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Improvement of the sound environment for supporting communication at nursery facilities: Approaches for changing room acoustics and users' minds

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ABSTRACT

Nursery facilities in Japan have recently been experiencing problems with their sound environments, such as insufficient sound absorption and high volume of generated sound. We therefore examined some approaches to creating an acoustic environment that supports communication in the classroom. As a result of addressing room acoustics by installing materials with an average sound absorption coefficient of 0.25 or more in the classroom, both the impression of the sound and the teacher's reported ease in listening to children's voices when many sounds were generated was improved. To address users' minds, we conducted a workshop for 5- to 6-year-old children and their nursery teachers to make them conscious of the daily sound environment and to instruct them in how to identify pleasant sounds and to allow them to experience the corners of the room, treated with sound absorption materials. As a result, the children and preschool teachers came to understand that unnecessarily loud speech led to environmental noise, and that they could relax and enjoy sounds in spaces surrounded by sound absorption materials.

Keywords: Acoustic environment, Preschool facility, Sound absorption, Workshop for children

1. INTRODUCTION

In early childhood, when mental and physical development is critical, creating the right environment for supporting smooth communication is an important consideration. In Japan, acoustic environmental issues such as noise or persistent reverberations exist in early childhood education facilities (1). These are some of the factors that disrupt communication between children and preschool teachers. It has been reported that the installation of sound absorption materials in classrooms is an effective method to mitigate noise (2) and improve speech intelligibility (3).

We have previously reported on the influence of sound absorption conditions on childcare activities (4). In this paper, we consider the acoustic environment and its influence on communication between children and preschool teachers.

Based on this, we present a practical approach for changing room acoustics and users' minds to improve the sound environment in order to support communication at nursery facilities. We investigated the impact of these approaches on communication and educational activity from various perspectives.

2. METHODOLOGY

Our research was conducted at two nursery facilities where the teachers have had conscious of problems with the sound environment. The facility outlines are presented in Tab.1.

At S Kindergarten, our approach addressed room acoustics. Rock wool sound absorption board was already installed on the ceilings of the classrooms. However, one classroom used to teach 4-year-olds was a converted warehouse and no sound absorption materials had been installed. The

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class teacher was concerned about sound reverberation, and so this class was targeted.

At U nursery school, our approach involved addressing users' minds. At this facility, large rooms were used for a variety of age groups. The corners of the rooms are set up for different activities. Although the sound absorption efficiency of the rooms was high, the teachers had a problem in terms of overall noise levels when all 80 children (including 3-, 4-, and 5-year-olds) were active. Therefore, in order to think a comfortable sound environment with the children and to address the problems described by the teachers, we made the corners of this room and ran a workshop for children.

Table 1 – Outline of the facilities

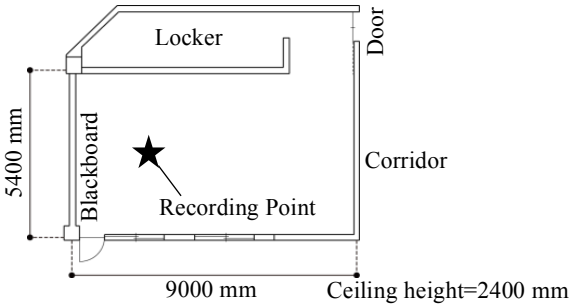
	S kindergarten	U nursery school
Background information	School corporation, established in 1956, Kanagawa prefecture	Social welfare corporation, established in 1954, Saitama prefecture
Architecture	Built in 1978, repaired in 2013 Structure: Reinforced concrete Location: Residential area, adjacent to university and temple [Classroom] Floor space: 51.6 m², Ceiling height: 2.4 m, Ceiling finish material: Rock wool sound absorption board (Except for target room A which contained a decorated plaster board ceiling)	Built in 2011 Structure: Reinforced concrete Location: Residential areas, adjacent to temple [Classroom] Floor space: 215 m², Ceiling height: 2.4 m, Ceiling finish material: Perforated gypsum board
Number of occupants	Staff (preschool teachers): 25 (14) Children (3, 4, 5 years old): 288 Each one of the three grade 3 classes	Staff (preschool teachers): 33 (24) Children (0-5 years old): 150 Multi-age class (0, 1 / 2 / 3, 4, 5 years old)

3. AN APPROACH TO CHANGING ROOM ACOUSTICS: A FIELD EXPERIMENT INVOLVING THE INSTALLATION OF SOUND ABSORPTION MATERIALS

3.1 Experimental methodology

3.1.1 Experiment procedure

An outline of the target room is shown in Fig.1. In this experiment, in order to find the most effective sound absorption conditions for the classroom, we set up four different arrangements. The experiment schedule is shown in Tab.2, the experimental conditions are shown in Tab.3, and a photograph of the installation is shown in Fig.2.



(a) Floor plan

(b) Original state of the classroom

Figure 1 – Outline of classroom A

Table 2 – Experiment schedule

Schedule	Condition	Survey
Oct. 17th, 2017 – Oct. 31th	*A*	[1] Survey for condition *A1* (prior to installation -1)
		Installation of sound absorption materials
Nov. 6th – Nov. 17th	*B*	[2] Survey for condition *B*
		Removal of some of the sound absorption materials
Nov. 20th – Dec. 1st	*C*	[3] Survey for condition *C*
		Removal of all the sound absorption materials
Dec. 4th – Dec. 14th	*A*	[4] Survey for condition *A2* (after removal)
		Installation of sound absorption materials
Jan. 22th – Feb. 2nd	*D*	[6] Survey for condition *D*

Table 3 – Experimental conditions

Condition	*A*	*B*	*C*	*D*
Installation area (Ceiling) [m^2]		22.8	3.1	7.5
Installation area ratio		44.3%	5.9%	14.5%
Number of POLYWOOL® pieces installed (170*400*50 mm, Fukoku Co., Ltd., a porous sound absorption materials made of polyester)		336	45	110
Reverberation time (1 kHz) [s]	0.77	0.36	0.54	0.44
Avg. sound absorption coefficient (1 kHz)	0.14	0.30	0.20	0.25

Figure 2 – Condition *D* installation

Condition *A* (average sound absorption coefficient $\bar{\alpha}$ = 0.14) did not involve the installation of sound absorption materials, condition *B* ($\bar{\alpha}$ = 0.3) involved the installation of the maximum possible amount of sound absorption material, condition *C* ($\bar{\alpha}$ = 0.2) involved an installation that was equivalent to the recommended values for school classrooms, and condition *D* ($\bar{\alpha}$ = 0.25) was midway between conditions *B* and *C*. In order to facilitate the preschool teacher's evaluation of the installation's suitability for educational activities, we changed the installation to match the Japanese recommended values for school classrooms after first presenting conditions that made it easy to detect changes in the acoustic environment.

3.1.2 Survey method

To verify the effectiveness of the sound absorption material installation, an acoustic environment survey, an observational survey, and an interview with the preschool teacher were conducted.

The acoustic environment survey involved capturing the characteristics of the acoustic environment by listening to and analyzing the generated sound. The sound was recorded using a sound level meter microphone (RION NL-42) and a recorder (OLYMPUS DS-901). In the observational survey, observational records and video data were acquired. The characteristics were organized according to the particulars of the acoustic environment, the state of communication between the children and the preschool teacher. The interview was conducted with the preschool teacher in room A (*T(a)*). During the experiment, we asked her about her impression of the acoustic environment and its influence on the activities performed in the class.

3.2 Results

3.2.1 Effects of installation changes on the acoustic environment

In this section, the improvements in the acoustic environment were extracted from reference (4) and outlined. The typical daily sound levels ($L_{Aeq,\ 1min}$) prior to the experiment are shown in Fig. 2 along with some photographs of the types of activities taking place at each station as shown in Fig. 3.

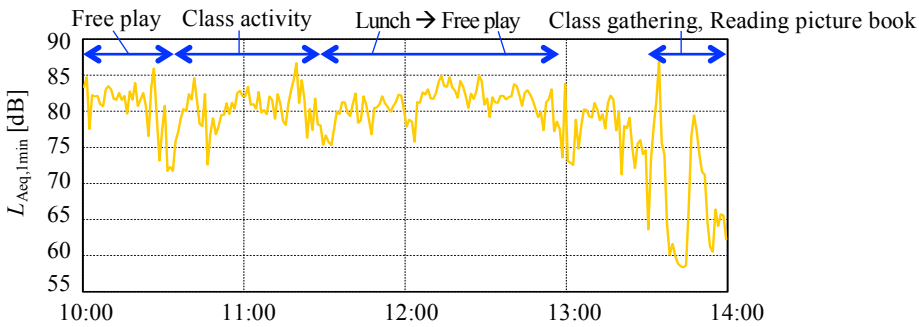


Figure 2 – Changes in sound pressure levels ($L_{Aeq,\ 1min}$) and type of associated activity occurring in room A

(a) Lunchtime

(b) Free play

Figure 3 – Types of activities

In free times, such as play and lunch, sound was generated simultaneously and frequently, and the level was as high as 80-85 dB. At the storytelling situation, the sound levels were less than 70 dB, creating an environment where the children could listen quietly.

Based on these characteristics, in order to analyze the noise mitigation effect of the installed sound absorption materials, we analyzed the lunchtime and free play times after lunch. Fig. 4 shows the frequency distribution for $L_{\mathrm{Aeq,\ 1min}}$ under each condition (*A:* [1] prior to installation -1).

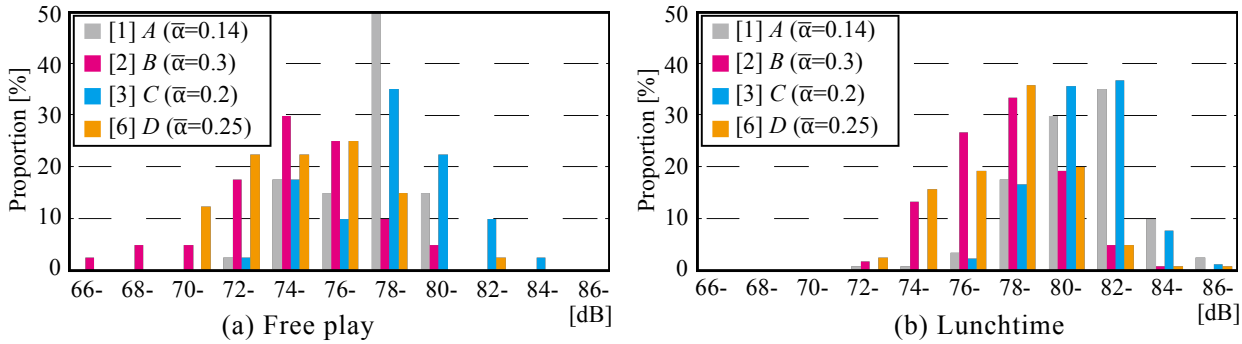


Figure 4 – Frequency distribution for the A-weighted sound pressure levels ($L_{\mathrm{Aeq,\ 1min}}$)

In both activities, it could be confirmed that for [2] *B* and [6] *D*, the distribution of low sound pressure levels was large as the sound absorption efficiency was high, and in [1] *A* and [3] *C*, the distribution at high sound pressure levels was large. It could be concluded that the sound absorption efficiency effectively reduced the noise levels for an average sound absorption coefficient of 0.25 or greater when sounds were simultaneously and frequently produced.

3.2.2 Influence on communication

In this section, we will discuss the acoustic environment's influence on communication in terms of the results of the interviews (4) and the observational surveys. In the interview, we asked about the teacher's impressions of the acoustic environment, the behavior of the children, and the acoustic environment's influence on the teacher's educational activities. The interview results regarding the influence on communication are listed in Tab.4.

Table 4 – Results from the interviews with preschool teachers

Condition	Influence on communication
[1]○, [4]● *A* ($\bar{\alpha}$=0.14)	○*T(a)* experienced discomfort within the acoustic environment but did not experience any particular influence on her educational activities. ●The children's speech became louder so as to be heard over the background noise. ●*T(a)* could not discern the children's voices at play time, although she was aware that they were speaking. ●*T(a)* was less able to use sound levels than when she was exposed to condition *C*. ●The number of times the piano was used to signal clearing up increased compared to condition *C*.
[2] *B* ($\bar{\alpha}$=0.3)	·*T(a)* became able to discern the children's voices during free play. ·*T(a)* became able to add sound intonation. (Use of the piano, voices intonation during storytelling, etc.) ·It was easy for children to sing and they could sing with meaningful lyrics. ·At play time, an activity was held during which the children enjoyed conversations, such as talking secretly or speaking to people at a distance. ·The children were able to listen to *T(a)*'s voice and were able to understand it well.
[3] *C* ($\bar{\alpha}$=0.2)	·Children's voice grew louder. ·The children's voices became difficult to hear. ·*T(a)* led the children playing with the instrument to another play. ·*T(a)* tried to suppress the intonation of the sound because of the excess reverberation. ·The number of times the piano was used to signal clearing up increased. ·*T(a)* had to alert the children about the loudness of their voices more often
[6] *D* ($\bar{\alpha}$=0.25)	·At play time, T(a) felt that the children were interested in another play in a different place. ·At play time, *T(a)* could more easily pay attention their play in remote areas and react to them. ·*T(a)* felt that the ease of storytelling and music activities was identical to Condition *B*. ·The children and *T(a)* were able to enjoy the sound of playing.

In the interview, *T(a)* indicated that the sound levels caused hearing discomfort and were noisy under conditions *A* and *C*. However, under conditions *B* and *D*, the hearing discomfort was eliminated, and the sound could be clearly discerned and their impression of the acoustic environment improved. These points were identical for the observer. Under the conditions *A* and *C*, the high-pitched sounds made by children playing with toys were amplified, and the voices of children also appeared to grow louder. Hearing discomfort was experienced under such circumstances and it was difficult for the participants to talk. We could not hear children speaking in close proximity to us when at play, and we had to rely on visual information to decode their behavior. On the other hand, in conditions *B* and *D*, there was no associated hearing discomfort and it was an environment in which we could listen to sounds and voices even at a distance.

The influence on communication was mentioned in terms of its effects on vocalization, listening, behavior, and educational activities. Under conditions *A* and *C*, the children's voices tended to be loud, and the teacher used a method to draw their attention that did not rely on raising her voice, such as using the piano to create a signal tone. At the free play, the teacher could not hear the children's voices and speech intelligibility was thus poor. On the other hand, in conditions *B* and *D*, both the children and the teacher were able to listen to each other's voices, and communication appeared to be smooth. It was proposed that this was because the speech transmission performance was improved by the reduction of the noise levels and the improvement of the sound absorption efficiency. In addition, it was mentioned that it became possible to communicate for enjoyment of the sound, such as engaging in sound play, storytelling, and music activities. Tab. 5 described a specific case example that was indicative of the acoustic environment's influence on educational behavior.

Table 5 – Specific case example of educational behavior at the play station under condition *D*

An example of a popular play amongst the children was sending letters. One child (*C(a)*) drew a picture on a piece of paper and handed it to another child (*C(b)*), but *C(b)* would not receive it because *C(b)* did not understand that it was a letter. When *T(a)* was interacting with another child at a distance, she heard the dialogue. Therefore, *T(a)* prepared some pieces of papers by drawing a picture of an envelope on it in support of the letter play. According to *T(a),* she had always wanted to hear the children's voices but she had not been able to listen to any voices other than the children she was directly speaking with.

In this case, the improvement of the acoustic environment led to educational action in terms of the proposal of new material for play. In other words, the speech intelligibility improvement made it possible to pay attention to each conversation and grasp the content of multiple, simultaneous conversations. Thereby, it became possible for the teacher to intervene in communication between the children as required. Since preschool teachers always act on a holistic understanding of the situation, environments where the voice can be heard support the behavior of the preschool teacher in terms of listening to the voices of children and assisting them. The outcome of such activities is an improvement in the communication between the children and the preschool teacher, considered to be of great educational importance. In addition, in a better acoustic environment, it was also found that the teacher could determine own behavior such as returning words or watching over, and the children would thus play more calmly as a result of the teacher's change. It was suggested that the improvement of the acoustic environment would support the preschool teachers as they make such immediate situational judgments.

4. USERS' MINDS APPROACH: SOUND ENVIRONMENT WORKSHOP FOR CHILDREN

4.1 Outline

4.1.1 Pre-workshop trial

Prior to the workshop (WS), we prepared the corners of the room suitably for the planned activities in terms of the acoustic environment. Specifically, sound absorption materials were installed to create quiet places in a large, lively room. The schedule of activities is shown in Tab.6, and the corner installations are described in Fig.5. Two types of sound absorption materials (POLYWOOL®: 50mm, a porous sound absorption materials made of polyester, Fukoku Co., Ltd. and TAFNEL™: a long fiber nonwoven fabric, Mitsui Chemicals Inc.) were used. The corner installations were completed by installing the sound absorption materials in the corner or creating a space surrounded by sound absorption materials (such as the small space (5)). In each phase,

interviews were conducted with 3 teachers (the director, the chief teacher, and the teacher assigned to the 5-year-olds' class) for evaluation, and the results were fed back to this trial.

Table 6 – Schedule of trial

Schedule	Trial
Mar., 2018	First visit, measurement of reverberation time and sound pressure levels
Apr. – Oct.	Site meeting and making corner.
Oct. 31th	Reflection of making a corner, WS meeting
Nov.	WS planning and preparation
Nov. 21th	1st WS
Nov. 27th	2nd WS
Dec. 10th	Interview after WS
Dec. – Feb., 2019	WS follow up

(a) Floor plan (b) Relaxation corner: Small space for an individual child (c) Free corner: (d) Picture book corner: Small space for multiple children

Figure 5 – Corner arrangements

The relaxation corner and the picture book corner were noted as appearing to induce a sense of calm because of the surrounding sound absorption materials, and were used willingly. On the other hand, the purpose of the small space for some children was unclear (Fig. 5 (c)), so it was necessary to discuss its use. After assessing the corners, the staff pointed out the need to consider how to control the liveliness of the children's voices and how to use the corners in interacting with the children. Therefore, a WS was organized as an opportunity to consider the enhancement of the level of comfort of the sound environment.

4.1.2 Outline of the WS

We ran the WS to encourage children and teachers to review their daily environment along with their actions and their indoor spaces, focusing on the sound environment. The program on the day of the WS is shown in Tab.7.

Table 7 – WS program: "Let's think about comfortable sounds!"

[1st WS] Aim: Pay attention to the sound environment. Know the differences in how they experience sound with others.	[2nd WS] Aim: Experience the 3 corners and explore how to remain there and enjoy the sounds
1) Greeting, Introduction (10min.)	1) Greeting, Introduction (10min.)
2) Experience: Overall activity (40min.) X: Listening to the sound (Sound quizzes, talking about their most and least favorite sounds) Y: Think about noise pollution (After listening to the recorded lunchtime sounds, responding to the sound by raising their hand if they think it's unpleasant to hear the sound volume rising) Z: Think about how to act in response (Try to act with pleasant sounds using VoiceScale (6))	2) Experience: Group activity (40min.) x: Relaxation corner (Enter the small space alone and play the sound of a pleasant musical instrument) y: Sound laboratory (Learn how to make sounds with musical instruments, discover pleasant sounds) z: Picture book corner (Listen to picture books, enjoy reading aloud paying attention to the volume of the voice.)
3) Conclusion (10min.)	3) Conclusion (10min.)

The WS was conducted twice (Nov. 21th, 27th) in the morning on typical days. The participants included 26 5-year-old children, 3 teachers, and 5-6 WS staff. The first WS was an opportunity to discuss comfortable sounds while sharing in the experience of listening to and producing sounds with

all participants. At the second WS, the participants were divided into three groups and experienced three corners at which they could relax, enjoy sounds, and enjoy picture books. Then they considered how to remain there. The WS staff asked the children how to remain comfortable, and tried to explore the pleasant sound environment with the children. After the WS, we conducted a questionnaire and interviewed the 3 teachers, asking them to evaluate the WS and the changes in the children and preschool teachers subsequent to the WS.

4.2 Result

Based on the experiences at the WS and the results of teacher surveys, we could evaluate the WS. Some scenes from the WS are shown in Fig.6 and 7, and the WS activities are described in Tab.8.

(a) Y: “Raise your hand if you think it’s noisy”

(b) Z: “Let's stack dishes making a pleasant sound”

Figure 6 – Activity situations from the 1st WS

(a) x: Relaxation corner

(b) y: Sound laboratory

(c) z: Picture book corner

Figure 7 – Activity situations from the 2nd WS

Table 7 – Situation of WS activities

1st	X	・Many children answered quiz questions and shared their feeling of least favorite and most favorite sounds. ・The consensus was that there was a variety of feelings associated with sounds.
	Y	・The children listened to the typical, recorded lunch time sounds and concluded that loud voices cause noisy. ・It was difficult to experience the loudness because the recorded sound and the voices emitted during the WS overlapped.
	Z	・Both children who were taking part in the activity and those who were watching focused on being quiet while becoming aware that the display changed in accordance with the sound volume. ・Some statements from the children included: "I thought it was good because they were kind voices", and: "I thought it would be good to treat dishes carefully".
2nd	x	・The children entered the small space alone and had to work out how to play a pleasant sound and listened to it attentively. ・The preschool teacher told to the children that the sound generated by them was gentle and felt that it was an opportunity to spend time alone and to explore the pleasant sound.
	y	・Proposing a method of using sound that was different from the usual practice promoted exploration in order to find pleasant sounds.
	z	・It was commonly understood as a place to calmly read picture books and to enjoy reading aloud. ・The children appeared to concentrate on the picture books while relaxing.

In the 1st WS, “listening to the sound” was the common activity, and children and teachers discussed their favorite sounds, comfortable sounds and noisy sounds together. For children, listening to the sound of their daily activities and watching other children doing the activities seemed to be an opportunity to consider and reflect on their own behavior patterns. In the 2nd WS, the corner experiences helped participants to think about how to remain from the point of sound (x, z) and to enjoy listening to and generating sound (y, z). It seemed that it was appreciated as an opportunity for children to reflect on how to use the corner and to explore how to enjoy playing with sound. It also seemed that the preschool teachers benefitted by gaining a new point of view from their experiences

in the corners in terms of experiencing speech methods and sound enjoyment, and the effects of sound absorption materials. The teachers indicated that they were satisfied as a whole.

In the interview after the WS, the teacher indicated that the children had begun thinking about pleasant sounds and acting on these thoughts, leading to behavior such as advising the teacher not to use a loud voice or devising and playing instruments during music activity times. In addition, it seemed that the teachers also considered their response and were eager to use sound as a basis for future educational activities. In addition, the three proposed corners became quite popular, and teachers indicated that they would like to continue using them. In addition, one of the responses was that "by listening to the sounds that the children liked, we were able to deepen our understanding of how the children were experiencing their daily activities". This was considered a possible method of leading the children in their growing understanding through the use of sound.

From this exercise, the children and preschool teachers understood that unnecessarily loud speech led to noise, and that they could relax and enjoy sounds in the spaces surrounded by sound absorption materials. The activities presented in the sound experience WS were an opportunity for users to reflect on their daily sounds, become aware of pleasant sounds for themselves and others, and to consider creating a pleasant sound environment. In other words, the approach involving users' minds was thought to have led to improvements in their communication.

5. CONCLUSIONS

This study's aim was to improve the sound environment to support child–teacher communication in nursery facilities. We approached this in terms of both room acoustics and users' minds, and examined how they both affected communication. In terms of room acoustics, it was proposed that the improvement of the sound absorption efficiency made it possible to improve the quality of their communication in situations where sounds were emitted simultaneously, enhancing the educational behavior. In terms of users' minds, through mutual experience of the sound environment, the children and preschool teachers came to understand that unnecessarily loud speech led to noise, and that they could relax and enjoy sounds in the spaces surrounded by sound absorption materials. It was proposed that an improvement in awareness of the sound environment changed user personal behavior patterns and introduced the preschool teachers to new perspectives on education in terms of the creation of environments and associated educational activities.

It was thus suggested that the sound environment exerted diverse influences on preschool activities, and improvement of the acoustic environment enabled superior communication.

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