Pupils' experience of noise in two acoustically different classrooms

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Abstract

Purpose – This study aims to examine activity-related sound levels and pupils' perceptions of the acoustic environment in two classrooms, one of which was a traditional classroom (Reference classroom, reverberation time (RT) 0.54 s) and the other a refurbished classroom (Demo classroom, RT 0.32 s).

Design/methodology/approach – Three types of data were gathered: room acoustic measurements, activity sound levels during different activities and pupils' subjective experience concerning factors related to acoustics. Pupils, 10–11 years old ($N = 34$), estimated their subjective experience in general and after four test lessons. Teachers planned the test lessons to have four different lesson types: quiet work, one-person speaking, group work and activity-based work. The sound levels of activities were measured during the test lessons.

Findings – The activity sound levels were 2–13 dB L_{Aeq} lower in the Demo classroom than in the Reference classroom, depending on lesson type. Pupils were less annoyed by noise in the Demo than in the Reference classroom. Pupils' speech was the most annoying sound source. More pupils were annoyed by it in the Reference classroom (65%) than in the Demo classroom (15%). Hearing the teacher while not seeing her face, concentrating on teaching and sitting in one's place were estimated easier in the Demo classroom than in the Reference classroom.

Originality/value – This study offers a new approach using test lessons for studying activity sounds in schools. Activity sounds and their annoyance can be significantly diminished by classroom refurbishments.

Keywords Acoustic design, Activity sounds, School noise, Noise annoyance, Acoustic refurbishment

Paper type Research paper

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1. Introduction

Noise, i.e. unwanted sound, in schools has been found to affect children's cognitive behavior and learning (Klatte *et al.*, 2013; Stansfeld and Clark, 2015). External and internal sound pressure levels (SPL) of the classrooms were negatively related to 7 and 11 years old children's school attainment (Shield and Dockrell, 2008). External noise is crucial in areas with high environmental noise burden (Stansfeld *et al.*, 2005), but the situation is different when the such burden is low or absent. When examining the sound levels of 142 classrooms outside the flight paths into major airports, the external sound level of the schools influenced the classrooms' internal sound levels only during the quietest classroom activity (Shield and Dockrell, 2004). During other activity, the classrooms' SPL was determined by the school activity. Activity sounds also disturb both pupils and teachers. They rated chatter the most disturbing noise source while the second disturbing noise was sounds from the corridor and third scraping sounds from chairs and tables (Enmarker and Boman, 2004). Therefore, it seems that the main noise source of most schools is school activity.

1.1 Room acoustic design and relevant room acoustic measures

The aim of room acoustic design is to make the sound environment suitable for the functions of the space. In classroom environments, the target speech should be clearly heard, and all other sounds, called the masking sounds, should be so low that listening or producing speech is not complicated. Target sound means, for example, the speech of a teacher, a pupil in address or a video playback. Masking sound consists of all other sounds than the target speech: building service noise, teaching equipment noise, noise outside the classroom (other classrooms, environmental noise outside the building), clatter of furniture and other pupils' undesired speech (chatter). Activity sounds cover all the sounds produced by classroom activity. However, the challenge in modern classrooms is that the requirements of the space change depending on the activity. When only one person is talking, high speech intelligibility is desirable. However, during group work or active learning methods, it is desirable to hear only your group and for SPL not to rise too high. This means high speech intelligibility only at close distance.

In classrooms, for target speech to be heard properly, the signal-to-noise ratio (SNR), i.e. the difference between the SPL of target speech and masking sound, must be positive, at least +10 dB, to assure that normally hearing people distinguish the speech (IEC, 2020). For younger children, this ratio has to be larger than for older (Bradley and Sato, 2008).

Reverberation time (RT) [s] is the most usual room acoustic descriptor. It describes how long time it takes for the sound to decay by 60 dB. RT reduces with increasing the amount of sound-absorbing materials in the room (Bistafa and Bradley, 2000). In a quiet condition, classroom's long RT might not influence speech perception (Prodi and Visentin, 2022) and without background noise, short RTs created with acoustic panels can even reduce speech intelligibility, especially further from the speaker (Amlani and Russo, 2016). Long RT, however, makes the speech less intelligible because the fast modulations, i.e. level variations, of speech are blurred. During noise, long RT impairs speech perception compared to short RT (Klatte *et al.*, 2010c; Prodi and Visentin, 2022), and children are more affected than adults (Klatte *et al.*, 2010a; Neuman *et al.*, 2010). Children studying in classrooms with long RTs performed worse in a phonological processing task, reported a higher burden of indoor noise and rated less positively the relation to their teachers and peers as well as their achievement motivation compared to children studying in classrooms with short RTs (Klatte *et al.*, 2010b). Therefore, room acoustic design can influence many aspects of learning, teaching and even personal relationships.

The most adequate room acoustic measure objectively estimating speech intelligibility is speech transmission index (*STI*) (IEC, 2020) because it takes into account both SNR and RT. *STI* is almost linearly associated with the *subjective speech intelligibility* of random and meaningless syllables, which are the constructing elements of speech. As with *SNR*, pupils' age influences the relation of *STI* and speech intelligibility (Astolfi *et al.*, 2012).

1.2 Activity sounds in schools

Because school activity is the main noise source in most classrooms (Shield and Dockrell, 2004), the room's acoustic quality and activity together determine the perception of noise in the classroom. In one Finnish survey, the activity SPL in occupied classrooms was, on average, 69 dB L_{Aeq} (Sala and Rantala, 2016). This was concluded to be high, making the acoustic environment in these schools detrimental for speech communication and learning and a possible risk of occupational voice disorders (Sala and Rantala, 2016). However, the SPL represented the activity sounds overall – the values of target speech and masking sounds were not separately determined. One study tried to separate SPLs of target speech and masking sound by separating the activity sounds related to speech and nonspeech (Brill and Wang, 2021). The average SPLs in classrooms were 66.2 L_{Aeq} during speech and 49.3 L_{Aeq} during nonspeech. To examine the activity sounds and their influence on experience, a more detailed examination of activities is needed.

Another view is to examine SPL during a certain activity. The SPL of occupied classrooms were measured, and the type of activity was classified into six categories (Shield and Dockrell, 2004). Their six activities were as follows:

(1) children sitting at tables doing silent reading or tests;
(2) children sitting at tables or on the floor, with one person (teacher or child) speaking at any one time;
(3) children sitting at tables working individually, with some talking;
(4) children working individually, moving around the classroom, with some talking;
(5) children working in groups, sitting at tables, with some talking; and
(6) children working in groups, moving around the classroom, with some talking.

The study found a large difference between the quietest (Activity 1) and loudest (Activity 6) classroom activities (56 dB L_{Aeq} to 77 dB L_{Aeq}). The loudest classroom activity was related to group work and movement, which are emphasized in activity-based learning methods. For example, the new Finnish national core curriculum for basic education sees pupils as active learners who benefit from collaborative ways of learning (Opetushallitus, 2016). Therefore, active and collaborative formats of learning are often emphasized in the classrooms. This does not necessarily mean that during these active learning methods, high SPLs would be considered annoying. Activity in its different forms is crucial for the functioning of schools. However, the annoyance and other burdens of noise can be influenced by, for example, room acoustic design.

1.3 The present study

The aim of our study was to examine pupils' experiences during different classroom activities in two classrooms with different RTs: one classroom had gone through a room acoustic refurbishment (RT = 0.32 s), and the other had not (RT = 0.54 s). Our approach to classroom activities was examining test lessons teachers held representing different classroom activities (lesson types). The first research question was how noise is experienced in these classrooms in general. The second research question was how noise is experienced

in the classrooms during different lesson types. The third question was whether the SPLs in the classrooms differ during different lesson types.

2. Materials and methods

2.1 Design

We conducted this study in a school where one classroom (Demo) was refurbished in 2019 by paying special attention to room acoustic conditions. The Demo classroom was originally built to test alternative study environments. Two independent groups (school classes) were investigated simultaneously in this school: a reference group working in a nonmodified classroom and a demo group working in a modified classroom. Independent variables are *classroom type* (Demo classroom and Reference classroom) and *lesson type* (L1, L2, L3 and L4). *Lesson types* were based on Shield and Dockrell (2004) activity classification, explained in Section 1.2. Based on their study, we applied four *lesson types* described in Table 1. Dependent variables are *activity sound level* and subjective responses given by the pupils from these two *classroom types* in general and during each *lesson type*. Both groups were examined in their normally dedicated classrooms with their own teachers so that the pupils did not perceive any change in their normal routines during this experiment. The test lessons were held during January 2021.

2.2 Participants

Participants were 10–11 years old pupils of two fourth-grade classes. The Reference classroom had 21 pupils. The Demo classroom consisted of 18 pupils, of which five received special support for their learning. These five pupils were not included in the analysis of questionnaires to make the groups more comparable. The study went through an ethical review at the University of Turku (Ethical board statement 36/2020, 18.11.2020). The parents and the pupils gave written informed consent to participate in the study.

2.3 Classroom types

The dimensions of the Demo and the Reference classrooms were 9.0 × 6.7 × 2.9 m (60 m^2) and 7.7 ×7.8 × 2.9 m (60 m^2), respectively. Photos are presented in Supplementary material (Figures S1 and S2).

Both *classroom types* had a similar 20 mm mineral wool ceiling suspended by 200 mm. The ceiling was highly sound-absorbing and had a sound absorption class A according to ISO 11654 (ISO, 1997).

Table 1.
Lesson types L1—L4 and their descriptions

Lesson type	Name	Description
L1	Quiet work	E.g. reading a book quietly or an exam. This alternative is expected to produce the lowest noise
L2	One person talking	Teacher-led teaching/teaching discussion/making tasks independently. One person speaking at a time
L3	Group work	Pair or group work or an activity that produces similar SPL, where several people are speaking at the same time
L4	Activity-based learning	Several people speaking and moving in the classroom at the same time. This alternative is expected to produce the highest noise

Source: Authors' work

The Reference classroom had sound-absorbing panels (50 mm mineral wool, Class A) glued against the wall (2.9 m^2), the floor was hard and nonabsorbing (Linoleum) and desks and chairs had metal legs and wooden surfaces. Pupils stored their belongings in their desks that had opening tops. The Reference classroom had standard presentation equipment: a whiteboard and a display projector.

The Demo classroom had more sound-absorbing panels (50 mm mineral wool, Class A) glued against the walls (13 m^2), wall-to-wall textile carpet, sound-absorbing curtains, sound-absorbing (soft) furniture with four beanbag chairs, five stool cubes and four teepee space dividers. The tables and the rest of the seating had hard surfaces, but they moved silently on the carpet. Pupils' belongings were stored in a bureau, which drawer opened and closed silently. In addition to a whiteboard, the Demo classroom had two smart touch screens on two sides of the classroom. The refurbishment of the Demo classroom was finished one year prior to this experiment so that the pupils were already used to it.

The environmental noise was very low in the area (outdoor SPL under 50 dB L_{Aeq}) and could not be heard indoors. Windows were closed during the test lessons (under 0°C outdoors).

2.4 Room acoustic conditions

We wanted to know how the classrooms differ in *STI* and speech SPL at different distances from the speaker. Therefore, the room's acoustic properties were determined according to internationally established methods: ISO 3382–2 (RT) (ISO, 2008) and ISO 3382–3 (spatial decay of speech and *STI*) (ISO, 2012). The measurements were conducted in both *classroom types* in the same way by installing the loudspeaker in one position and measuring the conditions along a line including five positions at distances 1, 2, 4, 6 and 7 m from the loudspeaker (see Figure S3 for details). The measurement equipment included an omnidirectional loudspeaker (Nor276, Norsonic, Norway), a real-time analyzer (Sinus Soundbook MK2_4L, SINUS Messtechnik GmbH, Germany) and a condenser microphone (B&K 4165, HOTTINGER BRÜEL and KJÆR A/S, Denmark). The rooms were unoccupied during the measurements because room acoustic quantities describe only the acoustic properties of the room and its furniture.

Room acoustic conditions are summarized in Table 2, including the definitions of the room acoustic quantities. For enclosed unoccupied learning spaces, Finnish mandatory regulations are RT = 0.5–0.7 s within 250–2,000 Hz, $STI \geq 0.70$ and $L_{Aeq,B} \leq 33$ dB (Ministry of the Environment, 2018). Figure 1 demonstrates the spatial decay of *STI* and *SPL* of speech. Figure 2 describes the dependence of RT and background noise on frequency. The room acoustic conditions of the Demo and Reference classrooms differed essentially from each other and justified our experimental study.

	Demo	Reference
$L_{Aeq,B}$ [dB]	29	29
T_{20} [s]	0.32	0.54
STI	0.80	0.76
$L_{A,S}$ [dB]	52.3	54.7

Notes: $L_{Aeq,B}$ [dB] is the mean A-weighted SPL of background noise in an unoccupied room (due to ventilation). T_{20} [*s*] is the mean reverberation time within 125–8,000 Hz. *STI* is the mean Speech Transmission Index. $L_{A,S}$ [dB] is the mean A-weighted SPL of a single speaker
Source: Authors' work

Table 2. The summary of the room acoustic measurements

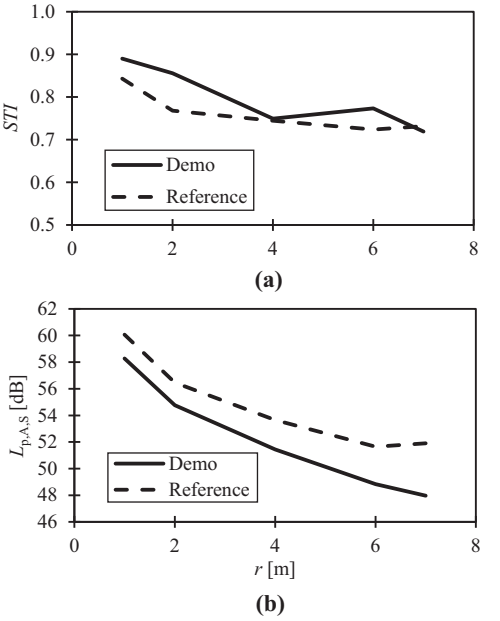


Figure 1.
(a) Speech transmission index (*STI*) and (b) A-weighted SPL of speech, $L_{A,S,}$ as a function of distance to the speaker, r, in the classrooms (Demo and Reference)

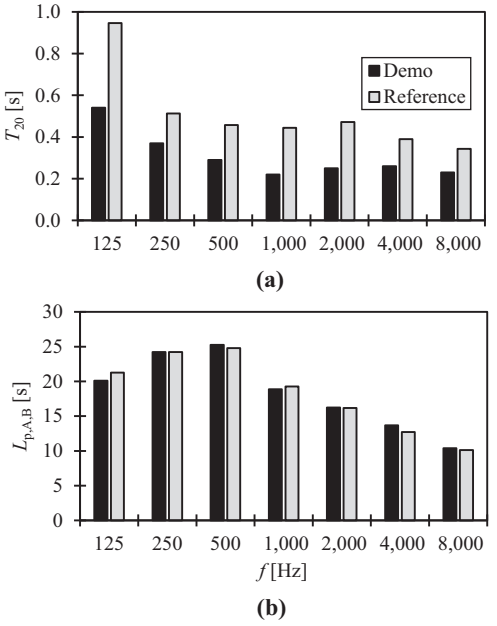
Source: Author's work

2.5 Activity sounds' monitoring

Activity sound level is the A-weighted equivalent SPL during the lesson. It was monitored with four similar sound level meters (Neutrik XL2, NTi Audio AG, Liechtenstein) equipped with a Type 2 microphone (M2211, NTi Audio AG, Liechtenstein). The system could reliably measure SPLs down to 25 dB L_{Aeq}, which was sufficiently low for our purpose. Two sound level meters were installed in both *classroom types*. The clocks were synchronized with an accuracy of 1 s. The sound level meters were calibrated before and after the measurements for reading 94.0 dB at 1 kHz. The monitoring was set to a time resolution of 1 min. The measured quantity was $L_{Aeq,1min}$, which is the 1-min equivalent A-weighted SPL. The meters were hidden from the sight of the pupils on top of the closets (height 2.1 m) facing the wall toward the aisle (Figure S3). The reported value is the equivalent A-weighted SPL during 30 min test lesson $L_{Aeq,30min}$. The teachers decided the times of the test lessons in advance. As the sound level meters were positioned above the closets, their measurements may not represent the SPL in the pupil zone. However, because both sound level meters in both classrooms were installed in similar positions, and they were not moved during the study period, the investigation of SPL differences between *classroom types* and *lesson types* is expected to be reliable.

2.6 Questionnaires

The questionnaires are described in Table 3, and the response scales are in Table 4. The general questionnaire (GQ) was presented once in the beginning of the study period before any test lessons were undertaken. Test lesson questionnaires (TLQ) were shorter, and they were presented at the end of each test lesson. The general annoyance question was



Source: Authors' work

Figure 2.
(a) Reverberation time, T_{20} and (b) A-weighted SPL of ventilation noise, $L_{p,A,B}$, as a function of frequency, f, in the classrooms (Demo and Reference)

formulated according to ISO/TS 15666 (ISO, 2003). The annoyance of different sound sources was modified from the article (Enmarker and Boman, 2004). Hearing acuity questions were modified from questions used by Dockrell and Shield (2004). Concentration questions were formulated to describe different types of situations and activities in any classroom.

2.7 Procedure

Activity sound levels were measured for two weeks continuously in both *classroom types*. The teachers of both *classroom types* agreed to have four test lessons L1—L4 that followed the *lesson types'* descriptions (Table 1) during these two weeks. The teachers decided themselves the topic and the timing of the test lessons. The lesson points in time are presented in Figure S4. The teachers wrote down the times of the test lessons and short descriptions of their contents as well as the number of people present in the classrooms.

2.8 Statistical analysis

The questionnaire data was analyzed using IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, NY). The variables' distributions were first examined for normality. Variables were considered normal enough for parametric tests if their kurtosis and skewness values were within –2 and +2. Otherwise, nonparametric tests were used. *General annoyance* was tested with Student's *t*-test for independent samples, and the effect size was examined using Hedges' g because the sample sizes were different. *Annoyance* estimations of test lessons were analyzed with Mann–Whitney *U* test, as it is

Variable	Question	Response scale code	Questionnaire
General annoyance	How much noise annoys you in this classroom in general?	A	GQ
Annoyance	How much noise annoyed you during this lesson?	A	TLQ
Annoying sound source	How much you are annoyed by the following sounds in this classroom in general (GQ)/during this lesson (TLQ)?		GQ and TLQ
Pupils' speech	Pupils' speech	B	
Corridor	Sounds from the corridor	B	
Neighboring classrooms	Sounds from the neighboring classrooms	B	
Furniture	Moving desks and chairs and other furniture	B	
Ventilation	Sounds from ventilation (hum)	B	
Devices	Sounds from teaching devices (e.g. a projector)	B	
Traffic	Sounds from cars outside	B	
School yard	Sounds from pupils in the school yard	B	
Hearing related ratings			
Hearing a teacher, when not her seeing face	How well do you hear your teacher's speech in this classroom, when you cannot see her face? (For example, when a teacher's back is at you and she writes on a board.)	C	GQ
Hearing a teacher during group work	How well do you hear your teacher's speech in this classroom, when doing pair or groupwork?	C	GQ
Hearing a teacher during silence	How well do you hear your teacher's speech in this classroom, when everyone is working quietly?	C	GQ
Hearing a pupil, when not seeing his/her face	How well do you hear other pupil's speech in this classroom, when you cannot see his/her face? (For example, when a pupil's back is at you and he/she writes on a board.)	C	GQ
Hearing a pupil during group work	How well do you hear other pupil's speech in this classroom, when doing pair or group work?	C	
Hearing a pupil during silence	How well do you hear other pupil's speech in this classroom, when everyone is working quietly? (For example, when the teacher asks and give a turn to the pupil raising hand)	C	
Concentration related ratings			
Concentrating on tasks	How easy it is to concentrate on making tasks yourself in this classroom (GQ)/during this lesson (TLQ)?	D	GQ and TLQ
Concentrating on teaching	How easy it is to concentrate on teaching in this classroom (GQ)/during this lesson (TLQ)?	D	GQ and TLQ
Concentrating on group work	How easy it is to make group work in ones places in this classroom?	D	GQ
Concentrating on moving group work	How easy it is to make group work when people move and many people speak at the same time in this classroom?	D	GQ
Sitting at one's place	How easy it is to sit still at your place in this classroom (GQ)/during this lesson (TLQ)?	D	GQ and TLQ

Notes: GQ = general questionnaire; TLQ = test lesson questionnaire
Source: Authors' work

Table 3.
The variables and questions presented in the general questionnaire and in the test lesson questionnaires. The answer scales are presented in Table 4

the nonparametric test examining differences between the groups. The descriptor of effect size was ($r = |z|/N^{1/2}$). Similarly, Mann–Whitney U test was used for hearing and concentration-related ratings. In Section 3, Results, the averages of scales are reported for clarity even though they do not always describe well non-normal distributions. For this reason, the distribution of estimations is presented in Supplementary material for *annoyance* (Figure S5), hearing-related ratings (Figure S6) and concentration-related ratings in general (Figure S7) and during test lessons for variables with significant differences between *classroom types* (Figure S8).

As the response scale regarding annoying sound sources (Table 3) was discontinuous, these variables were dichotomized. The response categories 1−2 (Table 4) were coded as "not annoying" and categories 3−4 were coded as "annoying". The differences between the *classroom types* in these dichotomized variables were analyzed using Fischer's exact test, and Cramer's V was used as the descriptor of the effect size. Fisher's exact test should be used to examine the proportions in different groups when the sample sizes are small (McDonald, 2014). This examination was performed only if altogether more than four pupils considered the sound source annoying. If less than five pupils considered a sound source annoying, the conclusion was that it was not annoying, and further analyses were not performed.

3. Results

3.1 Activity sounds' monitoring

The number of people in the *classroom types* and *activity sound levels* during test lessons are reported in Table 5. During some *lesson types,* the Demo classroom had two adults in the classroom (during *lesson types* 2 and 4). *Classroom types'* SPLs were the most similar during *lesson type* L2 (one person speaking). For other *lesson types*, SPL in the Demo classroom was lower than in the

Response scale code	Scale
A	1= Not at all, 2 = Only a little, 3 = To some extent, 4 = A lot, 5 = Extremely
B	1 = Sound is not audible, 2 = Sound is audible, but it does not annoy me, 3 = Sound annoys a little, 4 = Sound annoys a lot
C	1 = Extremely well, 5 = Not at all
D	1 = Extremely easy, 5 = Extremely difficult

Notes: 

Source: Authors work

Table 4. Response scale code descriptions. The codes are denoted in Table 3. For scales C and D, smiley faces (see below the table) denoted the five steps of the scales in addition to verbal descriptions in the ends of the scale

	N		$L_{Aeq,30min}$ [dB]	
Lesson type	Demo	Ref.	Demo	Ref.
L1 (Quiet work)	16	19	44.1	52.7
L2 (One person speaking)	17	22	50.6	52.5
L3 (Group work)	18	20	55.5	58.8
L4 (Activity-based work)	19	22	58.7	71.6

Table 5. *Activity sound levels*, $L_{Aeq,30min}$, during the test lessons in the demo classroom (demo) and the reference classroom (ref)

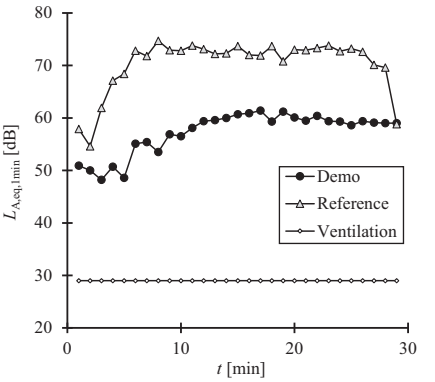
Reference classroom. SPL was even 12.9 dB lower during *lesson type* L4 (activity-based working). Figure 3 presents an example of the sound profile during *lesson type* L4 (activity-based working).

3.2 Annoyance

General annoyance was higher in the Reference classroom (Mean = 2.4, SD = 1.0) than in the Demo classroom (Mean = 1.7, SD = 0.6) ($t(32) = -2.3$, $p = 0.027$, $g = 0.09$). *Annoyance* was higher in the Reference classroom than in the Demo classroom also during *lesson type* L2 (one person speaking) ($U = 72$, $p = 0.029$, $r = 0.38$) and *lesson type* L4 (activity-based work) ($U = 87$, $p = 0.027$, $r = 0.38$), but not during *lesson type* L1 (quiet work) ($U = 96$, $p = 0.240$, $r = 0.21$) or *lesson type* L3 (group work) ($U = 82$, $p = 0.077$, $r = 0.31$) (Figure 4).

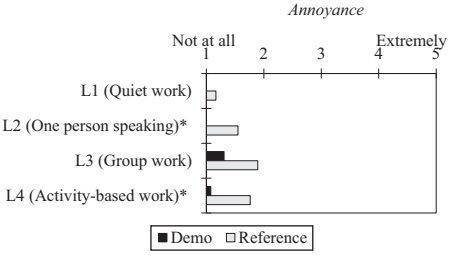
3.3 Annoying sound sources

More pupils reported being annoyed by other *pupils' speech* in the Reference classroom (65%; 13/20) than in the Demo classroom (15%; 2/13) ($p = 0.011$, $V = 0.49$) (Figure 5). Besides *pupils' speech*, other generally annoying sound sources were sounds from the *corridor*,



Source: Author's work

Figure 3.
Example of SPL profile during *lesson type* 4 (activity-based work) in the *classroom types* during the 30-min test lesson. The curves report the variation of SPL as a function of time, *t*. SPL is described by one-minute equivalent A-weighted SPL, $L_{Aeq,1min}$



Notes: *Denotes statistically significant differences between *classroom types* ($p < 0.05$)

Source: Author's work

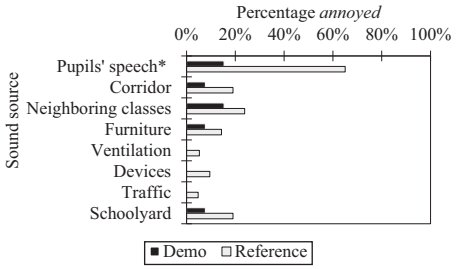
Figure 4.
The means of *annoyance* ratings for the four *lesson types* in *classroom types* Demo and Reference

neighboring classes as well as pupils' sounds from the *schoolyard*. However, differences between the *classroom types* were nonsignificant for these variables ($p > 0.05$) (Figure 5). Less than five pupils reported being annoyed by sounds from *furniture*, *ventilation*, *devices* or *traffic*. Therefore, these variables were not further examined.

During each test lesson type, only *pupils' speech* was rated annoying by more than three pupils. Therefore, during test lessons, other sound sources were not annoying, and *pupils' speech* was the only variable that was further examined between *classroom types*. *Pupils' speech* was the most annoying during *lesson types* L3 (group work) and L2 (one person speaking), but the differences between *classroom types* were nonsignificant ($p > 0.05$) (Figure 6).

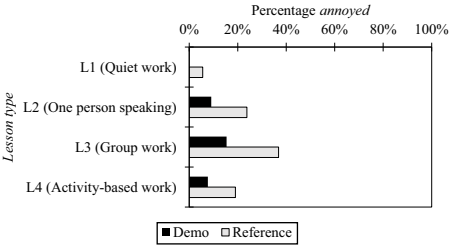
3.4 Hearing teacher or other pupils' speech in the classroom

In general, the pupils of the Demo classroom reported *hearing a teacher when not seeing her face* better than the pupils of the Reference classroom ($U = 85$, $p = 0.032$, $r = 0.37$) (Figure 7). There were no differences between *classroom types* in *hearing a teacher during group work* ($U = 94$, $p = 0.138$, $r = 0.29$), *hearing a teacher during silence* ($U = 134$, $p = 0.917$, $r = 0.04$), *hearing a pupil, when not seeing his/her face* ($U = 112$, $p = 0.381$, $r = 0.16$), *hearing a pupil during group work* ($U = 132$, $p = 0.889$, $r = 0.03$) and *hearing a pupil during silence* ($U = 122$, $p = 0.600$, $r = 0.11$). In general, in both *classroom types*, *hearing a pupil, when not seeing his/her face* was



Notes: *Denotes statistically significant differences between *classroom types* ($p < 0.05$)
Source: Author's work

Figure 5. The proportion of pupils annoyed by different sound sources in general for the *classroom types* inspected in the general questionnaire



Notes: Statistically significant differences were not observed
Source: Author's work

Figure 6. The proportion of pupils annoyed by other *pupils' speech* for four *lesson types* in *classroom types* Demo and Reference

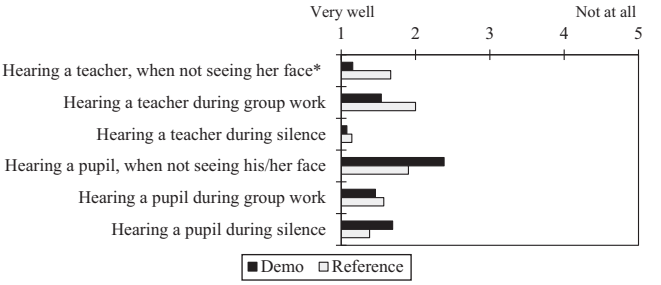


Figure 7.
Hearing related ratings in general in *classroom types* Demo and Reference

Notes: *Denotes statistically significant differences between *classroom types* ($p < 0.05$)
Source: Author's work

estimated as the most difficult. Furthermore, *hearing a pupil, when not seeing his/her face* was rated more challenging in the Demo classroom than in the Reference classroom, as was *hearing a pupil during silence*, even though this was not a significant difference.

3.5 Concentration

In general, *concentrating on teaching* ($U = 83$, $p = 0.041$, $r = 0.35$) and *sitting at one's place* ($U = 74$, $p = 0.009$, $r = 0.45$) were more difficult in the Reference classroom than in the Demo classroom (Figure 8). *Concentrating on tasks* ($U = 92$, $p = 0.071$, $r = 0.31$), *concentrating on group work* ($U = 91$, $p = 0.137$, $r = 0.25$) or *concentrating on moving group work* ($U = 106$, $p = 0.345$, $r = 0.16$) did not differ between the *classroom types*. In general, *concentrating on moving group work* was the most difficult.

Concentrating on tasks ($U = 63$, $p = 0.015$, $r = 0.43$) and *concentrating on teaching* ($U = 72$, $p = 0.008$, $r = 0.47$) were more difficult during *lesson type* L3 (group work) in the

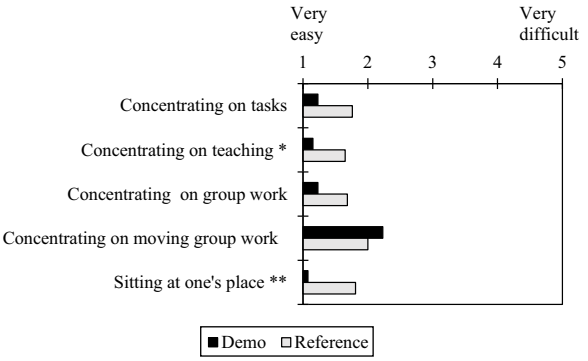


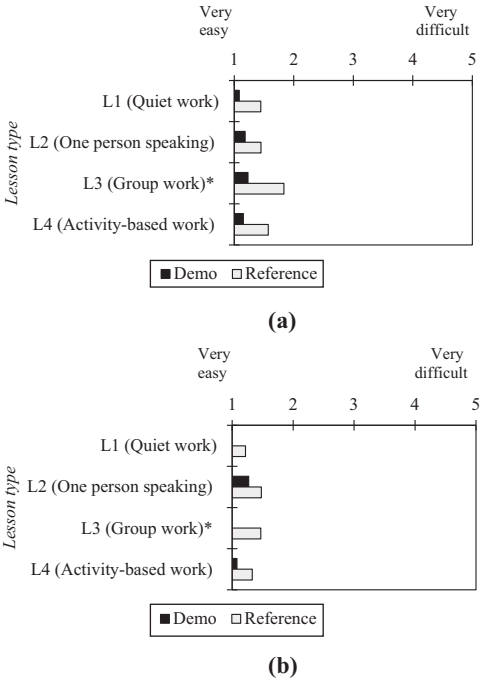
Figure 8.
Concentration-related ratings in general in *classroom types* Demo and Reference

Notes: * and ** denote statistically significant differences between *classroom types* ($p < 0.05$); ($p < 0.01$), respectively
Source: Author's work

Reference than in the Demo classroom (Figure 9). For other variables, the difference between *classroom types* was not significant ($p > 0.05$).

4. Discussion

The Demo classroom was refurbished and had a shorter RT than the Reference classroom because of additional wall absorbers, furniture, curtains and textile carpet. Textile carpet and quiet furniture in the Demo classroom inevitably reduced the noise emission caused by walking, item dropping and chair moving to some extent. *Activity sound levels* were lower during all *lesson types* in the Demo classroom compared to the Reference classroom. *Activity sound levels* were even 13 dB higher during *lesson type* L4 (activity-based work) in the Reference classroom than in the Demo classroom. The difference was the smallest during *lesson type* L2 (one person speaking) when SPLs differed between the *classroom types* less than 2 dB. *General annoyance* was lower in the Demo classroom. Furthermore, *annoyance* was lower in the Demo classroom during *lesson types* L2 (one person speaking) and L4 (activity-based work). Clearly, the most annoying sound source was *pupils' speech*. Here *classroom types* differed from each other: Even 65% of the pupils in the Reference classroom reported being annoyed by other *pupils' speech*, while this was only 15% of the pupils in the Demo classroom. *Hearing a teacher, when not seeing her face*, was reported more difficult in the Reference classroom than in the Demo classroom as was *concentrating on teaching* and



Notes: *Denotes statistically significant differences between *classroom types* ($p < 0.05$)
Source: Author's work

Figure 9. The average rating on *concentrating on tasks* (a) and *concentrating on teaching* (b) in the *classroom types* Demo and Reference for different *lesson types* L1–L4

sitting at one's place. During *lesson type* L3 (group work), *concentrating on tasks* and *concentrating on teaching* were more difficult in the Reference classroom than in the Demo classroom.

Chatter, noises from the corridor and scraping sounds from chairs and tables were the most disturbing sound sources in Swedish schools (Enmarker and Boman, 2004). Our results agree with that, as the most annoying sounds were *pupils' speech*, sounds from *neighboring classes*, *corridor* and *schoolyard*. These are all related to school activity. The absence of annoying external sound sources was not a surprise due to the low environmental SPLs of this specific school.

*RT*s measured in 21 German classrooms ranged from 0.49 s to 1.11 s (Klatte *et al.*, 2010b). The range in 40 Finnish classrooms was 0.41−0.85 s (Sala and Rantala, 2016) and 0.29−0.84 s in 220 American classrooms (Brill and Wang, 2021). Therefore, the Reference classroom with RT = 0.54 s represents well a good standard classroom. The RT of 0.32 s in the Demo classroom is exceptionally short. It is below the RT range required in Finnish building regulations (Section 2.4). Especially other *pupils' speech* was clearly more annoying in the Reference classroom than in the Demo classroom, which suggests that the acoustic refurbishment has diminished the annoyance toward other *pupil's speech*. As young pupils benefit from short RT during noise more than adults (Klatte *et al.*, 2010a; Neuman *et al.*, 2010), reducing RT even below the regulated level might bring benefits for pupils in this age group.

However, shorter RT might reduce speech intelligibility, especially further from the speaker (Amlani and Russo, 2016). Our study does not indicate this, as hearing-related ratings agreed between Demo and Reference classrooms. Furthermore, both classrooms were relatively small, which guarantees sufficient audibility in the whole room. Unexpectedly, *hearing a teacher, when not seeing her face* was rated more difficult in the Reference classroom than in the Demo classroom. We do not believe that the finding was caused by shorter RT but by the lower *activity sound level* of the Demo classroom.

An earlier study showed activity SPLs to be 8–16 dB higher (Shield and Dockrell, 2004) than in our Reference classroom, which represents a standard situation in Finland. This might be partly due to a completely different measurement technique. In our study, the measurement devices were left in the side of the classrooms above the closets over the whole test lesson, whereas Shield and Dockrell (2004) conducted a manned 2 min-long measurement, during which the classroom activity was classified. In another study logging data for six complete school days, the speech-related SPL of occupied classroom ranged from 60 to 74 dB, whereas nonspeech values were 42–58 dB (Brill and Wang, 2021). Nonspeech values resemble the values during *lesson type* L1 (quiet work) and the speech-related range all other *lesson types* in our study.

In our study, the teachers designed the activity to correspond to the four test lesson descriptions. Our longer and specifically planned activity might give a more consistent result of the SPL related to certain classroom activities than previous studies did. *The activity sound levels* in the *classroom types* differed from each other clearly during all other *lesson types* except *lesson type* L2 (one person speaking). Therefore, using designed classroom activity to examine the activity SPLs and noise experience is a feasible and novel research method that could be used also in future classroom studies. It could show differences between classrooms and their suitability for different activities.

Shield and Dockrell (2004) reported over 20 dB difference in $L_{\mathrm{Aeq,2min}}$ between the quietest and the loudest activity. Similarly, in our study, the difference between *lesson types* L1 (quiet work) and L4 (activity-based work) was 21 dB L_{Aeq} in the Reference classroom and 14 dB L_{Aeq} in the Demo classroom. It is not possible to explain the smaller difference in the

Demo classroom by the additional absorbing materials it carried: the effect of additional sound absorbers in the Demo classroom on the SPL caused by a loudspeaker producing constant SPL was only 2.4 dB (see $L_{A,S}$ difference in Table 1) being smaller at a short distance from the source and larger at a long distance from the source [Figure 1(b)]. We expect that short *RT*, soft carpet and quiet furniture provide a calmer environment, which together foster silent behavior. Acoustic environment in the Demo classroom might influence pupils' behavior, making them to act less noisy. On the other hand, it is equally possible that also teachers behaved differently in the Demo classroom and the Reference classroom. The number of pupils in the classroom influences the activity SPL (Shield and Dockrell, 2004), which might be one-factor influencing results. However, the largest difference in the number of people in the classrooms was during *lesson type* L2 (one person speaking), when the difference in the measured SPLs between the classrooms was the smallest. During other test lessons, the difference was only 1—3 persons.

4.1 Strengths and limitations

The strength of our study is that we studied the impact of refurbishment on four different lesson types and measured both *activity sound levels* during the whole test lesson and subjective experience after each test lesson. As the pupils were examined in their own classroom with their own teacher, the study has a high ecological validity. Very few similar studies have been published where different lesson types with different expected activity sound levels have been defined and experimented in classrooms having large differences in room acoustic quality.

The main limitations are that we studied only two classrooms, and the teachers and pupils were different in these specified classrooms. This probably influenced the results at least to some extent. Even similar activity in classes might differ depending on the teachers and pupils performing them. The number of test lessons was also limited to one per *lesson type*. It is also possible that the teachers, consciously or subconsciously, behaved so that the expected results would be achieved (social desirability bias). Therefore, a more controlled study with a larger sample, more repetitions and a better design is needed. Originally, we proposed to the school to conduct this study with a better design where these two classes would work for six weeks in these alternative classroom types. That is, the classes would first work in their home classroom, then switch for two weeks and work again in their home classroom. The teachers found our original study design too demanding for young pupils, and we had to be satisfied with the current design. It must be accepted that the schools finally decide how the designs of experiments can look like. However, more classrooms, schools and classes should be examined for activity sound levels considering also classroom activity type. In addition to pupils' opinions on noise annoyance, also teachers' opinions should be examined, and the voice emission of each teacher should be measured in the near field to control the voice effort differences.

4.2 Conclusion

Pupils in the Demo classroom (refurbished, RT 0.32 s, soft floor) reported lower noise annoyance than pupils in the Reference classroom (RT 0.54 s, hard floor). Annoyance due to other pupils' speech was also lower in the Demo classroom. The activity sound levels were always lower in the Demo classroom than in the Reference classroom. It differed during activity-based work even by 13 dB, whereas the difference was only 3 dB during group work and 9 dB during quiet work. Hearing the teacher while not seeing her face, concentrating on teaching and sitting in one's place were estimated to be easier in the Demo classroom than in

the Reference classroom. Our study suggests that better room acoustic quality may improve pupils' experience about a sound environment. It is probable that the room acoustic solutions in the Demo classroom primarily affected the behavior of pupils because the reduction in activity sound level cannot be explained only by the higher sound absorption area of the Demo classroom. This study indicates that especially classrooms using activity-based learning methods might benefit from similar refurbishment, but more research is needed. Activity sounds in classrooms should be the focus of future research on school noise. Our methodology examining activity sounds during lesson types offers one interesting approach to this. More studies concentrating on classroom acoustic design and activity sounds during different activities in schools are clearly needed.

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Supplementary material

The supplementary material for this article can be found online.

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