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A field study of school teachersô noise exposure, teachersô speech levels and duration of speech during classroom teaching

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Objectives: To measure school teachersô noise exposure and to measure the voice utilization of the teachers during normal classroom teaching. Methods: Sound levels at the shoulder were measured in 37 school teachers (30 women) in 7 schools in Copenhagen, Denmark. Sound levels recorded by two microphones, one attached to the participantôs shoulder and another to the neck close to the larynx, allowing discrimination between the teachersô speaking and non-speaking periods. Thus, the total sound levels recorded at the shoulder could be broken down to estimate background noise levels (without the teachersô speech) and the teachersô voice levels during class. In this paper we report the distribution of background sound levels during teaching, the teachersô voice levels, and the total duration of teachersô speech during normal 45 min classroom lessons. The impact of background noise levels and room reverberation time on voice levels will be investigated, as well as the association between voice utilization and voice fatigue after the workday.

1 Introduction

Excessive noise and poor acoustical conditions in school classrooms can be a nuisance for both teachers and children. Noise can disturb the teaching, cause annoyance, impair communication, increase the cognitive load, lead to increased voice levels, and perhaps increased physiological stress, etc.[1-4] Poor room acoustics can aggravate these problems directly and indirectly, for example, by reducing the speech intelligibility and by leading to increased speech levels [5-7]. Although experimental studies of teachers or children in classrooms under ñschool-likeò conditions have been very valuable in establishing the adverse consequences of poor room acoustics and background noise in relation to teaching, empirical evidence gathered in the field during a real school day are important because of their higher ecological validity. One of the challenges in field settings is establishing the noise exposure and acoustical working conditions of the teachers. Indeed, most teachers alternate between different rooms during the day and during the week, and may therefore work in several different acoustical environments. A further challenge arises when trying to assess the noise exposure level. The standards for noise exposure measurements stipulates that this should be done close to the ear of the teacher [8]. However, a microphone placed on the shoulder of the teacher will also record the teacherôs voice. Given the microphoneôs proximity to the mouth and the strength of the voice compared to the ambient sound, it is compelling that the teachers will contribute significantly to the measured sound pressure levels.

The present study was conducted within the context of a larger study of the association between teachersô acoustical working conditions and mental fatigue. The aim was to measure the noise exposure of school teachers during teaching lessons. A second aim was to measure the voice levels of the teachers (how loud they are speaking during teaching), and to assess the relation between these measures and several potential determinants, including the reverberation time of

the classroom, the age of the children, the subject being taught, etc. Finally, and because voice problems is prevalent among teachers [9] and is a significant cause for sickness absence among teachers [10], a third aim was to investigate the connection between noise exposure and voice levels and the development of voice symptoms during a workday. In this paper, the methods and results will only be presented in overview, but a full-length paper with all detailed results of the study is under preparation for publication.

2 Methods

2.1 Teachers and schools

In total, 37 teachers from 7 schools participated. The group comprised 30 women (age 44 years, range 25-61) and 7 men (age 42 years, range 30-57 years). The study population from which teachers and schools were drawn has been described in two previous paper [1,2]. In brief, 10 schools in the Copenhagen area were invited to participate in the study. All 419 teachers on the 10 schools were invited to participate in a questionnaire survey. The results of this survey have been presented in the previously mentioned articles, and some results will also be presented on this conference. The survey had 283 respondents, and subgroup of 104 teachers participated in a study at the National Research Centre for the Working Environment that included assessment of the social climate at work, audiometric measurements, and cognitive testing. Some of the results of this part of the study are also being presented on this conference.

2.2 Procedure

In the morning of the workday each teacher filled in a questionnaire on various fatigue symptoms. The question used in this study to assess voice symptoms read ñHow are you feeling right now? Are you hoarse or feel fatigued in your voice?ò Response categories were ñNot at allò, ñVery littleò, ñA littleò, ñSomewhatò, ñConsiderablyò, and ñVery muchò, which were scored 1-6 in the statistical analysis. Next, the teacher conducted 3 computerized tasks aimed at testing attention and short-term functioning. After this, the equipment for noise exposure measurements and voice activity detection were mounted on the teacher (see below), and instructions were given. The working of the instruments was checked regularly, but the teachers were not under constant supervision in order not to interfere with the normal teaching routines. However, in order to ensure that the measurements were representative for ñnormalò classroom teaching situations, the classes were checked visually several times during a lesson (this is possible because classroom doors have window panes). Also, at the end of the workday each teacher was interviewed in order to identify any deviations from ñnormalò classroom teaching. After the workday, and after removal of measurement equipment, the teacher again filled in a questionnaire on fatigue symptoms and repeated the computerized cognitive work tasks.

2.3 Noise exposure measurements

Noise exposure assessment was made according to ISO 9612, following the requirements for measurements with personal noise dose meters. The dose meters, Brüel & Kjær Type 4445, were set up to measure the A-weighted equivalent sound pressure level L_{Aeq} as well as the C-weighted peak level L_{Cpeak} and to store results in profiles at 1-second intervals. At the beginning of each day the instruments were calibrated. The microphone was then mounted on the teacherôs shoulder approximately 10cm from the ear and 4cm above the shoulder.

In addition, to register voice activity a throat-microphone was attached to the subjectôs neck, close to the larynx. The signal from this sensor was continuously recorded as wave files using Brüel & Kjærôs SoNoScout recorder. The clocks of the dose meter and recorder were precisely synchronised.

Discrimination between periods where the teacher was speaking from periods with no teacher speech was then carried out on the PC using MATLAB. To suppress very low and high frequency components, the recorded signal was first sent through a band-pass filter. Then the energy in this filtered signal was determined within time blocks of 100ms length, giving ten values per second. Prior to the field measurements, an experiment had been conducted to determine a threshold value for voice activity. Each second, where the energy in at least one of these blocks exceeded this threshold, was marked to contain ñvoice activityò.

The first result of this analysis was the percentage of each teachersô voice activity during the various lessons. In addition, for each lecture three equivalent sound pressure level values were determined:

1. Considering only those sections of the profile, where the teacher did not speak gives a measure for the average ambient noise, created by the class or other sound sources in the room, $L_{Aeq,background}$.

2. Considering those sections of the profile where the teacher was speaking gives a measure for the added sound pressure level due to the teacherôs voice, $L_{Aeq,voice}$.

3. Considering the full profile for the lecture (i.e. the full 45 minutes) is the combination of result 1 and 2 and equal to the original value for each lecture indicated by the noise dose meters.

Each teacher was also given another noise dose meter (again Brüel & Kjær Type 4445) mounted to a tripod. The subjects were instructed to keep the instruments with them throughout the day and to place them at about 2m from them. The purpose of this was to provide a second estimate of the ambient sound pressure level for comparison with the shoulder measurements.

2.4 Measurement of reverberation time

The reverberation time (RT) of the classrooms where the teachers have been teaching were measured. The exception is one school, were refurbishments were initiated before the measurements could be done. The measurements of reverberation time were performed by impulse excitation and reverse integration of the impulse response, and were based on assessments of T30 from impulse decay, as described in ISO 3382-2 under the integrated impulse response method (International Organization for Standardization, 2008). The impulse was generated by the sudden release of pressurized air, and the response was measured by a Brüel & Kjær 2260 sound level meter and further analyzed in octave bands from 125 Hz to 8000 Hz using a Brüel & Kjær 7830 Qualifier. The measurements were based on 2 different sound source positions at 3 different microphone positions in classrooms without pupils.

2.5 Analysis

The influence on equivalent sound levels (background or voice) of the subject being taught and gender of the teacher were estimated in repeated measures mixed models with these variables as fixed factors and with teacher as random intercept. The daily average exposure to background noise ($L_{Aeq,background,day}$) and daily average voice level for each teacher ($L_{Aeq,voice,day}$) was calculated as the predicted values in repeated measures mixed models with teacher as the only fixed factor. Analyses of associations were done with Spearman rank correlations. Probability of the null-hypothesis, P, less than or equal to 0.05 were considered significant.

Table 1. Characterization of the teaching spaces in 6 schools

Type of teaching space	Volume (m^3)	Reverberation time		
		T30_low (s) (125-500 Hz)	T30_median (s) (2-4 kHz)	T30_high (s) (4-8 kHz)
Standard classrooms (n=59)				
Mean (sd)	175 (26)	0.59 (0.13)	0.48 (0.07)	0.46 (0.07)
Range	145-243	0.40-0.87	0.35-0.67	0.36-0.62
Special-subject classrooms (n=11)				
Mean (sd)	301 (123)	0.64 (0.13)	0.67 (0.12)	0.59 (0.12)
Range	229-525	0.50-0.86	0.50-0.87	0.42-0.75
Gymnasiums (n=8)				
Mean (sd)	1029 (38)	1.08 (0.16)	1.26 (0.13)	0.90 (0.18)
Range	969-1055	0.95-1.29	1.17-1.47	0.75-1.15

3 Results

3.1 RT and sound levels

The RT measurements are summarized in Table 1 by the type of room. Special-subject classrooms (for teaching science, home economics, music, etc) are typically larger than standard classrooms, and they usually differed from the standard classrooms in many other ways, for example, with respect to geometry, furnishing, ceiling, etc. Gymnasiums were larger than both standard classrooms and special-subject classrooms.

Equivalent sound levels ascribed to the background and to the teacherôs voice are presented in Table 2 for the 37 teachers in the 7 schools. There was no significant difference between men and women, neither for $L_{Aeq,background}$ nor for $L_{Aeq,voice.}$ There were no significant differences between Subjects with respect $L_{Aeq,background}$ or $L_{Aeq,voice}$, with the exception that $L_{Aeq,background}$ or $L_{Aeq,voice}$ for during Sports was higher than during other subjects. For all measurements, the equivalent sound levels ascribed to the teacherôs voice was higher than the corresponding equivalent background noise levels. In standard classrooms the mean difference was 10.5 dBA (range 4.9-19.5 dBA), in special-subject classrooms it was 9.1 dBA (4.9-13.7 dBA) and in gymnasiums 14.0 dBA (8.9-20.2 dBA).

Table 2. Equivalent sound pressure levels during school lessons by subject from the background and from the teacherôs voice measured at his/her shoulder

Subject		$L_{Aeq,background}$ (dBA)		$L_{Aeq,voice}$ (dBA)	
		Men	Women	Men	Women
Kindergarten class	Mean (SD)	72.7 (1.1)	70.6 (3.7)	83.2 (3.7)	79.9 (3.7)
	Range (n)	71.8-73.9 (3)	64.4-76.9 (13)	78.9-85.4 (3)	73.4-87.5 (13)
Danish/Social subjects	Mean (SD)	74.3 (4.1)	70.1 (4.0)	83.7 (5.0)	80.8 (5.6)
	Range (n)	67.5-79.2 (7)	62.8-79.7 (28)	77.5-91.2 (7)	65.0-89.5 (28)
English/German	Mean (SD)	ND	74.8 (4.6)	ND	83.1 (4.4)
	Range (n)	ND	66.5-81.7 (7)	ND	73.9-86.6 (7)
Home economics	Mean (SD)	ND	71.7 (3.5)	ND	82.5 (3.0)
	Range (n)	ND	67.7-74.9 (7)	ND	80.1-86.6 (7)
Sports	Mean (SD)	75.2 (1.8)	78.9 (2.6)	82.9 (1.5)	91.5 (4.5)
	Range (n)	73.9-76.5 (2)	76.2-83.0 (12)	81.8-83.9 (2)	86.2-98.9 (12)
Math	Mean (SD)	71.6 (2.2)	72.9 (4.5)	82.4 (4.4)	82.1 (4.8)
	Range (n)	69.4-73.8 (3)	66.6-81.8 (10)	77.6-86.3 (3)	75.4-90.1 (10)
Science	Mean (SD)	72.7 (1.7)	65.2 (0.0)	78.1 (1.6)	78.9 (ND)
	Range (n)	70.8-74.0 (3)	65.2-65.2 (1)	76.4-79.6 (3)	78.9-78.9 (1)

The combined duration of the time of teachersô speech are summarized in Table 3 by gender and subject. The combined length is expressed in percentage of the total time. There was no significant difference between men and women. Subject was marginally significant (P=0.087), and post-hoc analysis showed, that teachers were speaking a significantly smaller percentage of the time during sports compared to Danish/Social subjects.

3.2 Analyses of associations

In the following analyses the data for men and women were pooled, and only data obtained in standard classrooms were considered (that is, subjects such as Sports, Science, Home economics, and Music were excluded from the analyses) unless otherwise is indicated.

$L_{Aeq,background}$ were significantly positively associated with RT_low (Spearman rho=0.28, P=0.035, n=58). There was no significant association between RT_medium and $L_{Aeq,background}$. However, RT_high and $L_{Aeq,background}$ were negatively correlated (Spearman rho=-0.38, P=0.004, n=58). There were no significant associations between RT and $L_{Aeq,voice}$.

We found no association between the childrenôs age and the $L_{Aeq,background}$ or the $L_{Aeq,voice}$ (Spearman rho<0.1, P>0.8). However, the teachersô age were significantly negatively correlated with $L_{Aeq,voice}$ (Spearman rho=-0.38, P=0.003, n=59). Moreover, $L_{Aeq,voice}$ was linearly and significantly associated with $L_{Aeq,background}$ with intercept 26.6 dBA and slope 0.77.

Table 3. Combined duration of teachersô speech expressed as percentage of the time by gender and subject

Subject		**Duration of teacherôs speech (percentage of the time)**	
		Men	Women
Kindergarten class	Mean (SD)	49,6 (11,7)	51,1 (15,0)
	Range (n)	37,5-60,9 (3)	25,4-72,8 (13)
Danish/Social subjects	Mean (SD)	50,3 (20,4)	58,9 (18,0)
	Range (n)	18,7-72,0 (7)	17,1-94,0 (28)
English/German	Mean (SD)	ND	50,6 (17,6)
	Range (n)	ND	24,4-74,2 (7)
Home economics	Mean (SD)	ND	71,1 (14,9)
	Range (n)	ND	53,0-83,7 (7)
Sports	Mean (SD)	41,8 (1,8)	40,5 (18,1)
	Range (n)	40,5-43,0 (2)	17,9-75,8 (12)
Math	Mean (SD)	55,2 (8,0)	64,7 (16,2)
	Range (n)	48,2-63,9 (3)	34,3-93,2 (10)
Science	Mean (SD)	48,3 (7,2)	51,3 (ND)
	Range (n)	40,1-53,5 (3)	51,3-51,3 (1)

Neither voice symptoms in the morning nor in the afternoon were significantly associated with $L_{Aeq,background,day}$ or with $L_{Aeq,voice,day}$. However, when including all subjects (including Sports) the change in voice symptoms during the workday (estimated as the difference between afternoon and morning scores for voice symptoms), was positively and significantly associated with $L_{Aeq,background,day}$ (Spearman rho = 0.45, P=0.007, n=35), and close to be significantly associated with $L_{Aeq,voice,day}$ (Spearman rho = 0.32, P=0.067, n=35). When limiting the analysis to teachers working exclusively in standard classrooms, the correlation between change in voice symptoms and background noise exposure remained significant (Spearman rho = 0.44, P=0.044, n=21), while the association with $L_{Aeq,voice,day}$ disappeared

(Spearman rho = 0.16, P=0.48, n=21), The percentage of the time that the teacher was using his/her voice was not associated with voice problems.

4 Discussion

In this study we have measured the noise exposure of school teachers in teaching situations directly by separating ñteacher speakingò from ñnon-speakingò periods in the continuous recording of sound pressure levels. This method is different from the method of separating mixed Gaussians of the sound pressure level frequency-distribution curve [11,12]. The advantage of the direct method is that it does not depend on the assumptions that are necessary to separate mixed distributions, for example, that the teachers speech levels are always much higher than background noise exposure. Thus, the direct method can be used in situations where the teacherôs voice is low or the background noise level is high.

Modern teaching methods often entail a high degree of communication between teachers and pupils and the activities in the classroom are much diversified, from instructions given by the teacher, to group work, individual work etc. We expected beforehand that the noise associated with these activities should be positively correlated with the RT. Contrary to our expectations, there was no significant correlation between $L_{Aeq,background}$ and RT averaged over all octave bands. However, when analyzing the associations in different octave bands we observed a weak, but significant positive correlation between $L_{Aeq,background}$ and RT below 500 Hz and a stronger, but negative, correlation between $L_{Aeq,background}$ and RT above 4000 Hz. In the intermediate frequency range 1000-2000 Hz, no significant association with background noise levels was found. At present, the reason for the negative association between RT in the high frequencies and background noise is unknown. Speculatively, it is plausible that a room that is low-reverberant with respect to high frequency sounds does not support childrenôs speech communication as much as a more reverberant room would, and this circumstance may cause them to increase their voice levels.

In any event, we found a strong linear relation between $L_{Aeq,background}$ and $L_{Aeq,voice}$. In other words, the teachers speak louder the higher the background noise. The slope was 0.77, that is, the teachers increased on average their voice output by 0.77 dBA per 1 dBA increase in background noise level.

There is a considerable interest in voice problems of teachers, since voice problems may contribute to sickness absence [10]. It has been surmised that background noise levels and acoustical working conditions contribute to strain the voice of the teachers [12] because of the need to talk louder and to repeat messages. We observed that the change in voice symptoms during a workday was significantly correlated with background noise levels, but less strongly correlated with teachersô voice levels. The lack of a clear association between the objective measure of voice strain ($L_{Aeq,voice,day}$) and symptoms may be due to the fact that $L_{Aeq,voice,day}$ under the conditions of this study may be an imperfect measure of the true strain. For example, we only reported noise exposure (and hence, voice levels) during ñnormalò classroom activities. Conditions differing from ñnormalò may be visiting classes, or situations where the lesson takes place outside the classroom. Moreover, periods where the teacher was not teaching, such as staff meetings, breaks, time on playground duty, etc., were not analysed. Hence, it is possible that a more precise characterization of the voice utilization would result in a stronger association.

5 Summary

In this study we have used a new method for assessing the background noise exposure of school teachers during lessons. The procedure also allowed us to estimate the teacherôs utilization of his or her voice during the lessons as the equivalent sound level measured at the shoulder. The teachersô voice levels were strongly correlated with background noise levels. Moreover, we found that the change in voice symptoms during the workday was significantly correlated with background noise exposure, but less strongly with the teachersô voice levels.

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