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Acoustics and the well-being of children and personnel in early childhood education and care

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Studies implementing a multimethod perspective in evaluating the acoustics of early childhood education and care (ECEC) spaces both quantitatively and qualitatively are still scarce. In this study the acoustic environments (noise levels and reverberation times) of seven Finnish ECEC group's premises were examined in association with personnel's ($N = 22$) and children's ($N = 71$) well-being. Personnel's well-being and vocal health and children's well-being were assessed with questionnaires. The findings were further elaborated by documentation of the ECEC spaces and semi-structured interviews with the ECEC personnel detailing their views on the acoustic environment of the daycare buildings and how and if the acoustics should be improved. The results showed that noise exceeding 70 dB affected personnel's vocal health negatively, whereas no associations were found regarding acoustics and children's or personnel's well-being. Based on the interviews, sound spreading, poor insulation, and hard surfaces add to negative experiences of noisiness. ECEC groups need spaces that can be closed and acoustically separated from each other and from other groups. The possibility to close a space supports the perceived well-being of the users and provides a more varied and individualized use of the spaces.

KEYWORDS

early childhood education and care, acoustics, noise, reverberation time, well-being, vocal-health, children, educators

1 Introduction

Noise is a common stressor for learning space users. A study by Crukley et al. (2011) shows that early childhood education and care (ECEC) spaces are especially loud in comparison to school environments, and the highest noise levels are experienced by the youngest children in ECEC. The noise levels in ECEC are also less variable, with lower levels experienced mostly during the nap times (Crukley et al., 2011). The loud environments expose children and personnel to more potentially harmful effects of noise in comparison to schoolteachers and older children. This makes it important to understand how noise affects the well-being of children and personnel in the ECEC. However, research results focusing on the physical qualities of ECEC spaces from the perspective of well-being are still limited and contradictory. Especially studies implementing a multimethod perspective in evaluating ECEC spaces both quantitatively and qualitatively are lacking.

A growing number of research is underlining the importance that different stakeholders including educators, families, children, and architects have in designing optimal learning spaces (Berti et al., 2019). In this study we focus on acoustics in ECEC in relation to children's and personnel's well-being. We investigate both objectively measured noise and reverberation times and personnel's experiences of the ECEC auditory environments and how they should be improved. These results can benefit both improving existing ECEC environments and designing better spaces in the future. In the following chapters we review relevant literature on the topic and pose our research questions and hypotheses based on this background.

1.1 Noise and well-being

Studies regarding noise outside the classroom suggest that noise may have detrimental effects on well-being. Based on two systematic reviews (Clark and Paunovic, 2018; Zare Sakhvidi et al., 2018) environmental noise has been linked to hyperactivity and attention problems as well as emotional and conduct problems among children. However, both reviews also point out that the results are heterogeneous and more research on the topic form different environments is needed: future studies should focus on noise from such additional sources as indoors, schools, and different neighborhoods (Zare Sakhvidi et al., 2018).

Increased exposure to stress is a key mechanism explaining the detrimental effects of noise on well-being. Noise is known to increase stress (Basner et al., 2014), which has wide-ranging negative consequences on well-being throughout the lifespan (Lupien et al., 2009). Especially early-life stress can have long-lasting negative influences since children's self-regulative abilities are still developing (Blair, 2010), which increases their vulnerability to stress. This underlines the importance of better understanding how different sources of stress, such as noise, impact the well-being of under school aged children.

1.2 Objectively measured learning space acoustics and psychological well-being

In school environments noise is associated with students' poorer performance and annoyance based on a review by Shield and Dockrell (2003). However, only a few studies have focused on the effects of ECEC acoustics on well-being of under school-aged children (referring to children under the age of 7 in the Finnish educational system). A study by Groeneveld et al. (2010) found no association between ECEC center noise and child well-being among 1.7 to 3.3-year-olds. Well-being in this study was assessed using a validated video-observation method (Wellbeing Scale). The variation in noise was small in this study (M = 62.7 dB, SD = 3.6 dB in childcare centers), and the authors concluded that this may have explained the lack of findings. A study by Werner et al. (2015), using the same Wellbeing Scale, found that ECEC noise levels between 60 and 65 dB were optimal among up to 4-year-old children (mean age = 2.8 years, SD = 0.6 years), while both lower and especially higher levels than this were associated with decreased well-being. Furthermore, a Finnish study among 2-year-olds reported that noise negatively affected children's engagement in different activities in ECEC centers (Lipponen et al., 2010). Future studies among older children attending ECEC are needed to understand whether these findings are age specific.

Learning space acoustics also affect personnel. Increased exposure to noise has been linked to interpersonal and vocational strain among ECEC teachers (Grebennikov and Wiggins, 2006). Furthermore, teachers in school classrooms with long reverberations times (≥0.59 s) have reported lower job satisfaction, lack of energy after work, and higher interest in leaving their job (Kristiansen et al., 2013).

Nonsignificant findings on objectively measured noise levels and personnel's well-being also exist. Sjödin et al. (2012) studied the effects of both objectively (acoustic measurements) and subjectively (questionnaires) evaluated noise on preschool employees' stress. Most of the findings acquired via objective measures were nonsignificant whereas subjective negative experiences of the sound environment were associated with depression and burn-out symptoms and poor effort-reward balance (effort required by the work was perceived insufficiently rewarded). The authors hypothesized that the nonsignificant findings related to the objective measures may be due to low variance between the noise measurements in different spaces and that other aspects explaining stress may overshadow the noise-related effects. It is also possible that the perceived individual experience of noise is more important in terms of well-being than objectively measured noise levels. However, with cross-sectional findings it is not possible to make inferences about the causal relationships. Stressed individuals may also be more prone to experience noise as more disturbing.

1.3 Objectively measured learning space acoustics and teachers' vocal health

Vocal problems are common among teachers in general (Moreno et al., 2022) and this trend is also observed among ECEC teachers in Finland. One Finnish study among ECEC teachers found that only 6% of teachers reported no vocal symptoms (Kankare et al., 2011) and another study showed that 37% of the personnel had two or more vocal symptoms occurring at least once a week (Sala et al., 2001). In addition, vocal problems among Finnish ECEC teachers have increased over the years (Simberg et al., 2005). Acoustics may be one factor contributing to the prevalence of vocal problems among ECEC teachers: ECEC environments may be especially demanding for teachers' vocal health as noisier activities (e.g., free play) are common, which requires the ECEC teachers to speak loudly for extended periods (Sala et al., 2001; Crukley et al., 2011). More research is needed since the previous studies have predominantly focused on schoolteachers as reviewed below.

Previous studies have shown that higher noise levels are related to increased vocal problems (Augustyńska et al., 2010; Kristiansen et al., 2014; Karjalainen et al., 2020). Regarding reverberation times, the results are more complex: although short reverberation times may decrease noise levels, longer reverberation times support teachers by carrying their voice further (Rantala and Sala, 2007). Rantala and Sala (2007) found that longer reverberation times (as continuous variables) were associated with better vocal health especially in noisy school classrooms and concluded that good listening conditions may not always be linked with good speaking conditions. Accordingly, in terms of schoolteacher's vocal comfort, reverberation times between 0.45

and 0.6 s in occupied classrooms and between 0.6 and 0.7 s in unoccupied furnished classrooms have been recommended (Pelegrín-García et al., 2014). The recommendations are higher for unoccupied spaces due to the sound absorption introduced by the presence of humans (Beranek, 2005a,b). The Ministry of Environment in Finland recommends that reverberation times should not exceed 0.6 s in unoccupied ECEC premises, no lower limit was proposed in these recommendations (Kylliäinen and Hongisto, 2019; p 42).

Interpreting the recommendations for reverberation times is difficult due to discrepancies between different studies. For example, the recommended range for unoccupied classrooms in terms of vocal comfort (0.6 to 0.7 s; Pelegrín-García et al., 2014) would already lead to negative psychological effects according to the study by Kristiansen et al. (2013) mentioned above. Furthermore, it should be kept in mind that children with communication problems benefit from spaces with shorter reverberation times (0.3 s; American National Standards Institute, 2010).

The previously reviewed studies on vocal health focus on school environments, and it would be important to understand better how noise may affect ECEC personnel's vocal health.

1.4 Subjective experiences of noise in learning spaces

Issues related to perceived noise in ECEC centers have emerged in studies evaluating the physical environment. A post-occupancy evaluation of 101 children's centers in the UK was initiated by the former governmental commission for architecture and the built environment (CABE). It included on-site evaluations of the buildings, user questionnaires and personnel interviews. Excessive noise from hard surfaces and the lack of noise reduction were rated as poor or unacceptable [CABE, 2008].

A Swedish intervention study focused on the effects of group size on noise levels and the experiences of noise by personnel and children in three Swedish ECEC centers (Landström et al., 2003). The ECEC groups, all in all including 78 adults and 160 children were surveyed on three separate occasions, while the group size in two of the facilities was reduced from 19 to 16 children per group and the number of personnel from 3.5 to 3 per unit. Findings showed, however, that the reduction of group size was so small that it did not affect objectively measured noise levels. The personnel perceived noise as disturbing and tiring, and felt that noise affected their hearing abilities, caused stress and physical strain. When asked for means to ameliorate the soundscape, the staff proposed smaller group sizes, dividing the children in sub-groups, adding acoustic panels on ceilings and walls, better sound insulation between spaces, more textiles in the interiors and the planning of activities in ways to reduce noise.

Furthermore, the perception and understanding of sound have been approached in qualitative studies related to preschool children's experiences. Dellve et al. (2013) interviewed 36 children of ages 4 to 6 in their preschool setting and found that the degree of uncontrollability of sounds affected perceived distress and disturbance. When distressing, noise was experienced as physically and emotionally painful.

Outdoor ECEC environments have been emerging as alternatives to the noisy interior spaces. A qualitative study by Abbott and Flynn (2022) included seven semi-structured interviews with ECEC educators working in outdoor and forest school settings. Outdoor noise levels were considered lower than indoors by the educators, and the lower noise levels promoted high quality educator-child interactions outdoors. The lower outdoors noise levels supported a 'calmer, engaging and child led experience'.

Previous studies have shown that results involving well-being and individual's perceptions of the acoustical qualities of a specific space may not be in line with the measured acoustics (Sjödin et al., 2012). In addition to evaluating the learning spaces objectively, it is valuable to understand the findings from the users' perspective. Furthermore, the users of the space can provide valuable input on how to improve the spaces to achieve better working and learning environments.

1.5 Research questions and hypotheses

With the mixed results obtained by prior literature as reviewed above, further research is needed to better understand the role of acoustics in ECEC for personnel and children's well-being. In addition to objective measurements of the acoustic qualities of the learning spaces, architectural qualities of the spaces, and subjective experiences from the users should be considered.

In this study we examine the acoustic environments (sound pressure and reverberation times) of Finnish ECEC centers in association with (1) personnel and child psychological well-being, and (2) personnel vocal health. We further elaborate the data by documenting the architectural qualities of the ECEC spaces and by semi-structured interviews with the ECEC personnel detailing their views on the acoustic environment of the ECEC buildings and how the acoustics could be improved.

Based on previous work, we hypothesize that ECEC noise levels may have detrimental effects on both personnel's and children's well-being, whereas the reverberation times might influence children and adults in different ways: among personnel short reverberation times might be more detrimental in terms of increased vocal strain, while long reverberation times ($\geq$0.59 s), if present, might be detrimental to both personnel's and children's psychological well-being.

2 Materials and methods

2.1 Participants

This study was conducted as a part of a larger data collection related to a social–emotional learning intervention study carried out in Finnish ECEC centers in spring 2021. Altogether 15 groups from 9 ECEC centers from Southern Finland participated in the larger study. The groups were randomly assigned to two intervention conditions (5 groups each) and a control condition (5 groups). The intervention groups held activities during circle times aiming at supporting social–emotional development (e.g., reading together, talking about emotions and other mental states, and musical activities), the control group held their usual circle times during the intervention (Martikainen et al., 2023).

Of the ECEC groups taking part in the intervention study, seven groups from five ECEC centers were able to take part in the acoustic measurements as well. The participation rate was lower since the

acoustic measurement devices were set up after working hours and many ECEC centers were not able to let the researchers to the premises on evenings or weekends. Of the participating seven ECEC groups, data was available from 22 members of the personnel (all women) and 71 child participants (32 girls, 45%, age range 4 to 7 years; Table 1). Online supplement 1 shows the floor plans, sizes, and measurement points of the 5 ECEC centers participating in the study as well as the distribution of different daycare functions in the buildings, labeled from center A to center E. From center A and B two groups participated (A1, A2, B1, and B2), the corresponding measurement points are marked in the Online supplement.

In addition to the measurements, 11 semi-structured interviews were conducted during winter 2021 with the personnel from four of the five ECEC centers where the acoustic measurements were made. These daycare buildings were also on site evaluated by 10 members of the personnel together with an interdisciplinary group of five researchers and design professionals. One ECEC center (center B) was not evaluated, and interviews were not carried out, since this temporary ECEC building was not in use anymore at the time of the evaluations.

The University of Helsinki Ethical Review Board in the Humanities and Social and Behavioural Sciences approved the study protocol. The caregivers and the ECEC personnel provided written informed consent.

2.2 Measures

2.2.1 Objective acoustic measures

The ECEC centers were assessed in terms of the sound pressure level (SPL) and reverberation time values. In each group the measures were conducted in the group's main activity room, where the children spent most of their time together over the course of the day, see Online supplement 1 for schematic floor plans of the buildings, where the measurement points are indicated. The size of the main activity rooms varied from 31 to 47 m^2, and the number of children in each

TABLE 1 Descriptive statistics.

Variable	*N*	*M*	*SD*	Min	Max
Personnel					
N	22				
Age, years		40.8	11.1	26	63
Work experience, years		12.5	9.6	1	33
Educational background					
Up to high school diploma or applied degree	9				
Bachelor's degree or equivalent	11				
At least Master's degree or equivalent	2				
Number of voice problems (scale 0 to 7)		2.1	1.5		
WHO-5 (scale 0 to 25)		17.0	4.0		
Children					
N	71				
Girls	32				
Age, years		5.6	0.8	4.0	7.7
Parental education (highest of either parent)					
Up to high school diploma or applied degree	28				
Bachelor's degree or equivalent	16				
At least Master's degree or equivalent	27				
SDQ					
Internalizing problems (scale 0 to 20)		4.1	3.3	0	13
Externalizing problems (scale 0 to 20)		5.3	4.5	0	18
Prosocial behavior (scale 0 to 10)		6.0	2.4	1	10
Acoustics (when room in use)					
Measurement time, days				2	5
Room in use time per day, minutes		357	57	286	419
Average sound level, dB		56.8	1.2	55.2	59.3
Percentage of time over 70 dB		4.3	1.2	1.3	8.7
Reverberation time 30 (seconds)		0.4	0.1	0.3	0.5

SDQ = strengths and difficulties questionnaire, WHO-5 = World Health Organization's 5-item well-being scale.

group varied from 18 to 21. The children in the ECEC groups could be divided into 2 to 3 separated spaces (rooms of different sizes). All ECEC centers except center B, also had shared spaces to be used by all groups (see details in Online supplement 1).

The installation of the measurement equipment and the reverberation measurements were done after working hours. The measurements were conducted between 17th of May and 6th of June 2021. The teachers received an information letter stating that the microphones only measure noise levels and do not record speech. The teachers were asked to inform the children about the measurement and make sure that the children would not touch the devices.

The equipment used in the SPL measurements comprised of Behringer ECM8000 and G.R.A.S. type 46AF ½" measurement microphones, Motu Ultralite mk3 audio interfaces, and G.R.A.S. power amplifiers. The microphones were calibrated using B&K type 4321 sound-level calibrator prior to the measurement. Each measurement kit was controlled using a Dell laptop. For the reverberation time measurement, the G.R.A.S. type 46AF microphones were used. The measurement signal was a 3-s-long exponential sweep sine, which spanned frequencies from 20 Hz to 20 kHz. A Genelec 8030A acted as sound source.

The SPL values were A-weighted and gathered continuously for durations between 2 and 5 days, with the shorter periods resulting from technical difficulties related to remote control over the measurement equipment (see Table 1). The data was captured every 5 s, whereas the analysis of all results but the maximum SPL was performed on an equivalent sound level, L_{eq}, calculated over 250 s (4 min 10 s).

The amount of time that the ECEC facility was in use was determined by the L_{eq} values above a threshold estimated as the average background noise levels during the times when it was certain that the analyzed rooms were unused (from around 8 p.m. to 5 a.m.). The threshold values varied between 40 and 51.5 dB, depending on the facility. The analyzed rooms were used by the children and staff for between 4 h 27 min and 7 h 40 min (Table 1).

The average SPL values were calculated as the L_{eq} values over the time that the rooms were in use. Additionally, the SPL results were analyzed in terms of the time that the L_{eq} values were exceeding the annoyance threshold of 70 dB, which was established as having a harmful effect when persisting for an extended period (U.S. EPA Office of Noise Abatement and Control, 1974; Kristiansen et al., 2014). Finally, the maximum SPLs were calculated for each room.

The reverberation time values in this study were measured in the analyzed areas after the working hours. The data was gathered over one or two sound source locations and three sound receiver positions for each source position. For every measurement, the reverberation time was evaluated based on T30 values, determined over 30-dB decay range, between −5 and −35 dB. The final values were averaged over all measurement points.

Due to the difficulties in obtaining 60 dB of decay range (T60), reverberation time is typically assessed on a 30-dB decay range (T30). Although there are differences between T60 and T30, they are usually small and do not affect the accuracy of reverberation time estimation in a significant way.

2.2.2 Questionnaires

Personnel well-being was measured with the World Health Organization's 5-questions well-being scale (WHO-5; Topp et al., 2015). The scale's range is from 0 to 25 points, higher score indicates better wellbeing. The questionnaire was filled out between 12th of April and 28th of May 2021.

One-year prevalence of vocal problems was assessed with a questionnaire developed by Pekkarinen and colleagues (Pekkarinen et al., 1992), and has been used in Finnish studies measuring daycare personnel's vocal health (Sala et al., 2001; Lonka-Huotari, 2018). The questionnaire was filled out between 12th of April and 28th of May 2021. Scale range was 0 to 7, higher score indicated more problems (e.g., hoarse voice, sore throat, vocal fatigue).

Children's psychological well-being was assessed via the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) which was completed by the ECEC personnel before and after the intervention, which aimed at supporting social–emotional development at ECEC. The SDQ is a 25-item (answered on a scale from 0 to 2) behavioral screening questionnaire consisting of five five-item subscales (emotional problems, conduct problems, hyperactivity, peer problems, and prosocial behavior) and the composite scales of internalizing problems (sum of emotional and peer problems) and externalizing problems (sum of conduct problems and hyperactivity). In this study, the scales of internalizing (scale 0 to 20, higher score indicates more problems) and externalizing problems (scale 0 to 20, higher score indicates more problems) and prosocial behavior (scale 0 to 10, higher score indicates more prosocial behavior) were used as recommended for community-based research (Goodman and Goodman, 2009). This study was part of a larger intervention study, which was found to support children's social–emotional well-being (Martikainen et al., 2023), therefore we used the data that was collected before the intervention so that the results would not be confounded by the potential effects of the intervention. The data was collected between the 2nd of February and 18th of March 2021.

The parents completed a brief questionnaire about the child's gender, date of birth, verbal development, languages spoken at home and child's strongest language, their own educational level, and reading at home together with the child. The ECEC personnel completed a background questionnaire detailing their gender, age, work experience and educational background.

2.2.3 Statistical analyses

The associations between acoustics and personnel's and children's well-being were analyzed using one-way analyses of covariance (ANCOVA). Due to small sample sizes per each ECEC group and to the fact that the acoustic parameters in some of the groups were very close to each other the ECEC groups were divided into groups. Previous studies have also grouped learning spaces based on reverberation time: Kristiansen et al. (2013) divided schools into "low" (0.41 to 0.47 s), "medium" (0.50 to 0.53 s), and "high" (0.59 to 0.73 s) based on reverberation times (T30). In our study no group space exceeded 0.59 s reverberation time. Accordingly, two groups were used: low (range: 0.34 to 0.45 s, 4 groups: A1, B1, B2, D1) and medium (range = 0.48 to 0.53, 3 groups: A2, E1, C1).

As explained earlier, noise exposure was measured as the percentage of time spent in noise exceeding 70 dB, which was also divided into two groups: low (range: 1.3 to 4.2%, 4 groups: A2, B1, C1, E1) and high (range: 5.2 to 8.7%, 3 groups: A1, B2 and D1). This categorization was chosen to include groups that had very similar values into the same category (e.g., B1: 4.15% and A2: 4.19%; B2: 5.17% and A1: 5.20%).

Analyses among the personnel were adjusted for educational background and age (all members of the personnel were female, so no adjustment were made for gender), and analyses among children were adjusted for gender, age, and parental education as an indicator of socioeconomic status. All analyses were tested for normality of the dependent variables, correlations between the covariates and dependent variables, homogeneity of variances, and homogeneity of regression slopes.

2.2.4 Qualitative methods

The research team visited 4 ECEC centers. Each evaluation visit lasted approximately 2 h and the participants consisted of staff members, representatives of the administration, researchers, and design professionals. The buildings were documented by collecting floor plans and photographing. Considering the acoustic features of the different spaces was part of the assessment of the physical environment.

Eleven members of personnel from four ECEC centers participating in the acoustic measurements were individually interviewed with semi-structured interviews. The aim of the interviews was to get further background information on how the respondents related to the physical environments of the ECEC units and to give the respondents an opportunity to freely comment, without the presence of colleagues. Questions regarding the personnel's views on the acoustic environment, such as soundscape, noisiness, quiet spaces, and reverberation, were part of the semi-structured questions (interview questions, see Online supplement 3). All personnel willing to participate were interviewed, and in some cases, these included members of personnel from other groups than the ones that participated in the acoustic measurements, who were experienced users of the whole ECEC building. The interviews were conducted via video calls and took place after the ECEC evaluation visits.

The interviews were numbered (H1–H11) in the order of their conduction. The interviews were analyzed thematically by categorizing comments into themes according to sensory responses, experiences related to the use of spaces and their functional performance with focus on the acoustic experience.

3 Results

3.1 Descriptive statistics

As Table 1 shows, the average sound levels at the ECEC groups varied from 55.2 to 59.3 dB ($M = 56.8$, SD = 1.2) when the room was in use, and from 40 to 51.5 dB (M = 46.3, SD = 3.3) when the room was not in use. The percentage of time spent in over 70 dB noise varied from 1.3 to 8.7% ($M = 4.3$, SD = 2.0), reverberation times varied from 0.342 to 0.528 s ($M = 0.416$, SD = 0.068 s). Figure 1 illustrates the measured L_{eq} values for each of the considered ECEC groups, with the average values, standard deviations, and maximal values indicated.

Mean age of the participating children was 5.6 years (SD = 0.8), 43 (60.6%) of the children had at least one parent with a university degree (Master's or Bachelor's). Twenty-one (29.6%) of the participating children came from families speaking more than one language at home and 60 (84.5%) spoke Finnish as their strongest language.

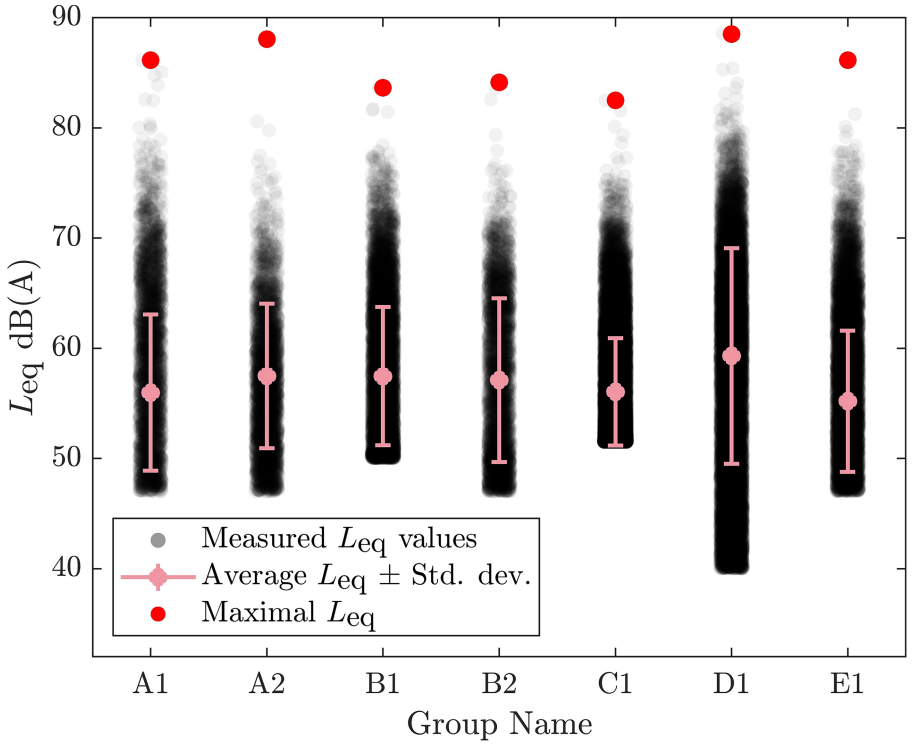

FIGURE 1
Measured L_{eq} values for each of the considered ECEC groups, with the average values, standard deviations, and maximal values indicated.

The mean age of the personnel was 40.8 years (SD = 11.1), and they had on average 12.5 (SD = 9.6) years of work experience in ECEC. Of the 22 members of personnel 16 (72.7%) reported having at least two vocal symptoms over the course of the year and the average number of vocal problems reported was 2.1 (SD = 1.5).

3.2 Effects of ECEC group's acoustics on personnel and children

There was a significant effect of the percentage of time spent in over 70 dB noise on personnel's vocal problems [$F(1, 18 = 7.642)$, $p = 0.013$, $\eta p^2 = 0.298$; Table 2].

Group differences regarding reverberation times and personnel's (WHO5) and children's (SDQ) well-being were nonsignificant (p-values > 0.526). Group differences regarding reverberation times and personnel's voice problems were close to being statistically significant ($p = 0.062$). Group differences regarding time spent in over 70 dB noise and personnel's and children's well-being were nonsignificant (p-values > 0.13) as Table 2 shows.

3.3 The interviews

On a general level, the ECEC personnel described the daily activities as loud and noisy in the interviews. Noise and sound were seen as an inevitable part of children participating in daily ECEC activities – "Children and noise go together" (H4) – and a silent environment was not an objective *per se*, as children learn through moving, playing, singing, and talking, which generate sounds. Occasionally, the personnel also pointed out sounds generated by the equipment, such as the humming sound of a drying closet, but most issues connected with disturbing sounds related to children's activities. However, even though noise was seen as a natural part of children's play; a loud environment was perceived as a significant stress factor for adults and children alike. "Everyone gets tired from the noise" (H1, center A). A good acoustical environment was seen as important to personnel's work satisfaction and well-being (H5, H7, and H10), as well as impacting on children's concentration and verbal development (H4).

When looking at the results on a detailed level and in parallel with how the physical environment was used, four subthemes were identified to affect the perceived noise in ECEC centers: (1) group and space size, (2) reverberation in space, (3) sound transmission between rooms, and (4) the spreading of sound within open spaces.

3.3.1 Group and space size

The interview responses highlight that the number of children in the room has a substantial impact on the perceived noise levels. At the same time, sound levels tend to rise within smaller spaces, which makes it difficult to create a calm environment for the children. Interviewee from ECEC center E describes: "The smaller the space, the louder the noise feels" (H7). The question about space size was also reflected in the acoustic measures where the daycare groups with the smallest group space (D, 31 m^2 and A1, 35.7 m^2) also had the highest

TABLE 2 Associations between acoustics and ECEC personnel's and children's well-being.

Variable	Reverberation time								
	Low (0.34 to 0.42 s)				Medium (0.48 to 0.53)				
	N	EMM	95% CI		N	EMM	95% CI		*p*
Children, *n*[a]	46				25				
Internalizing problems		4.2	3.1,	5.2		4.0	2.5,	5.4	0.811
Externalizing problems		5.1	3.9,	6.3		5.5	3.9,	7.2	0.721
Prosocial behaviour		6.2	5.5,	6.9		5.8	4.8,	6.8	0.526
Personnel, *n*[b]	12				10				
WHO-5		17.3	14.7,	19.8		16.7	13.9,	19.5	0.768
Voice problems		2.7	1.9,	3.5		1.5	0.6,	2.4	0.062
	Percentage of time over 70 dB								
	Low (1.3 to 4.2%)				High (5.2 to 8.7%)				
	N	EMM	95% CI		*N*	EMM	95% CI		*p*
Children, *n*[a]	36				35				
Internalizing problems		4.6	3.3	5.8		3.6	2.4	4.9	0.336
Externalizing problems		5.0	3.6	6.4		5.5	4.1	7.0	0.642
Prosocial behavior		6.4	5.5	7.2		5.7	4.8	6.6	0.313
Personnel, *n*[b]	13				9				
WHO-5		18.1	15.8	20.4		15.4	12.7	18.1	0.130
Voice problems		1.5	0.8	2.2		3.0	2.2	3.9	0.013

SDQ = strengths and difficulties questionnaire, EMM = estimated marginal mean, CI = confidence interval.
[a]Analyses involving children are adjusted for gender, age, and parental education.
[b]Analyses involving personnel are adjusted for educational background and age.

percentage of time spent in over 70 dB noise (8.7 and 5.2%, respectively).

Large groups in small spaces were the most challenging combination. The educators noted that the ability to divide larger groups (up to 21 children) into smaller sub-groups (5–7 children) was an impactful way to improve sound levels. This requires that the ECEC group has multiple separate spaces available to utilize for this purpose; a good example was in ECEC center A, where each group had two group rooms of their own and a separate small group space that was shared with another group on a weekly basis.

Respondents agreed that operating in smaller groups is a helpful way to reduce and control noise, creates a more peaceful environment for the children and allows them to concentrate better (H1, H2, H4, H6, H7, H8, H9, H10). Operating in a smaller group also allows the educators to use less volume themselves. The larger groups of children (up to 21 individuals) naturally generate more noise, even if the children are not loud.

3.3.2 Acoustical quality of the room

According to the respondents, an acoustically pleasant room had surfaces that reduce reverberation. These surfaces were textiles, such as curtains and rugs (centers D, E), carpeted flooring (center C), furniture with acoustical treatment (centers A, D) and acoustic panels. Especially in centers A, D, and E, where acoustical panels had been added recently, the panels were mentioned to contribute to the good acoustics of the room (H5, H6, H8, and H11). Hard surfaces, such as concrete flooring and tiled walls in bathrooms, were often considered to cause undesirable sounds, such as echo. These observations were not systematically reflected in the acoustic measures from the main activity rooms: both the noise levels and reverberation times varied in the spaces that had acoustically pleasant attributes. For example, center C had a medium reverberation time (0.53 s) whereas center D had a low reverberation time (0.34 s). In terms of noise, center C had low percentage of over 70 dB noise (1.3%), and center D had the highest noise percentage (8.7%).

Respondents in ECEC centers A, C, and E reported that spaces with tall ceilings seemed to escalate the noise levels (see photos in Online supplement 2). "This space is tall, so the sound level is also quite high" the staff commented in center A (H1). In spaces where the volume levels increase, the respondents noticed effects on their voice usage. This finding was also reflected in the statistical analyses on objectively measured noise: personnel in the noisier spaces reported significantly more vocal problems (see Table 2).

3.3.3 Sound transfer

Sound leaking through walls and doors was reported as an issue in all ECEC centers. Especially spaces, which were used for other than their original purpose, had problems with sound transmission. These included center D, a residential building later adapted for ECEC purposes, and some rooms in center E, such as vestibules, later transformed into small group rooms. Center D had also the highest percentage of noise exceeding 70 dB according to the acoustic measurements.

Respondents from all centers emphasized the importance of proper sound insulation between rooms. The ability to block sounds from surrounding spaces created a more peaceful environment for the children. Especially noises leaking from rooms used by other groups were seen as troublesome, as those noises are more difficult to predict and control. The respondents noted that doors between spaces are a simple but effective way to control noise if these do not transmit sound. Respondent from ECEC center C describes the impact of sound transmission: "It helps that there are spaces with good sound insulation. We can divide children into small groups, and everyone gets their peace to work. You can close the door, and it is quiet in the room" (H9, center C). On the other hand, some respondents did not see sounds as a problem, as many children are used to even sleeping in environments that are not completely quiet.

In addition to the lack of disruptions, the respondents also noted that good sound isolation is essential to children's privacy, as some internal conversations about personal matters between personnel or between personnel and parents need to remain confidential.

3.3.4 Sound-spreading within an open space

The respondents in all ECEC centers perceived shared, open spaces as the most challenging for noise control. See diagrams in Online supplement 1 demonstrating open areas within ECEC centers. Open shared spaces affect the everyday activities; noise control requires teamwork, scheduling, and agreement between personnel as well as the cooperation of the children to keep the sound levels low.

The respondents noted that open spaces connecting multiple groups often interrupt and disturb the activities of others, which in turn impact on the children's behavior; "the corridor brings noise, as it does not have a dividing wall between the groups" (H1, center A) and "the more open the space, the more restless are the children" (H10, center D). Therefore, the respondents appreciated a layout of spaces that allowed each group to operate independently without interruptions.

Especially certain noisy activities, such as the commotion of dressing outerwear in the vestibules, lead to time scheduling challenges in ECEC centers that shared entrance spaces. By contrast, centers where each group had their own entrance were praised: "We have multiple entrances, and the other group also has their own entrance, so no one needs to pass through the group room" (H8, center A).

In ECEC centers with large open spaces, the respondents wished that dividing building elements, such as walls or doors, could be added to the space afterwards. "There is one very essential thing, there needs to be a door that you can close. The door is important to each room. … they allow you to divide the space, and you can create peace within the room." (H9, center C).

4 Discussion

In this study we investigated the acoustic environments (sound pressure and reverberation times) of seven Finnish ECEC group's premises in association with personnel's and children's well-being. We further interviewed the personnel about their experiences on the acoustic environments in the ECEC centers.

4.1 Objectively measured acoustic features of ECEC spaces

The noise levels measured in the ECEC premises in our study were generally rather low and the reverberation times were short when

compared to previous studies. The average noise levels of the ECEC groups' main activity rooms varied between 55.2 and 59.3 dB during the times when the ECEC space was in use, and the reverberation times varied between 0.34 and 0.53 s.

To our knowledge only three previous reports exist on the average noise levels from ECEC environments in Finland (Lipponen et al., 2010; Haatainen and Jokitulppo, 2015; Lonka-Huotari, 2018). Of these, the study by Lipponen et al. (2010) used similar methodology as this study. They measured average noise in 14 ECEC groups between 8 AM and 4 PM, when the children were present in the room where the measurement was done. This study reported average noise levels between 69 and 72 dB depending on the ECEC center (Lipponen et al., 2010), which are notably higher than the noise levels in our study. However, the children in Lipponen and colleagues' study were younger (2.2 years on average), which may account for the difference. In the future, more comprehensive studies on the noise levels are needed to better understand what the typical variance in noise in the Finnish ECEC centers is, and whether the noise levels found in our study are representative of typical ECEC environments.

The recommendations for reverberation times in learning spaces are varied. The reverberation times in our study were below the recommended levels for unoccupied spaces (0.6 to 0.7 s) by Pelegrín-García et al. (2014), but in line with U.S. recommendation for learning spaces (<0.6 s; American National Standards Institute., 2010) and the recommendation for ECEC group spaces by the Ministry of the Environment in Finland (<0.6 s; Kylliäinen and Hongisto, 2019 p 42).

4.2 Associations between acoustics and personnel's well-being

When investigating the associations between ECEC center acoustics and personnel well-being, we found that the percentage of time spent in noise exceeding 70 dB was associated with a higher number of self-reported vocal problems. Earlier studies have also linked noise with vocal problems among schoolteachers (Augustyńska et al., 2010; Kristiansen et al., 2014; Karjalainen et al., 2020). Our results add to this literature showing that being mindful of noise levels exceeding 70 dB (depending on the measurement methodology) is especially important when evaluating and planning ideal ECEC learning spaces especially from the perspective of speaking conditions.

In previous work from schools, both short reverberation times (Rantala and Sala, 2007) and noise (Augustyńska et al., 2010; Kristiansen et al., 2014; Karjalainen et al., 2020) have been reported as detrimental for teacher's vocal health. In environments with very short reverberation times or high background noise, teachers need to raise their voice to be heard, which in turn may result in increased vocal load and vocal problems (Pelegrín-García et al., 2014). The association between reverberation time and personnel's vocal problems was not statistically significant in our data. It would be interesting to investigate this further with a larger dataset, since this association was close to statistical significance implying that low reverberation times could relate to more vocal problems in line with the previous work. However, also children's needs should be kept in mind, guidelines from the U.S. recommend, for example, that spaces for children with communication disorders should not exceed 0.30 s reverberation times (American National Standards Institute, 2010). Ideally, the rooms' qualities should be modifiable to accommodate different users' needs. In general, the number of vocal problems among the participating personnel was high in our study: 76% of the personnel reported having at least two vocal symptoms over the year. However, we did not inquire about the frequency of personnel vocal problems as previous studies have done. An earlier Finnish study from 2001 reported that 37% of the ECEC personnel had two or more vocal symptoms occurring at least once a week when measured with the same questionnaire (Sala et al., 2001). A study by Simberg et al. (2005) also reported an increase in vocal problems among Finnish ECEC teachers between the years 1988 and 2001 (Simberg et al., 2005). This raises a concern that vocal problems may be coming more and more prevalent over time among Finnish ECEC personnel. However, our results cannot be directly compared to the previous studies as the frequency of the occurrence of voice problems was not inquired as mentioned above.

We did not find any associations between the ECEC acoustics and personnel's self-reported well-being. The reverberation times in our study were, however, shorter than 0.59 s in all measured spaces, which may explain the lack of findings. Our results are in line with the findings of Sjödin et al. (2012) where few significant associations between objectively measured noise and personnel's well-being were found: higher average noise levels correlated with hoarse throat, but not with other vocal problems, annoyance, or sound fatigue. Similarly, as in their study, it may be that other more impactful factors mask the potential effects of noise on well-being. Furthermore, it may be that the average noise levels in the ECEC premises measured in our study were still moderate enough not to increase psychological distress among the personnel. It is, however, possible that other aspects of the acoustic environment than objectively measured noise and reverberation times can be perceived disturbing also in the ECEC premises within our study, this is addressed later in the discussion about the semi-structured interviews.

4.3 Acoustics in association with children's well-being

No associations between the acoustics features of the ECEC space and children's psychological well-being were found. The study by Werner et al. (2015) found that the relationship between noise and children's well-being at the ECEC setting might not be linear. Both low and high noise levels were associated with decreased psychological well-being, with optimal average noise levels being between 60 and 65 dB (Werner et al., 2015). Noise is known to increase stress (Basner et al., 2014), which can explain the findings related to higher noise levels and poorer well-being, it is also possible that very low levels of noise relate to a ECEC culture that is not encouraging of positive interaction and free play. The noise levels between this study and Werner and colleagues' study are not comparable as the methodology to measure noise levels was different, however our lack of findings may relate to low levels of average noise and a small variance in noise levels between the groups.

Furthermore, recent studies show that the acoustics of a specific environment should be measured in more elaborate terms than reverberation times and sound pressure. For example, the irritability of lower intensity noise can also play an important role in the perceived acoustics of a specific space (Oliva Elorza, 2022). The nature of the sound source, e.g., how predictable or controllable the sound is,

might also be impactful on the perceived disturbance and distress in line with the study by Dellve et al. (2013), and should hence be considered. We used semi-structured interviews to better understand what types of noise are especially contributing to the potential acoustic annoyance in the ECEC environment. The results from the interviews are discussed below.

4.4 The interviews

Four subthemes were identified contributing to perceived noise in ECEC centers: group and space size, reverberation in space, sound transmission between rooms, and the spreading of sound within open spaces.

The personnel viewed that group and space size directly impact sound quality and levels in ECEC centers. The respondents perceived the acoustical environment as more manageable when operating in smaller sub-groups of five to seven children. This means that the bigger units of 21 children (the recommended group size in Finnish ECECs) need three separate spaces to which they can disperse the children. The findings are in line with previous studies (Landström et al., 2003) where the personnel participants recommended the division of children into smaller groups to ameliorate the soundscape. The question about space size was also reflected in the acoustic measures where the daycare groups with the smallest group space also had the highest percentage of time spent in over 70 dB noise.

While hard surfaces are often practical due to cleanability and durability, soft surfaces such as carpets and acoustical panels improve the perceived acoustical quality of the room. Paying attention to furniture and material selection helps to reduce noise in ECEC centers. Hard surfaces and the lack of noise reduction were found problematic in the extensive UK post-occupancy study of Sure Start centers [CABE (The Commission for Architecture and the Built Environment), 2008]. The perceived acoustic qualities were not directly reflected in the objective measurements, for example the spaces with added acoustic panels did not have systematically lower reverberation times or noise levels. However, it is possible that adding the panels has been successful in reducing the reverberation times in these spaces to a level that was closer to other spaces. The measures also show that although the reverberation times were among the lowest in center D (0.34 s), the noise levels still exceeded all other centers.

Sound transmission between spaces disturbs and interrupts group activities. Wall partitions, interior windows, and doors with appropriate sound insulation are required to prevent sound transmission. Sound transmission is important to consider already during the design phase of ECEC centers, as remediating problems might be difficult and costly after building construction. Another important consideration for sound transmission is that spaces might be used for other purposes than originally intended, which poses a further challenge for acoustical design. Also, the layout of spaces with the least possible traffic through the room as well as placing activities that require silence further away from noisy activities, would be means to reduce undesirable disruptions to activities and improve ECEC environments.

Finally, open spaces were considered challenging for noise control. Large open spaces required considerable additional work in scheduling and arranging activities with other groups to keep the sound levels low. Dividing building elements (such as walls and doors) were a common suggestion to manage the noise levels.

4.5 General discussion

We found that objectively measured noise levels of ECEC premises did not contribute to the personnel's or the children's psychological well-being. However, personnel in noisier spaces reported more vocal problems. In terms of vocal comfort these findings suggest that reducing time overall time when noise levels in a specific room exceed 70 dB is of importance. Further research with a larger number of spaces is needed to confirm these suggestions.

Although the objectively measured reverberations times were short in all the measured spaces, perception of reverberation via tall ceilings and hard surfaces was considered as negative in the interviews. Based on these findings, it could be optimal to convey a pleasant perception of a space via soft surfaces such as textiles and acoustic panels while still taking the noise levels into account. Especially small group spaces may be subjected to increased noise levels as observed in the interviews and objective measurements.

Even though objectively measured noise did not associate with psychological well-being of personnel or children, the interviewed members of the personnel viewed that ECEC premises are inherently noisy and a possibility to divide the children into smaller groups within physically separated spaces (at least three separate spaces per ECEC group) is important to maintain optimal noise levels. In addition, the layout of spaces should be such that noisy through-traffic is minimized and the shared spaces with functions that by nature cause much sound and restlessness such as the facility entrances, do not excessively limit the group schedules and everyday activities. Furthermore, poor sound isolation and spreading of sound between spaces was considered problematic. This type of noise is not necessarily very intense and is not detected in the sound pressure measurements, but can be considered irritable, and disturbing the group's functions. Insufficient sound proofing of meeting rooms can cause additional worry as confidential conversations should not be audible outside the meeting rooms.

4.6 Limitations and future work

This study has some weaknesses. The data was part of a larger study on interventions, which were known to influence children's well-being, thus only the questionnaire data about the children prior to the intervention was used. Consequently, there is a time difference of several weeks between the children's well-being measurement and the noise measurement. However, all measures were still collected during the same term, and furthermore, results obtained with measures such as the SDQ used in this study are considered stable over time (Muris et al., 2003) which increases the reliability of the findings.

In this study we categorized the ECEC groups into two categories based on the exposure to noise (above or below 5% of time spent in noise exceeding 70 dB). This is a limitation as no previous studies providing justification for this categorization exist. These results may not be directly generalizable to settings outside of this study and more research on the cut-off points for acceptable noise levels in Finnish ECEC spaces is needed.

Furthermore, data from only one room per ECEC group was measured, and consequently noise exposure from other spaces cannot be considered in this study. Future studies should focus on the noise levels of each ECEC space used by the group separately, which would give a more comprehensive picture of the soundscape of all the spaces used by the ECEC groups. It would be valuable also to have data on how many children are present in the room each time since there are differences in how the groups were able to be divided within the ECEC premises. Interviewing the children would also be valuable to understand the perceived effects of noise from the children's perspective.

4.7 Conclusion

A conclusion based on the objective measures and the interviews is that in Finnish ECEC premises, noise exceeding 70 dB affects the personnel's vocal health negatively whereas other associations between acoustic measures and personnel's or children's well-being were not found. However, objective measures alone are not enough to evaluate the perceived irritability and disturbance caused by different types of noise. Based on the interviews, sound spreading, poor insulation, and hard surfaces add to negative experiences of noisiness. ECEC groups need spaces that can be closed and acoustically separated from each other and from other groups. The possibility to close a space supports the perceived well-being of the users and provides a more varied and individualized use of the spaces.

Data availability statement

The datasets presented in this article are not readily available to protect the participants. We do not have participant consent to openly share the data. Requests to access the datasets should be directed to silja.martikainen@helsinki.fi.

Ethics statement

The studies involving humans were approved by the Research Ethics Committee in the Humanities and Social and Behavioural Sciences, University of Helsinki. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants or by the children's legal guardian/next of kin.

Author contributions

SM: planning of the study design, literature search, data collection, data analysis, data interpretation, writing the manuscript, and compiling the figures and tables. KP: planning of the study design, literature search, data collection, data analysis, data interpretation, writing the manuscript. FS-A and IL: planning of the study design, literature search, data collection, data analysis, data interpretation, writing the manuscript, compiling the online supplements. KK: planning of the study design, data collection, reviewing the manuscript. VV: planning of the study design, data interpretation, reviewing the manuscript. MT: planning of the study design, data interpretation, reviewing the manuscript, leader of the research group. All authors contributed to the article and approved the submitted version.

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Conflict of interest

FS-A and IL are employed by JKMM Architects.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1244428/full#supplementary-material

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