Assessment of kindergarten noise by means of psychoacoustic metrics

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Summary
This study presents the first results of a series of assessment studies of noise in kindergarten environments. In a first study, the impact of noise at the working environment was assesed by means of questionnaires by childcare workers in a real kindergarten site. In addition, categorical loudness of real kindergarten sounds was assessed by normal-hearing listeners in a laboratory study. The questionnaire-based assessment revealed that daytime, weekday, season, activity as well as the age group of the children have a considerable impact on the perceived noise exposure. The categorical loudness scaling revealed that realistic kindergarten test signals differ considerably in loudness at the same level and that categorical loudness cannot be easily predicted by standardized and established instrumental measures.

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1. Introduction

In several studies evaluating the health situation of kindergarten child care workers in Germany, the high noise level in the facilities has been pointed out as one of the most stressful factors and approximately 70% of the employees rate noise as a major problem [1, 2, 3]. Noise is also considered as one of the main reasons leading to early retirement or work place change. Although some studies have reported that in kindergarten rooms a noise level that can cause permanent physiological hearing impairment is never reached continuously over 8 hours, the factor noise is clearly and consistently reported as highly annoying and stressful.

This study presents results of subjective assessments of various kindergarten sound scenes recorded in a real kindergarten environment within the collaborative research project SmartKita (https://www.smart-kita.com/). The kindergarten was located in a major German city and comprised different groups of children, separated in the two age groups 0-3 years (German "Krippe") and 3-6 years (German "Kindergarten"). In a laboratory experiment, the loudness of the sounds was measured by means of categorical loudness scaling with normal-hearing listeners, and the experimental data were compared to standardized methods to compute loudness. The goal was to test if existing metrics can reliably predict the loudness of kindergarten noise. In an additional field experiment, the employees (child care workers) of the kindergarten were asked to assess the perceived noise at their working place by means of questionnaires. The results of the questionnaire-based assessment were compared to long-term level-monitoring measurements, during which daily kindergarten noise had been measured over a period of several weeks.

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2. Noise assessment at the kindergarten site

2.1. Methods

Subjective assessments of the perceived noise intensity were collected via questionnaires, which were distributed to different groups at the kindergarten. Questionnaires were returned by 8 employees working with children in the older age group and by 28 employees working with the younger group. The participants were asked to use scales between 1 and 5 to rate the perceived frequency (from rarely to often) and intensity (from low to high) of stress caused by noise with respect to different categories. These categories included the influence of rooms (e.g. group room, exercise room), the influence of day time, week day, or season, as well as the cause of the noise (e.g. playing noise, environmental noise, particular activities). Free statements with respect to noise and its impact could be given on a voluntary basis.

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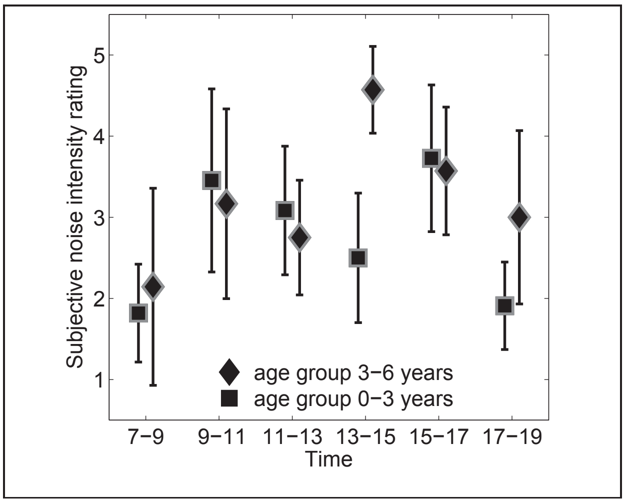

Figure 1. Dependence of mean subjective noise intensity ratings and standard deviations on day time for both age groups.

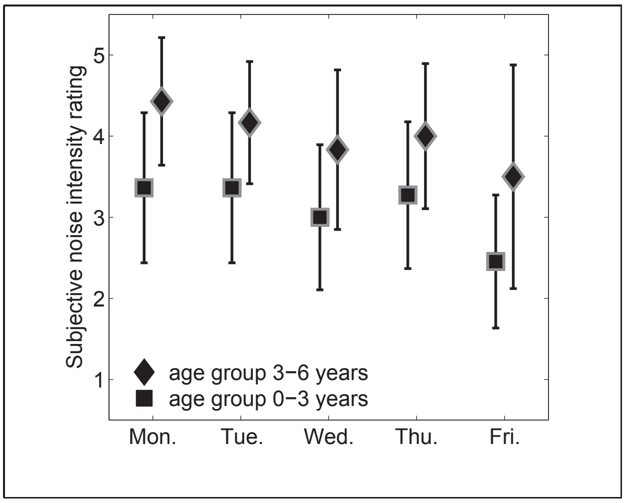

Figure 2. Dependence of mean subjective noise intensity ratings and standard deviations on week day for both age groups.

In addition, sound pressure levels were monitored over a period of several weeks using microphones that were placed 0.5 m below the ceiling in six rooms for each age group (including group rooms, bed rooms, exercise rooms, corridors).

2.2. Results

The assessment of noise in the daily working environment revealed that noise was considered a major factor for stress by the kindergarten employees participating in this study. The sounds directly emitted by the children and the noise produced by loud toys were rated to have the largest impact in both age groups. Likewise, ratings for both age groups were similar with respect to the most noisy rooms in that highest ratings were given to the group rooms and the exercise rooms.

A significant difference was observed with respect to the influence of day time (Figure 1). The employees of the younger age group rated the periods from 9-11am and from 3-5pm as most noisy (average about 3.5 on the five-point scale), while the period from 1-3pm achieved an average score of about 2.5, i.e., almost as low as the very early and very late periods of the day. In contrast, noise in the older age group was rated strongest in the period after lunch (1-3pm), which was consistent with the informal comments related to the sleeping behavior and the corresponding reduced level of activity and hence reduced noise.

Figure 2 illustrates the influence of week day. For both age groups there was a trend that perceived noise exposure reduced over the course of the working week, i.e., the ratings slightly decreased from Monday (mean about 3.5 and 4.5 for younger and older group, respectively) to Friday (about 2.5 and 3.5, respectively).

In general, ratings on the five-point scale were on average 1 scale unit higher for the older age group than for the younger age group, which was in line with informally expressed expectations and experience descriptions from employees who had worked in both age groups.

Two examples of the level monitoring data are shown in Figure 3. The left panel shows sound pressure levels in dB(A) averaged over intervals of 1 s over a period of one working day as recorded in a group room for children of the age group 0-3 years. An arbitrary day in December 2014 was selected for this example. The right panel shows data for the same day, but for a group room in the age group 3-6 years.

It can be observed that sound pressure levels vary considerably over the course of the day, in line with the strong dependence of subjective ratings on day time. These (arbitrarily chosen) examples also illustrates that the dependence of sound pressure levels on day times can differ considerably between age groups. For example, the levels recorded between about noon and 3pm time are considerably higher in the older group, which is consistent with the presumably sleep-related effect observed above. The examples also show that peak levels observed with an averaging interval of 1 s could be well in excess of 90 dB(A), the maximum level observed on that day being 95 dB(A).

3. Categorical loudness scaling

3.1. Subjects

Twenty normal-hearing subjects participated in the experiment. None of the subjects reported any hearing difficulties and all had pure tone thresholds not exceeding 15 dB HL at audiometric frequencies between 125 and 8000 Hz

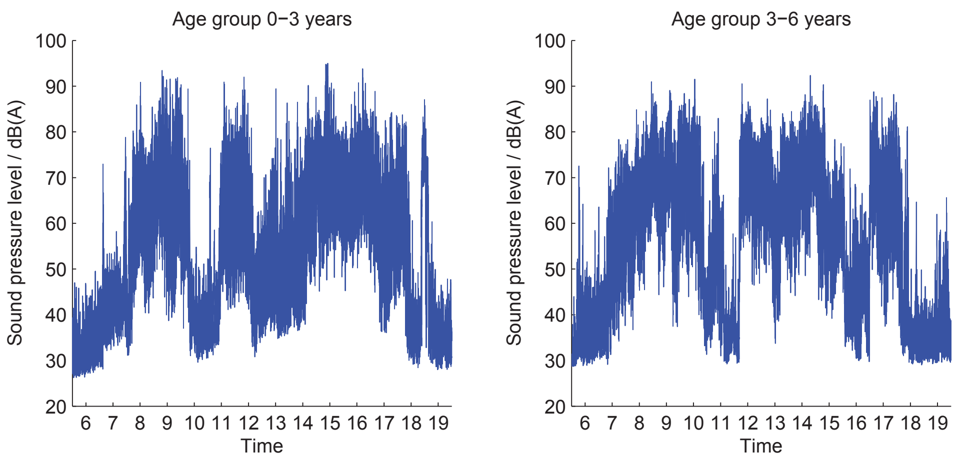

Figure 3. Exemplary sound pressure levels recorded in two group rooms of the kindergarten site over the course of one working day. Left: Age group 0-3 years, right: age group 3-6 years.

3.2. Stimuli

To select real samples of kindergarten sounds, audio recordings were conducted in different kindergarten rooms for each of the two age groups (e.g., group rooms, bed rooms, exercise rooms). The same microphones as for the level monitoring were used for the recordings. The recordings were made strictly following the requirements set up by an ethics committee to ensure that privacy aspects of all involved person (employees, children, parents) were protected. Among other things this included encrypting the recorded audio signals, enabling the persons in the kindergarten site to exclude specific periods of time from the recordings, and to delete any audio samples including intelligible speech. The recordings took place over a period of several weeks. From the resulting audio material, 32 audio samples were selected for the present study. These included sounds related to different activities (e.g., knocking or banging toys, rattling cutlery) as well as sounds related to persons (e.g., laughing, crying, coughing). The nature of these sounds was, in general, highly instationary. Some sounds had very distinct impulsive components (e.g., dropping of toy blocks). The duration of the selected sounds varied between about 300 ms and 3.5 s. All levels reported in this study were calculated from the root-mean-square (rms) values of the audio samples.

3.3. Procedure

Categorical loudness ratings were measured using the procedure proposed in [4], i.e., subjects rated a stimulus presented at different levels using an 11-point scale ranging from "inaudible to "extremely loud". The categories were assigned categorical units (cu) from 0 cu to 50 cu in steps of 5 cu. The first presentation level was always 80 dB SPL, followed by two interleaved tracks of increasing levels (step size 10 dB) and decreasing levels (step size 15 dB) to determine the levels at which the stimulus became uncomfortably loud and inaudible, respectively. The following presentation levels were chosen to be equidistantly spaced across the entire dynamic range from a model function fitted to the previous responses of the subject. This process of estimating and presenting was repeated four times. The presentation levels were not predictable for the subjects. The order of the signals was randomized, but the loudness scaling of each stimulus was always finished before the scaling of the next stimulus. For each signal and subject, the individual data points were fitted with the model function described in [4] by minimizing the rms error between the cu-level-function and the data in the horizontal direction. The stimuli were presented diotically to the subjects via Sennheiser HD650 headphones.

3.4. Loudness calculation

In addition to the experimental loudness measurement, loudness of the same stimuli was also calculated instrumentally using the German national standard [5] both in its stationary and time-varying form. The output of the calculation procedure is loudness in sone. To compare calculated and measured loudness, the resulting sone values were transformed to cu using the method proposed in [6].

3.5. Results

To derive categorical loudness functions for each test signal the data points were pooled across subjects and then the model function [4] was fitted to the data. Lines in Figure 4 show two of the 32 resulting categorical loudness functions. These were the loudest ("child screaming") and softest ("knocks") signals as revealed by comparing all loudness functions in the mid-level range. The loudness functions of all other signals were between these two curves except at sound pressure levels above about 70 dB SPL. It could be

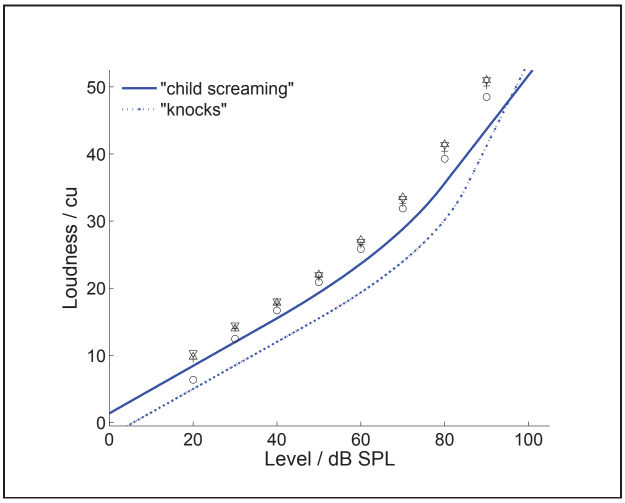

Figure 4. Experimentally measured categorical loudness functions of two of the test signals: "child screaming" (solid line) and "knocks" (dotted line). Symbols represent the calculated categorical loudness at different levels using the German standard [5] and the sone-cu-transform proposed in [6] (see text for details).

observed that the tested signals spanned a range of up to 10 dB at the same loudness indicating a strong variation in loudness at the same level.

Crosses and circles represent categorical loudness calculated using the German standard for stationary sounds for "child screaming" and "knocks", respectively. Downward-pointing and upward-pointing triangles represent the corresponding calculations of the standard for time-varying sounds. It could be observed that, while the shape of the calculated loudness functions corresponded reasonably well to the experimental results, there were two major discrepancies. First, calculated loudness was almost the same for the two test signals, i.e., the observed difference in loudness could not be predicted. Second, the categorical loudness was overestimated by the standards, especially for the softer test signal "knocks". Calculated loudness was similar for both calculation methods, a small trend being that loudness calculated using the standard for time-varying sounds was larger than calculated using the standard for stationary sounds.

4. Discussion and conclusions

The results presented in this contribution constitute the first analyses within a systematic noise assessment of a real kindergarten site in the SmartKita project. The factor noise is clearly one of the main factors that negatively impact the working conditions of child care workers. While this has been qualitatively shown in previous studies as well, there is still a gap in existing analyses with respect to a more detailed analysis of temporal factors (such as day time, week day, season), a systematic investigation of the most prominent noise sources, and effects of children age on noise exposure in this working environment. The present contribution indicates these factors have a major impact on how noise is rated by child care workers. The trends of the noise scaling indicate that perceived stress due to noise decreases over the working week, strongly depends on day time (due to playing and sleeping behavior) and on season (due to the fact that the proportion of outside activities is smaller and, hence, the noise exposure is larger), and also on the children's age (older children apparently produce more noise).

A relation of the subjectively perceived noise intensity and instrumental measures have not yet been investigated systematically for this application context. The first analyses shown in this study confirm previous studies [7] which found that physiologically damaging noise levels and exposure times are not normally reached or exceeded in kindergarten environments. However, there certainly are particular periods of time and particular activities in which noise is perceived as highly prominent and stressful. Sound level monitoring data will probably be useful to shed more light on the relation of the trends and factors observed in the questionnaire assessments, but more detailed analyses are necessary.

Likewise, more work is needed to evaluate the applicability of existing loudness models to this type of sounds. The straight-forward approach of applying standardized loudness computation methods in combination with an established sone-to-cu mapping did not result in satisfactory prediction accuracy. At the same time, the test signals employed in this study differed by up to 10 dB at the same loudness indicating that sound pressure level alone is not a good assessment basis for kindergarten noise. Future work will therefore focus on testing different loudness prediction models and different methods to convert from sone to categorical loudness.

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