Measurement, assessment and modeling of loudness of kindergarten noise

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Introduction

In many studies conducted to monitor the health situation of kindergarten employees in Germany, the high noise level in the facilities has been pointed out by the employees as one of the most stressful factors [1,2,3]. It is also considered as one of the main reasons leading to early retirement or work place change. A reliable prediction of the perceived loudness of acoustic scenes and events in kindergarten environments would therefore be a helpful tool for characterizing these working places. This contribution presents results of a series of tests conducted in a real kindergarten. First, the perception of noise during the daily work was assessed by 36 employees using a questionnaire. The data indicated that various factors contribute to noise-related stress and that, despite being loud, some acoustic events are not perceived as annoying but are rather "wanted noise". Second, the physical sound levels present in different rooms of the kindergarten were monitored over a period of several weeks indicating strong temporal variations. Third, a psychoacoustical assessment of the loudness of kindergartens noise was conducted using categorical loudness scaling. The results of the tests are compared and the applicability of different models to predict perceived loudness is discussed.

Questionnaire-based noise assessment

The subjectively perceived noise intensity was assessed by employees of a kindergarten site in a major German city. Overall, 28 employees working with children in the age group 0 to 3 years (26 female) and 8 employees working in the age group 3 to 6 years (all female) took part in the study. The participants were asked to use five-point scales to rate the perceived frequency (from 1 "rarely" to 5 "often") and intensity (from 1 "low" to 5 "high") of stress caused by noise at their working places. The ratings were made with respect to different categories including the influence of rooms (e.g., group room, exercise room), day time, week day, season, as well as the activity related to the noise (e.g., playing children, crying, environmental noise). In addition to the scaling free statements could be provided.

The informal responses of the employees of both age groups indicated that noise was indeed a major factor related to working conditions at the kindergarten site under investigation. In particular, loud playing activities (toys, shouts, etc.) were rated to a considerable impact. This was also reflected in the subjective assessment of rooms, where highest ratings were given to the exercise rooms followed by the group rooms. The subjectively perceived influence of day time is shown in Figure 1. Assessments were provided for periods of 2 hours. Each symbol represents the mean across all responses for the respective age groups, error bars represent standard deviations. For both groups a considerable effect of day time could be observed. The younger group was characterized by two main periods of noisy activity (9-11 and 15-17) with ratings of about 3.5 on the five-point scale, while the remaining periods were rated with 2 to 2.5. This also included the period after lunch, which was due to the fact that many children usually take an after-lunch sleep as confirmed by the informal statements in the questionnaires. In contrast, this period was rated highest by employees of the older age group (about 4.5) indicating that it was in fact the noisiest period of the day.

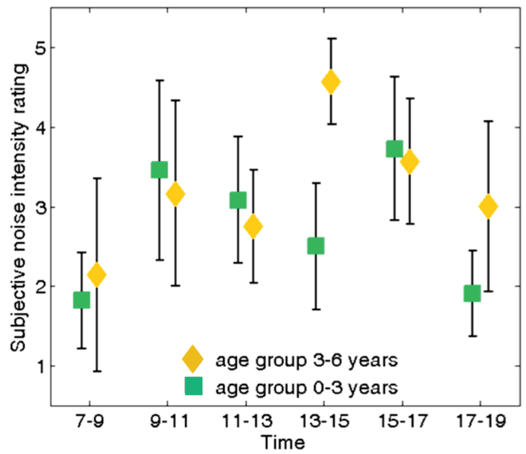

Figure 1: Influence of day time on subjectively perceived noise intensity for the younger (squares) and older age group (diamonds).

The noise ratings with respect to influence of week day are shown in Figure 2. For both age groups there was a decreasing trend over the course of a working week, decreasing from about 4.5 to 3.5 (3-6 years) and about 3.5 to 2.3 (0-3 years).

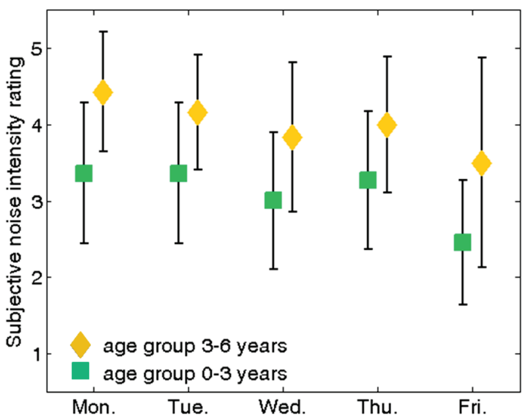

Figure 2: Influence of week day on subjectively perceived noise intensity for the younger (squares) and older age group (diamonds).

Continuous level monitoring

Sound pressure levels were monitored in twelve rooms of the same kindergarten site (six rooms in each age group, including group rooms, exercise rooms, hallways, and bed rooms). In each room, a microphone was placed at a central position 0.5 m below the ceiling. This study includes analyses of 13 entire weeks of recordings from 2014 and 2015, i.e., weeks in which individual days were not ordinary working days (holidays, etc.) were excluded from the analysis.

Figure 3 illustrates an exemplary level distribution for a single day in a group room of the older age group. For this representation, A-weighted sound pressure levels were recorded for non-overlapping intervals of 1 s. The data were then pooled for periods of 15 minutes, and for each interval the mean value (black line), standard deviation (gray area) and peak level (blue line) were calculated. This example illustrates that noise levels vary considerably over the course of a day and that, in general, there had been some sort of activity throughout the day. Peak levels (averaged for 1-s intervals) reached more than 90 dBA on this particular day.

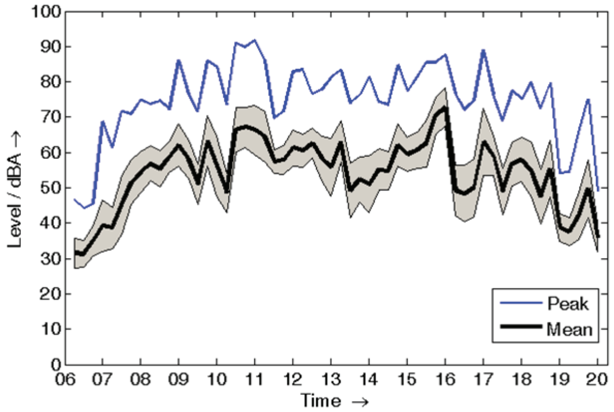

Figure 3: Exemplary A-weighted sound level pressure levels represented as mean (black line), standard deviations (gray area), and peak levels (blue line) derived from 1s-intervals across periods of 15 minutes for an arbitrary recording day in a group room of the age group 3 to 6 years.

To gain more insights into the level distributions, average levels were calculated for the time between 8am and 4 pm, which corresponds to the typical main working period. The distribution of these 8h-average levels are shown in Figure 4 as a function of week day. It can be observed that average levels ranged between about 65 dBA and 62 dBA, with a trend of decreasing levels across the working week. The same trend could also be observed for a group room of the younger age group (not shown).

Figure 5 shows the corresponding distributions of peak levels (for intervals of 1s) for the same group room and recording period. The median values of each week day were well in excess of 90 dBA. The largest observed peak level was about 97 dBA.

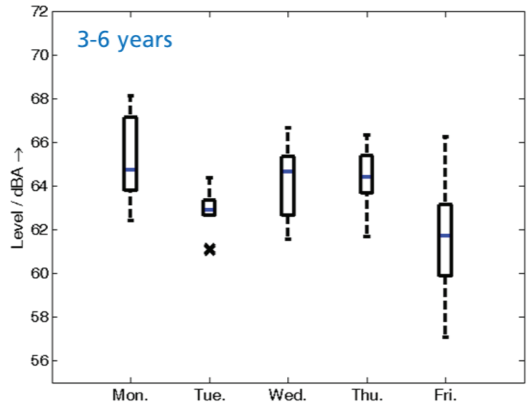

Figure 4: 8h-average levels (8am to 4pm) for week days across a period of 13 weeks as recorded in a group room of the age group 3 to 6 years.

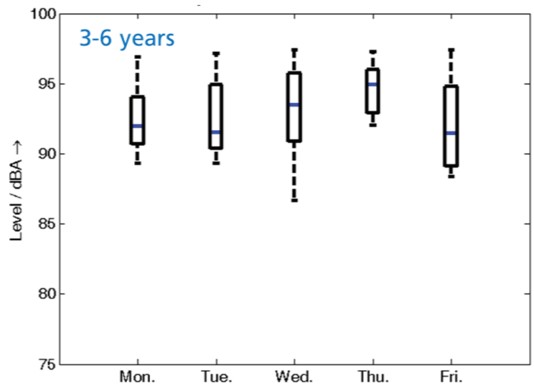

Figure 5: Distribution of A-weighted, 1s-interval peak levels for each week day across a period of 13 weeks as recorded in a group room of the age group 3 to 6 years.

Psychoacoustic loudness assessment

To test if existing instrumental measures for calculating loudness can be applied to kindergarten noise, real sound samples were recorded using the same microphones as for the noise monitoring. The recordings took place over a period of several weeks. From the audio material, 32 audio samples were selected representing various typical activities and types of sounds in the kindergarten (e.g., toy noise, playing noise, laughing or crying children). In general, the sounds were highly instationary; some had clear impulsive components (e.g., the dropping of toy blocks). The duration of the stimuli varied between 300ms and 3.5s.

To derive reference data for testing the models, loudness measurements were conducted in a sound-attenuated booth. The stimuli were presented diotically to 20 normal-hearing subjects via Sennheiser HD650 headphones at different levels. The task of the subjects was to judge the loudness on a categorical scale comprising 11 categories from "inaudible" to "extremely loud". The level presentation procedure was as described in [4]. For each sound, a categorical loudness function was derived from the data, relating the loudness (in categorical units, cu, from 0 corresponding to "inaudible" to 50 corresponding to "extremely loud") to presentation level.

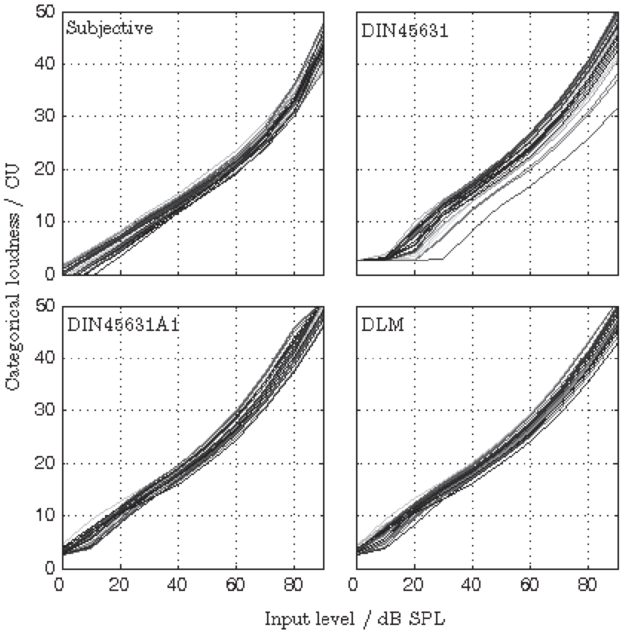

Figure 6: Top left panel: experimentally determined categorical loudness functions for all 32 stimuli. Other panels: calculated loudness function using different models as indicated in each panel. For all models, the same conversion from sone to cu was used [].

The pool of all 32 resulting loudness functions is shown in the top left panel of Figure 6. This data representation illustrates that the shape of the loudness functions was similar for all stimuli. However, the stimuli clearly differed in loudness at the same level or, vice versa, covered a range of 10 dB or more at the same loudness.

The corresponding calculated loudness functions using three instrumental measures are shown in the other panels of Figure 6. In this study, three models were tested: the German national standard both in its stationary version and the version applicable to time-varying sounds [5], and the dynamic loudness model (DLM) proposed in [6]. The output of all of these models is loudness in sone, which is not directly comparable to loudness in cu as measured in the experiment. Accordingly, the models' output was converted to cu using the method proposed in [7]. The resulting model output showed the expected trend of increasing categorical loudness. However, some significant discrepancies between data and predictions were observed. For example, the level range at equal loudness across stimuli was generally larger than observed in the experiment, especially for DIN 45631. In addition, calculated categorical loudness was generally too high at a given level: the mean prediction bias across signals ranged between about 4 cu (DIN 45631) and 8 cu (DIN 45631/A1). As an estimate of whether the rank order of loudness was predicted correctly, subjective and predicted categorical loudness for a fixed level of 70 dB SPL was compared. The rank correlation coefficients according to Spearman were 0.59 (DIN 45631 and DIN 45631/A1) and 0.42 (DLM), indicating a positive relation, but only a moderate prediction accuracy.

Discussion

Both informal statements of the employees and the systematic scaling of subjectively perceived stress due to noise showed that noise is a major factor affecting working conditions also at the kindergarten site under investigation. The sounds directly related to children' activities (crying, playing etc.) were identified as the main noise contribution. Both of these observations are in line with previous studies [1,2,3,7]. In contrast to previous studies, the present contribution additionally investigated the influence of different factors such as age group, day time, week day, season, and room. Subjective noise intensity ratings were generally higher for the older age group by about 1 scale unit. A higher level of stress due to noise was also reported informally by employees experienced in working with both age groups. The interviews indicated that this was related to a higher degree of (physical) activity in the older age group.

Rather strong temporal variations of subjective assessments were observed both within individual working days (reflecting, e.g., the sleeping behavior) as well as across working days. The trend of a decrease in perceived noise intensity from Monday to Friday was also reflected in the physical noise monitoring based on 8h-averages. These 8h-averages were between about 62 and 67 dBA, i.e., clearly below official limits for equivalent noise exposure levels. In other words, immediate physiological hearing damage due to the continuous noise exposure is not likely. On the other hand, the monitoring analyses also revealed that 1s-average peak levels were larger than 90 dBA on almost each day of the investigated period.

The investigation of psychoacoustic loudness related to real kindergarten noise showed that, clearly, real stimuli can differ considerably at the same level, i.e., the physical sound pressure level is not a suitable measure for loudness assessment. Other instrumental measures that aim at calculating loudness cannot be applied directly to categorical loudness scaling data, since their output in sones first has to be transformed to cu for a quantitative comparison. If a state-of-the-art transformation is applied to the output of the German standard for computing loudness or the DLM, the resulting loudness predictions are generally too high. This indicates that a straight forward combination of the models and the transformation is not sufficient. Further work is required to shed more light into the nature of the discrepancies. The general offset may be a result of the sone-to-cu transform, which might not be optimal for this type of stimuli. However, the rather low rank correlations between calculated and predicted loudness are not likely to result from this transformation, since sones and cu are monotonically related. These models, the transformation as well as other model approaches, such as the extended DLM [9,10] or the model proposed in [11] will have to be tested with the present data on an individual stimulus level to explore their applicability to kindergarten noise in more detail.

Acknowledgements

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