
Responses were scored in terms of a strict serial position criterion: each item not recalled in the correct position was scored as an error. The number of items correctly recalled was calculated for each list length and sound condition and converted into percent correct scores. A two-way analysis of variance with repeated measurements on these scores revealed significant effects of the sound conditions \((F(3, 60) = 21.67; P < 0.001)\) and list length \((F(3,60) = 88.05; P < 0.001)\) but no interaction \((F(9,180) = 1.08; P < 0.38)\). Bonferroni-corrected posthoc tests revealed that performance in the background speech was inferior to each of the other conditions, which did not differ significantly. Mean percent correct scores (pooled across list lengths) were 66.07, 66.34, 67.0 and 52.4 in the control, unfiltered train sound, filtered train sound and background speech conditions, respectively [Figure 4].

The results from experiments 1 and 2 were clearly replicated with the standard task used in studies on ISE. Performance was severely impaired by background speech but unaffected by the train sounds.

Discussion
Children’s performance in tasks requiring storage and
The results of the current study demonstrate that the effects of moderate-intensity noise on children's cognitive performance do not depend on the absolute level but on the quality of the sounds. Background speech significantly disrupted phonological storage and language processing whereas the effects of the train sounds were confined to speech perception. Importantly, background speech severely impaired storage and processing of heard information even under conditions of perfect speech intelligibility. Thus, the latter is not a good measure in order to exclude noise-induced performance decrements in complex listening tasks. In the following paragraphs, we will discuss the results with respect to their theoretical and practical implications.

Different theoretical accounts have been proposed on ISE. In the framework of the phonological loop model of short-term memory proposed by Baddeley, background speech has obligatory access to the storage component of the loop, where it interferes with the representations of the memory materials. According to this model, phonological coding of visual items is a precondition for the evocation of an ISE. An alternative explanation of the irrelevant speech effect has been proposed by Jones et al. These authors argue that the ISE results from interference between different sets of order cues. According to this view, a stream of auditory events is automatically represented in short-term memory as a sequence of objects joined by linkages. These linkages are supposed to disrupt the associations between the items in the to-be-remembered list. Following this account, the task must involve some kind of serial rehearsal for the ISE to occur.
As Elliott points out, both models have difficulties to explain the strong effect of irrelevant speech in young children as young children make less use of phonological recoding and serial rehearsal than adults. Thus, the impairment due to irrelevant speech should increase, but not decrease with age. Models which include attentional factors might be more appropriate to account for the developmental course of ISE. The necessity to ignore irrelevant sounds can be seen as a secondary task requiring a high degree of attentional control. Young children are less able to ignore irrelevant sounds and focus on the task at hand than older children and adults. Speech might be especially distracting for young children. Developmental studies have shown that infants prefer listening to speech than to nonspeech sounds. This “listening bias for speech” could endure into early childhood, thus leading to performance decrements in the presence of background speech. In line with this view, Elliott found a stronger effect of background speech as opposed to tones in children but not in adults.

Concerning the practical implications, the results have shown that background speech severely disrupts children’s performance in a range of cognitive tasks. Elliott has shown that nonspeech sounds also impair performance although to a lesser degree than speech. The affected functions play a significant role in the acquisition of oral and written language. Thus, it is reasonable to assume that permanent exposure to irrelevant sounds contributes to the development of language and reading disorders. Maxwell and Evans were the first to demonstrate chronic effects of noise in a preschool day care center on children’s prereading and language skills. The current study indicates that these effects might be mediated by the harmful effects of noise on children’s phonological memory.

The results demonstrate the importance of acoustical conditions in children’s learning environments. Reverberation and noise in classrooms and kindergartens do not only affect teachers’ well-being but also severely impair children’s cognitive performance. Maxwell and Evans have documented the positive effects of improved classroom acoustics on children’s learning. In addition to optimal classroom acoustics, teachers and parents should provide silence not only in listening situations but also when the children are occupied with visual tasks involving phonological processing and short-term memory, e.g., reading and spelling in beginning readers, mental calculation and learning the vocabulary of a foreign language.

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