Interaction effect of background sound type and sound pressure level on children of primary schools in the Netherlands

Zhang, Dadi; Tenpierik, Martin; Bluyssen, P.M.

DOI
10.1016/j.apacoust.2019.05.007

Publication date
2019

Document Version
Final published version

Published in
Applied Acoustics

Applied Acoustics 154 (2019) 161–169

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Interaction effect of background sound type and sound pressure level on children of primary schools in the Netherlands

Dadi Zhang *, Martin Tenpierik, Philomena M. Bluyssen

Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands

ARTICLE INFO

Article history:
Received 14 January 2019
Received in revised form 3 April 2019
Accepted 4 May 2019
Available online 9 May 2019

Keywords:
Primary school children
Phonological processing
Noise
Music
Sound pressure level
Interaction effect

ABSTRACT

The acoustic conditions of classrooms received a lot of attention in the last decades because of its important role in school children's comfort and performance. In a previous field study of 54 classrooms from 21 schools in the Netherlands, more than 85% of the 1145 primary school children reported that they were bothered by noise in the classroom. The objective of this study is to identify the effect of background sounds on children's performance, sound evaluation and influence assessment based on a lab study conducted in the SenseLab. 335 school children (9 to 13 years old) from the previous studied schools participated in the lab study. They were subjected to a series of listening tests and evaluations in two acoustic test chambers (acoustically treated or untreated) with one of seven randomly played background sounds: 45 dB(A) or 60 dB(A) traffic noise, 45 dB(A) or 60 dB(A) children talking, 45 dB(A) or 60 dB(A) music, or no sound (≈30 dB(A)). A two-way ANOVA was applied to analyse the interaction effect of sound type and sound pressure level (SPL) on children's performance, sound evaluation and influence assessment in each of the chambers. Statistically significant interactions between the impact of sound type and SPL on children's phonological processing performance and their influence assessments were found in the untreated chamber.

1. Introduction

As a learning environment, classrooms' main function is to ensure the information of teachers can be clearly transferred to children [1]. According to a field study conducted by Bluyssen et al. [2], noise is the most common annoyance for primary school children in the Netherlands; more than 85% of children reported that they were bothered by noise in their classrooms. Young children, especially younger than 13 years old, are more susceptible to noise than adults [3]. Therefore, the impact of the acoustic conditions of a classroom on children's sound perception and learning performance has attracted much concern throughout history. Many studies have examined the effects of different types of classroom noise, including external noise (e.g. aircraft noise, train noise and road traffic) and noise generated by the children themselves, while others have focused on the effect of different types of music (e.g. vocal music and instrumental music). These studies involved a large variety of performance tests including reading, mathematics, memory and attention tests. Besides, the sound pressure level (SPL) of background sound in classrooms and its impact have also been examined by several studies.

However, only few studies have compared the impact of music and noise on task performance. For these studies, their focuses were either on adults' performance [4] or on the relationship between personality (introverts or extraverts) and background sound [5,6]. Almost none of them looked at the impact of music and noise on children's task performance. In addition, the interactions of background sound type and sound level on children's performance, sound evaluation and assessment of influence of sounds also has been neglected by these studies.

Therefore, in an attempt to fill the research gaps addressed above, 335 children from the previous studied schools were invited to participate in a series of experiments, which was part of an experimental study performed in the SenseLab under well-controlled environmental conditions [7]. The SenseLab comprises of four test chambers (to test the four indoor environmental factors separately: thermal comfort, air quality, acoustics, and light) and one experience room (for integral research of the four indoor environmental factors) [8]. This current paper shows the results of the experiments conducted in the acoustics chamber. It aims to address the effects of background sounds, including different sound types and SPLs, on children's phonological processing, sound evaluation, and influence assessment by comparing their answers under different background sound conditions. Additionally, the effect of age and gender were also taken into consideration in this paper.

* Corresponding author at: Julianalaan 134, 2628 BL Delft, the Netherlands.
E-mail address: d.zhang-2@tudelft.nl (D. Zhang).

https://doi.org/10.1016/j.apacoust.2019.05.007
0003-682X/

2. Literature review

2.1. Impact of external noise

External noise consists of aircraft noise, train noise, road traffic noise, noise of outside people (including children on a playground), noise of lawn maintenance equipment, as well as the noise of nature, like rain. Some studies demonstrated that noise has a detrimental effect on children's performance, and this effect was more obvious on older children in primary schools because they suffer from noise in their classroom for a long time, and their school tasks require higher mental requirements [1,9]. They also indicated that aircraft noise is more impairing than road traffic noise, which in turn is more impairing than train noise, especially in terms of the impact on long-term memory [10,11]. However, there are also some studies indicating that noise may benefit children's performance. For example, a study conducted by Stansfeld [11] found that exposure to road traffic noise could improve children's episodic memory scores, and other studies involving white noise also concluded that continuous and persisting noise is beneficial for cognitive performance in children with Attention Deficit Hyperactivity Disorder (ADHD) [12]. Among all these external noises, road traffic, in particular cars, seems to be the most prevalent source, while aircraft noise was found to be the less common one [1].

2.2. Impact of internal noise

Internal noise inside classrooms includes the noise of teaching appliances (computers, projectors, etc.), noise of HVAC (Heating Ventilating and Air-conditioning) systems and plumbing systems, and noise generated by the children themselves (in their own classroom, in neighbouring classrooms or in corridors). Although in a field study conducted in 54 primary school classrooms in the Netherlands [2] children reported that the noise generated by themselves was the main annoyance in their classrooms, research into the impact of this type of noise has only started two decades ago. Hence, the knowledge could still be extended.

Shield and Dockrell [13] also found that the noise of children seems to be the dominant noise in the classrooms by conducting an internal noise survey in 140 primary school classrooms, and they proved that the presence of children, no matter what they are doing, could increase the noise level in classrooms. Later, they examined the impact of the noise caused by children's babble on their performance (verbal and non-verbal tasks) among 158 children aged around 8 years [14]. The result showed that two different noise conditions, namely 'babble' condition (the noise created by children) and 'babble and environmental' combined condition (the noise created by children plus the environmental noise, such as sirens and lorries), affected verbal and non-verbal tasks in a different way. For the non-verbal tasks, compared with the 'base' condition (typical quiet classroom), children performed worse in the 'babble' condition, and even worse in the 'babble and environmental' condition. For verbal tasks, compared with the 'base' condition, children performed worse in the 'babble' condition, but better in the 'babble and environmental' condition. According to Shield and Dockrell [14], the different time control rules of these tasks might be one of the possible explanations of these different effects.

2.3. Impact of music

Music is an indispensable part of the life of adolescents who usually spend about three hours per day listening to music, which not only satisfies their emotional needs but also helps them to understand the outside world [15]. The effect of music has been studied throughout history. As early as the 1950s, music was proved to have a positive impact on comprehensive reading tasks [16,17]. Several studies tried to find a theoretical understanding of how music affects people. Burleson [18] found music could reduce the off-task response and increase the task accuracy in psychotic children. This supported the previous studies by Fitzpatrick [19]. The reason why music could facilitate performance was explained by Richman [20]; he considered music as the mask of distractor (extraneous auditory) stimuli which could induce the off-task response. Hallam et al. [21] concluded that music could help school children to reach their arousal level so that they will perform tasks better. However, earlier studies are not consistent with these findings. Gianna and Raymond [5] compared the effect of music with high arousal potential (HA) and music with low arousal potential (LA). They found that both of them had a negative effect on task performance; and listening to HA music was more harmful than listening to LA music. This verified the conclusion of Konecni [22] and Hargreaves and North [23] that listening to music occupies cognitive capacity; so, the capacity for task performance would be impaired.

The different effects of music might be related to both the type of music and the type of task. Previous research has compared different types of music, and found a different effect of vocal music and instrumental music. Furnham et al. [24] found the presence of lyrics could enhance the negative effect of music by analysing pupils' performance with background vocal music and instrumental music. Iwanaga and Ito [25] also concluded that vocal music was more distracting for memory tasks than instrumental music. The underlying theory could be that the lyrics may impair phonological processing, which could interfere with the processing of verbal information [5]. In addition, the task-related factors also should be taken into consideration. The general consensus is that music may have a negative impact on complex mental tasks [5]. However music also may have a positive impact on routine tasks, which was confirmed by Smith [26].

2.4. Academic performance tasks

Many different performance tasks were used in previous studies with regard to testing the impact of acoustic conditions or noise on children. The phonological processing test is one of the common ones. Kattle et al. [27] used a task named "odd-one-out" to test the phonological processing in children. Eight lists of three monosyllabic words or CVC (Consonant Vowel Consonant) nonwords were played via a speaker. A CVC word is a word that is made up of a consonant, vowel and consonant sound (e.g. cat, hot, tip, man, etc.) [28]. Children were asked to point out the odd one word whose initial or final sound was to be analysed. The same type of test also was used in the studies of Bradley and Bryant [29]. Spelling is also a very common test [14,27]. Usually, in the spelling test, children were asked to write down the single words and sentences. Reading, including reading speed, reading accuracy and proof reading, is another common type of performance task used in previous studies [14,30,31]. Besides, memory tasks and mathematical tasks were also used as a method to measure learning performance in several studies [5,14,31,32]. Detailed information of these tasks can be found in Appendix A.

3. Method

3.1. Experimental setup

The acoustic experiment introduced here was part of a series of experiments in the SenseLab with children from the previous studied schools. The general procedure for these studies was introduced in the paper of Bluyssen et al. [7]. The acoustic experiment was based on a three factorial randomized design. The three factors were 'sound type' (with three levels 'children talk', 'traffic' and 'music'), 'SPL' (with two levels 45 dB(A) and 60 dB(A)) and 'acoustic treatment' (with two levels 'treated' and 'untreated'). In total, 335 children from 7 primary schools participated in the experiment that took place on 10 different days between February 13th and April 5th 2018.

3.1.1. Acoustic test chamber

The experiment was carried out in the acoustic test chamber of the SenseLab (width 2.4 m, length 2.6 m, height 2.1 m), that was equally divided into two parts (or two chambers) by a thick curtain. The walls, floor and ceiling of the chambers comprised of sandwich panels with a core of 80 mm Polyurethane and covered by thin steel lining. One of the two chambers had 11.6 m^2 of "Ecophon Akusto Wall A" acoustic absorption panels attached on the three walls and ceiling, so it was named the acoustically treated chamber (chamber B). The other chamber did not have added sound absorption material, and was therefore named the untreated chamber (chamber A). The difference between these two chambers and the effect of acoustic treatment on children was reported by Zhang et al. [33]. The estimated RT of these two chambers is shown in Table 1.

The layout and size of the two chambers were the same, each chamber had two small chairs and a loudspeaker placed in a corner of the room (see Fig. 1). The loudspeaker was directed to the centre of the two chairs.

3.1.2. Sound system

Each chamber was equipped with an ADAM A7X nearfield monitor connected to a Behringer U-Phoria UMC202HD audio-interface. The audio-interface was connected to a laptop from which the sound files were played through the software Audacity. The speakers were placed in a corner of the chamber having a distance of about 1.7 to 1.8 m from each of the chairs.

During the recording process, the words (see Appendix B) were read by a Dutch male speaker (age 38) in the acoustically treated chamber without any background sound and recorded with a Norsonic Nor 140 sound analyser that can also record and store a raw wave file. The wave files containing the words were then calibrated to have a SPL of a typical human voice at 1.8 m distance. There was about two seconds between words that belonged to the same question and 15 s between questions. Then these sound files were merged with calibrated sound files containing different background sounds at two different SPLs using the Adobe Audition software. In total, seven different background sound conditions were selected: 45 dB(A) or 60 dB(A) traffic noise, 45 dB(A) or 60 dB(A) classroom noise with children's talk, 45 dB(A) or 60 dB(A) piano music (a Bandari music named childhood memory), and silence

Table 1
Estimated RT [*] of the chamber.

Frequency [Hz]	$\frac{V}{6\bar{\alpha}S} \approx RT_{untreated}$[s]	$\frac{V}{6\bar{\alpha}S} \approx RT_{treated}$[s]
125	0.52	0.29
250	0.47	0.09
500	0.33	0.06
1000	0.24	0.06
2000	0.26	0.06
4000	0.29	0.06
Average 250–2000	0.33	0.07

[*] Since the two chambers are very small, modal behaviour was expected and it may therefore be difficult to define a reverberation time. The values in the table provide the calculated $V/6\bar{\alpha}S$ (where$V$ is the volume of the chamber [m^3], $\bar{\alpha}$ is the average coefficient [–], and S is the total geometrical area [m^2]) to give an indication of the amount of absorption in the chamber.

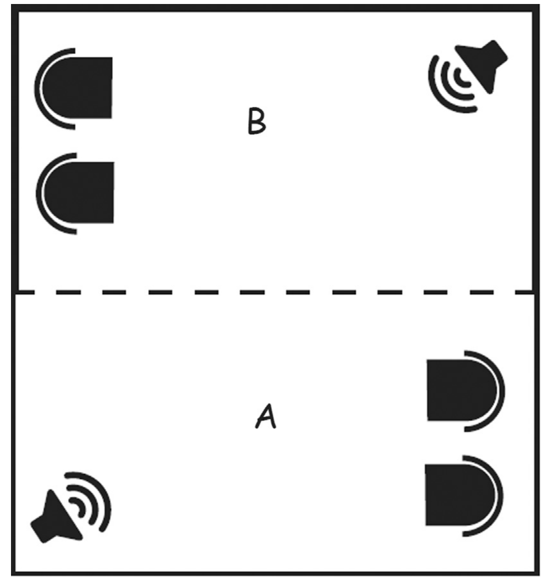

Fig. 1. The layout in the chambers.

(≈30 dB(A)). Each word-recording file was mixed with a 90 s episode of these background sounds.

3.1.3. Phonological processing task

The Phonological task that was performed in the experiments aimed to estimate children's hearing ability by only using spoken-words. It was similar as the 'odd one out' task used by Klatte [27], which contains four questions. In each question, three words, including two with similar pronunciation and one with different pronunciation were pronounced via a loudspeaker, and the children needed to pick up the different one. The children were not trained to do the tests but they were given instructions and one example to help them to understand the tests. All the words used in this test were CVC words (see Appendix B).

3.1.4. Daily procedure

At the beginning of the experiment, all children filled in a one-page personal information questionnaire, and then they were divided into groups of maximum 16 children. There was a maximum of three groups participating each experimental day. Every time only one group was further subdivided into four subgroups participating in the experiments in the four test chambers (thermal, air, acoustics, and light). Thus, there was a maximum of four children as a subgroup participating in the acoustic experiment. Before the experiments, the instructor handed every child a one-page acoustic questionnaire, then carefully explained the procedure to the children and practiced with an example task. The experiment consisted of two similar sections, and it was performed in the two chambers simultaneously. During one section of the experiment, all the children performed a phonological processing task that was mentioned in the above paragraph, then reported their sound evaluation during the task by means of a five-point scale (very noise-noise-neutral-quiet-very quiet) and assessed the influence of the background sound on their performance by means of a three-point scale (bad influence-no influence-good influence). After section one, these children changed their seat to another chamber and repeated the same procedure with another background sound and/or level. Each section was three minutes in length. At the end of the experiment, they were asked to point out which chamber they liked better from an acoustics point of view and what the reason for that was.

3.1.5. Participants

In all, 335 children, including 167 girls and 168 boys from 10 classrooms of seven Dutch primary schools that were visited in the year before this study, participated in this study. The mean age of these children was 10.6 years old. Among them, 14 children reported having hearing problems; they were excluded from the analysis. Besides, the 27 children that participated in the first day were also excluded because of the use of a wrong questionnaire, and 4 children of school 4 were excluded because of sound speaker failure. After the filtering, the data of 290 children were left and were considered to be valid. Considering the fact that each child participated in the same test twice under two different experimental conditions, each child was regarded as two subjects. For these reasons, data of 580 cases were collected and used in this study. Their characteristics including age and gender were analysed under different conditions, as shown in Table 2, there's no statistically significant difference of these children among those conditions.

3.1.6. Ethical aspects

After recruitment of the schools, the parents received an information letter and a consent letter from the school management, which usually occurred two weeks before the visit. On the day of the visit, the research team received the consent forms usually from the teachers accompanying the children. For the children without permission to join the experiments, the school management generally decided not to have them join the visit. Furthermore, the children always had the option to opt out if they no longer wanted to participate.

The Ethics committee of the TU Delft gave approval for the study.

3.2. Data analysis

3.2.1. Descriptive analysis

Descriptive analysis was used to describe children's general information (including age, gender, hearing problems etc.), the mean value of scores of their tests, sound evaluations and influence assessments, and the comparison of their preferred chambers. For the analysis related to the test, sound evaluation and influence assessment, every child was regarded as two participants since each child participated twice in the experiment.

3.2.2. T-tests and Spearman's correlation tests

To check the learning effect, namely the influence of the sequence of tests on children's test scores, the Paired-Samples t-tests was used to compare children's scores between the first score and the second score. For the evaluation of the effect of age and gender on children's performance, sound evaluation and influence assessment, the Independent-Samples *t*-test was used to compare children's responses between boys and girls (since there's no overlap of the participants in these two groups, they are independent from each other), and Spearman's correlation tests were applied to identify the relations between children's age and their responses. Additionally, this study tried to determine the impact of children's sound perceptions in their real classrooms on the responses from the children in the experiments reported here. So, all the results were compared between children who were bothered by noise in their classroom and children who were not by an Independent-Samples *t*-test (because children in these two groups are different, they are independent from each other).

3.2.3. Two-way analysis of variance

Children's performance, sound evaluation and influence assessment were analysed with a two-way analysis of variance (ANOVA), with repeated measures on two factors: SPL with two levels (45 and 60 dB(A)) and sound type with three levels ('children talk', 'traffic' and 'music'). It should be noted that the test was conducted for the two chambers separately because every child participated in the experiment in both of the chambers. This means the participants in each chamber were the same, so the chamber could not be considered as another factor for the ANOVA. Differences between the levels of the within factors were examined by the comparison tests, and the effect of one factor was evaluated by holding the other factors fixed. If there was a statistically significant difference among the three levels of sound type, then three pairwise comparisons were conducted to compare each two levels.

4. Result

4.1. Performance test

Children's performance was evaluated by the phonological processing test scores; one score for each question. The *t*-test of the test scores proved no significant effect of the test sequence ($t_{565.7} = -1.365,\ p = 0.173$), and no effect was shown ($r = 0.097$). The t-value measured the size of the difference relative to the variation in the sample data. The greater the t-value (either positive or negative), the greater the evidence that there was a significant difference. The average score for the first test was 2.92, while for the second test this was 3.03. In addition, the Spearman's correlation test showed no significant effect of age on the test score ($rho = -0.015,\ p = 0.715$; *rho* indicates the strength of the relation between these two variables, the greater the absolute value, the stronger the relations), which might be because the age range was narrow (8–13 years old). However, the scores differed significantly with respect to gender ($t_{552.4} = -3.493,\ p = 0.001$), and it represented a small effect ($r = 0.292$). In general, girls performed better (with an average score of 3.15) than boys (with an average score of 2.83).

4.2. Sound evaluation

The five-point scale (very noisy-noisy-neutral-quiet-very quiet) of the sound evaluation was coded into a score from 1 to 5 correspondingly in SPSS. The mean value was 2.85 ($SD = 1.11$). The noise evaluation approximately was normally distributed, with 38.5% of children voting for noisy (including very noisy), 34.4% of children voting for neutral, and 27.1% of children voting for quiet (including very quiet). According to the result of the Spearman correlation test and *t*-test, neither age ($rho = -0.023,\ p = 0.582$) nor

Table 2
Characteristics of children in different experiment conditions.

	45 dB (A) children talk	60 dB (A) children talk	45 dB (A) traffic	60 dB (A) traffic	45 dB (A) music	60 dB (A) music	No noise	P value
n	95	64	75	113	73	94	66	–
Age Mean (SD)	10.7 (1.0)	10.5 (1.0)	10.8 (1.0)	10.7 (1.1)	10.7 (1.1)	10.4 (1.1)	10.6 (1.1)	0.155[a]
Gender (% Girls)	53.7	42.2	56.0	52.2	49.3	40.4	53.0	0.282[b]

[a] P-value obtained from ANOVA test
[b] P-value obtained from Chi-squared test.

gender ($t_{552.8} = -0.130,\ p = 0.897,\ r = 0.009$) had a significant impact on children's sound evaluation.

4.3. Influence assessment

With regard to the assessment of influence of sounds on their school performance, the three-point scale (bad influence-no influence-good influence) was coded into a score from 1 to 3 in SPSS. The mean value of it was 1.87 ($SD = 0.75$). 35.4% of the children assessed the influence of sounds on their performance as bad, 41.9% of the children assessed it as "no influence", and 22.7% assessed it as good. The assessment didn't differ significantly between boys and girls ($t_{543} = -0.331,\ p = 0.740,\ r = 0.027$), and it didn't have a relationship with age ($rho = -0.080,\ p = 0.060$)based on the Spearman correlation test.

5. Discussion

The two-way ANOVA tests were conducted to examine the interaction of sound type and SPL on children's phonological processing performance, sound evaluation and assessment of the influence of sounds. Table 3 shows the main results of the tests. Only in the untreated chamber, the interaction between the impacts of SPL and sound type on children's phonological processing performance was statistically significant. The same was found for their influence assessment. Besides, the interaction between these impacts on children's sound evaluation tended to be significant for this chamber. The details of these results are discussed in this section.

Comparing to the treated chamber A, there's no significant interaction between the sound type and SPL was found in the untreated chamber B, this might be caused by the difference between the nominal and the real SPLs of the sounds in chamber B. All the sound files were calibrated to have 45 dB(A) and 60 dB (A) in chamber A. At the seating position in chamber B, the same sound files actually sounded lower than in chamber A. According to the Sabine-Franklin-Jaeger's SPL equation, the difference of SPL between these two chambers was 12 dB(A). Therefore, at the seating position in chamber B, 45 dB(A) and 60 dB(A) were actually 33 dB(A) and 48 dB(A), respectively. This means that both of SPLs met the standard of the study room specified by BB93 [34], and these lower SPL sounds might be the reason that no significant interaction effect of SPL and sound types was found in this chamber.

5.1. Impact on children's performance

There was a statistically significant two-way interaction between the impacts of SPL and sound type on children's performance in chamber A, $F(2, 280) = 6.278,\ p = 0.002$ (The F value is the ratio of two mean square values. A large F (either positive or negative) value means the null hypothesis is wrong, or in other words, the data are not sampled from populations with the same mean; The P value is determined from the F value). The means of children's test scores for the six conditions (two SPL × three sound types) in chamber A are plotted in the left part of Fig. 2. However, there was no statistically significant two-way interaction between SPL and sound type in chamber B, with respect to the impact on children's performance. The means of children's test scores in chamber B are plotted in the right part of Fig. 2.

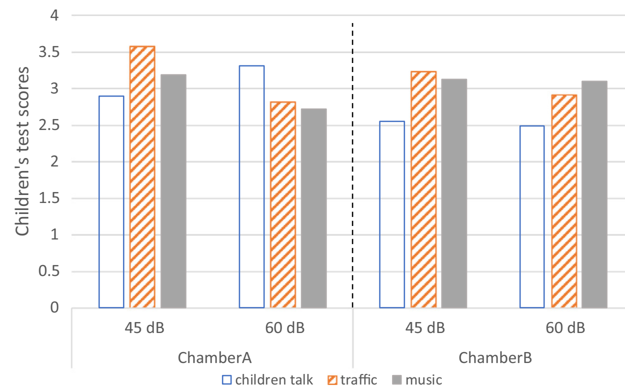

Fig. 2. Mean values of children's test scores in different experimental conditions for chamber A and B.

In chamber A, a statistically significant difference of children's test scores between different sound types was found ($F(2, 280) = 4.318,\ p = 0.014$) for a SPL of 45 dB(A). When the sound was 'children talk' the mean value of children's test score was the lowest. When the sound was 'traffic' their average score increased significantly ($p = 0.004$). No other significant difference was found for the other two pairwise comparisons. When the SPL was 60 dB(A), no statistically significant difference of children's test scores was seen among these three types. When comparing the SPL situation of 60 dB(A) with 45 dB(A), no statistically significant difference of children's test scores was seen during the 'children talk' sound, but when 'traffic' sound was played, their test score was significantly higher in the 45 dB(A) situation, ($F(1, 280) = 11.388,\ p = 0.001$) and when 'music' sound was played, their test score showed a tendency to increase in the 45 dB(A) situation ($F(1, 280) = 3.740, p = 0.054$).

In chamber B, children's test scores differed significantly among different sound types in both SPL situations (45 dB, $F(2, 276) = 4.724,\ p = 0.010$; 60 dB, $F(2, 276) = 3.275$, $p = 0.039$). When the SPL was 45 dB(A), children's test score significantly increased during both the 'traffic' sound ($p = 0.005$) and the 'music' sound ($p = 0.022$) compared with the 'children talk' sound. In the situations with 60 dB(A) sounds, children's test score was significantly higher during the 'music' than the 'children talk' sound ($p = 0.012$), but no statistically difference of children's scores was found in the other two pairwise comparisons. There was no statistically significant difference of children's test score between 45 dB(A) and 60 dB(A) situations with any sound types. This could be explained by the fact that the SPL of sounds at the seating position in chamber B was 12 dB(A) lower their nominal values and the SPL of those sound files met the standards.

Table 3
Results of the two-way ANOVA[a].

	Chamber A (untreated)			Chamber B (Acoustically treated)		
	SPL	Sound type	SPL* Sound type	SPL	Sound type	SPL* Sound type
Test scores	0.348	0.052	**0.002**	**0.001**	0.329	0.641
Sound evaluation	**<0.001**	**<0.001**	0.053	**0.005**	**<0.001**	0.253
Influence assessment	**0.009**	0.107	**0.032**	**0.002**	0.124	0.798

[a] The P values are presented; P-values in bold mean statistically significant at the 5% level.

5.2. Impact on children's sound evaluation

There was a strong tendency for the interaction between the impacts of SPL and sound type on children's sound evaluation in chamber A ($F(2, 271) = 2.975$, $p = 0.053$). However, no statistically significant interaction between SPL and sound type on children's sound evaluation was found in chamber B. The means of children's sound evaluations in the six conditions in each of these two chambers are plotted in Fig. 3.

In chamber A, no statistically significant difference of children's evaluation of sound was seen with an SPL of 45 dB(A). While with an SPL of 60 dB(A), a significant difference was found among the three sound types ($F(2, 271) = 7.626$, $p = 0.001$). However, only one significant pairwise difference was found between the situations with the 'children talk' sound and the 'music' ($p = 0.040$). Compared with 60 dB(A), children's evaluation scores of sounds were significantly higher (quieter) in the 45 dB(A) situations with the 'children talk' sound ($F(1, 271) = 22.815$, $p < 0.001$) or the 'music' ($F(1, 271) = 10.332$, $p = 0.001$), while no significant difference of children's evaluation was seen between 45 dB(A) and 60 dB(A) 'traffic' sounds.

In chamber B, still no statistically significant difference of children's evaluations of sounds was seen when the SPL was 45 dB(A), while a significant difference was found among the three sound types ($F(2, 268) = 5.504$, $p = 0.005$) when the SPL was 60 dB(A). Compared with the 'children talk' sound, children's evaluation scores for the 'traffic' sound ($p = 0.007$) and the 'music' sound ($p = 0.002$) were significantly higher. But there was no significant difference of children's evaluations between the 'traffic' sound and 'music'. For the comparison of children's evaluations of sounds between two SPLs, children evaluated the 45 dB(A) sounds significantly higher. This difference was statistically significant for the 'children talk' ($F(1, 268) = 10.650$, $p = 0.001$) and 'traffic' sound ($F(1, 268) = 4.709$, $p = 0.031$).

5.3. Impact on children's influence assessment

There was a statistically significant two-way interaction between the impacts of SPL and sound type on children's influence assessments in chamber A ($F(2, 265) = 3.495$, $p = 0.032$). The means of children's assessment in the six conditions in chamber A are plotted in the left part of Fig. 4. No statistically significant two-way interaction among SPL and sound type in chamber B was found. The means of children's assessments in chamber B are plotted in the right part of Fig. 4.

In chamber A, with an SPL of 45 dB(A), no statistically significant difference of children's assessment of influence of sounds was seen between the three sound types, while when the SPL was 60 dB(A), there was a significant difference ($F(2, 265) = 6.886$, $p = 0.001$). The differences between each two sound types were also found to be significant: children thought the influence of the 'children talk' sound was the most negative, the 'traffic' sound was significantly better than the 'children talk' sound ($p = 0.035$), and the 'music' was significantly better than both the 'children talk' sound ($p < 0.001$) and the 'traffic' sound ($p = 0.049$). According to the results of the comparison of children's influence assessment between 45 dB(A) and 60 dB(A), only when the sound type was 'children talk' a significant difference of children's assessment scores of the influence of sounds was found ($F(1, 265) = 8.851$, $p = 0.003$).

In chamber B, when the SPL was 45 dB(A), still no statistically significant difference of children's assessments of the influence of sounds was seen among the three sound types. However, when the SPL was 60 dB(A), a significant difference was found ($F(2, 264) = 4.429$, $p = 0.013$): compared with the 'children talk' sound, children's assessment scores of the influence of the 'traffic' sound ($p = 0.026$) or the 'music' ($p = 0.004$) were significantly higher, but there was no significant difference between the 'traffic' sound and the 'music'. The comparison between 45 dB(A) and 60 dB(A) didn't show any significant difference of children's assessment of the influence of sounds, no matter what sound type it was. This might be due to the fact that the SPLs in Chamber B were lower than chamber A. In fact, both SPLs in chamber B met the standard of a classroom. So, they might not have had the negative influence on children's performance as was intended.

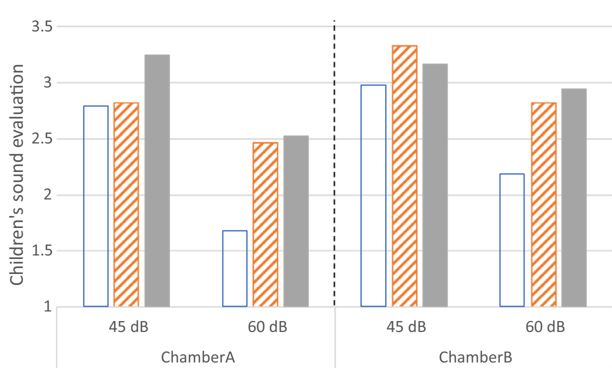

Fig. 3. Mean values of children's evaluations of sound in different experimental conditions for chamber A and B.

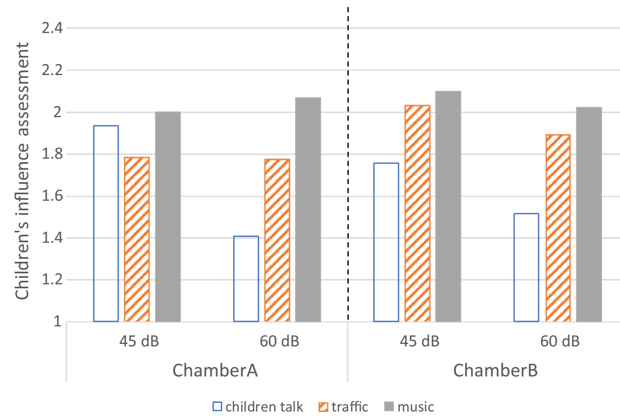

Fig. 4. Mean values of children's influence assessment in different experimental conditions for chamber A and B.

5.4. Relation to children's real classrooms

In the year before this study, a field study was conducted in the schools that the children participating came from. That study showed that 87% of children were bothered by noise in their classrooms [2]. Among the children who participated in this study, 220 children participated in the previous field study, and 90% (195) these 220 children reported to be bothered by noise in their classrooms. To find out whether this previous assessment has an impact on children's response in this study, t-tests were conducted to compare the children who were bothered by noise in their classrooms and the children who were not. As shown in Table 4, there were statistically significant differences in children's test scores and influence assessment between these two groups of children, and both of them presented small effects. Children who were bothered by the noise in their classroom got higher test scores, but evaluated lower on the influence assessment than children who were not bothered.

Table 4
Comparison between children who were bothered by noise in their classrooms and children who were not.

Bothered by noise	Yes (Mean)	No (Mean)	t[a]	P-values[b]	Effect size
Test scores	3.06 (1.08)	2.70 (1.13)	$t_{432} = 2.075$	**0.039**	**0.330**
Sound evaluation	2.83 (1.10)	2.79 (1.01)	$t_{419} = 0.244$	0.808	0.037
Influence assessment	1.79 (0.74)	2.05 (0.72)	$t_{411} = -2.117$	**0.035**	**0.352**

[a] The t-value obtained from t-tests, measured the size of the difference relative to the variation in the sample data. The greater the t-value (either positive or negative), the greater the evidence that there is a significant difference.
[b] P-values obtained from t-tests. P-values in bold mean statistically significant at the 5% level.

On one hand, this might be explained through some children's acute hearing. The previous field study showed that different children can have different concerns in terms of the factors of IEQ, and some children were more concerned about sound in their classrooms [35]. It is hypothesized that these children were prone to be bothered by noise, but at the same time, they could have a better performance in the phonological processing because of their acute hearing. On the other hand, it also might be explained through children's different intelligence. According to a publication of Psyke 59 Grader Nord, children with high intelligence are usually more sensitive to outside stimuli including sound, smell and taste [36]. Therefore, these gifted children could have a better performance in the test, but they might also be more easily distracted by irrelevant sounds. Bost of these hypotheses need to be tested in the future.

5.5. Limitations

With respect to the limitations of this study, two main weaknesses should be mentioned. One is the setting of the experimental chambers, the small size and the thick curtain causing a low RT in the chambers, even for the untreated chamber. Both reached the highest class of the acoustic requirements for primary schools in the Netherlands. Future studies would better be conducted in real classrooms or in rooms with similar size and similar acoustic conditions as real classrooms.

The second limitation is the single performance task. Previous studies have demonstrated many different tasks. However, due to the limitations of time (pupils had to undergo many different tests also on other indoor environmental factors), only one phonological processing task was used in this study. So, the impact on children's other performance still needs to be evaluated. Future studies should adopt more tasks to conduct a full assessment of children's performance.

6. Conclusion

The current study provides evidence for the impact of acoustic conditions on children. In addition to the review of the well-documented influences of different types of sounds on children's performance, this study reported the interaction between sound type and SPL on children's performance, sound evaluation and influence assessment. Statistically significant interactions between the impact of SPL and sound type on children's phonological processing performance and assessment of the influence of sounds were demonstrated in the untreated chamber (whose RT interestingly got close to a class A classroom in the Netherlands according to the Requirement of Fresh Schools [37]). In this chamber, the simple main effects analysis showed that children performed better under the 45 dB(A) conditions than the 60 dB(A) conditions when the sound type was 'traffic', and children evaluated the 45 dB(A) sound to have a better influence than the 60 dB(A) sound when the sound type was 'children talk'. Additionally, a significant effect of sound type on children's performance was found when the SPL was 45 dB (A), and on children's influence assessment when the SPL was 60 dB (A).

Although this study was conducted in a lab environment and all the background sounds were played through a speaker, its findings still have practical significance, especially the one that showed the interaction effect of the sound type and SPL on children. Additionally, the study showed that the two-way ANOVA analysis method could be an appropriate method to test the interaction between two characteristics of a sound.

Declaration of interest

None.

Acknowledgements

This study was sponsored by the fellowship of Philomena Bluyssen provided by the Delft University of Technology under the chair of Indoor Environment and the China Scholarship Council (CSC).

Appendix A

The list of studies that used performance tasks.

Type of tasks	Reference	Detail task	Main finding
Phonological processing	Klatte, 2010 [27]	Chose the different word from the others with respect to the initial or the final sound.	Children performed better in the classrooms with a short RT.
Spelling	Shield, 2006 [14]	The English spelling test: 15 age-appropriate items spelling test.	Compared with typical quiet classrooms, children performed better in the classrooms with babble and environmental noise, but worse in the classrooms only with babble.

(*continued on next page*)

Appendix A (*continued*)

Type of tasks	Reference	Detail task	Main finding
	Klatte, 2010 [27]	The German spelling test: write down single words and sentences, the score is the number of correctly written graphemes.	There was no significant impact of the RT on children's spelling performance.
Reading	Shield, 2006 [14]	Reading test: Suffolk Reading Scale, A standardised reading test that consists of multiple-choice and sentence-completion questions.	Compared with typical quiet classrooms, children performed better in the classrooms with babble and environmental noise, but worse in the classrooms only with babble.
	Clark, 2005 [30]	Reading comprehension tests: nationally standardized tests were used (suitable for 8–13 years old children). In the UK, the 86-item Suffolk Reading Scale, level 2 was used; in the Netherlands, the 43-item CITO Readability Index for Elementary and Special Education was used; in Spain, the 27-item ECL-2 was used.	Aircraft noise had a detrimental effect on children's reading comprehension. This negative relation between aircraft noise exposure and children's reading comprehension were found in all three countries.
	Ljung, 2009 [31]	Reading speed and comprehension test: fill the intervals in a four-page story, in each interval, choose the appropriate word from three options.	With regard to reading speed, children performed slower in the traffic noise condition than in the silent or in the irrelevant speech conditions. Regarding reading comprehension, no significant effect of noise was found.
Memory	Cassidy, 2007 [5]	Immediate recall task: recall a short news story containing 21 'ideas'. Free recall task: recall 20 everyday six-letter words. Delayed recall task: recall the passage in the first immediate recall task.	Students performed worse on all tasks while listening to background sound, no matter whether it was music or noise.
Mathematic	Shield, 2006 [14]	Arithmetic: basic computation without verbal component.	Children performed better in typical quiet classrooms than in classrooms with noise generated by children.
	Ljung, 2009 [31]	Arithmetic: three division problems and three multiplication problems. Geometric: name points in a coordinate system. Understand the relationship between fractional expressions and areas of figures. Understand the relationship between distance and numerical expressions; measure distances.	Compared with silence, road traffic noise had a negative influence on children's mathematical performance.
Listening		comprehension	Klatte, 2010 [32]
Listening		comprehension task: mark the appropriate drawings based on the listening instruction.	Both background speech and classroom noise had a negative impact on children's listening comprehension, the younger the children the more vulnerable.

Appendix B

The list of words used in the phonological processing task.

1	kop	kup	fos
2	Sif	num	nom
3	lir	ler	nim
4	rol	nem	rul
5	pok	men	min
6	pik	lor	pek
7	sof	suf	weg
8	fis	van	fes

References

[1] Shield BM, Dockrell JE. The effects of noise on children at school: a review. Building Acoustics 2003;10:97–116.

[2] Bluyssen PM, Zhang D, Kurvers S, Overtoom M, Ortiz-Sanchez M. Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings. Build Environ 2018;138:106–23.

[3] Elliott EM. The irrelevant-speech effect and children: Theoretical implications of developmental change. Memory Cognition 2002;30:478–87.

[4] Schlittmeier SJ, Hellbrück J. Background music as noise abatement in open-plan offices: a laboratory study on performance effects and subjective preferences. Appl Cognit Psychol: Off J Soc Appl Res Memory Cognition 2009;23:684–97.

[5] Cassidy G, MacDonald RA. The effect of background music and background noise on the task performance of introverts and extraverts. Psychol Music 2007;35:517–37.

[6] Dobbs S, Furnham A, McClelland A. The effect of background music and noise on the cognitive test performance of introverts and extraverts. Appl Cognit Psychol 2011;25:307–13.

[7] Bluyssen PM, Zhang D, Hyun Kim D, Eijkelenboom AM, Ortiz M. First SenseLab studies with primary school children: exposure to different environmental configurations in the Experience room. under review 2019.

[8] Bluyssen PM, van Zeist F, Kurvers S, Tenpierik M, Pont S, Wolters B, et al. The creation of the SenseLab: a laboratory for testing and experiencing single and combinations of indoor environmental conditions. Intell Build Int 2018:5–18.

[9] Shield BM, Dockrell JE. The effects of environmental and classroom noise on the academic attainments of primary school children. J Acoust Soc Am 2008;123:133–44.

[10] Hygge S. Classroom experiments on the effects of different noise sources and sound levels on long-term recall and recognition in children. Appl Cognit Psychol 2003;17:895–914.

[11] Stansfeld SA, Berglund B, Clark C, Lopez-Barrio I, Fischer P, Öhrström E, et al. Aircraft and road traffic noise and children's cognition and health: a cross-national study. The Lancet 2005;365:1942–9.

[12] Söderlund G, Sikström S, Smart A. Listen to the noise: noise is beneficial for cognitive performance in ADHD. J Child Psychol Psychiatry 2007;48:840–7.
[13] Shield BM, Dockrell JE. External and internal noise surveys of London primary schools. J Acoust Soc. Am 2004;115:730–8.
[14] Shield BM, Dockrell JE. Acoustical barriers in classrooms: the impact of noise on performance in the classroom. Br Educ Res J 2006;32:17.
[15] North AC, Hargreaves DJ, O'Neill SA. The importance of music to adolescents. Br J Educ Psychol 2000;70:255–72.
[16] Hall JC. The effect of background music on the reading comprehension of 278 eighth and ninth grade students. J Educ Res 1952;45:451–8.
[17] Mitchell AH. The effect of radio programs on silent reading achievement of ninety-one sixth grade students. J Educ Res 1949;42:460–70.
[18] Burleson SJ, Center DB, Reeves H. The effect of background music on task performance in psychotic children. J Music Ther 1989;26:198–205.
[19] Fitzpatrick F. The use of rhythm in training severely subnormal patients. Am J Mental Deficiency 1959;63:981–7.
[20] Richman JS. Background music for repetitive task performance of severely retarded individuals. Am J Mental Deficiency 1976.
[21] Hallam S, Price J, Katsarou G. The effects of background music on primary school pupils' task performance. Educ Stud 2002;28:111–22.
[22] Konecni V. Social interaction and musical preference, The psychology of music. D. Deutsch, New York: Academic Press; 1982.
[23] North AC, Hargreaves DJ. Music and consumer behaviour. Oxford Handbook of Music Psychol 2009:481–90.
[24] Furnham A, Trew S, Sneade I. The distracting effects of vocal and instrumental music on the cognitive test performance of introverts and extraverts. Personality Individ Differ 1999;27:381–92.
[25] Iwanaga M, Ito T. Disturbance effect of music on processing of verbal and spatial memories. Percept Mot Skills 2002;94:1251–8.
[26] Smith W. Effects of industrial music in a work situation requiring complex mental activity. Psychol Rep 1961;8:159–62.
[27] Klatte M, Hellbrück J, Seidel J, Leistner P. Effects of classroom acoustics on performance and well-being in elementary school children: a field study. Environ Behav 2010;42:659–92.
[28] de Graaff S, Hasselman F, Verhoeven L, Bosman AM. Phonemic awareness in Dutch kindergartners: Effects of task, phoneme position, and phoneme class. Learn Instruction 2011;21:163–73.
[29] Bradley L, Bryant PE. Categorizing sounds and learning to read—a causal connection. Nature 1983;301:419.
[30] Clark C, Martin R, Van Kempen E, Alfred T, Head J, Davies HW, et al. Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: the RANCH project. Am J Epidemiol 2005;163:27–37.
[31] Ljung R, Sorqvist P, Hygge S. Effects of road traffic noise and irrelevant speech on children's reading and mathematical performance. Noise and Health 2009;11:194.
[32] Klatte M, Lachmann T, Meis M. Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting. Noise and Health 2010;12:270.
[33] Zhang D, Tenpierik M, Bluyssen PM. "The effect of acoustical treatment on primary school children's performance, sound perception, and influence assessment," accepted for ptesentatoin at the CLIMA2019 conference. Romania: Bucharest; 2019.
[34] D. f. Education and Skills, "Building Bulletin 93: Acoustic design of schools," ed: The Stationary Office London, 2003.
[35] Zhang D, Ortiz MA, Bluyssen PM. Clustering of Dutch school children based on their preferences and needs of the IEQ in classrooms. Build Environ 2019;147:258–65.
[36] Psyke 59 Grader Nord. (2018, 23 Oct). High intelligence combined with High sensitivity. Available: http://psyke59gradernord.com/english/9-high-intelligence/4-high-intelligence-combined-with-high-sensitivity.
[37] Scholen PVEF. November, 2014. Sep Sci Technol 2015;49:16.