inter.noise 2010
noise and sustainability
13-16 June 2010 . Lisbon . Portugal
www.internoise2010.org

Effects of classroom acoustics on performance and well-being in elementary school children: A field study

M. Klatte[1,2], J. Hellbrück[3]

1) TU Kaiserslautern, Germany 2) University of Oldenburg, Germany
3) Catholic University of Eichstätt-Ingolstadt, Germany
e-mail: klatte@rhrk.uni-kl.de

Abstract
Children are more impaired than adults by unfavorable listening conditions such as reverberation and noise. Nevertheless, the acoustical conditions in classrooms often do not fit the specific needs of young listeners. This field study aimed to analyze effects of classroom reverberation on reading abilities, annoyance due to indoor noise, and school attitudes in second graders. Performance and questionnaire data were collected from 398 children from 17 classrooms differing in mean reverberation time from 0.49 to 1.1 seconds. The children from classrooms with poor acoustics performed worse in a phonological processing task assessing auditory-verbal precursors of reading, reported a higher burden of indoor noise in the classrooms, and judged their relationships to their peers and teachers less positively than children from classrooms with good acoustics. The results underline the importance of good acoustical conditions in elementary school classrooms.

Keywords: Classroom acoustics, reverberation, noise, children, phonological processing, annoyance, school attitudes

1 Introduction

In professional educational settings such as schools, preschool facilities and other learning environments, information is predominantly presented orally to the learners. Thus, listening is an important precondition for successful learning, and the acoustical conditions under which instruction takes place play a major role in learning facilitation. This is especially true for younger pupils, as the ability to recognize speech under adverse listening conditions does not reach adult levels until the teenage years [1,2]. Consequently, the issue of classroom acoustics has gained much interest in recent years [3,4,5]. The major determinant of room acoustics is reverberation time (RT), i.e., the time in seconds required for sound pressure at a specific frequency to decay 60 dB after the sound source has stopped. Long

reverberation times reduce the clarity of the speech and thereby intelligibility. In addition, undesired sounds, such as moving chairs, scraping feet, coughing, leafing through papers, and rattling writing utensils, remain longer in the room and consequently, noise levels increase. During common classroom activities such as group work, the increase in noise level due to reverberation is further boosted by the café effect, i.e., a manifestation of the Lombard effect in social situations [6,7]. When separate groups of children are working in the room, each group competes with the reverberant noise from other groups.

The current field study aimed to analyze the effects of classroom reverberation on children´s learning at school. Elementary school children from classrooms with favorable vs. unfavorable RTs were compared with respect to cognitive performance, annoyance due to classroom noise, and social-emotional school attitudes. We hypothesized that children from classrooms with poor acoustics feel more annoyed due to classroom noise than children from classrooms with good acoustics. Prior studies have shown that children whose schools are located in industrial or traffic noise areas reported a higher degree of annoyance when compared to children from quieter schools [8,9,10]. To our best knowledge, no study has yet addressed the effects of classroom reverberation on children's annoyance due to indoor noise.
Concerning social-emotional school attitudes, we hypothesized that poor classroom acoustics may, in the long term, impair the social and emotional atmosphere in the class, as a result of the permanent elevation in the workload of children and teachers. For teachers, instructing in loud and reverberant rooms means permanently speaking with a raised voice, a task which becomes strenuous after a time. The flow of instruction is interrupted by frequent repetitions of information and warnings for children to be quiet. Such a situation will not foster friendly and patient behavior when dealing with children. In line with this, teachers in noisy schools report greater fatigue, annoyance and less patience when compared to teachers from quieter schools [11]. For the children, listening becomes more effortful, and noise makes concentration and mental work more difficult. Furthermore, children may feel unfairly treated by the teacher, as they are blamed for excess noise, although they try to be calm. All in all, this may contribute to an atmosphere of tension and reluctance to learn. In order to test this hypothesis, a questionnaire on social and emotional school attitudes in elementary school children was included in this study.
With respect to performance, there is evidence that permanent exposure to unfavorable acoustical conditions in the learning environment affect children´s language and reading acquisition [9,12,13]. Research in this field has been mostly concentrated on traffic noise, but Maxwell and Evans [13] provided evidence for the chronic effects of excessive indoor noise due to poor interior acoustics in a preschool daycare centre on children´s language acquisition and pre-reading skills. Thus, learning in reverberant and, as a consequence, noisy classrooms may impair auditory-verbal functions which are relevant in written language acquisition. In the current study, a phonological processing task and a standard German reading test were included in order to assess reading level and reading-related verbal abilities.

2 Method

2.1 Recruitment of the sample of classrooms

Aiming to recruit a sample of classrooms with marked differences in reverberation times but low outside noise levels, acoustical measurements were performed by our project partners from Fraunhofer Institute for Building Acoustics in 60 classrooms from 18 elementary schools

in the region of Stuttgart, Germany [21]. The resulting sample consisted of 17 second grade classrooms from 8 schools, with RTs (T20) ranging from 0.49 to 1.1 s, and ambient noise levels (LAeq) in the unoccupied rooms not exceeding 39 dB.

2.2 Participants

Participants were 398 second graders (197 male), who were instructed in the selected classrooms since school entry. Their mean age was 8 years, 6 months (SD = 6 months). 24 further children from these classrooms could not be included due to illness or lack of the parental consent.
The children were divided into three groups on the basis of the reverberation times in the classrooms. In the following, these groups are referred to as RT_1, RT_2, and RT_3, respectively. In group RT_1, the classroom reverberation times (T20, averaged across frequencies) were shorter than 0.6 s (range 0.49 to 0.56), which is considered as optimal for classrooms according to international guidelines [20]. This group consisted of 5 classes from 2 schools, with a total of 126 participants. In group RT_2, reverberation times ranged from 0.69 to 0.92. This group consisted of 8 classrooms from 5 schools with a total of 175 participants. The third group (RT_3) comprised the classrooms with reverberation times longer than 1 second. This group consisted of 97 participants from 4 classrooms in 3 different schools. Slight variations in the number of participants in the analyses described below are due to temporary absences of individual children due to illness, or unwillingness to participate in specific tasks.

2.3 Tasks and materials

Reading performance
Reading was assessed by means of a standardized German reading test, the 'Salzburger Lesescreening' [14]. In this test, children must read the given sentences silently and indicate for each sentence whether it is true or false (e.g. 'Bananas are blue'). The dependent variable is the number of sentences correctly answered within three minutes.

Nonverbal intelligence
In order to control for general intellectual abilities, a short form of the Colored Progressive Matrices was used [15]. In this test, visual patterns are presented in which one piece is missing. The children have to select the missing item from 6 alternatives. 12 tasks are performed with increasing difficulty.

Phonological processing
In this task, the children have to decide which of three spoken words or nonwords differs from the others with respect to the initial or the final sound. This is a standard task in the assessment of reading-related phonological abilities in children called 'odd one out' [16]. In each trial, three monosyllabic words or CVC-nonwords were presented via loudspeaker with an interstimulus-interval of one second. Then, a picture appeared on the screen as a cue indicating whether the initial or the final sound of the words was to be analyzed in the particular trial. The position of the 'odd' word in the sequence had to be marked on a prepared response sheet. The children had 13 seconds to mark their response. Trials requiring the analysis of initial and final sounds were mixed randomly with the constriction that no type of task was encountered more than three times in succession. The task consisted of eight word trials followed by eight nonword trials. Prior studies have shown that performance in this task is closely related to reading and spelling ability, and that the task is highly sensitive to the negative effects of acute noise [17].

Noise questionnaire
The noise questionnaire consisted of statements concerning noise within the classroom (e.g. 'Our teachers often reprove us for silence', 'My classmates often behave noisily') and noise from outside (e.g. 'During the lessons, I can hear the traffic from outside'). The statements were read aloud by the experimenter. The children marked one of the response alternatives 'yes, correct' or 'no, not correct' on prepared answer sheets.

Social and emotional school attitudes
The children's social and emotional attitudes towards school were assessed by means of a questionnaire, 'Fragebogen zur Erfassung emotionaler und sozialer Schulerfahrungen von Grundschulkindern' (questionnaire on emotional and social school experiences of elementary school children) [18]. The questionnaire consists of seven scales, namely social integration (e.g. 'My schoolfellows help me when I cannot solve a task'), class atmosphere ('In our class, all children stick together'), relation to the teachers ('My teachers speak with me in a friendly way'), academic self-concept ('I am good at reading'), achievement motivation ('I try to solve even difficult tasks'), pleasure of learning ('I often ask the teacher for additional tasks') and school attitude ('After the holidays, I look forward to going to school again'). The statements were read aloud by the experimenter. The children marked one of the response alternatives 'yes, correct' or 'no, not correct' on prepared answer sheets.

Parental questionnaire
The parental-questionnaire contained questions concerning the child (mother language, age etc.), and sociodemographic variables (income, mothers' education). A further item was included concerning the child's annoyance due to noise in his or her classroom.

2.4 General procedure

All data was collected within a period of 8 weeks, with a maximum of one week per school. In the first session, the experimenter concisely introduced the project and affirmed that the data was for the researchers and was not given to the children´s parents or teachers. The tasks were performed in whole class groups. The pupils' desks were arranged in four to five rows in each classroom. Paper boards were placed between adjacent seats in order to avoid distraction due to recognition of the neighbour's answers (see Figure 1).

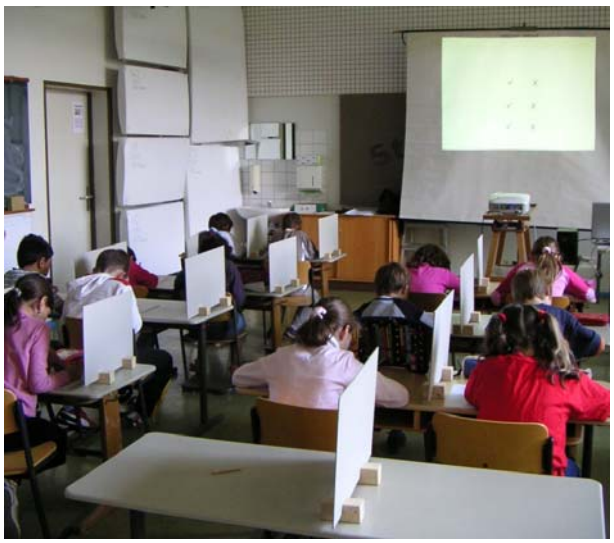

Figure 1. Second-graders performing the reading tasks in a classroom equipped with sound-absorbing materials.

For the phonological processing task, the pictures were presented via a notebook and a low-noise projector on a screen in front of the classroom. The speech materials were presented via a loudspeaker located on the teacher's desk, with a signal level of 65 dB(A) in a one meter distance, corresponding to a teacher talking with a raised voice. The presentation of the pictures and sounds was controlled by means of standard presentation software. The task was carefully explained to the children and practiced with examples. Importantly, in order to avoid confounding acute and chronic effects of the acoustical environment on performance, the phonological processing task was always performed under conditions of favorable interior acoustics (RTs ranging from 0.49 s to 0.54 s). When necessary, sound-absorbing materials were installed for the time of the study in order to achieve this aim (see Figure 1).

3 Results

3.1 Sociodemographic variables

Comparability of the groups with respect to parents income and education of the mother was analyzed by means of the parental questionnaire. Concerning mothers' education, valid data was available for 82 % of the participants. Concerning income, valid data was available for 74 % of the participants (the remaining parents refused to provide this information). Chi-square tests on these data yielded no significant differences between the groups (mothers' education: $p = .38$, income: $p = .16$).
The percentage of children with a non-German mother language was 40.5 in group RT_1, 35.4 in group RT_2, and 25.8 in group RT_3. A Chi-square test found these differences to be marginally significant ($p = .07$). However, this will underestimate, rather than exaggerate the potential effects of poor classroom acoustics on performance.

3.2 Cognitive performance

Reading
A one-way analysis of variance (ANOVA) proved a significant effect of RT group on reading ability, $F(2, 390) = 4.64$, $p < .01$. Bonferroni-corrected post-hoc tests revealed that children from group RT_3 performed better when compared to those of group RT_1 and RT_2, which did not differ. However, the main effect of group on reading was strongly reduced when mother language was controlled, $F(2, 389) = 2.98$, $p = .052$, and was eliminated when mother language and parents income were controlled, $F(2, 288) = 2.21$, $p = .11$. Thus, the effect is attributed to differences in sociodemographic variables in favour of group RT_3.

Phonological processing
The analysis is based on 363 children, 103 from RT_1, 168 from RT_2, and 92 from RT_3. A one-factorial ANOVA on the number of items correctly solved yielded a significant main effect of classroom reverberation, $F(2, 360) = 4.67$, $p < .01$. Mean percent correct scores were 70.3, 64.7, and 61.7 in the groups RT_1 (short reverberation), RT_2 (medium reverberation), and RT_3 (long reverberation), respectively. Bonferroni-corrected post-hoc tests confirmed better performance in the children from classrooms with short reverberation (RT_1) when compared to the children from classrooms with long reverberation (RT_3), $p < .01$. Because of the group differences in sociodemographic variables, the analysis was repeated with mother language and parents income as covariates. This analysis yielded a significant main effect of reverberation, $F(2,266)=5.15$, $p < .01$. Post-hoc tests confirmed better performance in the children from group RT_1 when compared to RT_2 and RT_3 ($p < .05$ in both cases). The effect of reverberation on phonological processing cannot be attributed to differences in

general abilities between the groups. Performance of the same children in the nonverbal intelligence test did not differ with respect to reverberation time, $F(2, 357) < 1$.

3.4 Noise annoyance and school attitudes

Noise ratings

As expected, the groups did not differ with respect to ratings of noise from outside, $F(2, 372) < 1$. However, there was a significant effect of classroom reverberation time on annoyance due to indoor noise, $F(2, 372) = 11.81$, $p < .001$. Mean noise ratings were 4.3 (SD = 1.88), 5.0 (SD = 1.37), and 5.3 (SD = 1.45) in the groups RT_1, RT_2, and RT_3, respectively. Bonferroni-corrected post-hoc tests confirmed that indoor noise ratings were lower for the children whose classrooms had short reverberation (RT_1) when compared to children from classrooms with medium and long reverberation ($p < 0.001$ in both cases). Figure 2 depicts the percentage of 'correct' answers with respect to reverberation group for the exemplary items 'My classmates often behave noisily', 'Our teachers often reprove us for silence', and 'When we are doing silent work, there really is silence'.

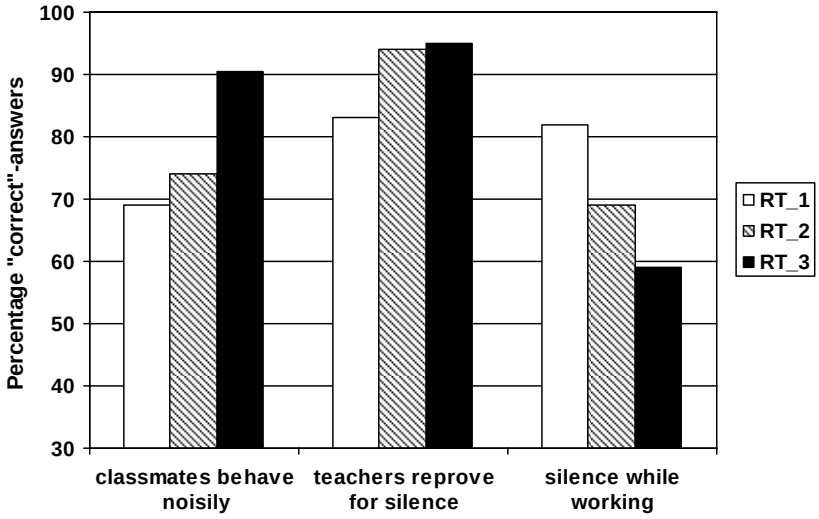

Figure 2. Percentage of 'correct'-answers to statements concerning noise in the classroom with respect to classroom reverberation time.

The effect of reverberation on children's annoyance due to classroom noise was further confirmed by an analysis of the parental questionnaire. The statement 'My child suffers from the noise produced by his/her classmates at school' was answered affirmatively by 44 percent of the parents whose children were from classrooms with short reverberation (RT_1), 51 percent of the parents whose children came from classrooms with medium reverberation (RT_2), and 61 percent of the parents whose children were from classrooms with long reverberation (RT_3). The answer frequencies differed significantly between the groups (Chi Square = 6.02; $p < .05$).

Social and emotional school experience

Raw scores were computed for each participant for each of the seven scales. The higher the score, the more positive the judgement of the particular dimension. Children who left out or gave invalid answers to more than two items of a particular scale were discarded from the analysis of that scale. Significant effects of reverberation were found for the scales

'achievement motivation', $F(2,386) = 4.78$, $p < .01$, 'relation to the teachers', $F(2,377) = 7.06$, $p < .001$, 'class atmosphere', $F(2,384) = 7.96$, $p < .001$ and 'social integration', $F(2,382) = 7.83$, $p < .001$. Bonferroni-corrected post-hoc tests revealed that the children whose classrooms had long reverberation (RT_3) judged these aspects less positively than the children from classrooms with medium (RT_2) and short reverberation (RT_1), $p < .05$ in both cases. For illustration, Figure 2 depicts the percentage of affirmative answers to items of the scale 'relations to the teachers'. The reliable differences in the children's judgments of the teachers' behavior fit well with the assumption that the work stress due to unsatisfactory acoustical conditions affects the teachers' ability to deal with children in a patient and friendly way.

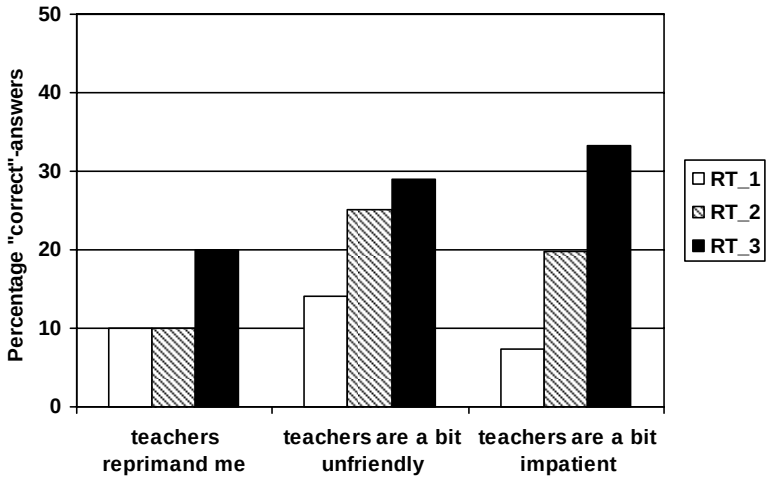

Figure 3. Children´s responses to statements concerning the relations to their teachers with respect to classroom reverberation times. 'My teachers reprimand me too often', 'My teachers are a bit unfriendly with me', 'My teachers are a bit impatient with me'.

4 Discussion

In the current study, the effects of classroom reverberation on speech perception, phonological processing, noise ratings, and school attitudes were analyzed in second-graders from 17 classrooms with reverberation times ranging from 0.49 to 1.11 seconds.
Children whose classrooms had long reverberation (RT_3) performed worse than children from classrooms with short reverberation (RT_1) on a phonological processing task involving identification, storage and phonological analysis of spoken words and nonwords. The effect cannot be attributed to the acoustical conditions during the test episode, as all children were tested in comparable classrooms with short reverberation. Differences in general abilities can also be ruled out, as the groups did not differ in a test of nonverbal intelligence. It must be kept in mind that in group RT_1, the percentage of children with non-German mother language was higher and, as a consequence, reading comprehension was lower when compared to RT_3. Since oral language and reading ability are positively related to phonological processing, better performance in group RT_3 would have been expected in the phonological processing task. However, despite of their advantageous preconditions, the children from group RT_3 were outperformed by their counterparts from RT_1. When sociodemographic variables (mother language and parents income) were controlled in the analysis, the children from group RT_1 were proven to perform better than both other groups. In line with prior studies [12,13], the current results indicate that permanent exposure

to unfavorable listening conditions in the learning environment may impair the development of auditory-verbal functions which are relevant in learning to read and spell. The well-documented effect of intense environmental noise, e.g., in aircraft noise areas, on reading [9,12] might be mediated by noise-induced impairments of phonological processing abilities.
Concerning noise ratings, the results suggest that an increase in ambient noise level due to reverberation is registered by children. Statements of the parents further confirmed that children from reverberant classrooms felt more annoyed by the noise produced by their peers in the classroom. This may be due to the fact that, with reverberation, the sounds evoked by the pupils' activities increase in level, and are thus more difficult to ignore.
The assumption that poor interior acoustics negatively affect the social-emotional class atmosphere was based on prior studies on the effects of noise and reverberation on health and well-being in teachers. Interview studies have shown that noise is one of the most important sources of stress in teachers [11,19]. Clearly, teachers who feel stressed will hardly be able to interact as patiently and friendly with the children as teachers who do not. Teachers' misattributions of the indoor noise to a lack of the children's effort to behave calmly may also contribute to an unfavorable social atmosphere. To our best knowledge, the current study is the first to demonstrate significant relations between the acoustical quality of classrooms and the children´s school attitudes.
Attempts to improve the quality of institutional education should also take into consideration the environment in which learning and instruction take place. Although the current data are correlational and thus do not allow causal inference in a strict sense, they provide further support for the importance of adequate listening conditions in classrooms. It must be brought to mind that poor interior acoustics affect learning and teaching permanently. The negative impact of excessive reverberation is thus much greater than that of most determinants of building acoustics, such as deficient insulation of the doors to the corridors, which are in general empty during lesson time. With respect to interior acoustics, a relatively small financial investment may considerably improve the preconditions for successful and enjoyable learning and teaching.

Acknowledgments

The work described here is part of a study which was incorporated in the research network "Lebensgrundlage Umwelt und ihre Sicherung" (BWPlus), and funded by the Ministry for the Environment, Baden-Württemberg, Germany. A comprehensive review of the study is provided in [22]. We wish to thank Philip Leistner and Jochen Seidel, Fraunhofer Institute for Buildung Acoustics Stuttgart, for the successful cooperation in this project. Thanks also to August Schick for valuable advice concerning methods and design, and to all the children, teachers and parents who participated in this study.

References

[1] Johnson C.E. Children´s phoneme identification in reverbaration and noise. *Journal of Speech, Language, and Hearing Research*, Vol 43, 2000, 144-157.

[2] Talarico, M., Abdilla. G., Aliferis, M., Balazic, I. Effect of age and cognition on childhood speech in noise perception abilities. *Audiology and Neuro-Otology*, Vol 12, 2007, 13-19.

[3] Klatte, M., Lachmann, T., Meis, M. Effects of noise and reverberation on speech perception and listening comprehension in children and adults in a classroom-like setting. *Noise and Health – Special Issue: Noise, Memory, and Learning* (in press).

[4] Shield, B., Dockrell, J. E. The effects of noise on children at school: A review. *Building Acoustics*, Vol 10, 2003, 97-116.

[5] Shield B, Dockrell J. The effects of environmental and classroom noise on the academic attainments of primary school children. *Journal of the Acoustical Society of America*, Vol 123, 2008, 133-144.

[6] Lubman D, Sutherland L. Role of soundscape in children´s learning. *Proceedings of first Pan-American/Iberian Meeting on Acoustics,* Cancun, Mexico, 2002.

[7] Whitlock, J.A., Dodd, G. Speech intelligibility in classrooms: Specific acoustical needs for primary school children. *Building Acoustics,* Vol 15, 2008, 35-47.

[8] Evans, G. W., Hygge, S., Bullinger, M. Chronic noise and psychological stress. *Psychological Science,* Vol 6, 1995, 333-338.

[9] Haines, M. M., Stansfeld, S. A., Berglund, R. F., Head, J. Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children. *Psychological Medicine,* Vol 31, 2001, 265-277.

[10] Dockrell, J. E., Shield, B. Children's perceptions of their acoustic environment at school and at home. *Journal of the Acoustical Society of America,* Vol 115*,* 2004, 2964-2973.

[11] Evans, G., Hygge, S. Noise and cognitive performance in children and adults. In L. M. Luxon & D. Prasher (Eds.), *Noise and its Effects,* 2000, 549-566. New York: Wiley.

[12] Evans, G., Maxwell, L. Chronic noise exposure and reading deficits: The mediating effects of language acquisition. *Environment and Behavior,* Vol 29*,* 1997, 638-656.

[13] Maxwell, L., Evans, G. The effects of noise on pre-school children´s pre-reading skills. *Journal of Environmental Psychology,* Vol 20*,* 2000, 91-97.

[14] Mayringer, H., Wimmer, H. Salzburger Lese-Screening (SLS) für die Klassenstufen 1-4. Göttingen: Hogrefe. 2003.

[15] Raven, J. *Coloured progressive matrices*. Frankfurt a. M.: Swets & Zeitlinger. 2002.

[16] Bradley, B., Bryant, P. Categorizing sounds and learning to read: A causal connection. *Nature,* Vol 310*,* 1983, 419-421.

[17] Klatte, M., Meis, M., Sukowski, H., Schick, A. Effects of irrelevant speech and traffic noise on speech perception and cognitive performance in elementary school children. *Noise and Health*, Vol *9*, 2007, 64-74.

[18] Rauer, W., Schuck, K. Fragebogen zur Erfassung von emotionalen und sozialen Schulerfahrungen von Grundschulkindern erster und zweiter Klassen (FEESS). Göttingen: Hogrefe. 2004

[19] Schönwälder, H. G. *Die Arbeitslast der Lehrerinnen und Lehrer*. Essen: Verlag Neue Deutsche Schule. 2001.

[20] Berglund, B., Lindvall, T., Schwela, T.H. (Eds.). *Guidelines for Community Noise*. World Health Organization. 1999. Retrieved 03/13/2010 from http://www.who.int/docstore/peh/noise/guidelines2.html.

[21] Seidel, J., Weber, L., Leistner, P. Acoustic properties in German classrooms. Proceedings of the Forum Acusticum Budapest, 2005, pp. 2065-2069.

[22] Klatte, M., Hellbrück, J., Seidel, J. & Leistner, P. Effects of classroom acoustics on performance and well-being in elementary school children: A field study. Environment and Behaviour (in press).